The development of novel tools for the assessment of UK firefighter nutritional status for use in a multi-component worksite nutrition intervention programme

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Abstract

Firefighters are at elevated risk of cardiovascular disease and myocardial infarction. Overweight and obesity prevalence in this occupational group may be greater than in the general population. This is the first nutrition-based study for UK firefighters, involving 28 fire stations and 575 firefighters based in London. This study was designed to develop population specific tools: body composition reference charts, a validated food frequency questionnaire (FFQ) and a cookery book for use in a multi-component worksite intervention.

The validity of BMI for classification of firefighter adiposity status was investigated. Combined prevalence of male firefighter (n=497) overweight and obesity by BMI was 80%, which contrasted widely with the adiposity indices: percentage body fat (BF%) (63%), waist circumference (WC) (43%) and waist-to-height-ratio (WHtR) (59%). Female firefighters (n=78) exhibited lower combined prevalence of overweight and obesity compared to the male firefighters: BMI (43%), BF% (18%), WC (36%) and WHtR (27%). However, misclassification caused by BMI was widespread for both sexes, showing BMI's specificity to be particularly poor, leading to high rates of false positives. This represents the first study to assess the adiposity of UK female firefighters and the first to comprehensively identify BMI to generate widespread misclassification of UK firefighters. Following this, a novel body composition reference system for UK firefighters was developed. This took the form of centile reference curves illustrating age-related changes in fat mass and skeletal muscle mass of firefighters, offering an improvement upon the limitations of BMI and BF%. Overweight and obesity cut-offs were defined at the 85th and 95th centiles which were chosen due to relative suitability and good agreement (97%; Kappa 0.86, p< 0.001) between the BF% reference curves and the fat-mass index reference curves at these centiles.

A novel FFQ was developed via population specific modification of the EPIC-Norfolk FFQ and validated against three 24hr recalls. Correlations between the methods were significant (p< 0.01) for energy (r=0.42), carbohydrate (r=0.42), protein (r=0.42), fat (r=0.35), fibre (r=0.34), saturated fatty acids (r=0.36), monounsaturated fatty acids (r=0.32), polyunsaturated fatty acids (r=0.24, p=0.05), vitamin C (r=0.26), calcium (r=0.45), iron (r=0.38) and sodium (r=0.32). Bland-Altman (BA) analyses indicated good agreement between methods for energy and each nutrient, with an average of 96% of cases falling between the limits of agreement. Cross-quartile analysis identified a low mean rate of misclassification (4.2%). In terms of reproducibility, the mean correlation between repeat administrations was 0.7 (p< 0.01), with >95% of cases falling between the BA limits of agreement. This constitutes the first FFQ validated for UK firefighters.

A worksite cookery workshop intervention and accompanying cookery book were developed and tested, demonstrating practical methods of healthy meal preparation along with environmental modification suggestions designed to ameliorate the established obesogenic food environment. This resulted in several key significant (p< 0.01) improvements to the mess, including 8 firefighting watches reinstating smaller plates, 10 watches leaving leftovers in the kitchen, 11 watches incorporating wholegrain products and 8 watches switching to making sauces/soups from scratch.

Finally, the efficacy of a fire station-based nutrition intervention was tested in a cluster-controlled trial. This encompassed group education on non-communicable disease risk factors and the health benefits of adopting a Mediterranean diet. Dietary assessment was undertaken utilising the newly developed FFQ, which informed personalised nutrition consultation for each participant. Mixed design ANOVAS demonstrated significant improvements at 4-months post-intervention (p< 0.01) in daily mean intakes of energy (-244 kcal), total fat (-12 g), saturated fatty acids (-5g), sodium (-311 mg), sugars, preserves and snacks (-19 g). This contributed to concomitant mean body composition improvements in fat mass (-2 kg), BF% (-1.7%), WC (-1.7 cm), weight (-1.7 kg), BMI (-0.5 kg/m^2), mood (+0.9) and energy level (+1.2) compared with the control group increasing in WC (+1.9 cm).

In conclusion, the population specific tools can be utilised in a worksite intervention which led to improvements in nutrient intake and body composition. The external validity of the tools, along with the intervention's high level of feasibility further renders it suitable for rollout on a national level.

Published Abstracts

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Lessons, G., Bhakta, D., and McCarthy, H. (2020). Development of body composition reference curves for UK firefighters. *Proceedings of the Nutrition Society, 79*(OCE1), E29. doi:10.1017/S0029665119001502.

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Awards

Winner of the Health and Nutrition Award 2020. Awarded by Public Sector Catering to Greg Lessons in September 2020 ‘in recognition of good practice in the delivery of a clear health and nutrition strategy, encouraging the concept of eating for health within an organisation’.

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Abbreviations

ANOVA	Analysis of variance
ASMM	Appendicular skeletal muscle mass
BF%	Percentage body fat
BFR	Standard adult male body-fat ranges
BIA	Bioelectrical impedance analysis
BMI	Body mass index
BP	Blood pressure
BPM	Beats per minute
CFA	Combined fire authority
CFOA	Chief Fire Officers Association
CHD	Coronary heart disease
CO	Carbon monoxide
CPAQ	Concise physical activity questionnaire
CRF	Cardiorespiratory fitness
CT	Computerised tomography
CVD	Cardiovascular disease
DRV	Dietary reference value
DXA	Dual energy x-ray absorptiometry
EAR	Estimated average requirement
ECG	Electrocardiogram
EI	Energy intake
EmER	Estimated minimum energy requirement
EPIC	European Prospective Investigation into Cancer and Nutrition
FETA	FFQ EPIC Tool for Analysis
FFM	Fat free mass
FF-FFQ	Firefighter food frequency questionnaire
FFQ	Food frequency questionnaire
FM	Fat mass

FMI	Fat mass index
FRA	Fire and rescue authority
FRS	Fire and rescue service
GI	Glycaemic index
GIS	General information sheet
HDL	High density lipoprotein
IAFC	International Association of fire chiefs
IAFF	International Association of firefighters
IPAQ-SF	International physical activity questionnaire - short form
IQR	Interquartile range
LDL	Low density lipoprotein
LER	Low energy reporter
LFB	London Fire Brigade
LSA	Long-term sickness absence
LVH	Left ventricular hypertrophy
MDRI	Military Dietary Reference Intakes
MET	Metabolic equivalent of task
MetS	Metabolic syndrome
mi	Motivational interviewing
MI	Myocardial infarction
mMDS	Modified Mediterranean diet score
MRI	Magnetic resonance imaging
MUFA	Monounsaturated fatty acids
NCD	Non-communicable disease
NFCC	National Fire Chiefs Council
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NSP	Non-starch polysaccharides
NVFC	National Volunteer Fire Council
PA	Physical activity

PAL	Physical activity level
PFT	Peer fitness trainer
PPE	Personal protective equipment
PTI	Physical training instructor
PUFA	Polyunsaturated fatty acids
RCT	Randomised controlled trial
RNI	Reference nutrient intake
ROI	Return on investment
SAT	Subcutaneous adipose tissue
SCD	Sudden cardiac death
SD	Standard deviation
SFA	Saturated fatty acids
SMM	Skeletal muscle mass
SMMI	Skeletal muscle mass index
UK	United Kingdom
UR	Under reporter
USA	United States of America
VAT	Visceral adipose tissue
VLDL	Very low density lipoprotein
VO2 max	Maximum oxygen uptake
WC	Waist circumference
WFI	Wellness Fitness Initiative
WHR	Waist-to-hip ratio
WHtR	Waist-to-height ratio
WTR	Waist-to-thigh ratio

Chapter 1. General introduction and review of literature

Overview

Exposure to intense heat whilst firefighting has been shown to impair vascular function and increase cardiovascular strain. The firefighters at greatest risk of suffering MI are those with an underlying cardiovascular risk factor. Prevalence of firefighter overweight and obesity has been estimated to affect 60 - 88% of personnel although misclassification by BMI is a ubiquitous problem for firefighters, misclassifying up to 65% of cases, thus bringing into question the validity of BMI for classifying firefighter adiposity. Even so, firefighters appear to be an occupational group exhibiting high adiposity. This may be partially explained by fire stations being characterised as obesogenic, with a food environment abundant in energy dense foods high in sugar, salt and saturated fat. Furthermore, a historic lack of routine physical fitness testing in civil fire brigades both in the UK and USA is likely to have enabled a widespread substandard level of physical fitness affecting 34% - 56% of firefighters. Worksite interventions aimed at improving firefighter dietary and lifestyle behaviour have generally yielded modest results, leading to attenuation of weight gain/moderate weight loss and moderate amelioration of cardiovascular risk factors. The majority of firefighter health research to date has been conducted on USA firefighters, with a paucity of research in the UK.

1.1. Health risks and occupational exposures of firefighting

Whilst it is widely acknowledged that the role of a firefighter entails hazardous work, the public misconception may be that the majority of firefighter on-duty fatalities are caused by building collapses and burns. However, the most prominent cause of work-related firefighter fatalities is sudden cardiac death (SCD), accounting for 44% of all firefighter work-related deaths in the USA (Fahy and Molis, 2020). UK firefighters may be exposed to similar risks, as a review of firefighter deaths over thirty years from 1978 to 2008 found that 36 (30%) of fatalities were attributed to acute myocardial infarction (MI) taking place at operational incidents or soon afterward (Labour Research Department, 2008). Data from USA research shows that firefighters are 10 to 100 times more likely to suffer a sudden cardiac event during/after firefighting compared with the undertaking of station duties, which may explain the increased rate of on duty firefighter MI related deaths, which is more than double that of on duty paramedics and police (Kales *et al.*, 2007). The extreme conditions which can be experienced during firefighting can involve performing physically strenuous work in incredibly high ambient temperatures, exposed to noxious contaminants whilst under psychological stress

(Duran, Woodhams and Bishopp, 2018). This combination of interacting exposures is the basis of the cardiovascular strain leading to acute cardiovascular events in firefighters (Smith *et al.*, 2016). The magnitude of the strain is mediated by physical fitness and health status of the individual (Cheung and McLellan, 1998; Wu, Snieder and de Geus, 2010). Figure 1.1 illustrates the additive/interactive effect of risk factors.

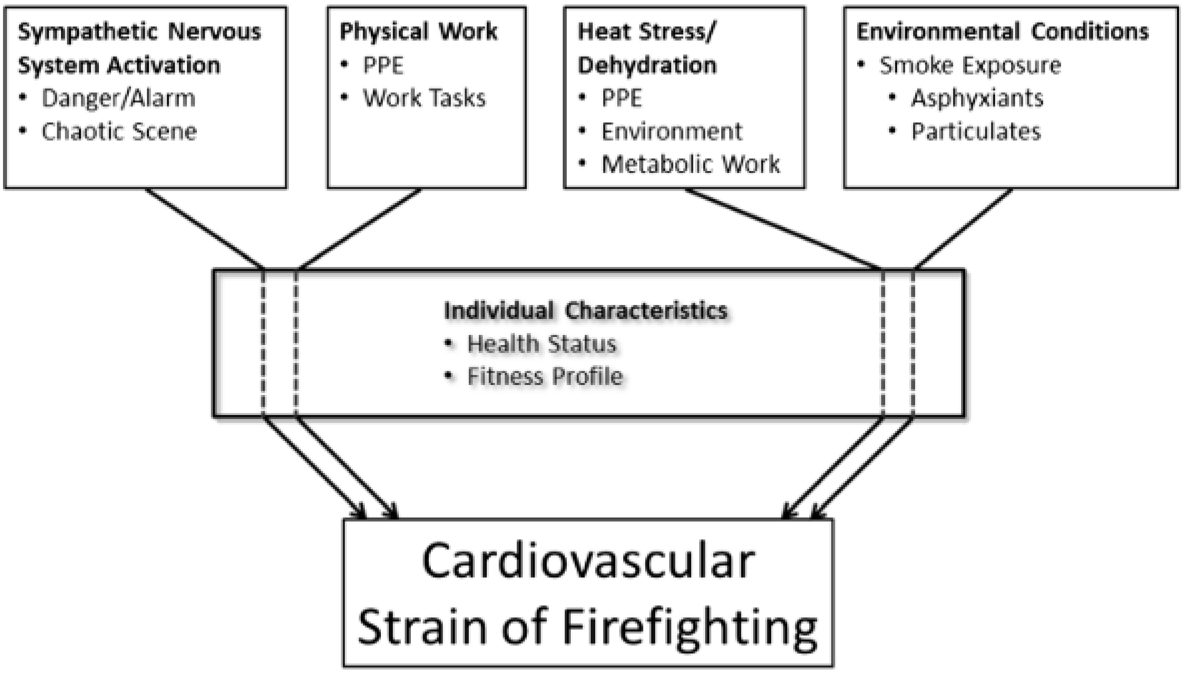


Figure 1.1. Factors influencing the cardiovascular strain of firefighting. PPE: personal protective equipment (Smith, Barr and Kales, 2013).

A systematic review of cardiovascular disease (CVD) in USA firefighters (Soteriades *et al.*, 2011) identified that, although firefighting causes significant cardiovascular strain, the majority of personnel can tolerate this strain without suffering a cardiac event. This is largely dependent upon whether there are underlying CVD risk factors. The review found smoking status, diabetes, hypertension and old age all to be associated with reduced tolerance and greatly increased risk of cardiac death. The greatest risk was associated with a previous diagnosis of coronary heart disease (CHD). Additionally, substandard cardiorespiratory fitness is a likely contributor to elevated risk of cardiovascular events (Baur *et al.*, 2011), which is concerning given the high prevalence of substandard fitness of firefighters (see section 1.6). Overweight and obesity are modifiable risk factors which have also been associated with increased risk of CVD in firefighters (see section 1.6). The systematic review by Soteriades *et al*. (2011) identified obesity to increase the relative risk of on-duty SCD threefold. This again is highly concerning given the high prevalence of excess adiposity in firefighter cohorts from around the globe (Munir *et al*., 2012; Choi *et al*., 2016; Damacena *et al*., 2020) (see section 1.9).

A seminal study by Barnard and Duncan (1975) found firefighter heart rates to accelerate by a mean of forty-seven beats per minute (bpm) upon the fire station emergency call bells sounding. This regular activation of the sympathetic nervous system, along with the elevated heart rates of firefighters during firefighting in intense heat, which the study measured to be between 150 and 188 bpm for durations of up to fifteen minutes, were suggested as being instrumental in the study observing electrocardiographic abnormalities suggesting ischemia in firefighters.

1.1.1. Pathological mechanisms

Chronic hypertension has been strongly and independently associated with on-duty firefighter injury, early retirement, early termination of duty, cardiovascular events and on-duty fatalities of firefighters (Kales *et al.*, 2002). Furthermore, hypertension typically leads to left ventricular hypertrophy (LVH) (Smith *et al.*, 2016) which is often associated with fatal cardiac arrythmia (Tavora *et al.*, 2012). A post-mortem study of USA firefighters who died from CHD/SCD found 76% of them to have LVH (Kales *et al.*, 2003), a phenomenon which is not confined to older firefighters, as a study of USA firefighters under 45 y of age found the heart weight of SCD cases to be 100 g heavier compared with control cases (Yang *et al.*, 2013). BMI has been identified as the most consistently strong independent predictor of LV mass in firefighters (Korre *et al*., 2016). Whilst obesity is also linked with chronic hypertension in firefighters (Fahs *et al.*, 2009), the results of a recent study of *n*=77 USA firefighters, most of whom (84.9%) were overweight or obese, suggested that obesity and the interaction between increasing BMI and systolic BP lead to adverse changes in electrocardiogram (ECG) waveform in the form of significantly prolonged QRS duration, which may reflect myocardial thickening (Dzikowicz and Carey, 2019).

The cardiac strain of firefighting may also be implicated in the vascular responses of firefighters. A study by Horn *et al.* (2011) measured firefighter heart rates to be elevated for up to one hour post-firefighting. This was coupled with fairly intense physical exertion for thirty to sixty minutes which the study found to elicit mild hypotension by as much as 23 mm Hg which was considerably greater than expected. Working in heavy PPE in intense heat also resulted in a reduction in plasma volume which can further compound post activity hypotension, and is established as being more prominent in people with hypertension (Horn *et al.*, 2011), which is highly prevalent in firefighters (Kales *et al.*, 2002; Fahs *et al.*, 2009; *Smith et al*., 2020). Horn *et al.* (2011) also noted another haemodynamic change post-firefighting in the form of a reduction in sub-endocardial viability ratio, which is indicative of ischemia (Horn *et al.*, 2011). This was measured in firefighters following participation in simulated real fire training events.

A more recent British study was conducted in a similar setting, finding further mechanistic responses to intense heat and physical exertion experienced by firefighters. Hunter *et al*. (2017) investigated the effect of simulated firefighting on the vascular function of *n*=19 healthy non-smoking firefighters with a mean age of 41 y (16 males and 3 females). Following a brief exposure to simulated real fire training, the study demonstrated pathogenic changes in measures of cardiovascular function. This included an increased risk of thrombus formation, increased platelet activation and impairment of vasomotor endothelial function, all of which are mechanistically implicated in the pathogenesis of acute MI (Hunter *et al.*, 2017).

1.1.2. Exposure to smoke and fire by-products

Many by-products of incomplete combustion are present in smoke at fire incidents. A major by-product is carbon monoxide (CO), which has a greater affinity with haemoglobin, equating to 200-250 times greater than oxygen's affinity with haemoglobin. Exposure to CO can therefore inhibit oxygen uptake and delivery resulting in tissue hypoxia (Ernst and Zibrak, 1998). This can have a significant adverse impact upon myocardium tissue, which requires a continuous oxygen supply, leading to myocardial hypoxia (Satran *et al.*, 2005). Short-term exposure to CO levels exceeding 200 parts per million (ppm) is considered dangerous, and death can occur at an estimated exposure of 1,200 ppm (Lees, 1995). Ambient CO levels have been measured up to 27,000 ppm at fire incidents, often remaining above the safe level of 200 ppm after the fire is extinguished, and whilst firefighters routinely overhaul the combusted material and debris, often without wearing respiratory protection (Bolstad-Johnson *et al.*, 2000) thereby exposing themselves to clinically significant levels of CO. This presents a further significant occupational risk factor to the cardiovascular health of firefighters (Soteriades *et al.*, 2011).

1.1.3. CVD risk of female firefighters

To date, most firefighter research has been conducted using male subjects. A recent study of *n*=41 women firefighters serving in Quebec Canada aimed to evaluate the prevalence of CVD risk factors (Gendron *et al.*, 2018). Whilst the authors noted that self-reported obesity and hypertension in the sample were not significantly different compared with age-matched women in the Quebec general population, a high proportion of the women firefighters were identified as having moderate (11% of the sample) or high (65% of the sample) CVD risk. This was despite just 12% of the sample being classified as obese by BMI. One modifiable CVD risk factor was reported by 73% of the sample, 22%

reported two modifiable risk factors, 54% reported at least one major CVD symptom and one third of the sample suffered from known CVD or pulmonary disease. The study identified that 82% of the subjects did not meet the minimum cardiorespiratory fitness standard of 12 metabolic equivalent of task (METS), which is consistent with previous research on USA women firefighters by Jahnke *et al*. (2012) (see section 1.9.5.1) which found that 78% of study subjects failed to meet the minimum standard. In the Quebec study, Gendron *et al*. (2018) did not look for statistical associations between cardiorespiratory fitness and CVD risk therefore no firm conclusions can be made regarding the seemingly apparent inverse association between cardiorespiratory fitness and CVD. It should be noted that limitations of the study included its purposive sampling strategy which may have been prone to selection bias along with the further limitation of self-reported height and weight as opposed to objective measurements.

1.1.4. Associations between firefighting and cancer

Firefighting has been associated with various genito-urinary, hematopoietic, and aerodigestive cancers, malignant melanoma and brain cancer (Lidoriki, Prieto and Smith, 2019). Specific cancers which have been associated with firefighting include: esophagus, colorectal, prostate, testicular, multiple myeloma, non-Hodgkin lymphoma, leukaemia, kidney, bladder, brain/central nervous system, lung, malignant mesothelioma, pharynx and larynx (LeMasters *et al*., 2006; Daniels *et al*., 2014; Tsai *et al*., 2015). Firefighting and overhauling combusted materials during post-incident work can expose firefighters to carcinogens including asbestos, acrolein, benzene, formaldehydes and free radicals which can be inhaled or absorbed through the skin (IARC Working Group, 2010; Fent *et al*., 2018). Firefighting as a profession has been associated with greater cancer incidence and cancer mortality (IARC Working Group, 2010; LeMasters *et al*., 2006). A cohort study of 30,000 USA firefighters observed increased cancer incidence of 9% and increased cancer mortality of 14% compared to the general population (Daniels *et al*., 2014). The exposures listed above are likely to have causal roles in this increased risk, and, with the exception of bladder, Lung, malignant mesothelioma, pharynx and larynx cancers, the majority of the cancers associated with firefighting have also been associated with obesity/excess adiposity (Lauby-Secretan *et al*., 2016; Kyrgiou *et al*., 2017). Therefore, obesity reduction may present an opportunity to reduce risk of several firefighting related cancers. Furthermore, there is a growing evidence base showing significant associations between dietary behaviour and risk of cancer incidence and cancer survival, with the Mediterranean diet showing an inverse association with several cancers, particularly colorectal cancer (Schwingshackl *et al*., 2017). This presents a further potential avenue of intervention for reducing cancer risk. Other lifestyle modifications should also be addressed in attempts to reduce risk of cancer whilst providing other health benefits (IARC Working Group, 2010).

Overall, there is a strong evidence base, suggesting firefighters to be at increased risk of non-communicable diseases related to their working environment.

1.2. Fitness requirements of firefighters in England

Firefighters are called upon to perform physically strenuous tasks in hot, humid and hazardous environments and can be called upon to perform more than twenty distinctive movements including running, squatting, bending, climbing, pulling, lifting and carrying (Office of the Deputy Prime Minister, 2004). The operational watch-based roles (firefighter, leading firefighter, Sub-officer and Station-officer) therefore require a varied range of physical abilities. Some of the most demanding activities involved in firefighting may be required to be performed infrequently, however, they remain critically important to the role when required. These can include carrying and pulling firefighting hose weighing 25 kg when dry, carrying casualties whilst wearing 25 kg of PPE, carrying and pitching ladders weighing up to 100 kg and operating cutting apparatus weighing 40 kg. For these tasks to be executed effectively and safely in extreme temperatures over a sustained duration of up to thirty minutes (the approximate duration that a single cylinder of compressed air lasts whilst working in breathing apparatus), minimum standards of cardiorespiratory fitness, muscular strength and endurance are required. Physical fitness is positively correlated with the effective performance of simulated work-related firefighting tasks (Rhea, Alvar and Gray, 2004; Elsner and Kolkhorst, 2008; Michaelides *et al.*, 2008).

1.2.1. Cardiorespiratory fitness

Firefighting demands a high standard of cardiorespiratory fitness to effectively and safely execute operational activities (von Heimburg, Rasmussen and Medbø, 2006). Elsner and Kolkhorst (2008) identified a strong inverse correlation between cardiorespiratory fitness and time taken to execute simulated firefighting tasks. Due in part to the requirement for firefighters to be able to support their body weight whilst undertaking firefighting tasks, most research in this area has focused on measuring cardiorespiratory fitness in terms of relative maximum oxygen uptake (VO2 max) (VO_2 ml/kg/min^{-1}). Whilst it remains difficult to accurately quantify these physical demands in a live fire scenario, simulated firefighting activities enabled earlier researchers to ascertain VO2 max using indirect calorimetry. This resulted in early estimates of the mean cardio-respiratory requirements of firefighting activities ranging from 23 ml/kg/min^{-1} to 44 ml/kg/min^{-1} (Bilzon *et al.*, 2001; Holmér and Gavhed, 2007). This variation may be due to methodological heterogeneity between studies, with the latter study using a more realistic simulation which combined work related tasks over a duration of twenty-two minutes. This identified stair climbing whilst carrying firefighting apparatus, followed by casualty rescue to be the most taxing activities eliciting a mean oxygen cost of 44 ml/kg/min^{-1}. More recent research commissioned by the Chief Fire Officers Association (CFOA) aimed to derive a national cardiorespiratory fitness standard for firefighters in the UK using simulated work-related firefighting tasks encompassing hose running, equipment carrying, stair climbing and casualty evacuation. The mean metabolic demand of these tasks with weighted adjustment produced the minimum cardiorespiratory fitness standard for UK firefighters, which was calculated as 42.3 ml/kg/min^{-1} (Siddall *et al.*, 2016).

1.2.2. Muscular strength and endurance

Adequate muscular strength and endurance are critical for the safe and effective execution of many firefighting tasks (Gledhill and Jamnik, 1992; Bilzon *et al.*, 2002; Jamnik, Gumienak and Gledhill, 2013). Even so, research has generally focused on the cardiorespiratory fitness levels required of firefighters. A recent study identified suitable surrogate assessments of muscular strength and endurance using gym-based tests (Stevenson *et al.*, 2017). Seated shoulder press, seated rope pull-down (single and repeated) were used as surrogate measures of work-related criterion tasks which were: ladder lift, ladder lower and ladder extension. Using sensitivity-specificity analysis, the study derived minimum muscular strength and endurance standards which equated to performance standards of 35 kg in the seated shoulder press (surrogate for ladder lift), 60 kg in the seated maximal single rope pull-down test (surrogate for ladder lower), and 23 repetitions of 28 kg (at 35 pulls per minute) in the seated repeated rope pull-down test (surrogate for ladder extension). The authors concluded that these gym-based standards are effective surrogate measures for assessing the operational readiness of UK firefighters for performance of occupational activities involving muscular strength and endurance.

1.2.3. Fitness testing

Up until 2020 there were no statutory national fitness standards in the English fire and rescue services (FRSs). In the London Fire Brigade (LFB) applicants underwent a basic fitness test at the selection stage. After this, aside from a routine occupational health medical check every three years, firefighters were not obliged to maintain their physical fitness. There was no standardised national fitness standard to attain, with some FRSs doing little or nothing in terms of physical fitness, whilst others had thorough fitness testing and training programmes (Williams, 2014). Due to a reduction in fires, firefighters are not exposed to fire-related physically demanding scenarios frequently enough to build and maintain role related physical fitness (Office of the Deputy Prime Minister, 2004). Gymnasiums are provided at fire stations, however, an ever-increasing administrative workload placed upon firefighters can reduce opportunity and motivation to use the gym along with other influences (Dobson *et al*., 2013). The Chester treadmill fitness assessment, along with a timed series of work-related tasks are the primary and secondary tests used in UK FRSs to test the cardiorespiratory fitness of firefighters. The minimum standards are based on the aforementioned study by Siddall *et al.* (2016), with the work related tasks test adapted by LFB to be more reflective of brigade specific working practices. Most other UK FRSs follow the protocols devised by Siddall *et al.* (2016). In early 2020 LFB introduced mandatory periodic fitness testing for all watch-based operational personnel . The Chester treadmill fitness assessment is a steady paced (3.9 miles/hour) twelve-minute walking incline treadmill-based test with incrementally increasing gradients of 3% every two minutes (from 0% to 15% gradient). Completion of the test resulted in passing the firefighter as fully fit for duty. A fail resulted in the firefighter being given a fitness improvement plan by one of four LFB fitness advisors, followed by returning to the testing centre in Paddington London after a brief remedial period to undertake the work-related tasks (secondary test). This is carried out with the firefighter wearing full fire gear (fire boots, leggings, tunic, helmet and gloves). Depending on the level of failure, the firefighter would either be referred and issued with an improvement notice or would be taken off operational duty and placed on light duties until their cardiorespiratory fitness improved sufficiently. Both tests reflect the VO2 max of 42.3 ml/kg/min^{-1} required of a firefighter (Siddall *et al.*, 2016). In March 2020 fitness testing in LFB was suspended due to the Covid-19 global pandemic.

1.2.4. Absence of testing muscular strength

Despite Stevenson *et al.* (2017) concluding that the minimum muscular strength and endurance standards derived from their study should be applied to all UK firefighters, UK FRSs have failed to adopt these standards. Furthermore, there are no known future plans to test these important components of occupational fitness for UK firefighters, therefore muscular strength and endurance is not routinely tested. This oversight may be due to bureaucratic concerns that the minimum standards recommended by Stevenson *et al.* (2017) may result in widespread failure and removal of of firefighters from operational duties, thus depleting resources and reducing fire cover. This concern may be exacerbated by an aging workforce, many of whom now have to work until age 60 y to collect a pension (Williams *et al*., 2013). Indeed, declines in strength and power occur in males and females from age 40 y caused by aged-related loss of skeletal muscle mass (SMM) (Metter *et al.*, 1997). Acknowledging this phenomenon, and furthermore the prediction that a significant proportion of serving firefighters between ages 55 and 59 y would indeed fail an occupational muscular strength test, the 2012 Fire Service National Pension Association Review by Williams *et al*. (2013) recommended that FRSs implement a national fitness policy that includes strength training. Despite this recommendation, LFB have simply manadated personnel to undertake two 75 minute sessions of physical exercise per week without clear stipulation of strength training within the fitness policy.

Whilst firefighting requires relatively high levels of physical fitness, there has been an historic absence of fitness testing. This concern is exacerbated due to an aging workforce.

1.3. Structure, governance and funding of the English fire services

1.3.1. Political structures

All of the English FRSs are governed by fire and rescue authorities (FRAs). There are forty-five FRAs (see Figure 1.2). Where FRSs share a boundary with a singular upper tier council, that council acts as the FRA. In this instance, the FRS is an integral component of the council, along with other public services including education, highways, social care and public health. Fifteen FRAs of this structure currently operate in England.

For non-metropolitan regions where the FRS's boundary encompasses multiple upper tier councils, a stand-alone combined fire authority (CFA) becomes the governing body. CFAs consist of elected councillors appointed by those in charge of each constituent council, with the proportion of members from each being dictated by relative population size, with the largest CFA comprising approximately twenty-five members. Twenty-three CFAs currently exist in England. Metropolitan regions follow a similar governance structure to this, whereby members are appointed from constituent metropolitan councils. Five FRAs of this structure currently operate in England.

London and Manchester have a different governance structure, with London recently adopting a similar structure to Greater Manchester fire service which is controlled by the mayor who is the FRA. As such, the mayor has responsibility for discharging the duties of the FRA, supported by a Fire Committee of fifteen members appointed from the ten Greater Manchester local authorities. Similar to Manchester, the mayor of London has responsibility for the FRS, however, the London Fire Commissioner fulfils the statutory role of the FRA and is therefore the Greater London Authority's functional body for fire. This unique arrangement in London came into effect in 2018, and like the aforementioned governance structures, is likely to change over time as the political landscape changes (Local Government Association, 2017).

1.3.2. Fire brigade sizes and rank structure

London Fire Brigade (LFB) also differs to the other FRSs in its size, operating 103 full-time fire stations manned by almost 4.7 thousand full-time firefighters, making it the largest UK FRS, with over 1,000 more firefighters compared with Scotland which is the second largest UK FRS. The other UK FRSs range from 235 full-time firefighters in Oxfordshire to 1.4 thousand in West Midlands (Statista, 2019). Furthermore, whilst most other FRSs still use a role-based hierarchical structure, LFB reinstated its rank structure in October 2019. The ranks are as follows: Firefighter, Leading firefighter, Sub-Officer, Station-Officer, Station-Commander, Group Commander, Deputy Assistant Commissioner, Assistant Commissioner, Deputy Commissioner, Commissioner. Unlike the military, all senior officers begin their career as a rank and file firefighter before passing promotional assessments.

1.3.3. Firefighter demographics

Around two thirds of the firefighters in England are wholetime, with the remainder being 'on-call' (part-time firefighters who usually have a full-time job elsewhere). The proportion of wholetime firefighters has gradually diminished from around three quarters in 2002 (Home Office, 2019). On-call firefighters are usually based in more rural areas where population density is lower. Firefighters make up the vast majority of the FRS workforce, with the average age of a firefighter in England being 41 y. Currently, 35% of firefighters are aged between 46 and 55 y, 4% are aged 18 to 24 y, therefore the majority (around 60%) are between 25 and 45 y (Home Office, 2020). This is now likely to become an aging workforce due to the imposition of a later retirement date for firefighters beginning service after 5th April 2006. Prior to this, firefighters could retire as early as 50 years of age after thirty years of service. The new firefighter pension scheme has set the minimum retirement age to 60 y. This was carried through as legislation despite a government commissioned independent review concluding that the majority of firefighters currently in service were unlikely to maintain physical capability to perform the role of firefighter up to age 60 y (Williams *et al.*, 2013).

1.3.4. Fire stations and watch-based rank structure

Fire stations are either equipped as 'single appliance' (one fire engine) or 'multi-appliance'. Most multi-appliance stations contain two fire engines however some contain three or more. A typical single-appliance firefighting team (watch) comprises one Sub-Officer who is the officer in charge of the watch; one leading firefighter who is the most junior officer and is delegated administrative responsibilities by the Sub-Officer; and five firefighters. At a two-appliance fire station this staffing level is roughly doubled, with a Station-Officer in charge instead of a Sub-Officer. At a one-appliance fire station there are typically five personnel on duty at any given time manning the fire engine. At a two-appliance station there are typically eight personnel on duty (four per fire engine). In previous years when staffing levels allowed, a two-appliance fire station would be staffed by ten personnel (five per fire engine). Wholetime fire stations operate a four-watch shift system to provide 24hr fire cover 365 days per year. The four watches are named: blue, green, red and white, with each watch typically being on duty for 42 hours per week (LFB therefore have 412 firefighting watches). This system follows an eight-day cycle whereby each watch is on duty for two consecutive days from 9:30am to 8pm, followed by two consecutive nights from 8pm to 9:30am, followed by four days off-duty.

1.3.5. Fire station routines

A typical day duty may involve the undertaking of emergency equipment inventories and testing, skills training, lunch, home fire safety visits (HFSVs), gym usage and dinner. A typical night duty may involve emergency equipment inventories and testing, a light meal, a training lecture and relaxation before a ‘stand-down’ period between midnight and 07:00hrs during which personnel are allowed to sleep. At any given moment firefighters can be mobilised to attend emergency incidents involving: fire suppression activities; water rescues; rescuing persons trapped; animal rescues; flooding; road traffic collisions; and hazardous material containment.

1.3.6. Governance

The governance method of FRAs is similar to that of local authorities, with FRA members being responsible for directing the policies of their FRS; setting a budget to facilitate delivery of those policies; and scrutinising performance to ensure that agreed outcomes are achieved within budget and in compliance with statutory regulations.

1.3.7. Funding

FRA funding is mainly derived from council tax and central government funds which are issued via local government finance settlements in the form of revenue support grants. FRAs also generate revenue by charging for some services which may not constitute an emergency e.g. regularly being called to false alarms at commercial premises. Some FRAs generate additional funds via commercial trading enterprises, i.e. LFB’s ‘Brigade Enterprises’. LFB’s annual budget is currently £400m approximately, although budget cuts amounting to £45m over the next four years have been announced by the mayor of London, partially due to the Covid-19 global pandemic financial contingency measures.

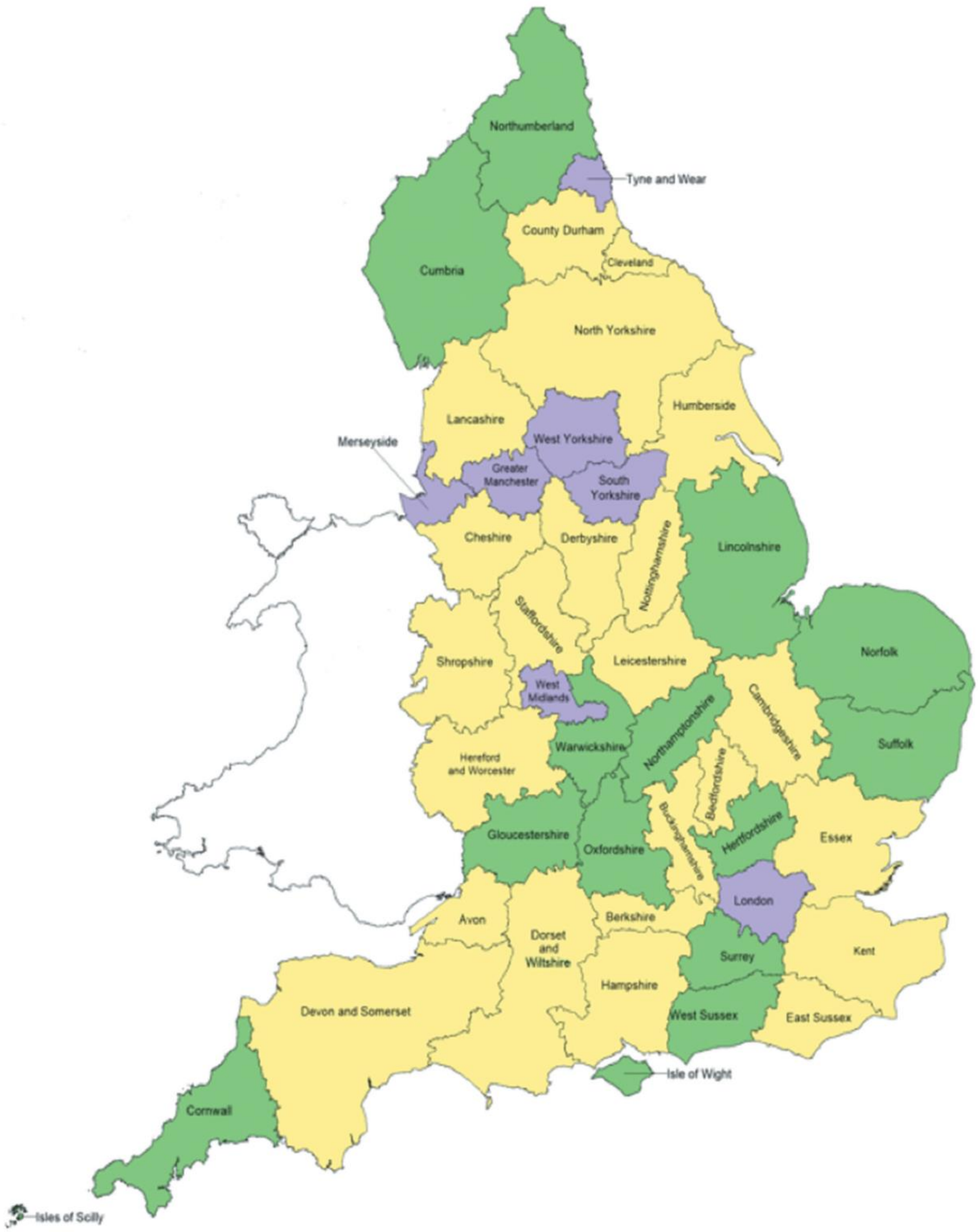
1.3.8. A changing workforce

The funding reductions have resulted in a diminishing workforce from a high of 31,761 wholetime firefighters employed in England in 2002, to 22,580 in 2018 (Office for National Statistics, 2019). This period has seen a demographic shift from female firefighters comprising 1.7% of the English FRSs in 2002 to 6.4% in 2019 (Home Office, 2019). This is mainly due to a decrease in the number of male firefighters which decreased by just over 9,900 between 2009 and 2018, as opposed to an increase of around 350 females within the same period (Office for National Statistics, 2019). The total number of firefighters in England has decreased by 23% since 2009 (Home Office, 2019). Between 2011 and 2018 the percentage of ethnic minority firefighters increased from 3.5% to 4.1% (Office for National Statistics, 2019).

1.3.9. A changing profession

English FRSs attended 241,500 fires in 2009 compared with 167,300 fires in 2018, equating to a 31% decrease (Home Office, 2020). This decline may be attributed to governmental smoking legislation, flame-retardant home furniture, and an increase of working smoke detectors whereby 90% of households had one by 2017 (Home Office, 2018). Figure 1.3 illustrates the changes in the numbers and types of incidents attended by English FRSs in the last decade.

This decline may be a product of the shift from a focus on emergency response to fire preventative work due to the Fire and Rescue Services Act (2004) introducing a statutory obligation to actively promote fire safety. Combined with the abolition of a perverse funding scheme which rewarded FRSs with greater funding if they attended more fires, this shifted the focus to a more proactive approach compared with the traditional reactive approach. This approach encompasses regular activities including HFSVs, arson preventative initiatives such as working with young offenders, and other community engagement initiatives (Home Office, 2018). Whilst the reduction in firefighting activities has reduced over time, a once active profession has steadily become more sedentary.



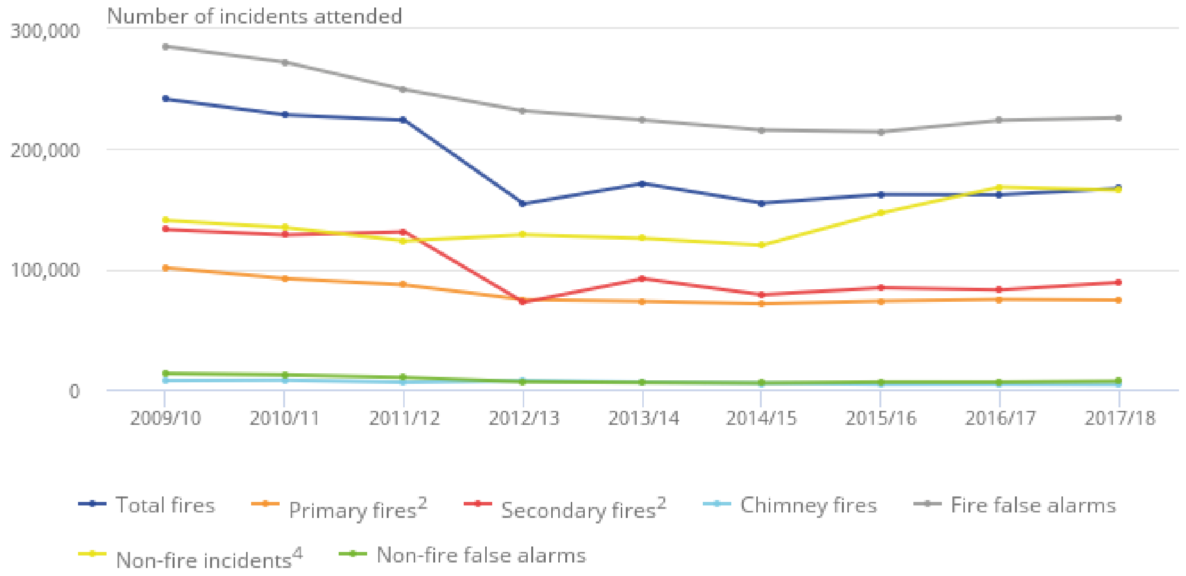
Metropolitan fire and rescue authorities, the London 'mayoral', and 'mayoral' fire authority in Manchester.

Combined fire and rescue authorities

County council fire and rescue authorities

Figure 1.2. Map of English fire and rescue authorities.

Source: Fire and rescue services in England (Local Government Association, 2017).



Source: Home Office, Fire statistics data tables, FIRE0102: Incidents attended by fire and rescue services in England, by incident type and fire and rescue authority, Table 0102

Figure 1.3. FRSs are attending fewer fires compared with 2009, although they are attending more non-fire incidents

1.4. Firefighter overweight, obesity, fitness and health

Amongst forty-one male dominated occupations in the USA, firefighting ranks as the third most obese (Caban-Martinez *et al*., 2005; Choi *et al*., 2011). Similar to the USA general population who have a higher overweight/obesity prevalence than the UK (Organisation for Economic Co-operation and Development [OECD], 2014), using BMI, early studies of USA firefighters quantified the combined prevalence of overweight and obesity to range from 73-88% (Kales *et al*., 1999; Clark *et al*., 2002; Soteriades *et al*., 2008; Tsismenakis *et al*., 2009; Donovan *et al*., 2009), suggesting a greater prevalence than the USA general population (Flegal *et al.*, 2010). Overweight/obese firefighters struggle with maintaining physical fitness, demonstrating significantly less cardiorespiratory fitness, muscular strength and endurance than firefighters of a healthy weight (Clark *et al*., 2002; Donovan *et al*., 2009; Tsismenakis *et al*., 2009; Poston *et al*., 2011; Mayer *et al*., 2012; Nogueira *et al*., 2016). This poses a huge problem, as research by Tierney *et al*. (2010) showed aerobically unfit firefighters to be at 90% increased risk of suffering an MI compared with aerobically fit firefighters. Obese firefighters are also less exercise tolerant and more susceptible to heat stress consequences and disorders (Donoghue and Bates, 2000; Chung and Pin, 1996).

1.4.1. Overweight/obesity prevalence of USA firefighter recruits

This problem is not confined to seasoned veterans, as over 75% of USA recruits start their careers as overweight/obese (Tsismenakis *et al*., 2009). Tsismenakis *et al*. (2009) found 7% of overweight recruits, and 42% of obese recruits failed to attain the suggested minimum aerobic capacity of 12 METS for safe and effective performance of firefighting tasks (Donovan *et al*., 2009). Conversely, the same study found that every recruit of a healthy weight successfully attained/surpassed 12 METS (Tsismenakis *et al*., 2009).

1.4.2. Firefighters gain weight over time

USA firefighters often accumulate excessive amounts of adipose tissue throughout the duration of their career (Poston *et al*., 2011). A five-year longitudinal cohort study found that the prevalence of obesity increased from 34% to 40%, equating to a 0.5 kg/y increase (Soteriades *et al*., 2005). This is conservative compared with other research observing USA firefighters to accumulate an approximate average of 1.5 kg/y (Elliot *et al*., 2007). Whilst UK firefighters have also been observed to gain body weight and fat as they age, research suggests it may be at a slower rate than in their USA colleagues, and more in alignment with UK general population age-related weight gain. Williams *et al.* (2013) reported a more gradual average increase in body mass of approximately 10 kg between ages 20 and 50 y in UK male firefighters, and approximately 5 kg between ages 25 and 50 y in UK female firefighters. This was reflected by an average increase in body fat percentage from 19% in male firefighters aged 20-24 y, to 26% in male firefighters aged 55-59 y (Williams *et al.,* 2013). Prior studies also indicate that firefighter overweight/obesity prevalence increases over time (Glueck *et al*., 1996; Ide, 2000; 2012; Davis *et al*., 2002). Indeed, the average BMI of LFB firefighters increased from 25.6 kg/m^2 in 2011 to 27.6 kg/m^2 in 2018 (see Chapter 4, Figure 4.1).

1.4.3. Aetiology of firefighter obesity

Qualitative research into the contributors to firefighter overweight/obesity has been carried out by Haddock *et al*. (2011). This suggested fire station eating habits to be a problem, where energy dense food in large portion sizes is often consumed. This was accompanied by a snack culture of high sugar foods resulting in a culture of over-nutrition. Whilst informative, these findings are limited with respect to understanding the multifactorial perpetuators of overweight/obesity, as explained in the UK Government Foresight report (2007) (see Figure 1.4). This concluded with the report recommendations from Haddock *et al*. (2011) going no further than suggesting that healthy food option advice should be offered to firefighters.

Qualitative research by Dobson *et al*. (2013) concurred with Haddock *et al*. (2011), also associating an obesogenic occupational environment with behavioural drivers of USA firefighter overweight/obesity. Dobson *et al.* (2013) took it a step further and identified five themes which contribute to this occupational group suffering one of the greatest overweight/obesity rates. The themes were: a culture of over-consuming energy dense food in large portions during mealtimes; sleep interruption from nocturnal emergency calls; a lack of supervisor encouragement regarding physical fitness/firehouse gym usage; sedentary work when not responding to emergencies or engaging in training on the drill ground; and generational influences. A UK fire station-based dietary and lifestyle intervention pilot trial by Lessons and Bhakta (2018) along with the lead author's extensive prior experience of seventeen years as a full-time LFB firefighter suggests that the same themes driving USA firefighter weight gain are indeed highly likely to be driving UK firefighter weight gain.

1.4.4. Psychological stress and obesity

Firefighters comprise an occupational group who suffer the added exposure of high levels of physical and psychological stress (Kales *et al*., 2009; Duran, Woodhams and Bishopp, 2018; Rodrigues *et al*., 2018). Research has identified associations between occupational stress and obesity (Schulte *et al.*, 2007; Kales *et al.*, 2009).

1.4.5. Shift work and health

Firefighters are generally shift workers, which is an independent risk factor for increased adiposity, overweight and obesity, with evidence supporting an inverse association between sleep deprivation and blood glucose control (Van Cauter *et al.*, 2008), and sleep deprivation's adverse effect on food choice (Spiegel *et al.*, 2004). Shift work and sleep deprivation may adversely affect regular eating patterns (Karlsson, Knutsson and Lindahl, 2001; Schulte *et al.*, 2007), and has also been suggested to interrupt the regular physical exercise of firefighters both on and off duty (Kales *et al.*, 2009). Indeed, shift work is strongly associated with poorer health via obesity, CHD, metabolic syndrome, type-2 diabetes, peptic ulcer disease, and mental illness (Akerstedt, 1990; Boggild and Knuttson, 1999; Harrington, 2001; Knutsson, 2003; Wang *et al*., 2011). It is worth mentioning that firefighters may be less exposed to disorders associated with shift work compared with other shift workers due to nocturnal duty sleeping arrangements. Nevertheless, sleep interruption is an integral feature of firefighting shift systems and has been linked with metabolic dysregulation (Knutsson *et al.*, 2007) possibly directly contributing toward obesity and type 2 diabetes (Knutsson and Van Cauter, 2008).

1.5. The consequences of overweight and obesity

1.5.1. Global prevalence

It is well established that excess body fat is detrimental to the fitness and health of humans via significant increased risk of non-communicable diseases (NCDs) (Jokinen, 2015). Overweight and obesity have become a global pandemic (Ortega, Lavie and Blair, 2016; Sung *et al.*, 2018), and are defined as abnormal or excessive fat accumulation that may impair health (World Health Organisation [WHO], 2020). Around a third of the global population is overweight or obese (Chooi, Ding and Magkos, 2019). Worldwide obesity has almost trebled since 1975, leading to a prevalence of 13% of the world's adult population, with a further 39% of adults being classed as overweight in 2016 (WHO, 2020). The majority of the global population reside in countries where overweight and obesity kills more humans than underweight (WHO, 2020). The USA has the greatest prevalence of adult obesity (38.2%) in the world. The UK has the sixth highest prevalence of adult obesity (26.9%) in the world (OECD, 2017).

1.5.2. Health and financial burden of obesity

Obesity is causally linked with chronic disease including CHD, hypertension, dementia, type 2 diabetes, joint pain, back pain, musculoskeletal disorders (particularly osteoarthritis), depression, sleep apnoea, several cancers, liver and kidney disease, reducing life expectancy by three to ten years (National Health Service [NHS], 2016). In terms of financial impact, obesity is costing the global economy an estimated 1.573 trillion pounds annually (Tremmel *et al.*, 2017). On a domestic level overweight and obesity are also likely to overburden the UK National Health Service (NHS) as well as the wider economy due to sickness absence from work and reduced productivity. This amounted to an NHS cost of £4.2 billion in 2007, as well as indirect costs estimated at £15.8 billion due to approximately 16 million lost working days arising from overweight/obesity associated sick leave (Van Duijvenbode *et al*., 2009; Foresight, 2007).

1.5.3. Aetiology of obesity, gender and ethnicity differences

The aetiology of obesity can involve: a positive energy balance (Sallis and Glanz, 2009), genetic effects (Speakman, 2013), gene-environment interactions (Phelan and Link, 2005) and social determinants (Arroyo-Johnson and Mincey, 2016). Males and females have differing regional distribution of adipose tissue, with males typically storing excess body fat in the abdominal region which is referred to as the android phenotype, and females typically storing excess body fat in more benign regions peripherally around the body which is referred to as the gynoid phenotype (Karastergiou *et al.*, 2012). Different ethnicities also have heterogenous physiological responses in terms of adipose tissue storage e.g. Afro-Caribbean females have the greatest obesity prevalence when using waist-to-height-ratio (WHtR) as the classification system, whereas Bangladeshi females have the greatest obesity prevalence if waist-to-hip-ratio (WHR) is used (Gatineau and Mathrani, 2011). It is also widely acknowledged that South Asian populations are at higher risk of adiposity related co-morbidities at lower BMIs compared with European populations (Gatineau and Mathrani, 2011). Additionally, the Chinese population has been identified as a high risk group for hypertension at lower BMIs compared with European populations (Razak *et al.*, 2007).

1.5.4. Metabolic syndrome (MetS)

MetS is a complex clustering of interrelated risk factors for type 2 diabetes mellitus and CVD. Prevalence of MetS is widespread and is increasing in prevalence around the globe, becoming a clinical and public health problem which is related to obesity and sedentary behaviour (Alberti *et al.*, 2009). The risk factors included are: hypertension (systolic BP ≥130 and or diastolic BP ≥85 mmHg); hypertriglyceridemia (triglycerides ≥1.7 mmol/l); low HDL-cholesterol (<1.0 mmol/l for men, and <1.3 mmol/l for women); hyperglycaemia (fasting blood glucose ≥5.6 mmol/l or non-fasting blood glucose ≥7.8 mmol/l defined as <3 hours between most recent meal and blood collection); elevated waist circumference (WC) (≥94 cm for non-Asian men, ≥90 cm for Asian men and ≥80 cm for women) (Alberti *et al.*, 2009). If an individual's MetS components are below the risk threshold due to medication, they are technically classified as positive for the relevant risk factor(s). If an individual has ≥ three of the aforementioned risk factors, they are classed as having MetS (Alberti *et al.*, 2009).

A recent case-cohort analysis of 17,733 adults from eight European countries assessed the independent and combined effects of weight status, central adiposity and metabolic health on CHD (Lassale *et al.*, 2018). The study found greater CHD risk for those with elevated BMI and WC. Whilst the associations between BMI and CHD were greatly attenuated when controlling for WC, the positive association between WC and CHD remained robust when controlling for BMI. Overweight and obese "metabolically healthy" (those without MetS) subjects were at greater risk of CHD compared with their healthy weight counterparts. To date this is the largest study to support the positive association between overweight/obesity (including people who are otherwise healthy on a metabolic level) and early morbidity/mortality. This has important health policy implications as currently, overweight individuals who present with no standard cardiometabolic risk factors are not advised weight reduction treatment by USA or UK guidelines (Jensen, Ryan and Apovian, 2014; NICE, 2014). Overweight and obesity are preventable (WHO, 2020), however this is a complex condition which is influenced by many factors including the media, social, psychological, economic, food, activity, infrastructure, developmental, biological and medical (Foresight, 2007). This complexity is illustrated by the UK government obesity policy document (Foresight, 2007) and its obesity system map displayed in Figure 1.4.

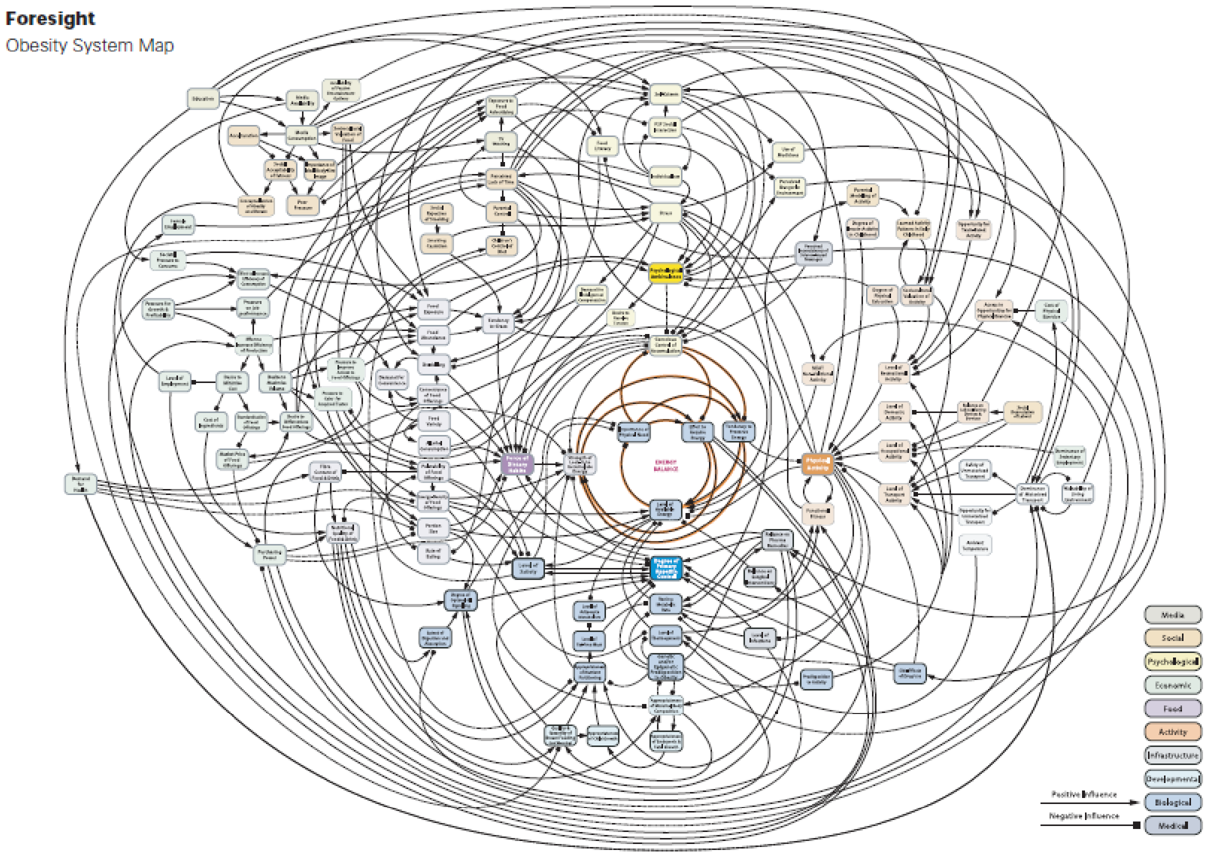


Figure 1.4. Obesity system map (Foresight, 2007)

1.6. Associations between firefighter adiposity and health

Several studies have investigated the relationship between obesity and the health of firefighters. This research is of particular importance, because when obesity affects emergency service personnel, the stakes are high, as due to impaired physical fitness (Michaelides *et al.*, 2011; Williford *et al.*, 1999) they are compromising personal safety, the safety of their colleagues and the public they serve (Moore, 2003). Table 1.1 summarises these studies, followed by a summary paragraph which describes the main findings. This is followed by a short review of each study within the context of adiposity and firefighter health.

Table 1.1. Summary of studies on the associations between male firefighter adiposity and health

Author/year	Sample and country	Study design	Methodology	Key findings
Ide, 2000	*n*=526 Scottish who retired in the decade beginning 1985.	Cross-sectional associations using data collected from routine periodic medicals.	BMI, BP, lipids.	Over the course of a career, BMI increased from 23.4 kg/m^2 to 26.6 kg/m^2. BP increased from 126/77 mmHg to 137/87 mmHg. fasting HDL cholesterol decreased whilst triglycerides increased.
Ide, 2012	*n*=114 Scottish FFs within 5 y of enlistment.	Cross-sectional associations using data collected from routine periodic medicals.	BMI.	Within 5 y, 84% of the firefighters had gained weight, with 8% of them became obese.
Soteriades *et al*., 2005	N=270 USA	Longitudinal cohort study 1996-2001	BW, BMI, lipids.	Accelerating weight gain of 0.52 kg/y. Obesity prevalence increased from 35% to 40%. Obesity correlated with a clustering of CVD risk factors.
Fahs *et al*., 2009	N=110 USA young (mean age: 30y)	Cross-sectional associations	BMI, BP, WC, β stuffness, elastic modulus.	Positive correlation between BMI and greater peripheral BP and arterial stiffness.
Poston *et al*., 2011	N=677 USA	Cross-sectional associations	BW, BMI, BF%, WC, BP, lipids.	Obese FFs had greater BP, LDL cholesterol, triglycerides, and lower HDL cholesterol.
Li *et al.*, 2017	N=1023 USA males and n=76 females	Cross-sectional associations	BW, BMI, BF%, CRF, MetS components.	Body fat significantly positively correlated with the number of MetS components among both sexes. Inverse correlation between CRF and the number of MetS components. Half of the sample failed to meet the minimum CRF standard. One third of them harboured at least 1 MetS component.
Smith *et al*., 2020 And Mathias *et al*., 2020	N=603 USA males and n=69 females	Longitudinal cohort study 5 years	BW, BMI, lipids, glucose, BP,	Females had lower CVD risk. Weight increased by 2.5 kg. LDL increased by 4.9 and 7.8 mg/dl^{-1} for males and females respectively. Male blood glucose increased by 2.6 mg/dl^{-1}. Hypertension increased. Male cholesterol increased. Obesity prevalence increased from 29-38% in the males and 10-15% in the females. Over the 5 y period, 12% of the sample lost >3% BW (losers). 50% gained >3% BW (gainers). The losers had reduced BP, LDL and increased HDL. The gainers had increased cholesterol, LDL, blood glucose and decreased HDL, and increased risk of 10 y risk of a CVD event.

Gendron et al., 2018	N=779 Canadian males	Cross-sectional associations	Self-reported: BMI, CRF, CVD risk factors, dietary intake, psychological stress.	Obesity prevalence and hypertension was greater than the age-matched general population. BMI predicted CVD risk. 86% of the sample reported at least 1 CVD risk factor and 59% reported at least 2. These firefighters had reduced estimated CRF. 13% had confirmed pulmonary, CVD or cardiometabolic disease. 44% were classified as high CVD risk. 42% had substandard CRF. There was a sig. association between psychological stress and the number of CVD risk factors. BMI category and CVD risk were both positively associated with SSB intake, and both inversely associated with fruit and vegetable intake.
Damacena *et al*., 2020	N=892 Brazilian male military firefighters	Cross-sectional associations	BMI, WC, CRF, blood lipids and glucose.	35% had substandard CRF. 23% had high cholesterol, 14% had high triglycerides and 31% had high glucose. All 3 biomarkers were positively associated with an 'at risk' WC. An at risk WC was inversely associated with CRF.

Abbreviations: BW, body weight; BMI, body mass index; BF%, body fat percentage; WC, waist circumference; BP, blood pressure; HDL, high density lipoprotein; LDL, low density lipoprotein; CVD, cardiovascular disease; MetS, metabolic syndrome; CRF, cardiorespiratory fitness; SSB, sugar sweetened beverage.

The main findings of the studies summarised in table 1.1 are that firefighter adiposity appears to increase over time, and excess firefighter adiposity is associated with adverse metabolic profiles and poorer cardiorespiratory fitness. Each of these studies have been reviewed in greater depth below.

1.6.1. Scottish firefighter adiposity and health

An early study to investigate associations between weight gain and CVD risk factors in firefighters was conducted on a sample of male Scottish wholetime firefighters (Ide, 2000). Analysing data collected during routine (three-yearly) medical examinations from *n*=526 firefighters who retired in the decade beginning 1985, the following results were found. Over the course of a career, mean (SD) BMI increased from 23.4 (2.6) kg/m^2 (healthy weight) at recruitment to 26.6 (3.2) kg/m^2 (overweight) at retirement. The proportion of obese firefighters increased from 1.8% to 17.2%. Significant increases in blood pressure were identified from 126/77 mmHg to 137/87 mmHg (systolic/diastolic). In addition to these significant longitudinal changes, fasting HDL cholesterol decreased whilst triglycerides increased. Based on these changes the author concluded that health educational initiatives had not been effective for this workforce (Ide, 2000). This early study alluded to a potentially obesogenic occupation with associated cardiovascular and cardiometabolic outcomes.

More recently the same author investigated changes in obesity prevalence of Scottish firefighters early in their careers (Ide, 2012). Of *n*=114 male firefighters followed from enlistment to an early (within five years) routine medical assessment, none were classified as obese at enlistment. Within five years, 84% of the firefighters had gained weight, with 8% of them becoming obese. The author suggested this to be a concerning indication of a decline in physical fitness. In 2008 the Grampian FRS within Scotland made headline news by taking a stand on its firefighter obesity problem (BBC, 2008). As a result, an obese firefighter was temporarily dismissed for failure to meet fitness targets, although this was quickly overturned following trades union involvement from the Fire Brigades Union (BBC, 2008).

1.6.2. USA firefighter adiposity and health

1.6.2.1. <u>Obesity and cardiovascular disease risk factors in firefighters: a prospective cohort study (Soteriades *et al*., 2005)</u>

An early study to investigate annual weight gain in USA firefighters and its relationship with CVD risk factors was a longitudinal cohort study of *n*=270 male firefighters in Massachusetts USA (Soteriades *et al*., 2005). From 1996 to 2001 the study reported an accelerating mean weight gain of 0.52 kg/y, identifying that younger firefighters (< 45 y) gained significantly more weight (double the rate) than older firefighters, and obese firefighters gained significantly more weight than non-obese firefighters. In that time the mean (SD) BMI increased from 29.0 (4.1) to 29.7 (4.3). Combined prevalence of overweight and obesity increased from 88% to 89.6%, however, prevalence of overweight reduced from 53% to 50%, whilst obesity prevalence increased from 35% to 40%. Obese firefighters were more likely to have high blood pressure than non-obese firefighters, and healthy weight firefighters were significantly more likely to have higher HDL-cholesterol than obese firefighters. The study also found obesity to be correlated with a clustering of CVD risk factors, which is also seen in the general population (Alberti *et al.*, 2009), and is consistent with the previous Scottish firefighter study by Ide (2000). The authors noted the concerning observation that weight gain accelerated over time and was of significantly greater magnitude in the younger personnel. This indicated an accelerating trend and a cohort effect more prevalent in the junior firefighters. This was later supported by the aforementioned study by Tsismenakis *et al*. (2009) which reported that 75% of USA recruits start their careers as overweight/obese. The authors acknowledged the limitation of classifying risk using BMI (which is unable to differentiate between fat and fat free mass) rather than BF%, although justified its use by the assumption that BMI is less likely to misclassify the obese or extremely obese. Whilst they also acknowledged the study limitation of no data on physical activity or dietary assessment, they concluded by stating the importance of addressing these modifiable risk factors via tailored physical activity programmes, dietary modifications and obesity surveillance (Soteriades *et al*., 2005).

1.6.2.2. Impact of excess body weight on arterial structure, function, and blood pressure in firefighters (Fahs *et al*., 2009)

Fahs *et al*. (2009) investigated the impact of excess body weight on arterial structure, function, and blood pressure (BP) in firefighters. The study involved a relatively young sample of *n*=110 firefighters with a mean (SD) age of 29.7 (8.0) y. The study grouped the subjects into tertiles by BMI, adopting a somewhat unorthodox grouping system of lean: <25.9 kg/m^2, overweight: 25.9-29.4 kg/m^2, and obese: >29.4 kg/m^2. As expected, the obese firefighters were significantly older and heavier with a greater WC compared with the lean and overweight firefighters. The same significant differences were found when comparing the lean and overweight groups. Compared with the lean firefighters, the overweight and obese firefighters had significantly higher systolic BP. A further difference was found in BP between the lean and obese groups in terms of significantly higher mean arterial BP and carotid systolic BP. Furthermore, compared with the lean and overweight firefighters, the obese firefighters had greater β stiffness and elastic modulus. The study concluded that in a sample of young firefighters, there was a positive correlation between BMI and greater peripheral BP and arterial stiffness, however, no impairment in endothelial function was observed. The slightly unorthodox BMI definitions highlights a limitation of the study, limiting its usefulness for comparisons with other studies. Even so, this study highlighted vascular impairment in overweight and obese firefighters.

1.6.2.3. The prevalence of overweight, obesity, and substandard fitness in a population-based firefighter cohort (Poston *et al*., 2011)

A cross-sectional study on a cohort of *n*=677 male firefighters serving in the Missouri Valley region of the USA assessed associations between weight and adiposity status with CVD risk factors including BP and fasting lipids (Poston *et al*., 2011). This study is reviewed in greater depth in section 1.9.2.1. in terms of BMI misclassifying 33% of the sample as overweight who BF% found to be obese (false negatives). The study found that regardless of the measure used (BMI/BF%/WC), obese firefighters had a greater likelihood of having adverse metabolic profiles compared with their non-obese colleagues in terms of greater systolic BP, diastolic BP, LDL cholesterol, triglycerides and lower HDL cholesterol (Poston *et al*., 2011).

1.6.2.4. Cardiac health and fitness of Colorado male/female firefighters (Li *et al*, 2017)

A recent study of 1099 firefighters, of whom 76 were women, serving in Colorado USA, focused on assessing the prevalence of MetS components (Li *et al*., 2017). The study found that, after controlling for age group, smoking status and alcohol intake, body fat was significantly positively correlated with the number of MetS components among both sexes. Overall prevalence of MetS was quite low (10% of the males and 5% of the females), although 36% of the males and 29% of the females had one MetS component, and 20% of the males and 11% of the females had two. The study also found an inverse correlation between cardiorespiratory fitness and number of MetS components. This finding is consistent with previous studies finding that high levels of cardiorespiratory fitness can attenuate the positive correlation between MetS components and CVD-associated mortality (Mcauley and Blair, 2011; Mcauley *et al.*, 2012). Considering that nearly half of the sample failed to meet the minimum cardiorespiratory fitness standard, and that around one third of the sample harboured at least one MetS component, these results support the recommendation by Storer *et al*. (2014) who stated that health professionals should be empowered to use their expertise in guiding intervention programmes with the aim of reducing incidence of SCD/stroke.

1.6.2.5. <u>Cardiovascular disease risk factor changes over 5 years among male and female US firefighters (Smith *et al*., 2020)</u>

A recent study by Smith *et al*. (2020) examined changes in the cardiovascular health of *n*=603 male and *n*=69 female firefighters serving in Virginia USA. Data on CVD risk factors were collected from two routine occupational medicals separated by five years. To date this is the only study to have examined longitudinal CVD risk factor changes in female firefighters. Consistent with previous studies (Jahnke *et al*., 2012; Choi *et al*., 2016; Li *et al*., 2017), the females had more favourable CVD risk factors than the males. After controlling for participant age, five years after baseline measures, significant changes were identified whereby body weight increased by 2.5 kg for the males and the females, which is consistent with the study on male firefighters by Soteriades *et al*. (2005) (see section 1.6.2.1). BMI increased by 0.8 and 1.0 kg/m^2, and LDL cholesterol increased by 4.9 and 7.8 mg/dl^{-1} for males and females respectively. Male blood glucose increased significantly by 2.6 mg/dl^{-1}, and BP decreased significantly for both sexes however this was attributed to a significant increase in anti-hypertensive medication. Despite this, 46% and 29% of the males and females respectively had stage one or two hypertension after five years. The proportion of male firefighters classed with above healthy cholesterol and blood glucose increased over five years. Whilst prevalence of obesity increased from 29-38% in the males and 10-15% in the females, associations between other CVD risk factors and obesity were not investigated. Overall, these results support the evidence base suggesting that both male and female firefighters show a high prevalence of obesity and CVD risk factors which increase over time and independent of age.

1.6.2.6. Changes in firefighter weight and cardiovascular disease risk factors over five years (Mathias *et al*., 2020)

The same research group (see section 1.6.2.5) measured changes in CVD risk factors within the study subjects who lost >3% body weight (comprising 12% of the sample), subjects who remained weight stable within ±3% body weight (comprising 38% of the sample), and subjects who gained >3% body weight (comprising 50% of the sample). The weight loss subgroup lost an average of 7.2 kg and showed significant reductions in total cholesterol (-8.5 ± 3.9 mg/dL^{-1}), LDL cholesterol (-6.7 ± 3.3 mg/dL^{-1}), and BP (systolic: -5.3 ± 1.3 mm Hg; diastolic: -4.2 ± 1.0 mm Hg), and an increase in HDL cholesterol (2.3 ± 1.0 mg/dL^{-1}). Conversely, the weight gain subgroup gained an average of 6.6 kg and showed significant increases in total cholesterol (+12.9 ± 1.8 mg/dL^{-1}), LDL cholesterol (+11.1 ± 1.6 mg/dL^{-1}), blood glucose (+2.9 ± 0.7 mg/dL^{-1}), 10-year risk of a CVD event (+2.6 ± 0.2%), and a decrease in HDL cholesterol (-1.3 ± 0.4 mg/dL^{-1}). The weight stable subgroup showed significant increases in blood glucose (+2.7 ± 0.9 mg/dL^{-1}), 10-year risk of a CVD event (+1.7 ± 0.2%), and decreased BP (systolic: -3.5 ± 0.8 mm Hg; diastolic: -3.7 ± 0.6 mm Hg). Over the 5-year study period, prevalence of obesity within the entire sample increased significantly from 27% to 36%. The fact that 50% of the sample were either weight stable/lost weight over the study period may be due to the 'Wellness Fitness initiative' (see section 1.12.2) which was adopted by the fire department being studied. Even so, 50% of the sample gained a significant amount of weight, leading the authors to conclude that future research is required to establish the most effective weight-loss strategies in terms of physical activity and dietary modification, stating that the amount of weight gain observed in this cohort provides strong evidence for the implementation of such programmes to improve firefighter health.

1.6.3. Canadian firefighter adiposity and health

Cardiovascular disease risk factors in Québec male firefighters (Gendron *et al.*, 2018)

A recent cross-sectional study of *n*=779 male firefighters serving in Quebec Canada quantified the prevalence of CVD risk factors and tested for associations with lifestyle variables (Gendron *et al.*, 2018). The study also tested the accuracy of BMI for correctly classifying obesity in the sample. This was undertaken by analysing associations between BMI classification and cardiorespiratory fitness, dietary behaviour, CVD risk profile and psychological stress. Whilst a strength of this study was a large sample size, two important limitations should be noted whereby recruitment was undertaken by staff email which could have attracted an unrepresentative sample due to potential volunteer bias. Furthermore, all of the data collected was self-reported via an online survey, which could be prone to varying levels of social desirability bias (Worsley *et al*., 1984), recall bias and other systematic errors generated by subjective measures. The authors suggested that obesity prevalence was possibly overestimated due to the absence of objective measures employed by the study. This is contrary to the prevailing evidence base which suggests that people generally underestimate their own body weight (Wise, 2015). Indeed, a study by Hsiao *et al*. (2014) investigated discrepancies between measured and self-reported anthropometric information in a large sample of USA firefighters, finding significant underestimations of weight by male firefighters (-0.4 kg) and female firefighters (-1.1 kg) and overestimations in height of 29 mm and 17 mm respectively.

Gendron *et al*. (2018) estimated the sample obesity prevalence to be 18.8% for the under-45 y age group, which was the same as Quebec male adults in the general population. For the firefighters ≥45 y, obesity prevalence was 28.9% which was 6.8% greater than the Quebec male adults in the general population. The authors mentioned the possibility of BMI generating false positive errors in populations possessing above average skeletal muscle, however, they then cited the findings of Poston *et al.* (2011) who found BMI to underestimate obesity. The authors of the current study extrapolated those findings to their own study, which concluded that it is likely that BMI does not overestimate the prevalence of obesity in Quebec male firefighters (Gendron *et al.*, 2018). A limitation of the study was that obesity prevalence was not quantified by any alternative measure of adiposity, therefore the validity of BMI for classifying obesity in this population remains unknown. However, the study found BMI to be an important indicator of CVD risk in the sample. This is consistent with research finding that elevated adiposity and obesity is associated with on-duty cardiac events in American firefighters (Geibe *et al.*, 2008). It is also consistent with the cross-sectional study of *n*=1,462 middle-aged firefighters serving in Canada which found significant inverse correlations between weight/adiposity measures (BMI, WC, WTR and WHtR) and measures of vascular function, which concluded that anthropometric measures of adiposity could help refine estimations of atherosclerotic burden (Martin *et al*., 2013).

For the Quebec male firefighters, self-reported hypertension within the 20-44 y age group was significantly greater (5.8% prevalence) than the age-matched Quebec adult male general population (3.8% prevalence). The older age group (45-64 y) was not significantly different (19.1% prevalence) compared with age-matched males in the Quebec general population (22.5% prevalence). This was an important finding of this study given that chronic hypertension has been associated with mortality of firefighters, as outlined earlier in this chapter. Excluding age, in terms of unmodifiable CVD risk factors, 86% of the sample reported at least one and 59% reported at least two. In terms of modifiable CVD risk factors, 80% reported at least one and 37% reported at least two. Crucially, 13.4% of the firefighters had confirmed pulmonary, CVD or cardiometabolic disease. In summary, 35% were classified as moderate CVD risk, and 44% as high CVD risk. General recommendations are that people in these risk categories should refrain from physical exertion of intensities > 85% of their maximal heart rate without medical clearance, although this can be exceeded during firefighting activities (Baker *et al.*, 2000; Bos *et al.*, 2004; Bugajska *et al.*, 2007). Concerningly, 42% of the sample failed to meet the minimum standard of cardiorespiratory fitness. This is consistent with studies of USA firefighters observing that between 34% and 56% of firefighters fall below the minimum cardiorespiratory fitness level (Baur *et al*., 2011; Poston *et al*., 2011). This study also identified that those with at least one CVD symptom had reduced estimated cardiorespiratory fitness compared with those without symptoms. This is consistent with prior research finding that increased cardiorespiratory fitness has favourable independent outcomes in terms of reduced CVD risk for firefighters (Baur *et al.*, 2011), and that a dose-response inverse association exists between firefighter cardiorespiratory fitness and the number of metabolic risk factors (Baur, Christophi and Kales, 2012). In terms of psychological stress, this study detected a positive association between the number of CVD risk factors and the level of perceived stress. In terms of dietary intake, BMI category and CVD risk were both positively associated with sugar sweetened beverage intake, and both inversely associated with fruit & vegetable intake. The authors concluded that dietary and lifestyle interventions should be designed and implemented to reduce the high prevalence of modifiable CVD risk factors in Canadian male firefighters (Gendron *et al.*, 2018).

1.6.4. Brazilian firefighter adiposity and health

<u>Obesity prevalence in Brazilian firefighters and the association of central obesity with personal, occupational and cardiovascular risk factors: a cross-sectional study (Damacena *et al*., 2020)</u>

A recent cross-sectional study of *n*=892 male military firefighters serving in Brazil investigated obesity prevalence and potential associations between central obesity with personal, occupational and CVD risk factors (Damacena *et al*., 2020). The study reported that despite 65% of the sample demonstrating sufficient cardiorespiratory fitness (≥ 12 METS), 62% of the sample reported a level of physical activity which the study criteria placed them ‘at risk’. This may be due to a limitation of the study methodology which employed an unvalidated self-reported measure of physical activity which may have been prone to unknown levels of error and bias. The mean BMI was 26.2 kg/m^2 and mean WC was 87 cm which indicates a disparity between measures which is discussed in greater depth later on in this chapter. 18.6% of the firefighters had a WC ≥ 94 cm (at risk), and the proportion of the sample above the recommended blood biochemical levels for cholesterol, triglycerides and glucose were 23%, 14% and 31% respectively. Significant positive associations were identified between those with an ‘at risk’ WC and age, family income, total cholesterol, triglycerides and blood glucose. Level of education was not significantly associated with having an at-risk WC. Significant inverse associations were identified between those with an ‘at risk’ WC and self-reported physical activity and cardiorespiratory fitness. Significant predictors of an ‘at risk’ WC were: being in the 50-

59 y age range, low physical activity, lower cardiorespiratory fitness, higher levels of blood glucose and triglycerides. The authors concluded that their results demonstrate a need for obesity and cardiometabolic disease intervention programmes for this population.

1.7. Measuring body composition

Measuring human body composition is usually undertaken to quantify deficient or surplus levels of a component that is considered to be associated with health risk e.g. the ability to assess levels of adiposity and bone mineral density enable clinical diagnosis of obesity and osteoporosis respectively. This information is then used to inform appropriate interventions to ameliorate/attenuate pathogenic disease states (Lee and Gallagher, 2008). Body composition analysis is usually achieved using the two-compartment (2C) model. This model partitions the body into two components: fat mass (FM) and fat free mass (FFM). The limitations of the 2C model are its assumptions of known and constant percentages of FFM in terms of water, mineral and protein. When these assumptions are violated i.e. in pregnancy, infancy, aging and in certain disease states, body composition estimation accuracy is compromised (Lee and Gallagher, 2008). The four compartment (4C) model partitions the body by body mass, volume, water and bone mineral. This is considered to be the most accurate way of assessing body composition and is often the criterion method against which other methods are validated. The limitations of the 4C model are that it requires expensive laboratory equipment confined to a research setting. This limits the availability of the 4C model to clinicians and researchers (Lee and Gallagher, 2008). Body composition can be assessed or measured in a variety of ways, each with its own strengths and limitations. Common methods which use the 2C method include the following: using skinfold callipers, underwater weighing (densitometry), air-displacement plethysmography, magnetic resonance imaging (MRI), computerised tomography (CT), dual energy x-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA). The level of health risk posed by abdominal (central) adiposity can be estimated using several anthropometric measures including: waist circumference (WC), or waist-to-hip ratio (WHR), or waist-to-thigh ratio (WTR), or waist-to-height ratio (WHtR).

1.7.1. BMI

BMI is not a measure of body composition, but a score for classification of a person's weight status. Its calculation is derived from the measure of a person's body weight which has been adjusted for individual height: BMI = weight (kg)/height (m)^2. A person's weight status is then classified using cut-offs displayed in Table 1.1. The strengths of BMI are its ease of administration on a population scale, its low financial cost, and its internationally agreed risk cut-offs (Gallagher *et al*., 2000). The main limitation of BMI is its intrinsic inability to differentiate between fat and fat free mass. This can lead to misclassification of individuals (Gallagher *et al*., 2000), a problem which is exacerbated in population groups possessing a relatively high ratio of fat-free mass to fat mass i.e. bodybuilders (generating false positive errors) (Gallagher *et al*., 2000; Choi *et al*., 2016), or population groups possessing a relatively high proportion of fat mass to fat-free mass i.e. South Asian populations (generating false negative errors) (Razak *et al.*, 2007). The validity of BMI as an assessment of adiposity related health risk is therefore reduced for various population groups.

1.7.2. Skinfold thickness

This method utilises purpose-built handheld callipers to measure the width of skinfolds which are pinched and clamped at several designated anatomical sites. Equations are then used to estimate the total amount of body fat. The strengths of this method are the low financial expense and the very lightweight portable equipment. The limitations of this method are that it requires a relatively high level of knowledge to administer with good precision and accuracy (Rodríguez *et al.*, 2005). This means that there is a relatively high chance of inter and intra-measurer variability leading to compromised accuracy and reproducibility, with accuracy and precision being further compromised when measuring obese subjects (Gray *et al.*, 1990). Furthermore, the skinfolds method mainly assesses subcutaneous fat (De Schutter *et al*., 2013), and the equations used in the skinfolds method assume that all humans have similar distributions of fat mass, which is known to be untrue (Razak *et al.*, 2007), therefore this method could be considered a relatively crude method for estimating total body fat. However, with a sufficient level of training and methodological rigour, skinfold-based BF% has shown good agreement against the more accurate method of DXA (Amaral *et al*., 2011).

1.7.3. Underwater weighing (densitometry)

This entails weighing the subject in air whilst submerged in a water tank. Formulas are then used for the estimation of body volume, density and fat percentage. The main strength of this method lies within its high level of accuracy (Biaggi *et al*., 1999; Kuriyan, 2018). Its limitations are the requirement of a research setting with the appropriate facilities, and it being a time-consuming process which may cause discomfort (Kuriyan, 2018).

1.7.4. Air-displacement plethysmography

The subject sits in a small chamber whilst the machine uses air pressure changes between the chamber being empty and occupied to estimate body volume, which then enables the calculation of FM. The strengths of this method include a high level of accuracy (Biaggi *et al*., 1999; Kuriyan, 2018), speed of administration, a good option for the elderly, pregnant women and obese subjects. Its limitations are the financial expense of the machine and that it requires a research setting, therefore it is not feasible for use in the field.

1.7.5. MRI and CT

These are the most accurate methods for measuring body composition. Their main strength is that they can differentiate between and accurately quantify the distribution of subcutaneous adipose tissue (SAT), visceral adipose tissue (VAT), intermuscular adipose tissue, skeletal muscle, smooth muscle, organs and bone (Heymsfield *et al*., 1997; Lee and Gallagher, 2008). Their limitations include their financial expense and the requirement of a laboratory setting due to the lack of equipment portability. Furthermore, Due to ionising radiation levels emitted by CT scans, this method should not be used on children or pregnant females (Hoshiko *et al.*, 2014). Some CT and MRI machines may not be built to accommodate very large people (BMI of ≥ 40 kg/m^2) (Lee and Gallagher, 2008).

1.7.6. DXA

This method uses two x-ray beams to quantify FM, FFM and bone mineral density. Its main strength is a high level of accuracy and reproducibility (Lee and Gallagher, 2008), providing regional body composition analysis, and assessment of nutritional status in disease states. Its limitations include its financial expense, confinement to a laboratory setting, It cannot accurately differentiate between SAT and VAT (Lee and Gallagher, 2008), and it should not be used on pregnant females due to the emission of low-dose radiation. Similar to MRI and CT scanners, most DXA machines are not built to accommodate very large people (Lee and Gallagher, 2008).

1.7.7. BIA

Based on the 2C method, BIA sends small electrical current signal(s) of either a single frequency or multiple frequencies around the body. The signals face greater resistance, reactance and impedance when passing through adipose tissue compared with FFM and water. Single-frequency BIA assesses total body water (TBW) and FFM but is unable to reliably distinguish between intracellular water (ICW) and extracellular water (ECW). Multifrequency BIA overcomes this limitation therefore enabling the valid assessment of hydration status and fluid balance (Heymsfield *et al.*, 1996). Both versions of BIA technology employ the use of algorithms (predictive equations) which are population specific, therefore a limitation of BIA is that accuracy is reduced for use in populations with phenotypic characteristics which differ from the reference population (Deurenberg, Deurenberg-Yap and Schouten, 2002; Kyle, Piccoli and Pichard, 2003), unless calibration equations are used to account for differences (Dehghan and Merchant, 2008) such as the aforementioned South Asian phenotype. The most accurate BIA systems are segmental analysers which measure the trunk and limbs individually (Verney *et al*., 2015), as opposed to inferior models which assume a constant fat distribution based upon an upper or lower body measurement using a hand-to-hand analyser or foot-to-foot analyser respectively. The strengths of BIA are its accuracy, relatively low financial cost, portability and fast assessment with minimal training, therefore making it a suitable choice for large scale studies (Pietrobelli *et al*., 2004). Its limitations include compromised accuracy depending on the hydration status of the subject, the point at which a pre-menopausal female subject is at in her menstrual cycle, underlying disease states and environmental conditions (Dehghan and Merchant, 2008). Recently developed, more sophisticated BIA analysers are more accurate, having been validated to be within 2% accuracy when using DXA as the reference method (Verney *et al*., 2015).

1.7.8. WC

WC is a proxy measure of central adiposity which utilises stretch resistant anthropometric measuring tape. WHO (2011) recommend measuring WC at the midpoint between the lower margin of the least palpable rib and the top of the iliac crest, however some researchers choose to measure WC at the level of the umbilicus. The main strengths of this method are speed of administration, the equipment is of minimal financial cost and highly portable therefore highly suitable for field work, and WC is positively associated with morbidity and all-cause mortality (Jayedi *et al.*, 2020). The limitations are listed below.

1.7.9. WHR

WHR is a calculated by measuring WC and hip circumference using stretch resistant anthropometric measuring tape, followed by dividing WC by the hip circumference at the widest level of the buttocks, over the trochanters. The strengths of WHR are the same as for WC. The limitations are listed below.

1.7.10. WTR

WTR is calculated by measuring WC and thigh circumference (usually of the non-dominant leg) using stretch resistant anthropometric measuring tape, measured at the mid-point between the inguinal increase and the proximal border of the patella. WC is then divided by thigh circumference. The strengths of WTR are the same as for WC and WHR. The limitations are listed below.

1.7.11. WHtR

WHtR is calculated by dividing WC by height. The strengths of WHtR are similar as for WC, WHR and WTR. The limitations are listed below.

1.7.12. General limitations of waist measurements and ratios

Similar to WC, WHtR is just as susceptible to inter and intra-measurer error, the magnitude of which is unclear (Verwweij *et al*., 2012). An absence of internationally agreed measurement protocols and a lack of training contribute to the problem, which may be exacerbated when administered around clothing. WC and WHtR's validity as reliable markers of intra-abdominal fat are also questionable as they are unable to differentiate between abdominal subcutaneous adipose tissue and visceral adipose tissue, which can vary significantly for a given WC (Thomas *et al*., 2012). Other general limitations of circumference indices include: inter and intra-measurer variability potentially reducing accuracy, precision and reliability of measurements; difficulty in identifying the correct anatomical measurement site, particularly in obese subjects; anthropometric measurement tape tension can compromise reproducibility; protocol heterogeneity between studies; inter-ethnicity variability with cut-off values often unavailable for many populations; ratio indices are more error-prone as two measurements are necessary; measuring WC depends on bone structure, phase of respiration, muscle mass, relaxation of abdominal muscles, fasting/postprandial state and posture of the subject (Medical Research Council [MRC], 2018).

Table 1.2. Analogous BMI, BF%, WC and WHtR weight status/adiposity status/health risk classifications

Adiposity measure		**Under-weight/ Under-fat**	**Healthy**	**Overweight/ Overfat**	**Obese**
BMI		< 18.5	18.5 – 24.9	25.0 – 29.9	≥ 30
BF%	Males 20-39 y	< 8	8 – 20	20.1 – 25	> 25
	Asian males 20-39 y	< 13	13 – 23	23.1 – 28	> 28
	Males 40–59 y	< 11	11 – 22	22.1 – 28	> 28
	Asian males 40–59 y	< 13	13 – 24	24.1 – 29	> 29
	Males 60-79 y	< 13	13 – 25	25.1 – 30	> 30
	Asian males 60-79 y	< 14	14 – 24	24.1 – 29	> 29
	Females 20-39 y	< 21	21 – 33	33.1 – 39	> 39
	Asian females 20-39 y	< 25	35 – 35	35.1 – 40	> 40
	Females 40-59 y	< 23	23 – 34	34.1 – 40	> 40
	Asian females 40-59 y	< 25	25 – 35	35.1 – 41	> 41
	Females 60-79 y	< 24	24 – 36	36.1 – 42	> 42
	Asian females 60-79 y	< 25	25 – 36	36.1 – 41	> 41
WC (cm)	Males		≤ 94	94.1 – 102	> 102
	Asian males		≤ 90		> 90
	Females		≤ 80	80.0 – 87.9	≥ 88
	Asian females		≤ 80		> 80
WHtR			< 0.5	0.5 – 0.59	≥ 0.6

Abbreviations: BMI body mass index, BF% body fat percentage, WC waist circumference (cm), WHtR waist-to-height-ratio. BMI and WC ranges derived from (WHO, 2000). BF% ranges derived from (Gallagher *et al.*, 2000). WHtR ranges derived from (Ashwell, 2011).

1.8. Classifying risk

The graded classification of adiposity status is important for enabling health care professionals, clinicians and researchers to identify individuals at increased risk of non-communicable diseases (NCDs), thereby indicating those who may benefit from interventions to reduce risk of poor health outcomes. NCD and mortality risk level in terms of body composition is generally defined in terms of adiposity, with little attention paid to skeletal muscle mass (SMM). This can be considered an oversight given that SMM is important as a regulator of whole-body glucose homeostasis via insulin-mediated glucose disposal. Low muscle fitness has been associated with increased metabolic risk (Steene-Johannessen *et al*., 2009), and muscle strength has been positively correlated with insulin sensitivity (Benson *et al.*, 2006). An ever-increasing automated environment is not only obesogenic, but also reduces the requirement for physical activity. Inadequate physical activity results in anabolic resistance leading to the atrophy of SMM, reduced mobility and, at the extreme end of the spectrum, sarcopenia (Morton *et al.*, 2018). In recent years researchers have begun to realise the importance of SMM's role in the progression of insulin resistance (Morton *et al.*, 2018). From a public health perspective this is particularly important in an ageing population such as that of the UK (Office for National Statistics [ONS], 2018). This recently manifested in Lee *et al*. (2020) producing the first SMM reference values for UK adults. These references act as a simple assessment tool for nutritional surveillance, enabling clinicians and researchers to identify adults with low SMM and those at risk of sarcopenia.

To some extent, body composition changes throughout the life course are inevitable. SMM typically declines from age 50 y with a gradual loss of muscle fibres resulting in an appendicular muscle fibre reduction of roughly 50% by age 80 y (Faulkner *et al.*, 2007). Conversely, FM increases with age (St-Onge and Gallagher, 2010). Whilst these deleterious effects of aging can be attenuated to some degree via nutritional and physical activity intervention (Morton *et al.*, 2018), the inevitable deterioration of body composition was the principle behind the production of the commonly used age-related BF% risk cut-offs (Gallagher *et al*., 2000).

This international study aimed to develop an adiposity risk classification system to overcome the limitations of BMI. A sample of *n*=1626 white, African American and Asian adults were evaluated in three research centres: UK, USA and Japan in the creation of the system. The resulting BF% ranges (see Table 1.1) were developed using reference methods (densitometry and DXA) for measuring total adiposity, which were then converted to sex, age and ethnicity specific BF% ranges analogous to the standard BMI ranges (Table 1.1). A conclusion of the study was that future studies should focus on the issue of age-related adiposity increase even when BMI remains constant. This alluded to the problem of a constant BMI value potentially masking synergistic body composition changes in terms of increasing FM and decreasing FFM. A cross-sectional study of *n*=64 Australian firefighters did indeed find that BMI masked differences in body composition between younger and older firefighters which were detected by DXA and BIA, whilst BMI and WC were not significantly different between age groups. The study concluded that BIA may be a practical alternative for assessing the body composition of professional urban firefighters (Smee *et al*., 2019).

This potential masking effect is not exclusively confined to anthropometric measures, as BF% can itself mask changes in body composition. Whilst BF% is a more valid body composition assessment tool than BMI, it is still prone to potentially high rates of misclassification (Rothman, 2008) due to limitations which are described in detail elsewhere (Bosy-Westphal and Müller, 2015). Briefly, because BF% is a proportional measure as opposed to an absolute measure of adiposity, it is affected by FFM, therefore high/low levels of FFM drive the BF% downward/upward respectively (see Figure 1.5a). Furthermore, characterising health risks via BF%, and comparing results between studies is challenging due to the lack of internationally agreed risk cut-off points for body fatness (Romero-Corral *et al*., 2010). The reference chart risk cut-offs which currently exist are devised for the general population (Gallagher *et al*. 2000) and therefore may not be appropriate for application to demographics who require a leaner body composition.

The problems associated with proportional (percentage) measures of body composition were overcome in the UK white adult body composition references developed by Lee *et al*. (2020), whereby both SMM and FM were adjusted for participant stature by dividing by height $(m)^2$. This converted SMM to the SMM index (SMMI) and FM to the FM index (FMI). Adjusting measures of SMM and FM for height overcomes a further limitation of proportional measures such as BF% i.e. two people of the same weight and BF% will have differing body composition status if they are of different heights, whereby the shorter person will have a greater FMI. For example, two people who each weigh 100 kg, of which 40 kg is FM, each possess 40% FM. If one of the people is 1.5 m and the other is 2 m in height, then the first person is overfat with an elevated FMI compared with the other person. This example is illustrated in Figure 1.5b (Bosy-Westphal and Müller, 2015).

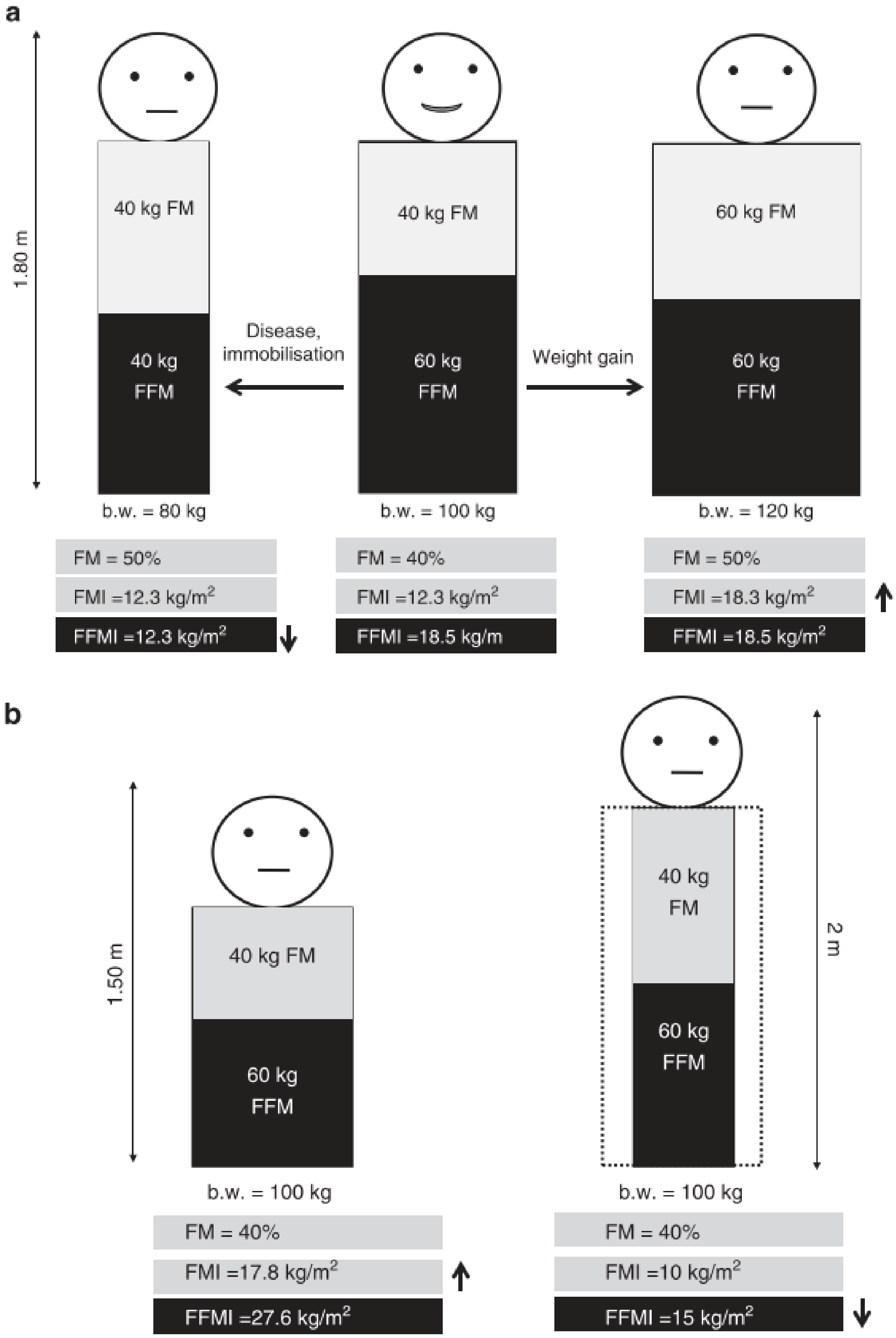


Figure 1.5. Justification for using height-adjusted indexes as opposed to proportional measures when classifying body composition. (a) The same percentage of body fat can result from a decline in FFM (left picture) or an accumulation of FM (right picture). (b) Two subjects with the same body weight, the same body fat percentage, but of differing heights will have different nutritional states i.e. Elevated FMI = greater adiposity (left picture), whereas lower fat-free mass index (FFMI) = lower muscle mass (right picture) (Bosy-Westphal and Müller, 2015).

1.9. Prevalence of firefighter overweight and obesity, and BMI-generated misclassification

Several studies have investigated the of firefighter overweight, obesity and how BMI misclassifies firefighters against other adiposity reference measures. This research is of particular importance, because populations with greater skeletal muscle are prone to greater risk of misclassification when using BMI. Table 1.3 summarises these studies, followed by a summary paragraph which describes the main findings. This is followed by a short review of each study within the context of overweight/obesity prevalence, adiposity and misclassification.

Table 1.3. Summary of studies on the prevalence of male firefighter overweight and obesity, and BMI-generated misclassification

Author/year	Sample and country	Study design	Methodology	Key findings
Munir et al., 2012	N=735 UK males	Longitudinal cohort study 2008-2011	BMI, BF%, WC.	Overweight & obesity prevalence: 65%. Significant increase in obesity prevalence of 2% after 3 y. Half of the overweight firefighters had a healthy WC.
Poston *et al.*, 2011	N=677 USA males	Cross-sectional	BW, BMI, BF%, WC, muscular strength.	BMI generated false positives: 3% (BF%) and 10% (WC). False negatives: 33% (BF%) and 13% (WC). Obese firefighters demonstrated significantly less muscular strength and CRF.
Jitnarin *et al.*, 2014	USA males (ethnically diverse sample)	Cross-sectional investigation into obesity misclassification	BMI, BF%.	BMI generated false positives (Caucasian): 5% (BF%). False negatives: 41%. BMI generated false positives (African American, Hispanic and Pacific Islanders): 13%, 7%, 21% respectively. False negatives: 28%, 27%, 14% respectively.
Jitnarin *et al.*, 2013	USA males (predominantly white Caucasian sample)	Cross-sectional investigation into overweight misclassification	BMI, BF%.	BMI generated false positives: 10% (BF%), 63% (WC). False negatives: 22% (BF%), 5% (WC).
Choi *et al.*, 2016	N=347 USA males	Cross-sectional	BMI, BF%, WC, CVD risk factors.	Combined prevalence of overweight & obesity: 80% (BMI), 56% (BF%), 49% (WC). BMI generated false positives (overweight cat.): 64% (BF%), 60% (WC). False negatives (obesity cat.): 35% (BF%), 27% (WC). 50% of the sample had a level of adiposity significantly associated with the majority of CVD risk factors. A

				third of them demonstrated substandard CRF.
Guerevich *et al*., 2017	N=167 Russian males	Cross-sectional	BMI, BF%, WC.	Obesity prevalence: 22% (BMI), 60% (BF%), 28% (WC). BMI generated false positives: 3% (BF%), 6% (WC). False negatives: 65% (BF%), 36% (WC).
Porto *et al*., 2016	N=3,822 Brazilian male military firefighters <50y of age	Cross-sectional	BMI, BF%.	Obesity prevalence: 13% (BMI), 16% (BF%). BMI generated false positives (obesity cat.): 7%. False negatives (obesity cat.): 53%.
Nogueira *et al*., 2016	N=4,237 Brazilian male military firefighters <50y of age	Cross-sectional	BMI, BF%, WC.	Overweight prevalence: 54%. Obesity prevalence: 15% (BMI), 17% (BF%), 13% (WC). Median BMI: 26.6. Median WC: 90cm. Median BF%: 21.7%. Around half of sample had substandard CRF. A strong sig. inverse association between CRF and weight/adiposity.
Damacena *et al*., 2020	N=892 Brazilian male military firefighters	Cross-sectional	BMI, BF%, WC, CRF, blood lipids and glucose.	Overweight prevalence: 49% (BMI). Obesity prevalence: 11% (BMI), 26% (BF%). WC >94cm: 19%. This 19% had sig. poorer CRF hyperglycaemia and hypertriglyceridaemia.

Abbreviations: BMI, body mass index; BF%, body fat percentage; WC, waist circumference; CVD, cardiovascular disease; CRF, cardiorespiratory fitness.

The main findings of the studies summarised in table 1.3 are that prevalence of firefighter overweight and obesity is generally high, and excess firefighter adiposity is associated with adverse metabolic profiles and poorer cardiorespiratory fitness. BMI misclassifies a high proportion of firefighter populations, and misclassifies differentially depending on a number of factors including: nationality of the firefighters, region (differential misclassification within the same country), ethnicity, the reference measure used and the BMI category being studied. Each of these studies have been reviewed in greater depth below.

1.9.1. English firefighters

1.9.1.1. Overweight and obesity in UK firefighters (Munir *et al*., 2012)

To date one study has investigated overweight and obesity prevalence of firefighters in England, investigating the weight status and adiposity of *n*=735 male firefighters serving in a UK county FRS (Munir *et al*., 2012). The proportion of overweight firefighters was measured to be greater than prevalence within the UK general population in 2008, with 65% of firefighters classified as either overweight or obese (54% and 11%). Whilst the proportion of overweight personnel reduced to 53%

in 2011, a significant rise in obese firefighters of 2% was measured. The authors suggested that for firefighters classified as normal weight, it was unclear whether weight gain was due to increased muscle mass or body fat development, suggesting further research into firefighter body composition. The authors also noted that their sample derived from a single county fire brigade and may not be representative of the entire UK fire service, which could reduce external validity. Their study identified mean individual weight changes to be minor, suggesting that obese personnel could benefit from weight loss intervention. In terms of misclassification, the results of this study indicated that approximately half of the overweight male firefighters had a healthy WC (false positives).

This study had two limitations which may have compromised the accuracy of anthropometric and body composition measurements. Firstly, they were taken by occupational health personnel, therefore inter and intra-measurer reliability is unknown. Secondly, to obtain BF% estimates, the Omron BF306 body composition monitor was used. This is a relatively inexpensive and crude analyser due to the technology making an estimate of overall adiposity based upon arm-to-arm upper body bioelectrical impedance analysis (BIA). The standard error of the estimate is reported as +/- 4.1% (manufacturer data), therefore adiposity characterised by BF% in this study should be interpreted with caution. A further study limitation was due to the study sample serving a single geographical region (an undisclosed English county). Furthermore, the mean age (SD) was 37.6 (8.5) y, which is younger than the average of firefighters in England (41 y) (Home Office, 2019), therefore generalisability to other English FRSs is limited. Further still, the considerably lower age of the study sample brings into question a conclusion of the authors who stated, “UK firefighters may not suffer the same fitness and health problems as USA firefighters” (Munir *et al*., 2012).

1.9.1.2. <u>A dietary and lifestyle worksite intervention to reduce high prevalence of overweight and obesity for London firefighters (Lessons and Bhakta, 2018)</u>

A later study on a small sample of *n*=38 UK firefighters by Lessons and Bhakta (2018) found BMI to classify 70% of the sample as overweight/obese. However, when assessed by BF% and WC, a reduced prevalence of 54% and 42% respectively was found, which was similar to the average English male: 54% (Health Survey for England, 2014). This indicates a sample overestimation of combined overweight and obesity by BMI of at least 16%. Most notably, overweight prevalence was far greater by BMI (54%) than by WC (18%) (Lessons and Bhakta, 2018). There remains a lack of research in UK fire brigades, especially those serving metropolitan cities.

Most studies have primarily used BMI to classify overweight and obesity, which Poston *et al*. (2011) investigated as a potentially misleading measure due to concerns regarding high rates of misclassification leading to false positive errors in athletic/active and/or muscular populations. This was the reasoning behind an early USA epidemiological cross-sectional study to assess firefighter adiposity status using a variety of measures in an attempt to overcome this issue, and also to assess associations between weight status, fitness and CVD risk factors.

1.9.2. USA firefighters

1.9.2.1. The prevalence of overweight, obesity, and substandard fitness in a population-based firefighter cohort (Poston *et al*., 2011)

An early investigation by Poston *et al*. (2011) into the validity of BMI to correctly categorise the adiposity status of USA firefighters found that when using the analogous indices of BF% and WC as reference measures, BMI generated very few false positives (3% and 10% respectively) despite the widely held perception that firefighters typically possess greater levels of SMM. In fact, the opposite occurred whereby BMI misclassified 33% of the sample as overweight who BF% found to be obese (false negatives). The BMI-generated false negative error rate was lower against WC (13%), indicating that 20% of the firefighters in this study with a non-obese BMI were above the BF%-defined cut-off for obesity (which was defined as 25%), and below the WC-defined cut-off for obesity (102 cm) highlighting the differences between adiposity measures and their risk cut-offs. The authors noted that significant differences between BF%-based obesity and BMI-based obesity disappeared upon analysing firefighter adiposity using the athletic algorithm on the BIA analyser. It should be noted that the athletic setting is not appropriate for indiscriminate use in people who are not highly active. Furthermore, given the difficulty associated with accurately assessing individual physical activity levels, it has been suggested that BIA produces the most accurate measurements using the standard setting regardless of physical activity level (Verney *et al.,* 2015). The study by Poston *et al*. (2011) therefore found BMI lacked sensitivity for classifying obesity in their sample, which the authors characterised as “skinny fat” obesity. The authors then went on to suggest that this phenomenon “at least in women, confers greater risk of CVD-related mortality” (Poston *et al*., 2011). This was in reference to a secondary analysis of the NHANES III data (Romero-Corral *et al.*, 2010) which used a lower BF% cut-off of >23.1% (compared with >25%) for defining male obesity, thus highlighting potentially important heterogeneity between studies. As Poston *et al.* (2011) found BMI-based obesity to generate a similar proportion of false positives (10%) and false negatives against WC (13%), along with the high false negative error rate against BF% (33%) this suggests low SMM of the sample (which would have contributed to the false negative error rate), however, this was not measured or mentioned. The authors did however note that obese firefighters in the study demonstrated significantly poorer muscular strength, as well as significantly poorer cardiorespiratory fitness. They further stated that, regardless of weight status, only 39% of full-time firefighters and 24% of volunteer firefighters attained or surpassed the minimal fitness standard of 12 METS (Poston *et al*., 2011). In the absence of objective data for SMM, the poor strength measured in this study alongside the BMI-based false negative rate of 33% and the sample mean BF% of 25.3% and WC of 96 cm identified a workforce of high adiposity, low SMM, poor strength and poor cardiorespiratory fitness. Whilst the authors acknowledged the limited external validity of the results due to the fire stations being based solely in one geographical region (Missouri Valley), the study concluded that it was clear from their data that in a population-based sample, BMI has a greater propensity to underestimate obesity than overestimate it when compared with two other measures of body composition.

1.9.2.2. Accuracy of body mass index-defined obesity status in US firefighters (Jitnarin *et al*., 2014)

A further limitation of the previous study by Poston *et al*. (2011) was a lack of ethnic diversity. A subsequent study therefore investigated BMI's validity for classifying obesity in a larger sample of firefighters of greater ethnic diversity (Jitnarin *et al*., 2014). This study identified differential misclassification by BMI according to ethnicity, whereby Caucasian firefighters suffered a relatively high rate of false negative errors (41%) when using BF% as the reference measure, and a relatively low rate of false positives (5%) which is consistent with the previous study by Poston *et al*., (2011). The rate of false negative errors was considerably lower for African American firefighters (28%), Hispanic firefighters (27%), and Pacific Islander firefighters (14%), as opposed to the rate of false positive errors which was higher for African American (13%), Hispanic (7%), and Pacific Islanders (21%). This study therefore highlighted body composition heterogeneity between ethnicities, thus further diminishing BMI's validity for accurate classification of firefighter obesity.

1.9.2.3. Accuracy of body mass index-defined overweight in firefighters (Jitnarin *et al*., 2013)

The same research group conducted a similar investigation into BMI's validity for classification of firefighters into the overweight category (Jitnarin *et al*., 2013). This study's introduction referred to the earlier study by Poston *et al*. (2011), stating that misclassification of BMI-based obesity is not a significant issue among firefighters (Jitnarin *et al.,* 2013). This declaration was made despite a 33% false negative error rate when compared with BF% (Poston *et al*., 2011). It is the opinion of this author that a 33% false negative error rate demonstrates a concerningly poor level of sensitivity which could of course lead to the related underestimation of health and fitness discrepancies, followed by a lack of intervention. Jitnarin *et al.* (2013) conducted a secondary analysis of data from the Poston *et al.* (2011) study (comprising predominantly white Caucasian firefighters), once again finding a low rate of false positives (10%) and a moderate rate of false negatives (22%) generated by

BMI compared with BF%. When comparing BMI with WC, misclassification changed dramatically, finding a false positive error rate of 63% and a false negative error rate of 5%. The authors noted that the majority of the firefighters who were overweight by BMI and healthy by WC were just below the WC overweight cut-off of 94 cm. This again highlights the rigid nature of universal cut-offs for defining adiposity status. This study also added to the evidence base which identifies BMI's poor specificity for correctly identifying healthy firefighters. This misclassification may then of course overestimate morbidity and mortality risk of firefighters. This was further investigated in a different region of the USA (California) (Choi *et al*., 2016).

1.9.2.4. <u>Comparison of body mass index with waist circumference and skinfold-based percent body fat in firefighters: adiposity classification and associations with cardiovascular disease risk factors (Choi *et al.*, 2016)</u>

Choi *et al.* (2016) examined 347 male firefighters, finding that combined prevalence of overweight and obesity was 80.4% by BMI, 55.6% by BF% and 48.7% by WC, thus BMI was found to overestimate combined prevalence by at least 25%. Consistent with Jitnarin *et al*. (2013), prevalence of overweight was far greater by BMI (57%) than by WC (25%), however, Choi *et al*. (2016) also found BMI to overestimate overweight prevalence (albeit to a lesser extent) when compared with BF% (38%). In terms of misclassification, BMI showed poor sensitivity for detecting obesity, misclassifying 35% and 27% of firefighters as non-obese against BF% and WC respectively. Misclassification was about twice as likely in the opposite direction (false positives) in the overweight BMI category, with 64% and 60% of the male firefighters being misclassified by BMI as overweight compared with BF% and WC respectively. When compared with the previous USA firefighter studies, these findings suggest that the relationship between USA firefighter populations differs depending on geographical region, however there was some consistency between the USA studies whereby prevalence of overweight firefighters as characterised by BMI was consistently substantially greater than by WC, leading to an inflated combined prevalence of overweight and obesity by BMI compared with WC. Regarding BMI and BF%, the study by Choi *et al.* (2016) identified results which were the opposite to the previous studies i.e. the other studies found combined prevalence to be higher by BF% than by BMI. The poor specificity demonstrated by BMI for correctly identifying healthy weight firefighters in this study was supported by weak associations between BMI-based overweight and CVD risk markers when compared with the healthy weight group. When the investigators analysed this relationship after redefining overweight by BMI from 25-29.9 kg/m^2 to 27.5-29.9 kg/m^2, the associations between overweight and CVD risk became relatively strong. This redefining of the BMI overweight category also strengthened the levels of agreement between BMI and the other two adiposity measures. The authors therefore suggested this alternative definition of

BMI-based overweight for firefighters in the absence of more valid measures of adiposity. This study also emphasised that 50% of the firefighters examined presented with a level of adiposity significantly associated with the majority of CVD risk factors, with one third of them failing to attain the minimum cardiorespiratory fitness level of 42.3 ml/kg/min^{-1}. This was despite the authors stating that the fire department studied had one of the strongest and most durable 'Wellness-Fitness' programmes (see section 1.12.2) compared with other USA fire departments (Choi *et al*., 2016).

1.9.3. Russian firefighters

Obesity prevalence and accuracy of BMI-defined obesity in Russian firefighters (Gurevich *et al.*, 2017)

To date one study has investigated obesity prevalence and misclassification of firefighters in Russia (Gurevich *et al.*, 2017). This identified obesity prevalence to be 22%, 60% and 28% by BMI, BF% and WC respectively in *n*=167 male firefighters. False positive rates generated by BMI-based obesity were low against BF% (3%) and WC (6%). Conversely, false negative rates generated by BMI-based obesity were high against BF% (65%) and WC (36%). The quality of the measurement procedures for this study was unknown due to measurements being taken during routine annual medical assessments, thus inter and intra-measurer error could have affected accuracy. Even so, such a high rate of false negatives suggests a population group of high adiposity. The authors noted that the generalisability of the results was limited due to the sample serving in a single region (Moscow), although the prevalence of obesity was similar to the male Russian general population. This study provides another example of excess firefighter adiposity and differential misclassification by BMI, highlighting the importance of using other measures of greater validity for measuring adiposity. The particularly high level of obesity observed in this study is consistent with a cross-sectional study of South African firefighters which reported a 42.5% prevalence of obesity alongside a high prevalence of significantly correlated risk factors for cardiometabolic disease (Achmat, Leach and Onagbiye, 2019). The authors concluded that urgent intervention in terms of lifestyle modification and weight management is required for this occupational group.

1.9.4. Brazilian firefighters

1.9.4.1. Agreement between BMI and body fat obesity definitions in a physically active population (Porto *et al.*, 2016)

A large cross-sectional study of *n*=3,822 male military firefighters serving in Brazil investigated the sensitivity and specificity of BMI for classifying obesity against the reference measure of BF% (Porto *et al.*, 2016). Data was used from standardised annual physical fitness evaluation records which were collected in 2009. Firefighters over 50 y of age were excluded due to a differing physical evaluation, and a further 182 (4.3%) eligible firefighters were excluded because of incomplete data or physiologically implausible values. This may suggest that the measures were taken and/or recorded with a lack of adherence to strict protocols. Furthermore, BF% was assessed by measuring skinfold thickness, which is prone to high levels of inter and intra-measurer variability, possibly leading to results of low precision and accuracy compared with more sophisticated methods suitable for field work such as BIA (Marriott and Grumstrup-scott, 1990). Finally, the BF% cut-off of 25% was used to define obesity, which is 3% lower than suggested by Gallagher *et al*. (2000) for assessing BF% of non-Asian males between 40 and 59 y of age. This of course would have resulted in a greater proportion of firefighters being classified as obese by BF% in this study, therefore results of this study should be interpreted with these points in mind. The mean BMI of the sample was 26.5 kg/m^2. Prevalence of obesity by BMI and BF% was 13.3% and 15.9% respectively. Specificity of BMI for correctly classifying non-obesity was 93.1%, however BMI's sensitivity for detecting obesity was poor (47.4%). This level of sensitivity is poorer than USA male firefighter studies which reported BMI's sensitivity for detecting obesity (using BF% as the reference) to be 67%, 59% and 65% (Poston *et al*., 2011; Jitnarin *et al*., 2014; Choi *et al*., 2016) respectively. Although BMI's specificity appears to be relatively good, the fact that prevalence levels are similar between BMI and BF% reveals that over half of the firefighters classified obese by BMI must have a non-obese BF% (false positives). This highlights the importance of not just assessing sensitivity and specificity, but to also assess the proportions of false positives and false negatives within each BMI category. Indeed, the fact that obesity is an extreme condition means that specificity against a reference measure will generally appear to be relatively good by virtue of the fact that two categories exist below obesity, i.e. there may be many false positives in the overweight BMI category, but the measure of specificity in terms of the obesity category, will classify those cases as being correctly classified as non-obese.

The prevalence of obesity (13.3%) in this sample of Brazilian firefighters was considerably lower than observed in USA firefighters (23-36%) (Choi *et al.,* 2016; Poston *et al.,* 2011). This may be due to the Brazilian fire brigade being a military institution with physical training policies (Nogueira *et al.*, 2016) compared with USA fire departments which are civil organisations with loosely based, if any fitness requirements. The authors suggested that a lower BMI cut-off to define obesity could be considered for physically active populations. Upon investigating this option within the study, this improved BMI's sensitivity for detecting obesity, however it compromised specificity and reduced overall agreement between BMI and BF% by ≥10%. The authors concluded that, "BMI is an excellent screening tool to estimate obesity prevalence in this physically active population" (Porto *et al*., 2016). Whilst obesity prevalence by BMI may have been similar compared with BF%, many individuals in this study were misclassified by BMI.

1.9.4.2. Body Composition is Strongly Associated With Cardiorespiratory Fitness in a Large Brazilian Military Firefighter Cohort: The Brazilian Firefighters Study (Nogueira *et al.*, 2016)

A study of male military firefighters serving in Brazil investigated the associations between cardiorespiratory fitness and body composition using a variety of adiposity measures (Nogueira *et al.*, 2016). Data was collected on *n*=4,237 18-50 y old male firefighters during routine occupational physical examinations in 2011. Weight/adiposity indices included BMI, BF% and WC. The median BMI was 26.6 kg/m^2 and prevalence of overweight and obesity was 54.3% and 14.7% of the sample respectively. The median cardiorespiratory fitness was 42.4 ml/kg/min^{-1} with around half of the sample with VO2 max scores >12 METS. The median WC was 90 cm and BF% was 21.7%. A strong significant association was found between cardiorespiratory fitness and body composition regardless of age and the method of weight/adiposity assessment. This prevailed across a variety of statistical analyses (correlation, group comparison, and estimated risk) and across different weight/adiposity indices. The consistency of these results led the authors to recommend that both cardiorespiratory fitness and measures of body weight/adiposity can be used interchangeably to assess operational readiness. Whilst the authors acknowledged widespread concerns that BMI may overestimate overweight and obesity among some occupational groups, due to this study finding a similar obesity prevalence characterised by BMI, BF% and WC of 14.7, 16.8 and 13.2% respectively, along with research on Brazilian firefighters by Porto *et al.* (2016) finding BMI not to overestimate obesity (see section 1.9.4.1), the authors of this study concluded that BMI appears to be the optimal method for body composition assessment. This conclusion failed to acknowledge the many individuals who were misclassified by BMI in the study by Porto *et al.* (2016).

1.9.4.3. Obesity prevalence in Brazilian firefighters and the association of central obesity with personal, occupational and cardiovascular risk factors: a cross-sectional study (Damacena *et al.*, 2020)

A more recent study of *n*=892 male military firefighters serving in Brazil quantified the prevalence of overweight to be 49% and obesity to be 11% characterised by BMI (Damacena *et al.*, 2020). Whilst BF% and WC were measured, the sensitivity and specificity of BMI for classifying overweight and obesity was not investigated. 19% of the sample had a WC >94 cm, suggesting a high rate of false positives generated by BMI. Prevalence of obesity as characterised by BF% was greater (26%), once again highlighting complex differences in body composition internationally, regionally and ethnically. The study reported associations between those firefighters with a WC >94 cm and the 50-59 y age range, poor cardiorespiratory fitness, hyperglycaemia and hypertriglyceridaemia (Damacena *et al.*, 2020).

1.9.5. Female firefighter body composition and obesity

To date, no studies exist to characterise UK female firefighter body composition, weight status or overweight/obesity prevalence. This can be attributed to females accounting for a small minority (6.4%) of UK firefighters (Home Office, 2019). The research undertaken thus far has focused on North American female firefighter obesity, generally neglecting the overweight category, with the exceptions being (Jahnke *et al.*, 2012) and (Choi *et al*., 2016).

1.9.5.1. The health of women in the US fire service (Jahnke *et al.*, 2012)

A study of a small sample of wholetime women firefighters (*n*=18) and volunteer women firefighters (*n*=13) in the Missouri Valley Region (Jahnke *et al.*, 2012) was part of the larger male firefighter study by Poston *et al.* (2011) (see section 1.9.2.1). The average age of the women was 33 y, making them considerably younger than the males. In general, the wholetime women firefighters demonstrated better health and fitness than their volunteer counterparts. For the wholetime women, BMI classified 17% of them as overweight and 17% as obese. Obesity prevalence increased to 39% when characterised by BF%, however, this dropped to 18% when characterised by WC. Compared with their male counterparts (Poston *et al*., 2011) and the general USA adult female population, prevalence of overweight and obesity was lower by BMI, BF% and WC in the women firefighters. Whilst the Jackson Strength Evaluation System found 71% of the wholetime women to be within the high range for strength, and the sit & reach test found a similar proportion to fall within good/excellent flexibility ranges, only 22% of them achieved the minimum cardiorespiratory fitness recommendation of 12 METS. The accuracy of the cardiorespiratory fitness data may be questionable due to the indirect assessment method (Jackson *et al*., 1990) of a non-exercise-based method which is a self-reported, crude method of estimating VO2 max. In terms of misclassification, the rate of obesity was almost double by BMI compared with BF%, suggesting poor specificity of BMI. The study also revealed that over half of the women firefighters reported at least one session of binging on alcohol in the preceding month although the authors noted that the alcohol scores derived from the validated questionnaire did not give rise to concern in terms of potential adverse occupational or social outcomes. The study also reported that around 25% of the women firefighters fell within the range of concern for depression, as measured by the CESD-10 (Irwin, Artin and Oxman, 1999), which was higher than the USA women average of 10% (Centers for Disease Control and Prevention, 2010). The authors noted that further research was required for female firefighters, as firefighters are acknowledged as being at increased risk of mental health concerns due to the stressful nature of the occupation (Murphy *et al.*, 1995, 1999; Corneil *et al.*, 1999; Duran, Woodhams and Bishopp, 2018). The study's main limitation was its very small sample size therefore, along with its focus on firefighters in the Midwest of the USA, the external validity of the results is very limited. This study represented the first look at the health of women firefighters (Jahnke *et al.*, 2012).

1.9.5.2. Comparison of body mass index with waist circumference and skinfold-based percent body fat in firefighters: adiposity classification and associations with cardiovascular disease risk factors (Choi *et al.*, 2016)

The study by Choi *et al*. (2016) (reviewed in section 1.9.2.4. for male firefighters), also assessed the body composition of a very small number of female firefighters (*n*=8) in California USA, finding 12.5% (*n*=1) to be overweight by BMI, 25% (*n*=2) to be overweight by WC, and none by BF%. In terms of obesity, 12.5% (*n*=1) was classified as obese by all three measures. Similar to the male firefighters in the study, all three adiposity measures were strongly correlated with one-another, although the pattern of association appeared to be slightly different in the females whereby the correlations between BMI and the other two measures were stronger, however the correlation between BF% and WC was weaker compared with the male firefighters. This can be attributed to genetic differences between males and females characterised by android and gynoid phenotypes i.e. males being more likely than females to store adipose tissue centrally (Karastergiou *et al.*, 2012). Interestingly and counterintuitively, the study also found age to be inversely associated with all three adiposity measures in the women firefighters (Choi *et al*., 2016), however such a small sample size precludes any meaningful generalisability.

1.9.5.3. Cardiac health and fitness of Colorado male/female firefighters (Li *et al*., 2017)

A USA study of a greater sample size of female firefighters (n=76) found a similar rate of obesity (compared with the California study in section 1.9.5.2) by BMI (11%) which was about half the prevalence level of obesity in the male firefighters (23%). This study also measured mean BF% to be 22% in the females and 21% in the males, thus women firefighters appeared to be considerably leaner relative to their biological requirement to store more body fat than males (Karastergiou *et al.*, 2012). This study did not report detailed sampling methodology therefore selection bias may have compromised the generalisability of the results, although the proportionally larger sample of male firefighters (*n*=947) may suggest that selection bias was not a major issue, as the female firefighters comprised 8% of the total sample, indicating a lower likelihood of purposive sampling of female firefighters.

1.9.5.4. Cardiovascular disease risk in female firefighters (Gendron *et al.*, 2018)

A study of *n*=41 female firefighters in Quebec Canada reported a mean (SD) BMI of 23.7 (3.5) kg/m^2 and, similar to the previous two studies, an obesity prevalence of 12% (Gendron *et al.*, 2018). This study's sampling strategy of emailing questionnaires to women firefighters yielded a sample equating to 7% of all women firefighters in Quebec. This may well have attracted an unrepresentative sample which, when considered along with the further limitation of self-reported height and weight as opposed to objective measurements, there is a chance of possible errors within this study's results.

1.9.5.5. Cardiovascular disease risk factor changes over 5 years among male and female US firefighters (Smith *et al.*, 2020)

This study of *n*=69 female firefighters in Virginia USA (reviewed in greater depth in section 1.6.2.5.) reported a mean (SD) BMI of 25 (3.7) kg/m^2, BF% of 28.9 (8.6), and WC of 82.1 (10.7) cm (Smith *et al.*, 2020). The study classified 10% of the female firefighter sample as obese by BMI, however this prevalence doubled to 20% when characterised by WC. This suggests poor sensitivity of BMI for classifying female firefighter obesity which warrants further investigation.

Whilst prevalence of obesity appears to be lower in North American female firefighters compared with their male colleagues, a paucity of research is available for women firefighters globally. Furthermore, none of the female firefighter studies to date have investigated the sensitivity and specificity of BMI for classifying weight status against other measures of adiposity. Similar to the male firefighter studies, the assessment of skeletal muscle also seems to have been overlooked by researchers thus far.

1.10 The dietary behaviour and assessment of USA firefighters

A paucity of research exists characterising firefighter dietary intakes, mainly confined to USA studies. Early studies used qualitative research techniques to investigate firefighter dietary behaviour (Haddock *et al*., 2011; Jahnke *et al*., 2012; Dobson *et al*., 2013). Interviews with USA firefighter focus groups suggested fire stations to be obesogenic environments which are unofficially governed by social norms which are uniquely resistant to change. When questioned about the fire station food environment, a culture of peer pressure to overeat became apparent, along with the overriding demand for fire station food to be plentiful, inexpensive and highly palatable. This has resulted in a worksite food environment which is dominated by excessive portion sizes, refined starch, saturated fat, free sugars and a lack of fibre (Haddock *et al*., 2011; Jahnke *et al*., 2012; Dobson *et al*., 2013).

Focus group comments included, "You eat a big steak and a potato. And then we put the social pressure around—but you got to eat with the crew, because if you don't eat with the crew then we're going to ostracize you." "I think there's an accepted perception that if you wanted a safe job, you probably should have been a teacher or something. We're risk takers by nature and so we don't like to face the fact that if you eat cheeseburgers that it will kill you or those type of things. It's an attitude that I think exists, that 'hey we're in a dangerous profession and you're worried about me eating a piece of cake?" (Jahnke *et al*., 2012). Research by Dobson *et al*. (2013) concurred with Haddock *et al.* (2011) and Jahnke *et al*. (2012). Dobson and colleagues went a step further by identifying five core themes driving the obesogenic food environment of USA fire stations (see section 1.4.3). Two recent studies have investigated the dietary behaviour of firefighters using a quantitative approach.

1.10.1. <u>The influence of habitual protein intake on body composition and muscular strength in career firefighters (Hirsch *et al.*, 2018)</u>

This study acknowledged the importance of implementing nutritional strategies to lower firefighter adiposity whilst maintaining SMM due to the high importance of adequate SMM for safe and effective firefighting performance. This was a cross-sectional study to assess relationships between protein intake, body composition and muscular strength in *n*=43 overweight/obese male firefighters. Dietary assessment was achieved using a three-day dietary record, body composition was measured by DXA, and muscular strength was measured by leg extension isokinetic dynamometry. Dietary analysis of the sample revealed the average reported macronutrient proportional intake to comprise 44% carbohydrate, 17% protein and 39% fat. Interestingly, despite a prevailing western dietary pattern, one-third of the sample reported consuming under the recommended protein guidelines of 0.8 g/kg^{-1}. This insufficiency could of course be inaccuracy derived from misreporting (see Chapter 5), although the authors suggested that the low intakes were more likely to be a product of caloric restriction caused by reactivity bias due to prospective dietary assessment, as opposed to underreporting. The primary results revealed that the firefighters reporting higher protein intakes relative to their body weight possessed less body fat and greater percentage FFM. The firefighters who reported the lowest protein intakes (< 0.8 g/kg^{-1}) possessed more body fat and less percentage FFM than their colleagues with higher protein intakes. In terms of muscular strength, results unsurprisingly showed an association between a less favourable body composition (greater FM, BF% and less %FFM) and reduced muscular strength. The authors stated that these results suggested that increasing relative protein intake above 0.8 g/kg^{-1} may elicit beneficial effects upon body composition. However, this causality cannot be concluded due to the cross-sectional design of the study. Furthermore, physical activity was not assessed, which of course is an important confounding variable responsible for stimulating muscle protein synthesis (Atherton and Smith, 2012). The authors concluded that protein supplementation via protein shakes or high protein meal replacement shakes could prove an effective approach for increasing protein intakes and reducing obesity rates of firefighters. This seems to be an excessively bold conclusion considering the extensive limitations of the study. Furthermore, the financial expense incurred from regular protein supplementation of an entire occupational group would potentially render this as unviable in a financially challenged public sector organisation, however this was not considered by the authors. Further still, promoting long-term nutrient supplementation above a 'food first' approach could be considered unethical considering that excessively high protein intakes could elevate risk of non-communicable diseases (Delimaris, 2013).

1.10.2. Evaluating nutrient intake of career firefighters compared to military dietary reference intakes (Johnson and Mayer, 2020); SACN position statement on military dietary reference values for energy (Scientific Advisory Committee on Nutrition [SACN], 2020)

The most recent study to assess firefighter dietary intakes is by Johnson and Mayer (2020). Similar to the previous study, this was a cross-sectional design utilising three-day dietary records of *n*=150 USA male firefighters. The purpose of the study was to quantify nutrient intakes relative to the Military Dietary Reference Intakes (MDRI). In doing so, the results showed that that the majority of the firefighters reported certain nutrient intakes below the MDRI. This included low intakes of total energy, percentage of total energy from carbohydrate, fibre, linoleic and alpha-linoleic acid, calcium, magnesium, zinc, potassium, folate and vitamins D and E. Conversely, the sample reported nutrient intakes above the MDRI for percentage of total energy from fat, sodium, iron, selenium, phosphorus, vitamin A and the B vitamins. In terms of micronutrient requirements, the USA MDRI recommends that military personnel consume more calcium, iron, magnesium, selenium, phosphorus, folate and vitamin C than the USA general population (Johnson and Mayer, 2020). The UK military dietary reference values (DRVs) contrast with the USA MDRI, concluding there to be insufficient evidence to warrant micronutrient DRVs for UK military personnel which differ from the UK general population (SACN, 2020).

The rationale behind Johnson and Mayer (2020) using the MDRI as a reference, was based on their analogy of firefighters being classed as 'tactical athletes' whose nutritional demands are likely to be more closely aligned with other tactical athletes such as military personnel than with the nutritional demands of the general public. These military guidelines may however be inappropriate for application to firefighters due to the intermittent and unpredictable workload that firefighters may be required to perform. Indeed, as discussed earlier in this chapter, firefighting has gradually become a more sedentary and obesogenic occupation. This is reflected in an occupational group suffering from a high prevalence of overweight and obesity, as characterised earlier in this chapter. In contrast, military personnel are forced to maintain higher levels of physical fitness through frequent training (Canino *et al*., 2019). Military personnel (i.e. soldiers) in a non-operational setting can afford to train vigorously for long periods as they are not generally mobilised into warfare at a moment's notice. The frequent training therefore increases carbohydrate requirement as it is the primary energy substrate (Mata *et al*., 2019). The UK military DRVs reflect this increased energy demand by stipulating that military personnel have estimated average requirements (EAR) for energy which, depending on their role range between 600 kcal and 1,700 kcal above the daily energy demands of the general population (SACN, 2020). The proportional intake of carbohydrate is also recommended to increase to comprise up to 65% of total energy intake for the most physically demanding military roles. This is 15% greater than the proportional intake of carbohydrate recommended for the UK general population (SACN, 2015), and is based upon the physical performance demands of elite athletes (SACN, 2020). These guidelines do however acknowledge inter-individual differences in energy demand amongst military personnel. As such, they advise risk managers to consider these differences when allocating rations for activities, particularly in less predictable operational settings, being aware of individuals within the 25th and 75th centiles having differing energy requirements. Even so, it is clear that these guidelines promote considerably greater intakes of energy and carbohydrate which are well above the general population requirements (SACN, 2020). Herein lies a key difference between occupations, as firefighters cannot afford to physically deplete energy reserves and fatigue themselves whilst exercising at station to anywhere near the same level due to their requirement of being operationally ready for high intensity firefighting operations at a moment's notice. Furthermore, firefighters are not forced to exercise whilst on duty and are sometimes even deterred from doing so due to administrative duties (Dobson *et al*., 2013). As a result, the MDRI and UK military DRVs may exist because it is easier to quantify the habitual energy expenditure of military personnel. To attempt to feed more sedentary firefighters a similar amount of carbohydrate and total energy may well result in positive energy balance, leading to *de novo* lipogenesis and concomitant increased adiposity (Strable and Ntambi, 2010). The premise of the MDRI study by Johnson and Mayer (2020) may therefore be fundamentally flawed. Whilst firefighters may have similar nutritional requirements to athletes on occasion, positive energy balance should be avoided, as excess adiposity is likely to have a far greater adverse impact on physical fitness and occupational competency of firefighters compared with sub-optimal muscle glycogen stores. Furthermore, a firefighter is highly unlikely to deplete glycogen stores within the typical timeframe of intense firefighting, which is approximately thirty minutes (dictated by the standard duration of a compressed air breathing apparatus cylinder). Johnson and Mayer (2020) concluded by stating that firefighting is an occupation which requires future research to focus on developing customised DRVs. Given the unstandardised nature of fire station physical exercise regimes and the heterogeneity in emergency call volumes between fire stations, this is likely to be unfeasible, as individual energy demands will vary considerably in an unpredictable manner. Futhermore, fire station meals are cooked in a family-style manner, therefore wide variation exists between firefighting watches in terms of the types and amounts of foods being consumed. This makes standardisation of firefighter dietary intakes unfeasible, compared with the catering arrangements of the armed forces, which operate a canteen-based meal system (when not on operational deployment) or ration-pack based meal system (when on operational deployment), both of which are far more feasible to control nutritionally.

These extensive differences between occupations were largely overlooked by the researchers who stated that the occupational demands of professional firefighting are much more closely aligned with the military than the general population (Johnson and Mayer, 2020). The authors assumed accurate self-reported dietary intakes, therefore concluding that the firefighters were consuming inadequate energy, thus implying them to be in negative energy balance. This assumption seemed to overlook the high average adiposity of the sample which was a mean BF% of 22%, which would suggest that the firefighters are more likely to be in positive energy balance, as indicated by the vast majority of firefighter adiposity studies to date (see section 1.9).

1.10.3. <u>Preliminary development of a tactical athlete nutrition score (Johnson and Mayer, 2020b)</u>

Johnson and Mayer (2020) (reviewed in section 1.10.2) alluded to the need for validated methods for assessing firefighter dietary intake. As a preliminary response to this, the same authors developed the 'Tactical athlete nutrition score' (TANS) using the same dietary intake data from the sample of *n*=150 male firefighters (Johnson and Mayer, 2020b). An individual TANS (0-10 point-scale) was derived from intakes of energy, protein, omega-3 fatty acids, total sugar and fruits & vegetables. The researchers focused on these five nutritional domains because of their relevance to firefighter health and performance. The authors suggested TANS cut-offs of 0-2 = low risk; 3-6 = moderate risk; and >6 = high risk, although they acknowledged that the TANS is yet to be validated. Using this system, Johnson and Mayer (2020b) categorised 95% of the sample as moderate/high risk, suggesting that a small minority of firefighters report optimal dietary intakes within the five nutritional domains. The authors concluded that firefighter dietary improvement is required via nutrition interventions (Johnson and Mayer, 2020b).

1.10.4. Modified Mediterranean diet score and cardiovascular risk in a North American working population (Yang *et al*., 2014)

The only known dietary assessment method validated for firefighters is a fifteen item questionnaire devised to assess adherence to a Mediterranean diet (Yang *et al.*, 2014). This however does not quantify nutrient intakes, rather it generates a modified Mediterranean diet score (mMDS), which Yang *et al.* (2014) found to be predictive of anthropometry and bio-markers implicated in MetS i.e. greater adherence to the Mediterranean diet as characterised by a higher mMDS score was inversely associated with obesity and MetS. The questionnaire was also able to highlight differences between obese respondents and healthy weight respondents in terms of the obese firefighters consuming more fast/take-away foods and sugar sweetened beverages with meals. In contrast to the studies by Hirsch *et al*. (2018) and Johnson and Mayer (2020; 2020b) which were performance related in terms of the physical demands of firefighting, this study focused purely on firefighter health promotion. The mMDS was later validated against the reference methods of a more comprehensive FFQ validated for the general population and bio-markers (Sotos-Prieto *et al.*, 2019) in a cohort of USA firefighters. Whilst the mMDS questionnaire demonstrated good agreement with the mMDS score derived from a more comprehensive 131-item FFQ, there was very little agreement with biomarkers. The authors suggested that this could be due to limitations of the study including a small sample size and possible selection bias. The same research group subsequently published a study which looked for associations between mMDS scores and anthropometric and biochemical indices in *n*=460 USA firefighters (Romanidou *et al.*, 2020). The results showed that most of the expected associations between the mMDS and CVD risk factors became statistically non-significant when controlling for physical activity. The remaining significant associations were between a unitary increase in mMDS score and HDL cholesterol, and a preferable total colesterol/HDL ratio (Romanidou *et al.*, 2020). Whilst the mMDS provides a method for gauging general mediterranean diet adherence in USA firefighters, there remains an absence of validated dietary assessment tools to comprehensively quantify firefighter dietary intakes.

This highlights the importance for developing and validating tools to comprehensively assess the nutritional status of firefighters, and to utilise the fire station worksite setting for staging interventions designed to ameliorate modifiable risk factors such as overweight and obesity.

1.11 General worksite interventions

1.11.1. Systematic reviews and meta-analyses from which common denominators of failure and success can be learned

1.11.2. Worksite weight-loss programmes

A systematic review of worksite weight-loss interventions, which consisted mainly of randomised controlled trials (RCTs), reviewed by Benedict and Arterburn (2008) identified worksite interventions to be effective for modest, short-term weight loss of participants who finish programmes. Consideration for weight maintenance or loss beyond six months was not reported by most studies, with the question of programme durability remaining unanswered. Intensity of Interventions were found to be partially associated with programme success, i.e. interpersonal contact with study subjects more regularly than monthly was identified to be a hallmark of programme efficacy, when compared with interventions involving less than one meeting per month. This review found that adequately controlled trials, both nonrandomised and randomised were suffering from poor programme design. The majority of studies did not report their attrition rates or participant recruitment methods. The review stated that further research is necessary due to widespread study heterogeneity.

1.11.3. Worksite physical activity and nutritional interventions for the control of overweight/obesity

A systematic review by Anderson *et al.* (2009) also identified strong evidence of a moderate but consistent influence on weight loss. This was consistent for both sexes in a varying plethora of workplace settings. A common problem identified was that not all measured outcomes were being fully reported, thus indicating potential confirmation bias and as such possibly compromising internal validity. Again, programme intensity was positively associated with programme impact, with structured programmes, in terms of directed scheduled sessions, showing greater efficacy than unstructured programmes (self-directed). Behavioural counselling in conjunction with information was found to be more effective than information alone. Programme efficacy was found not to be dependent on group leader level of expertise (lay vs professional). Although the differential effects of programme focus were inconclusive, it was identified that greater weight loss was achieved with multi-component intervention programmes.

1.11.4. Worksite health promotion intervention effects on dietary behaviour

Mhurchu, Aston and Jebb (2010) suggested that workplace interventions have a moderately beneficial impact on dietary behaviour. Eating habit questionnaires and FFQs were most commonly utilised for dietary assessment. Common faults of studies were identified which included: reporting of multiple outcomes without a pre-stated hypothesis or primary outcome, a paucity of objective outcome measures, and statistical analyses were regularly inappropriate. Due to ubiquitous poor study quality, it was concluded that future studies should use objective measures, comparison/control groups which are well matched; and multi-level interventions (incorporating worksite environmental modification) of extended duration to assess long-term efficacy. It was also suggested that combining qualitative with quantitative process evaluation is required to better understand reasons for success or failure of interventions with such complexity.

1.11.5. Evidence-based workplace interventions: an overview

Schroer, Haupt and Pieper (2013) identified that dietary behaviour, physical activity and weight loss outcomes may be influenced by interventions, but no evidence was found for one type of intervention outperforming another. It was concluded that the focal point of worksite health promotion initiatives should target either nutrition behaviour, physical activity or weight loss. Dietary behaviour can be influenced by interventions based entirely on nutritional education or in conjunction with environmental modification. Physical activity was found to be improved by multi-component interventions including organisational changes, step counting and active commuting. Again, the question of sustained change remains unanswered due to short duration studies of less than 6 months. It was once again concluded that multi-component interventions were the most likely to have the greatest impact on weight reduction.

1.11.6. Shift work intervention: Preventing Obesity Without Eating like a Rabbit (POWER) (Morgan *et al*., 2011)

The majority of shift work interventions have attempted to modify shift patterns, controlling dark and light exposure, and pharmacological intervention to promote sleep, wakefulness and adaption. A rare RCT to use a behavioural change modality for shift workers, provided strong and robust evidence of its benefit. The POWER trial assessed the efficacy of a worksite weight loss programme for overweight male shift work employees. The intervention components involved a single face-to-face informational session designed to educate participants on diet, energy balance, physical activity, weight loss and behavioural change strategies which included self-monitoring, goal setting and social support. The study utilised a free of charge, open access website for weight loss, which they used as a vehicle for weekly body weight reporting alongside daily exercise and food diaries. In return, the participants were given individual feedback via email throughout the three-month intervention. The feedback comprised of energy intake reduction, personalised weight loss, and physical activity integration strategies. Participant queries were answered by research assistants in weekly email contact. All participants were provided with a pedometer and a weight loss handbook. Significant favourable results were achieved in terms of WC, body weight, resting heart rate (RHR) physical activity and systolic blood pressure. This RCT indicated that a multi-component, low dose weight loss worksite intervention consisting of a single one-to-one session, online support and a workbook could be efficacious. Previous efficacious interventions had been more intensive regarding face-to-face contact (Benedict and Arterburn, 2008).

1.12. Fire station-based health interventions (see Table 7.17, pp. 212-214 for a summary of firefighter dietary and lifestyle interventions published to date)

1.12.1. The 'Heart-Healthy Firefighter Programme' (National Volunteer Fire Council [NVFC], 2003 – present day)

The NVFC attempted to ameliorate the firefighter overweight/obesity crisis, with the aim of lowering firefighter deaths from MI. The 'Heart-Healthy Firefighter Programme' focused on cardiovascular health improvement via fitness, nutrition and educating on risk factors of heart disease. This multi-component programme provided web-based information and resources targeted to promote healthy behaviours and empower firefighters to start their own health and wellbeing programmes. Programmes are self-regulated by participants and not measured for health outcomes, essentially devolving responsibility for funding and utility to individual departments and firefighters. The nutritional recommendations on the website have not been updated since 2011. The website now offers the 'U.S. Fire Administration Health and Wellness Guide for the Volunteer Fire and Emergency Services' which can be downloaded. This document was published in 2009 and has not been updated since. Although the main graphic on the front of the PDF file is a photograph of an apple, the advice within focuses on physical activity with no information regarding dietary behaviour. An element of the programme was to train firefighters as department health and wellbeing advocates. This initiative was to be built upon in the IAFF/IAFC Wellness Fitness Initiative.

1.12.2. Wellness Fitness Initiative (WFI) (International Association of Firefighters [IAFF] and International Association of Fire Chiefs [IAFC], 2018)

Launched in 1996, the WFI is the most widespread and longest running programme which has evolved and been adopted by many provinces and states across Canada and the USA. The programme aims to improve firefighter quality of life via a comprehensive approach including the following components: fitness, nutrition and behavioural health, injury rehabilitation and prevention as well as annual medical evaluations. An informational website accompanies the programme, offering instruction for departments on how to set up their own WFI, including offering health tips, the nutrition component of which, is very limited. The main feature of the WFI is the certification of peer fitness trainers (PFT's), who are firefighters that are trained to provide personalised fitness programmes for their colleagues, including provision of nutrition advice. PFT's also monitor individual annual progress via measuring aerobic capacity, muscular endurance, strength and body-composition assessment. A theme running throughout the WFI has been the collection and analysis of clinical and health outcome data collected from ten jurisdictions which could be representative of general US firefighter populations. Poston *et al*. (2013) evaluated the efficacy of the WFI by comparing health outcomes of 522 fire departments which had adopted key WFI components (WA departments), and comparing them with 480 departments that were similar by call volume, size, staff level and catchment area, but which had not adopted the key WFI components (standard departments). The key components included: yearly medical examinations; an assigned health/fitness coordinator; PFTs; and allocated physical training time for all on-duty personnel. Outcomes included BF%, BMI, WC, self-reported physical activity level and blood pressure. Work stress, self-reported depression scores and job satisfaction levels were also assessed. Results found WA firefighters to be of leaner body composition across all three measurement indices, rendering them significantly less likely to be classified obese. They were also significantly less likely to be hypertensive, significantly less anxious, more physically active, significantly less likely to smoke, reported better morale and job satisfaction. The cross-sectional design of the study presents a limitation, reducing its ability to show temporality between health promotion programmes and health outcomes, as it is possible that WA departments comprise healthier firefighters because they attract people who have a greater interest in health. This study did attempt to overcome this limitation via proper use of selection criteria and appropriate statistical analyses which controlled for confounders. It offers reasonable evidence of an association between fire service health promotion and firefighter health & wellbeing. It was noted that prospective cluster-controlled trials or quasi-experimental studies of health promotion programmes for firefighters are necessary to provide stronger evidence for the advantages of wellbeing programmes. Future studies were recommended to also assess sleep quality and dietary intake as being important health related outcomes for firefighters (Poston *et al*., 2013).

The WFI published its fourth edition in 2018 (IAFF and IAFC, 2018). Once again, this focuses on physical fitness, with less than one page dedicated to nutrition advice, culminating in the suggestion of hiring a professional nutritionist to run nutrition interventions within fire departments.

1.12.3. Promoting Healthy Lifestyles: Alternative Models' Effects (PHLAME) (Elliot *et al*., 2007)

From 2002 to 2004, PHLAME compared two intervention modalities (individual vs. team-based) focusing on nutrition, physical activity and body weight. Five hundred and ninety-nine firefighters were randomised by station (cluster controlled) to a control group or one of two intervention groups. The intervention arms were: (a) a team oriented, peer led education syllabus or (b) Individual counselling. Teams in group (a) were given lesson plans administered by a team elected leader. These comprised eleven 45-minute scripted lessons which were informed by a 'team leader instruction booklet', with corresponding workbooks provided for other team members. Core curriculum content included energy balance, physical activity and nutrition. Firefighters in group (b) were provided with face-to-face lifestyle counselling which was conducted by counsellors trained in motivational interviewing (mi). Participants within both intervention arms received an accompanying booklet comprising nutrition, physical activity and lifestyle related health information. Outcomes included weight change, dietary behaviour, physical activity and overall well-being.

Results after one year showed both intervention arms to be successful in terms of significant weight gain attenuation compared with the control group. Vegetable and fruit intake also increased within both intervention arms, as did wellbeing. A limitation of this study was the inability to directly compare the two intervention modalities. This was partially due to differing content and format. Duration of mi counselling sessions was less than in team lessons. This occurrence was partially due to this intervention arm's unstructured nature, whereby mi firefighters determined the number of meetings, which further impairs our ability to make meaningful comparisons. Financial expense was also an issue, with the expense of mi counsellors being relatively high. Conversely it was reported that team study materials were inexpensive. The internal validity of this study may have been compromised via BF% being measured, but not reported as an outcome.

This study advocated use of peer led activities in alignment with previous programmes, and the study showed the importance of team cohesion and the usefulness of group dynamics in the design of a worksite health intervention for firefighters. Indeed, this study illustrated that group support for healthy behaviours such as nutritional and physical activity improvement can change previous social norms and create consensual commitment and accountability for adherence to health improving behaviours. This is an important dynamic to harness in successfully overcoming cultural resistance to behaviour change (Ranby *et al*., 2011). Unfortunately, follow-up outcomes over subsequent years were not as efficacious, indicated by the successful first year effect dissipating over the following four years (MacKinnon *et al*., 2010). Mackinnon *et al*. (2010) proposed that this could be due to the cessation of further interventions being introduced after initial programme delivery. This might suggest that in order to sustain desirable behaviour changes, periodic reinforcement of healthy messages and evolution of intervention components in order to combat the obesogenic environment, could be effective strategies.

1.12.4. A low-glycaemic nutritional fitness program to reverse metabolic syndrome in professional firefighters: Results of a pilot study (Carey *et al.*, 2011)

This programme aimed to improve risk factors for MetS over a 12-week intervention period. The intervention comprised physical activity exercise sessions and dietary education which were delivered for two-hours of each of the 12 weeks by a physical training instructor (PTI), a physician and a nurse. The sessions were conducted at a firehouse in New-York USA, using a sample of one platoon (watch/team) of male firefighters who exhibited an above average prevalence of MetS at baseline (70%). The sessions were conducted whilst the firefighters were on duty, with the participants keeping daily physical activity and dietary diaries. The dietary education component promoted adherence to the low-glycaemic index (GI) diet which was based upon Mediterranean and DASH dietary concepts. The low-GI recommendations for the firefighters included the promotion of eating in the following proportions: 50% fruit and vegetables, 30% protein and 20% starch. This approach promoted minimising fats and free sugars, whilst increasing fibre and omega-3 fatty acid intake. The firefighters were supplied with food lists educating them on the GI of certain foods which categorised carbohydrates in terms of low/medium/high GI. They were also supplied with daily multivitamin and omega-3 supplements for the 12-weeks. Additionally, a meal replacement strategy was employed over the study period which involved replacing breakfast with a low-GI shake and replacing one of the two daily allowable snacks with a low-GI snack bar. The platoon was educated via verbal instruction and literature provision throughout the 12-weeks in terms of GI, food labelling, macro and micronutrients. Daily physical activity sessions delivered by the PTI included daily sessions of mild-moderate intensity exercise lasting 60-90 minutes. The modes of exercise encompassed yoga, resistance training and cardiovascular exercise. The study identified a greater prevalence of MetS and its constituent risk factors in firefighters compared with the general population, although it was acknowledged by the researchers that a small sample size taken from a geographical area which has a greater prevalence of obesity than the rest of the USA, may have produced an unrepresentative sample. The intervention resulted in a significant reduction in prevalence of MetS from 70% to 30%, with the mean number of MetS risk factors decreasing significantly from 3.2 to 1.9. A major limitation of this pilot study was the absence of a control group therefore it is impossible to confirm the true impact of the intervention itself. Unfortunately, six months post-intervention the beneficial results were beginning to fade, with the researchers suggesting that maintenance of health improvements could be achieved by strategically incorporating the intervention programme around annual compulsory physical assessments.

It was noted that a strength of the study was the cluster design whereby a platoon of firefighters was selected to receive the intervention. This enabled the researchers to harness the cohesive social group effect, which was suggested as being a useful strategy for the successful outcomes of future interventions.

1.12.5. Maryland Firefighter Food Intervention, Research and Evaluation (FFIRE) Study (Goheer, 2017)

Johns Hopkins Bloomberg School of Public Health in partnership with the NVFC conducted a study to reduce firefighter risk factors for heart attacks. Study aims were to investigate barriers to, and facilitators of firefighter health and wellbeing. This was followed by the implementation of a pilot trial intervention informed by these findings. The intervention took the shape of nutritional education sessions, healthy eating tool provision, and kitchen-based cookery workshops.

The study sample comprised *n*=115 firefighters from eight fire stations (two control, six intervention). Three of the intervention stations had two or three firefighters trained as peer health and nutrition advocates by the Johns Hopkins Weight Management Centre. Intervention stations received monthly nutrition education and cooking sessions. Grills and nutrition books were provided, and firefighter discounts on healthy foods at nearby restaurants were arranged. Education on sourcing healthy foods locally was also provided. A weight loss competition was held between intervention stations in an attempt to harness the competitive nature of firefighters. Objective outcome data included BF%, WC, blood pressure, glucose, cholesterol and body weight. Dietary assessment was administered via an online FFQ. Fire station food environment assessments were also included.

Aside from weight loss at the 6-month mark, preliminary results showed that control stations exhibited equivocal or superior results across all other outcomes at six months and one-year follow-up. This finding is consistent with Bankhead *et al*. (2003), that assessment alone can significantly impact behaviour favourably. Plausible reasons for these poor results are an absence of personalised consultation/support, a paucity of goal setting (structure) and a lack of physical activity component.

1.12.6. Weight loss advice and prospective weight change among overweight firefighters (Fuel 2 Fight) (Brown *et al*., 2016)

Fuel 2 Fight was a prospective cohort study which tested the efficacy of standard health advice administered by health professionals (physicians/nurses/other) to overweight and obese USA firefighters. Data was collected from overweight/obese male firefighters who had received health advice from a health care professional within the preceding year. Data was collected at baseline (2011) and six-months later (2012), with follow-up data collected for *n*=458. The results were modest, with participants losing an average of 0.55 kg in body weight and a significant mean improvement in systolic blood pressure of -3.75 mmHg. These improvements were however not associated with the healthcare advice, which is consistent with previous research suggesting there to be little benefit from routine primary care low-intensity weight reduction advice (Noël *et al.*, 2012). Indeed, only 15% of the ‘Fuel 2 Fight’ sample managed to reduce their weight by the clinically meaningful amount of 3-5%, suggesting that more sophisticated intervention programmes are required for firefighters.

1.12.7. Eating habits of professional firefighters (Torre *et al.*, 2019)

A small prospective study on a sample of *n*=28 firefighters serving at an airport in Switzerland attempted to improve dietary behaviour and body composition over a one-year period. The dietary and physical activity intervention comprised a one-hour group education session, one hour of one-to-one dietary counselling from a dietician, and a cookery class. After one-year there were no significant changes in dietary behaviour, anthropometry or body composition of the sample. The authors considered no significant weight gain to be a potential success, however, due to no control group, it is impossible to know the true effect of the intervention. The authors suggested that the observation by Jahnke *et al*. (2012) whereby firefighters may be uniquely resistant to change due to strongly rooted traditions in the fire station food environment, may have been responsible for a lack of adherence to dietary intervention advice in this study. The study concluded that culturally relevant, tailored interventions hold potential to establish a culture shift in the fire station food environment. Other observations included the importance of a multi-level approach in terms of intrapersonal intervention, interpersonal intervention and organisational and environmental intervention strategies. They emphasised that an individual and group approach appeared essential and complementary.

1.12.8. A 28-day carbohydrate-restricted diet improves markers of cardiometabolic health and performance in professional firefighters (Waldman *et al*., 2019)

This intervention study investigated changes in glucose tolerance, fat oxidation, other markers of metabolic health, and physical exercise performance (aerobic and muscular endurance) in *n*=15 USA firefighters. The intervention comprised a brief education session on how to restrict daily carbohydrate intake to < 25% of total energy intake (TEI), and a four-day per week bodybuilding resistance exercise regime. Other macronutrients (fat and protein) were allowed to be consumed ad libitum. At 28-day post baseline, three 24hr recalls recorded that daily carbohydrate intake decreased from 47% to 23% TEI whilst daily protein intake increased from 0.9 to 1.3 g/kg^{-1}. Body composition improved with body fat decreasing by 2.2% whilst lean mass remained stable. Systolic BP decreased by 6 mm Hg, however, there was no change in glucose tolerance, although significant changes were observed in substrate utilisation during exercise, with decreased carbohydrate oxidation and increased fat oxidation. Performance improvements were observed in terms of a 2.4 km run being performed 41 seconds faster, and a muscular endurance test improvement of +3 pull-ups. Whilst initial improvements appear promising, the study limitations may reduce the external validity of the results. This includes potential confounding from the resistance training regime protocol, a relatively low average age (33.5 y) and an undisclosed sampling strategy. Furthermore, there was no control group, therefore the true effects of the intervention cannot be confirmed. The long-term effects of carbohydrate restriction on firefighter health and performance remain unknown as this is the first study of its kind for firefighters, therefore further research is required.

1.12.9. The effects of a Mediterranean diet intervention on targeted plasma metabolic biomarkers among US firefighters: a cluster-randomised trial (Sotos-Prieto *et al*., 2020)

The sample for this study was a subset of participants (*n*=48) drawn from a larger USA fire station-based intervention study (*n*=400), the rationale and design of which is described in detail by Sotos-Prieto *et al.* (2017). Briefly, the intervention comprised educational sessions and videos designed by an accredited nutritionist, a leaflet and promotion of the Mediterranean diet and lifestyle, recipes tailored for firefighters (via modification of firefighter preferred meals by a nutritionist and chef to align with the principles of the Mediterranean diet), fire station-based cookery demonstration and food samples, and discount coupons for healthy food items redeemable at a supermarket chain. The objective of this study was to identify changes in plasma metabolic biomarkers related to the Mediterranean diet. The mMDS (Yang *et al*., 2014) (see section 1.10.4) was the primary method used for assessing adherence to the Mediterranean diet. After six months, the mMDS did not change significantly from baseline. Following Bonferroni correction for multiple testing, a modest decrease in medium-VLDL cholesterol esters for the control group was the only biomarker which was significantly different from baseline. The authors attributed the lack of detectable changes to limitations of the study design which included a small sample size, possible selection bias, heterogeneity between the groups i.e. the control group had a higher mMDS score at baseline. Furthermore, the control group were not a pure control group because they had received the same intervention one year prior to the baseline of this study. The study also investigated the cross-sectional linear association between mMDS and biomarkers, finding that a one-unit increase in mMDS score was associated with more favourable biomarker values of lipid metabolism. The researchers concluded that more powerful study designs with larger sample sizes are required. The parent study from which this study subset was derived is yet to be published.

1.13. The importance of harnessing team cohesion

Interventions aiming to improve health within the fire service need to acknowledge the importance of team cohesion which is a clear cultural characteristic exhibited by this occupational group, therefore health interventions at fire stations could benefit from targeting the whole firefighting watch rather than just focusing on individuals (Ranby *et al*., 2011). Team cohesion is not only important for the safe and effective resolution of emergency incidents (Driessen, 2002), it also affects fire station life in terms of decisions and behaviours. Indeed, cohesiveness manifests in firefighting watches when expectations, rules and consensus are established in terms of routine practices (Banes, 2014). Cohesiveness and group consensus are therefore important factors which can either hamper or facilitate interventions designed to improve the health of firefighters (Banes, 2014).

1.14. Summary

Firefighting is an occupation associated with a complex combination of exposures which increase the risk of firefighters suffering from NCDs. These exposures are not confined to the fire ground, as this occupational group suffer from a high prevalence of overweight and obesity, with the fire station worksite having been identified as obesogenic, thus potentially compounding an already increased risk of NCDs. A vital first step toward ameliorating firefighter body composition is to accurately assess individual levels of fat mass and skeletal muscle, however, to date the primary methods of assessment have included BMI, BF% and WC, all of which present limitations which can lead to widespread misclassification of firefighter adiposity status, particularly BMI. A vital step toward ameliorating dietary behaviour is to be able to assess dietary intake, therefore a validated dietary assessment tool is required to capture the effect of a fire station-based dietary intervention. A multi-component worksite nutrition intervention could help to ameliorate the obesogenic environment along with improving firefighter dietary and lifestyle behaviours.

Chapter 2. General Methods

2.1. Research aim and objectives

Aim

To develop novel tools for the assessment of UK firefighter nutritional status and to develop and test the feasibility and efficacy of a multi-component fire station-based nutrition intervention.

Objectives

1. Investigate the levels of misclassification generated by BMI using BF%, WC and WHtR as reference measures.
2. Develop firefighter body composition centile charts to improve upon misclassification produced by BMI, offering occupational health care professionals a simple reference tool to use for classification of UK firefighter phenotypes. This can in turn inform appropriate health maintenance/improvement advice.
3. Create and test the validity of a dietary assessment tool to enable simple, effective and efficient screening of firefighter dietary behaviour and for use in a dietary intervention to detect changes in dietary intakes. This could also be utilised by health care professionals to inform appropriate administration of dietary advice.
4. Create and test the feasibility and efficacy of a fire station kitchen-based cookery workshop to educate those responsible for food purchase and preparation on the importance of nutrition and its relationship with health.
5. Develop, implement and evaluate a fire station-based dietary and lifestyle intervention involving group education, dietary assessment, body composition analysis and individual education. This will be geared toward an integrated system feasible for rollout across the LFB.

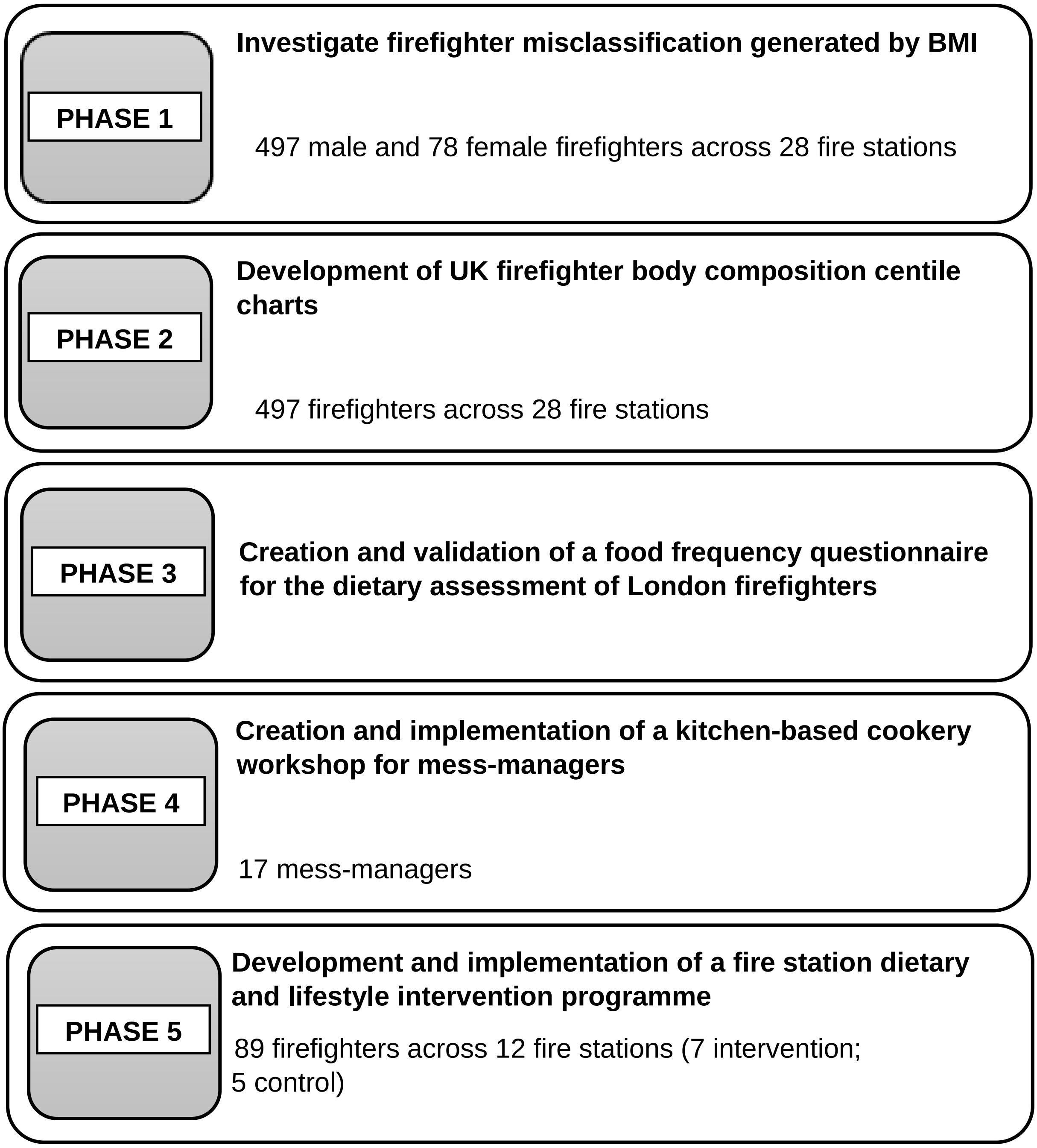


Figure 2.1. Ph.D. study phases

2.2. Ethical approval

The research was authorised by an Assistant Commissioner of the LFB (appendix 2.1) and the London Metropolitan University School of Human Sciences Ethics Committee (appendix 2.2). The firefighters had the studies explained to them in full, and those who chose to participate were provided with a participant information sheet (appendix 2.3) and informed signed consent was obtained from each participant (appendix 2.4).

2.3. Participating fire stations

Stations were chosen for inclusion based upon their geographical location, ensuring an even geographical distribution of urban and suburban stations to attain representativeness. Where possible, the same personnel were involved in multiple studies, however due to differing sample sizes within each study, variation was inevitable, therefore the methods section of each study chapter provides demographic information for that particular study. Stations were also selected for inclusion on a practical level depending on the availability of personnel during the study period due to prior commitments such as scheduled skills training, fire inspections etc. Whenever possible, stations were recruited when they had a vacant training day which the lead researcher identified via liaising with the relevant LFB admin team, who were then able to allocate their training time to the study. This ensured no interruptions from emergency callouts. If the relevant team (watch) did not have an available training day during the study period, the lead researcher requested that the LFB admin team grant a short period of unavailability for emergency callouts for data collection purposes. On the occasions that none of the aforementioned scenarios could be arranged, the researcher liaised with the relevant watch commander directly to arrange a mutually convenient time for study participation and data collection. If the watch were called-out to an emergency incident during the study engagement session, the researcher used his professional judgement to decide whether to wait for the watch to return to station to resume the session, or whether to reschedule the visit for the next convenient date. This process of booking watches for study participation and data collection was made easier by the lead researcher's previous seventeen years spent as a full-time firefighter, thereby providing detailed knowledge of the LFB and its systems of work.

2.4. Logistics

LFB provided the lead researcher with an electric car for transportation of himself and all study equipment to and from participating fire stations. This was stored at Hornchurch fire station overnight. The community safety centre adjacent to Hornchurch fire station provided the lead researcher with office space to complete various administrative tasks, with computer terminals, access to the LFB internal intranet and communications systems and secure document and equipment storage.

2.5. Anthropometric and body-composition measurements

Measurements were taken by the researcher at fire stations. Height was measured using a portable stadiometer to the nearest 0.1 cm (model: Leicester - Marsden HM-250P) with firefighters standing in bare feet. Correct measurement protocols were adhered to including attention given to the participant's head alignment, ensuring it to be on the Frankfort horizontal plane to maximise intra-measurer reliability (Daboul *et al*., 2012).

Waist circumference (WC) was measured twice using stretch-resistant anthropometric tape (Myotape) to 0.1 cm at the midpoint between the lower margin of the least palpable rib and the top of the iliac crest as recommended by WHO (2011). If the two measurements were different, a third measurement was taken. The closest two results were then averaged to arrive at an accurate WC. Waist-to-height ratio (WHtR) was calculated using the standard equation: WC (cm)/height (cm).

BMI was calculated using the standard equation: weight (kg)/height (m)^2.

Body weight, skeletal muscle mass and body fatness were measured via BIA utilising the Tanita MC-780MA segmental multi-frequency body composition analyser (Tanita Corporation, Tokyo, Japan) with a 1 kg correction applied for LFB uniform (light clothing). Participants were not fasting prior to measurement. The measurement protocol began with the researcher entering participant data into the compatible BIA software programme (GMON health monitor – version 3.4.2), including date of birth, ethnicity and height. The participant was then asked whether they had an empty bladder, as it was explained that bladder fluid could alter the accuracy of the measurement due to overestimated extracellular water (Kyle *et al.*, 2004). Once the participant was confident of their bladder being empty, they were asked to empty their pockets and stand on the analyser platform so that their bare feet were covering all four foot-electrodes. The subject was then instructed to stand upright and still to ensure an accurate weight measurement (to the nearest 0.1 kg). Once this was obtained, they were asked to grasp the hand electrodes and hold them slightly away from the sides of their body at arms-length. The bioimpedance measurement took approximately 10 seconds per subject. Measurements were taken at a similar time of day to minimise diurnal variation.

Segmental BIA generates measures of trunk and limb composition separately. This enabled the measurement of appendicular skeletal muscle mass (ASMM) (kg) which was calculated by summing the muscle mass of the four limbs for each participant. This was measured because it is impossible to accurately quantify total SMM, and ASMM acts as a good proxy for total SMM as all lean limb tissue is either muscle or bone. Additionally, ASMM makes up more than 75% of adult total body SMM (Snyder *et al.*, 1975), and therefore is the major fraction of total body SMM integral for physical activities and ambulation and thus is likely to be the most modifiable fraction of total body SMM.

Both SMM and FM were adjusted for participant height by dividing by height $(m)^2$. This converted ASMM to the SMM index (SMMI) and FM to the FM index (FMI).

The prediction equation algorithms in the MC-780MA are based upon bioimpedance, age, sex, height and weight, and were calculated from calibration studies against whole-body DXA. The standard error of the estimate for body-fat and muscle-mass was a +/- 2% for both males and females (manufacturer data). The recently developed (2015) BIA scales used for this study have been validated against DXA in healthy young adults of varying demographics and physical activity levels (PAL), and have been found to be strongly correlated with DXA for assessing FM and FFM regardless of PAL ($r = 0.85$, $p<0.01$; $r = 0.98$, $p<0.01$ respectively), and superior to previous BIA technology (Verney *et al*., 2015). The MC-780MA has been awarded the following accuracy grades: MDD: Class 2a; NAWI: Class 3.

To ensure good hygiene, all surfaces coming into contact with study participants were cleaned between each participant by the researcher using mild detergent and water.

2.6. Dietary analyses

FFQ EPIC Tool for Analysis (FETA v2.53) software (Mulligan *et al*., 2014) was utilised to process FFQs to obtain participant nutrient profiles. Every row in part one of the FFQ is mapped to a potential six food item codes which were used based upon UK population and government survey data (Bingham *et al*., 1994; Gregory *et al*., 1990; MAFF, 1994). The codes are linked with 290 foods from the UK's food composition database, McCance and Widdowson's 'The Composition of Foods' (5th edition) and supplemental volumes (Welch *et al*., 2005). Portion weights were sourced from weighed food diaries of 40-74 year-old study participants and UK population data (MAFF, 1993; Bingham *et al*., 1994). FETA generates mean daily food group and nutrient intakes of participants following the coding and input of FFQ data. Intake data for fourteen food groups and forty-six nutrients were produced for each participant, followed by importation to a spread sheet and finally importation to statistical analysis software.

Nutritics dietary analysis software (Nutritics, 2019) was utilised to generate nutrient profiles for 24hr recall dietary intake data (Chapter 5) and to generate recipe nutrient profiles for the 'Healthy Mess Recipes' cookery book (Chapter 6). Nutritics used the 2015 COFIDS including McCance and Widdowson 7th edition, 2015 nutritional composition database. Nutritics database includes food photographs and suggested food portions.

Chapter 3. The validity of BMI for classifying UK firefighter adiposity status

Overview

Prevalence of firefighter overweight and obesity has been estimated to affect 60 - 88% of personnel. Previous research in firefighter populations outside of the UK has demonstrated BMI to generate varying levels of false positive and negative errors dependent upon demographic and geographic factors as well which reference measure of adiposity is used. To date this has not been investigated for UK firefighters. Anthropometric and body composition data were collected for 497 male and 78 female LFB firefighters. Combined prevalence of male firefighter overweight and obesity characterised by BMI was 80%, which contrasted widely with the other measures, BF% (63%), WC (43%) and WHtR (59%). In comparison to a high rate of false positives, BMI generated fewer false negatives, thus demonstrating better sensitivity than specificity. BMI demonstrates poor validity for classifying UK firefighters as overweight or obese.

3.1. Introduction

Obesity is a rapidly developing workplace epidemic, with obese employees taking an extra four sick days off per year (Harvey *et al.*, 2010), alongside being twice as likely to suffer long-term sickness absence (LSA) (Van-Duijvenbode *et al.*, 2009). Prevalence of overweight and obesity in UK firefighters may exceed that of the general population (Munir *et al.,* 2012; Lessons and Bhakta, 2018). Overweight and obese firefighters miss 2.7 to 5 times (depending on their level of overweight/obesity) the number of work-days due to injury compared with healthy weight colleagues (Poston *et al*., 2011). Obese firefighters are three times more likely to make a compensation injury claim compared with healthy weight colleagues (Kuehl *et al*., 2012). In terms of occupational performance, obese firefighters tend to have significantly less muscular strength and cardiorespiratory fitness (Poston *et al.*, 2011; Donovan *et el.*, 2009; Tsismenakis *et al.*, 2009; Clark *et al*., 2002). Furthermore, evidence indicates that overweight and obese firefighters have impaired vascular function and are at an increased risk of cardiovascular disease (Clark *et al*., 2002; Soteriades et al., 2005; Fahs *et al.*, 2009) which may compound the increased risk of acute myocardial infarction (MI) caused by intense heat exposure experienced by firefighters (Hunter *et al*., 2017). It is therefore imperative to accurately classify the adiposity status of firefighters. To date, body mass index (BMI) has been the primary health risk classification system used to categorise firefighter weight status.

BMI's global popularity can be attributed to its speed and ease of administration as well as being inexpensive. Due to BMI's inherent limitations it has been subject to criticism, particularly for classifying firefighters (Gallagher *et al*., 2000; Choi *et al*., 2016; Jitnarin *et al*., 2013). BMI is intrinsically unable to differentiate between fat-free mass (FFM) and fat mass (FM) (Choi *et al*., 2016). This often results in misclassification of individuals resulting in false negative and false positive errors, suggesting poor sensitivity and specificity of BMI (Gallagher *et al*., 2000; Choi *et al*., 2016). This problem is exacerbated in populations possessing above average skeletal muscle such as firefighters (Choi *et al*., 2016). A study on a small sample of UK firefighters by Lessons and Bhakta (2018) found BMI to classify 70% of the sample as overweight/obese. However, when assessed by body fat percentage (BF%) and waist circumference (WC), a reduced prevalence of 54% and 42% respectively was observed, which was similar to the average English male: 54% (HSE, 2014). This indicates a sample overestimation of combined overweight and obesity by BMI of at least 16%. Most notably, overweight prevalence was far greater by BMI (54%) than by WC (18%). 28% of firefighters assessed as 'healthy' by WC, were misclassified by BMI as being overweight (false positives) indicating poor specificity of BMI. These findings are consistent with a previous UK firefighter study by Munir *et al.* (2012), and USA firefighter adiposity studies by Jitnarin *et al.* (2013; 2014) and Choi *et al.* (2016), all of which identified concerning disparities between BMI and other adiposity measures. Although high rates of misclassification caused by BMI have been identified in these previous firefighter adiposity studies, the sensitivity and specificity of the BMI categories varied between studies. Furthermore, there remains a paucity of research characterising the misclassification of firefighter adiposity within UK firefighters, and to date, the adiposity status of female firefighters serving in the UK has not been studied.

WC as a cardio-metabolic risk screening tool is more valid than BMI although it is not infallible and can also be prone to misclassification of individuals. This is partially due to the arbitrary risk cut-offs which are universally applied to demographics regardless of their height, therefore possibly over- and underestimating health risks for taller and shorter people respectively (Browning, Hsieh and Ashwell, 2010). Waist to height ratio (WHtR) reduces this misclassification via application of personalised cut-offs dependant on height, with cardio-metabolic risk increasing above a ratio of 0.5 (Ashwell, 2011). Previous firefighter studies compared BMI with two commonly used adiposity indices (WC and BF%). To date none have compared BMI with waist-to-height ratio (WHtR).

The objectives of this study were to quantify the prevalence of overweight and obesity and to assess the levels of misclassification generated by BMI relative to three different indices of adiposity/health risk within a large sample of firefighters serving a major UK metropolitan city. Furthermore, the validity of WC for assessing the abdominal adiposity status of firefighters was investigated.

3.2. Methods

Participants

The study population comprised 497 full-time London Fire Brigade (LFB) white male and 78 full-time white female firefighters. All of the males and 32 of the females were recruited for the study from 28 Greater London fire stations (see Table 4.1 of Chapter 4) on their day shifts from June 2019 to March 2020 during scheduled fire station engagements. Stations were chosen for inclusion based upon their geographical location, ensuring an even distribution of urban and suburban stations. The remaining 46 female firefighters were recruited for the study by staff email. The firefighters had the study explained to them in full, and those who chose to participate were provided with a participant information sheet and informed signed consent was obtained from each participant (ethical approval: see Chapter 2). Figure 3.1 shows the participant flow through the study.

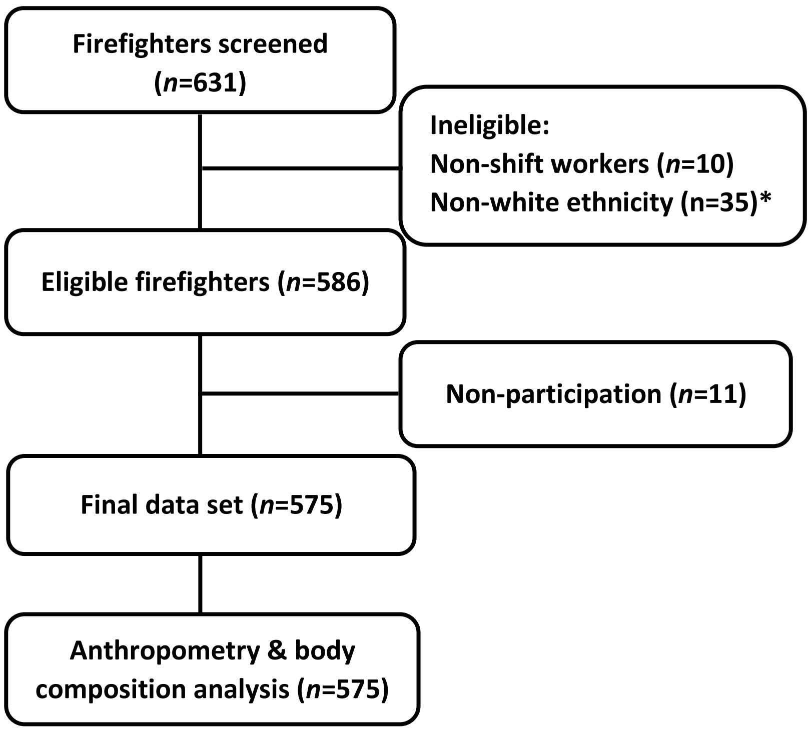


Figure 3.1. Participant flow through the study *all ethnicities were measured but not included in this data set due to inherent body-composition heterogeneity

Anthropometric and adiposity measurements

Measurements were taken at fire stations for the majority of participants, and at LFB Headquarters for the remaining 46 female firefighters. Height, weight, BMI, BF%, WC and WHtR were measured/calculated. Measurement protocols and calculations are described in Chapter 2. Table 3.1 displays the underweight, overweight and obesity cut-offs for each of the indices used in this study. Participants were categorised by BMI, BF%, WC and WHtR using analogous weight/adiposity/health risk cut-offs to quantify prevalence of overweight and obesity, and to determine levels of agreement between BMI and the other measures.

Table 3.1: BMI, BF%, WC and WHtR health risk classifications used for the study population.

Adiposity measure		**Underweight**	**Healthy**	**Overweight/ Overfat**	**Obesity**
BMI		< 18.5	18.5 – 24.9	25 – 29.9	≥ 30
BF%	Males 20 - 39 years	< 8	8 – 20	20.1 – 25	> 25
	Males 40 - 59 years	< 11	11 – 22	22.1 – 28	> 28
	Males 60 - 79 years	< 13	13 – 25	25.1 – 30	> 30
	Females 20 - 39 years	< 21	21 – 33	33.1 – 39	> 39
	Females 40 - 59 years	< 23	23 – 34	34.1 – 40	> 40
WC (cm)	Males		≤ 94	94.1 – 102	> 102
	Females		≤ 80	80.1 – 88	> 88
WHtR			< 0.5	0.5 – 0.59	≥ 0.6

Abbreviations: BMI body mass index, BF% body fat percentage, WC waist circumference (cm), WHtR waist-to-height-ratio. BMI and WC ranges derived from WHO (2000). BF% ranges derived from Gallagher *et al* (2000). WHtR ranges derived from Ashwell (2011).

Statistical analyses

Data was imported to IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). Data was checked for normality. Descriptive statistics were computed for sex, ethnicity, age, and years of service. anthropometric and adiposity measures were assigned as continuous variables. Normally distributed data was reported as mean +/- standard deviation (SD). Non-normally distributed data was reported as median +/- interquartile range (IQR). BMI, BF%, WC and WHtR were categorised and reported as *n* (%). The sample was stratified by sex prior to statistical analyses.

Spearman's rank correlations were computed to investigate associations between non-normally distributed continuous variables and Pearson's correlations were computed to investigate associations between normally distributed continuous variables. BMI classifications were compared with adiposity classifications of the other three measures. The agreement percentage was defined by the proportion of firefighters being in the analogous BMI and corresponding adiposity category e.g. 'overweight by both BMI and WHtR'. Kappa statistics were also computed to assess the agreement between BMI and adiposity categories (three by three tables). The sensitivity and specificity statistics of obesity by BMI were calculated against BF%, WC and WHtR categories. The same was undertaken for the overweight category only among firefighters with weight/adiposity statuses ≤ overweight. This enabled consistent comparisons with previous studies (Jitnarin *et al*., 2013; Choi *et al*., 2016). Stacked bar charts were generated to illustrate prevalence of overweight and obesity by BMI with corresponding 'within category' misclassification by BF%, WC and WHtR respectively. A histogram was generated to investigate the distribution of male firefighters possessing both a healthy WC and overfat WHtR, followed by undertaking an independent samples T-test to investigate a difference in stature between those males and the rest of the male firefighter sample. $P < 0.05$ was used to detect statistical significance.

3.3. Results

Table 3.2 displays study population characteristics of 497 full-time male firefighters from 28 LFB fire stations, and 78 full-time female firefighters from 42 LFB fire stations, showing the greatest proportion of participants to be white males aged 30 to 49 y. The mean (SD) age was 40.8 (8.6) y for the male firefighters and 38.1 (7.7) for the female firefighters. Not only were the male firefighters older, they had also served for longer, with a mean (SD) service period of 14.6 (8.3) y versus 9.9 (8.3) y. Table 3.3 displays anthropometric and adiposity characteristics of the study population, with correlation coefficients between each characteristic. As expected, the five measures of weight/adiposity status were strongly correlated, with body weight being more strongly correlated with body fat in the women, and body fat more strongly correlated with waist measurements in the men. Age was positively correlated with the four measures of weight status/adiposity in the men but not in the women.

Table 3.2. Demographic characteristics of the study population (*n* = 575)

		Males *n*=497 (86.4%) *n* (%)	Females *n*=78 (13.6%) *n* (%)
Age group (y)	20-29	59 (11.9)	11 (14.1)
	30-39	175 (35.2)	38 (48.7)
	40-49	181 (36.4)	22 (28.2)
	50-62	82 (16.5)	7 (9.0)

Table 3.3. Anthropometric and adiposity characteristics stratified by sex, with correlations between each characteristic.

Sex	Mean (SD)	BMI	BF%	WC	WHtR	Weight	Height
Males (*n* = 497)							
BMI (kg/m^2)[a]	27.7 (4.2)						
BF%	22.1 (5.4)	0.84**					
WC (cm)[a]	92 (12.8)	0.86**	0.90**				
WHtR (WC/Height)	0.52 (0.06)	0.85**	0.90**	0.94**			
Body weight (kg)	90.3 (13.5)	0.85**	0.75**	0.82**	0.70**		
Height (cm)	179.5 (6.5)	0.04	0.04	0.21**	-0.13*	0.51**	
Age (y)	40.8 (8.6)	0.26**	0.33**	0.37**	0.42**	0.16**	-0.15**
Females (*n* = 78)							
BMI (kg/m^2)[a]	24.3 (4.5)						
BF%	27.2 (6.1)	0.77**					
WC (cm)[a]	77 (11.5)	0.78**	0.77**				
WHtR (WC/Height)	0.47 (0.05)	0.84**	0.74**	0.93**			
Body weight (kg)	70.4 (10.4)	0.85**	0.83**	0.85**	0.78**		
Height (cm)	167.5 (5.5)	-0.15	0.12	0.14	-0.20	0.29*	
Age (y)	38.1 (7.7)	0.14	0.09	0.10	0.09	0.03	-0.10

[a]Median and interquartile range, Spearman's correlation. Abbreviations: BMI: Body mass index, WC: Waist circumference, WHtR: Waist-to-height ratio, BF: Body fat *$p < 0.05$; **$p < 0.01$

<u>Overweight and obesity prevalence</u>

Table 3.4 displays the proportional distribution of the study population across BMI, BF%, WC and WHtR risk categories, highlighting disparities in prevalence of overweight and obesity between each measure. The combined prevalence of overweight and obesity by BMI, BF%, WC and WHtR for males was 80.4%, 62.6%, 43.1% and 59.1% respectively. Overweight prevalence showed greater variation between measures compared with obesity prevalence. The female firefighters displayed consistently lower combined prevalence than the males across all four measures: 42.9%, 18%, 36.4% and 27.3% respectively. 15 males (3%) and 2 females (2.6%) were further classified as class 2 obese (BMI ≥ 35 kg/m^2). Another 3 males (0.6%) were further classified as class 3 obese (BMI ≥ 40 kg/m^2).

Table 3.4. Prevalence of overweight and obesity within the study population, classified by BMI, BF%, WC and WHtR.

	Males (*n* = 497)		Females (*n* = 78)	
BMI [a]	*n*	%	*n*	%
Underweight	0.0	0.0	0.0	0.0
Healthy	97	19.5	44	57.1
Overweight	289	58.1	25	32.5
Obese	111	22.3	8	10.4
BF%				
Under-fat	3	0.6	12	15.4
Healthy	183	36.8	52	66.7
Overfat	216	43.5	12	15.4
Obese	95	19.1	2	2.6
WC [b]				
Healthy	282	56.9	49	63.6
Overfat	137	27.6	16	20.8
Obese	77	15.5	12	15.6
WHtR [b]				
Healthy	203	40.9	56	72.7
Overfat	254	51.2	19	24.7
Obese	39	7.9	2	2.6

[a] *n* = 77 females due to missing data. [b] *n*= 496 (males), *n* = 77 (females) due to missing data. Abbreviations: BMI: Body mass index, WC: Waist circumference, WHtR: Waist-to-height ratio, BF: Body fat

Comparisons with the UK general population

Whilst the median BMI of males in this sample (27.7 kg/m^2) was similar to the adult male general population of England (27.6 kg/m^2), BMI characterised 80.4% of the males in this study as overweight or obese which is greater than the prevalence of 67% of adult males in England (Health Survey for England [HSE], 2017). Conversely, the median WC of the males in this sample was 5.8cm lower than adult males in England, and combined prevalence of overweight and obesity as characterised by WC in this male sample was 43.1% as opposed to the greater prevalence of 59% of males in England (HSE, 2017). The median BMI of white adult female firefighters in this study (24.3 kg/m^2) is lower than the adult female general population of England (27.8 kg/m^2), and prevalence of overweight and obesity of white female firefighters in this study was 42.9%, which is lower than the prevalence of 62% of female adults in England (HSE, 2017). The median WC for females in this sample was 12.4 cm lower than adult females in England, with prevalence characterised by WC in this female population (36.4%) being almost half the level observed in adult females in England (71%) (HSE, 2017).

Agreement of BMI classification with BF%, WC and WHtR

Figure 3.2 is a hypothetical example illustrating perfect agreement between BMI and WHtR within each risk category. The purpose of this example is to highlight the widespread poor agreement between BMI and the other three measures of adiposity displayed in Figures 3.3, 3.4 and 3.5, which illustrate the actual varying levels of misclassification within each BMI category using BF%, WC and WHtR as reference measures. This method of displaying misclassification within each BMI category was also used by Ashwell and Gibson (2018). Table 3.5 displays the total level of agreement between BMI classification and BF% classification, showing the sensitivity and specificity of the obesity, overweight and underweight BMI categories. Table 3.6 displays the total level of agreement between BMI classification and classification by waist indices, showing the sensitivity and specificity of the obesity and overweight BMI categories. This method of displaying agreement, sensitivity and specificity was also used by Choi *et al*. (2016) in the most comparable firefighter adiposity study.

Figure 3.2. Hypothetical example displaying 100% agreement between BMI and WHtR within each BMI category. Bar charts showing prevalence of overweight and obesity within the study sample as categorised by BMI (the bars), stratified by sex, highlighting percentages of misclassification found within each BMI category (coloured sections within each bar) using the analogous categories of waist-to-height-ratio (WHtR).

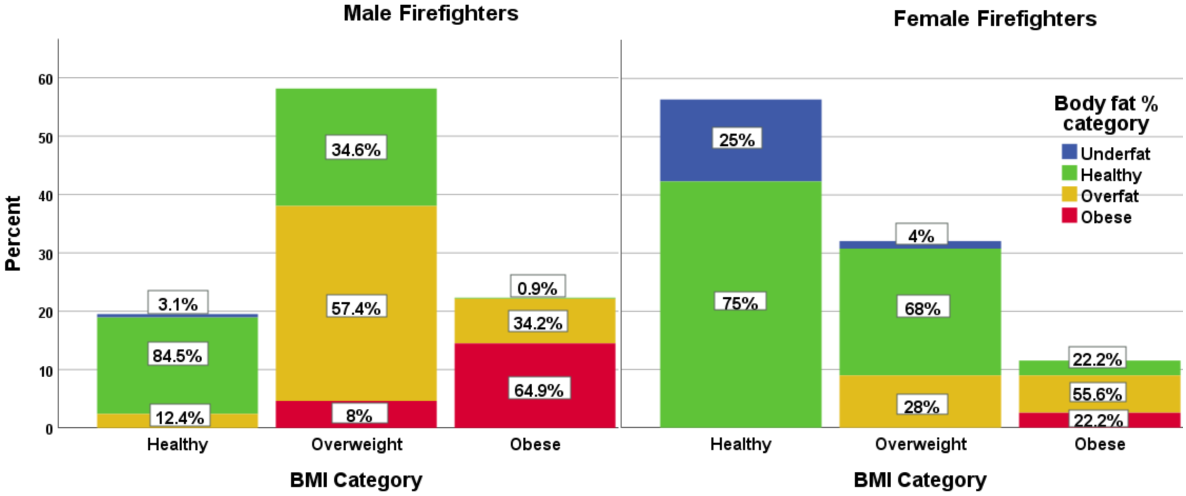


Figure 3.3. Stacked bar charts showing prevalence of overweight and obesity within the study sample as categorised by BMI (the bars), stratified by sex, highlighting percentages of misclassification found within each BMI category (coloured sections within each bar) using the analogous categories of body fat percentage.

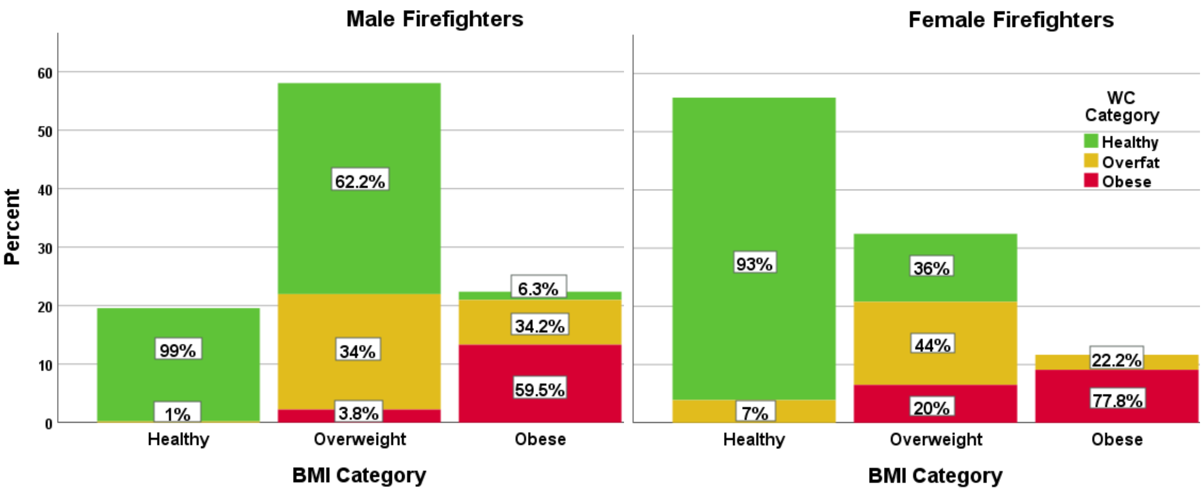


Figure 3.4. Stacked bar charts showing prevalence of overweight and obesity within the study sample as categorised by BMI (the bars), stratified by sex, highlighting percentages of misclassification found within each BMI category (coloured sections within each bar) using the analogous categories of waist circumference (WC).

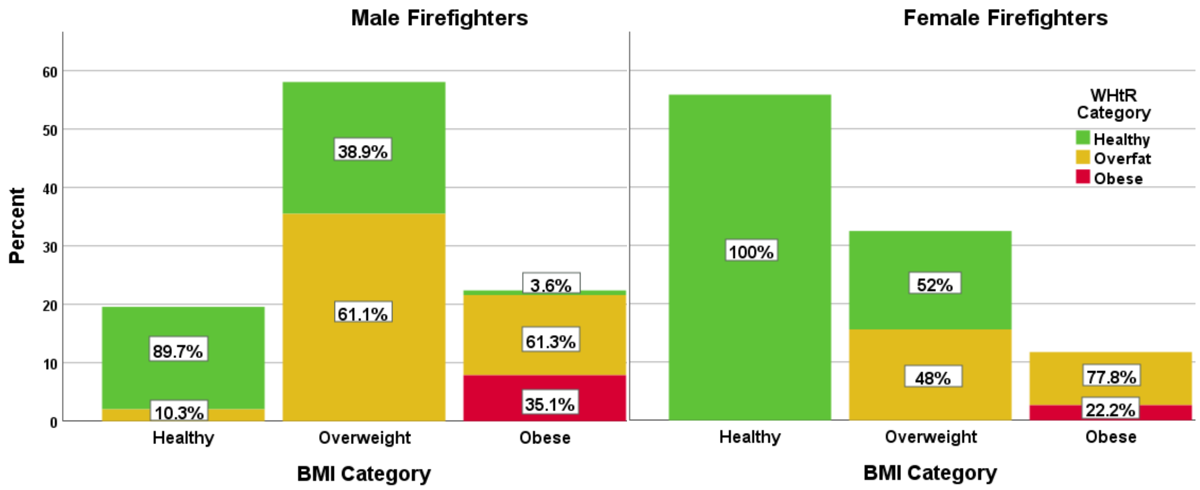


Figure 3.5. Stacked bar charts showing prevalence of overweight and obesity within the study sample as categorised by BMI (the bars), stratified by sex, highlighting percentages of misclassification found within each BMI category (coloured sections within each bar) using the analogous categories of waist-to-height-ratio (WHtR).

Table 3.5. Comparison of the adiposity classification between BMIs and body fat percentages (BF%) in 497 male and 78 female firefighters.

MALES n=497	**BF% Underfat**	**BF% Healthy**	**BF% Overfat**	**BF% Obesity**	**Total**	Agreement = 64.4 %
BMI underweight	0	0	0	0	0	Obesity sensitivity = .76 (72/95)
BMI healthy	3	82	12	0	97	Obesity specificity = .90 (363/402)
BMI overweight	0	100	166	23	289	Overweight[a] sensitivity = .93 (166/178)
BMI obesity	0	1	38	72	111	Overweight[a] specificity = .46 (85/185)
Total	3	183	216	95	497	Underweight sensitivity = 0 (0/3)
FEMALES n=78	**BF% Underfat**	**BF% Healthy**	**BF% Overfat**	**BF% Obesity**	**Total**	Agreement = 53.8 %
BMI underweight	0	0	0	0	0	Obesity sensitivity = 1 (2/2)
BMI healthy	11	33	0	0	44	Obesity specificity = .91 (69/76)
BMI overweight	1	17	7	0	25	Overweight[a] sensitivity = 1 (7/7)
BMI obesity	0	2	5	2	9	Overweight[a] specificity = .71 (44/62)
Total	12	52	12	2	78	Underweight sensitivity = 0 (0/12)

[a]Overweight sensitivity and specificity calculated using overweight, healthy and underweight subjects only.

<u>Simplified worked example (focusing on male firefighters):</u>

In Table 3.5, the male BMI obesity row shows that 72 out of 111 (65%) males who were classified as obese by BMI were also classified as obese by BF%, therefore BMI misclassified 35% of male firefighters as obese. BMI is therefore not a good way of classifying the obesity status of male firefighters. This problem is further exacerbated within the overweight category, however, 82 out of 97 (85%) males who had a healthy BMI also had a healthy BF%. In this context, the BMI 'healthy' category demonstrated a fairly low rate of misclassification.

Table 3.6. Comparison of the adiposity classification between BMIs and waist circumferences (WC), and between BMIs and waist-to-height ratios (WHtR) in 496 male and 77 female firefighters.

[A] MALES n=496	**WC Healthy**	**WC Overfat**	**WC Obesity**	**Total**	Agreement = 52.4 % (Kappa .31)
BMI healthy	96	1	0	97	Obesity sensitivity = .86 (66/77)
BMI overweight	179	98	11	288	Obesity specificity = .89 (374/419)
BMI obesity	7	38	66	111	Overweight[a] sensitivity = .99 (98/99)
Total	282	137	77	496	Overweight[a] specificity = .35 (96/275)
[B] MALES n=496	**WHtR Healthy**	**WHtR Overfat**	**WHtR Obesity**	**Total**	Agreement = 60.9 % (Kappa .35)
BMI healthy	87	10	0	97	Obesity sensitivity = 1 (39/39)
BMI overweight	112	176	0	288	Obesity specificity = .84 (385/457)
BMI obesity	4	68	39	111	Overweight[a] sensitivity = .95 (176/186)
Total	203	254	39	496	Overweight[a] specificity = .44 (87/199)
[C] FEMALES n=77	**WC Healthy**	**WC Overfat**	**WC Obesity**	**Total**	Agreement = 75.3 % (Kappa .56)
BMI healthy	40	3	0	43	Obesity sensitivity = .58 (7/12)
BMI overweight	9	11	5	25	Obesity specificity = .97 (63/65)
BMI obesity	0	2	7	9	Overweight[a] sensitivity = .79 (11/14)
Total	49	16	12	77	Overweight[a] specificity = .82 (40/49)
[D] FEMALES n=77	**WHtR Healthy**	**WHtR Overfat**	**WHtR obesity**	**Total**	Agreement = 74 % (Kappa .49)
BMI healthy	43	0	0	43	Obesity sensitivity = 1 (2/2)
BMI overweight	13	12	0	25	Obesity specificity = .91 (68/75)
BMI obesity	0	7	2	9	Overweight[a] sensitivity = 1 (12/12)
Total	56	19	2	77	Overweight[a] specificity = .77 (43/56)

[a]Overweight sensitivity and specificity calculated using overweight and healthy subjects only.
All kappas were significant ($p < 0.01$)

Simplified worked example (focusing on male firefighters):

In Table 3.6 section [A], the male BMI obesity row shows that 66 out of 111 (60%) males who were classified as obese by BMI were also classified as obese by WC, therefore BMI misclassified 40% of male firefighters as obese. BMI is therefore not a good way of classifying the central obesity status of male firefighters. This problem is further exacerbated within the overweight category, however, 96 out of 97 (99%) males who had a healthy BMI also had a healthy WC. In this context, the BMI 'healthy' category demonstrated a very low rate of misclassification.

BMI vs BF%

Table 3.5 shows that the agreement percentage between the BMI and the BF% categories was 64.4% for male fighters, and 53.8% for the female firefighters. The specificity of the obesity BMI classification was high and very similar for both sexes at 0.90 and 0.91 respectively, however, Figure 3.3 shows that 35.1% of the male firefighters and 77.8% of the female firefighters classified as obese by BMI, were simultaneously classified as non-obese by BF% (false positive errors). Of those misclassifications, one male and two females were classified as 'healthy' by BF%, with the rest being classed as 'overfat'. Table 3.5 shows that the sensitivity of the obesity BMI category was 0.76 for the males and 1.0 for the females, although only two females presented with BF% in the obese range. The overweight BMI category showed good sensitivity for males (0.88) and perfect for females (1.0), but poorer specificity for males (0.46) than for females (0.71) i.e. 54% of the males and 29% of the females classed as healthy by BF% were misclassified as overweight by BMI (false positives). However, Figure 3.3 shows that 34.6% of the males and 72% of the females who were classed as overweight by BMI, fell within their healthy BF% range. The underweight BMI category demonstrated no sensitivity for either sex.

BMI vs WC

Section [C] of Table 3.6 displays better overall agreement between BMI and WC for the females: 75.3 % (Kappa 0.56), compared with section [A] (the males): 52.4 % (Kappa 0.31). For the male firefighters, section [A] of Table 3.6 displays high sensitivity (0.86) and high specificity (0.89) of BMI for classifying obesity (using WC as the reference). However, when focusing exclusively on males who were classified as obese by BMI (the third bar of Figure 3.4), it can be seen that 40.5% of males classified as obese by BMI were non-obese by WC (false positives). For the overweight BMI category, section [A] of Table 3.6 displays overweight sensitivity (0.99) and specificity (0.35), i.e. 1% of male firefighters who were overweight by WC were misclassified as healthy by BMI (false negatives), whilst 65% of male firefighters who were healthy by WC were misclassified as overweight by BMI (false positives). For the females, section [C] of Table 3.6 displays BMI’s sensitivity for classifying obesity (0.58) to be poorer than its specificity (0.97). BMI’s sensitivity for classifying female firefighters as overweight (0.79) was similar to its specificity (0.82).

BMI vs WHtR

Section [D] of Table 3.6 displays better overall agreement between BMI and WHtR for the females: 74% (Kappa 0.49), compared with section [B] (the males): 60.9% (Kappa 0.35). For the male firefighters, section [B] of Table 3.6 displays perfect sensitivity (1.0) and high specificity (0.84) of BMI for classifying obesity (using WHtR as the reference). However, when focusing exclusively on males who were classified as obese by BMI (the third bar of Figure 3.5), it can be seen that 64.9% of males classified as obese by BMI were non-obese by WHtR (false positives). For the overweight BMI category, section [B] of Table 3.6 displays overweight sensitivity (0.95) and specificity (0.44). In other words, 5% of male firefighters who were overweight by WC were misclassified as healthy by BMI (false negatives), whilst 56% of male firefighters who were healthy by WC were misclassified as overweight by BMI (false positives). For the female firefighters (section [D] of Table 3.6) BMI showed perfect sensitivity for classifying overweight and obesity (using WHtR as the reference). BMI also demonstrated high specificity (0.91) for classifying female firefighter obesity. However, when focusing exclusively on females who were classified as obese by BMI (the sixth bar of Figure 3.5), it can be seen that 77.8% (*n*=7) of the females classified as obese by BMI were non-obese by WHtR (false positives). A similar situation occurs with female overweight specificity (0.77) (section [D] of Table 3.6), whereby, when focusing exclusively on females who were classified as overweight by BMI (the fifth bar of Figure 3.5), it can be seen that 52% (*n*=13) of the females who were classified as overweight by BMI were classified healthy by WHtR (false positives).

<u>WC vs WHtR</u>

For female firefighters, WC was the only reference measure to highlight false negatives within the overweight and obesity BMI categories. However, this misclassification could be caused by WC. Indeed, when using BF% or WHtR as the reference, BMI demonstrated perfect sensitivity for classifying female firefighter overweight and obesity. The false negatives highlighted by WC may therefore be a product of the female firefighters in this study being 5.6 cm taller than the average English adult female (HSE, 2016). The same occurred for male firefighters in this study, who were 3.9 cm taller than the average English male (HSE, 2016), whereby the 86% sensitivity of BMI for classifying male obesity (using WC as the reference, as displayed in section [A] of Table 3.6) improved to 100% sensitivity when using WHtR as the reference (as displayed in section [B] of Table 3.6). Conversely, for a subset of *n*=83 shorter male firefighters possessing healthy WCs, WHtR classified them as 'overweight'. Upon further investigation they were indeed found to be 5.8 cm shorter than the rest of the male firefighters ($p < 0.01$). Figure 3.6 shows that the majority of this subset were close to the 94 cm 'overweight' WC cut-off.

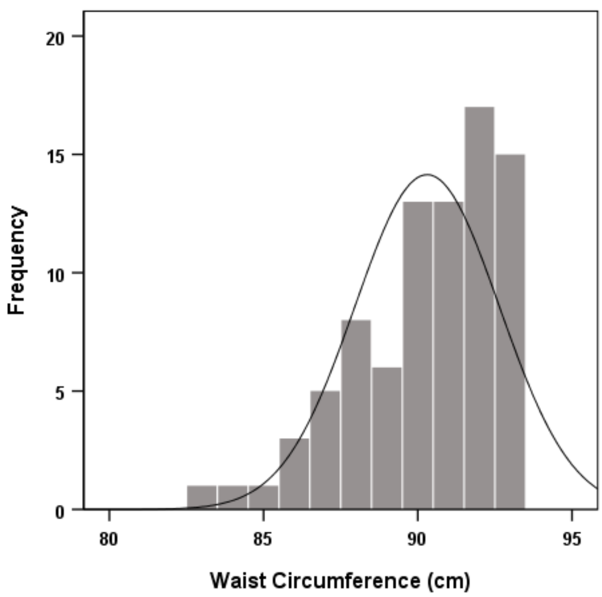


Figure 3.6. Distribution of WC for the 83 male firefighters possessing a healthy WC and an 'overweight' WHtR.

3.4. Discussion

For this study, the BMI, BF%, WC and WHtR of 497 male and 78 female full-time London firefighters was measured/calculated. BMI overestimated the prevalence of combined overweight and obesity for male and female firefighters by a minimum of 17.8% and 6.5% respectively compared with BF%, WC and WHtR. BMI demonstrated very poor specificity for classifying male firefighter 'overweight' status against BF%, WC and WHtR, indicating BMI to generate a high rate of false positives. WC also indicated possible differential misclassification of taller and shorter firefighters due to universal cut-off points. This is the first study to investigate the adiposity of UK female firefighters, and the first to investigate the misclassification of UK firefighter adiposity status.

Representativeness of the study population

Four hundred and ninety-seven male firefighters participated in this study with a mean age of 40.8 y, which is almost identical to the mean age of 41 y across the English fire services (Home Office, 2019). The median BMI of 27.7 in this study sample is also very close to the BMI of the average LFB firefighter (27.6 measured in 2018 - statistic provided by the LFB occupational health service). The slightly greater BMI in this study may be a reflection of the fact that LFB firefighter BMIs are increasing over time (displayed in Figure 4.1 of Chapter 4), as the statistics provided by the LFB occupational health service were from 2018. These similarities in age and BMI, coupled with the even spread of urban and suburban fire stations from which the study population were derived, strengthens the external validity of this study's findings for white male firefighters serving in the UK. With only 6.4% of firefighters in England being female (Home Office, 2019), the sampling strategy to obtain 78 white female firefighters required targeted email recruitment for the majority of the participating females. As such, this may have attracted a subsample of females (46 out of 78) who may not be representative, therefore results for this demographic should be interpreted with caution. Firefighters from ethnicities other than white Caucasian were not included in this study due to inherent body composition differences (Bosy-Westphal and Müller, 2015). As this demographic accounts for 4.3% of the English fire service (Home Office, 2019), investigating black, Asian and minority ethnic groups individually remains unfeasible.

Prevalence of overweight and obesity

The only previous English firefighter BMI study to date (Munir *et al.*, 2012) reported lower combined prevalence of overweight and obesity of males by BMI (66%) compared with the males in this study

(80.4%). The overweight prevalence of the males in this study (58.1%) was greater than in the study by Munir *et al*. (2012) (53%) although the greatest difference was found when comparing obesity prevalence (22.3% in this study vs 13%). It should be noted that the previous study is nine years older, therefore the established phenomenon of firefighter BMI increasing over time (Ide, 2000; Soteriades *et al.*, 2005; Smith *et al.*, 2020) is likely to have contributed to this difference seen between UK studies. Furthermore, the mean age (SD) was 37.6 (8.5) y, which is 3.2 y younger than the males in this sample. Munir *et al*. (2012) suggested that due to lower levels of BMI-based overweight and obesity compared with previous USA firefighter studies (73-88%) (Soteriades *et al*., 2008; Tsismenakis *et al*, 2009; Donovan *et el*., 2009; Poston *et al*., 2011), that UK firefighters may not suffer from the same fitness and health issues as USA firefighters. The 80.4% prevalence in this study is identical to the combined prevalence seen in the most recent and comparable study of Californian USA male firefighters (Choi *et al*., 2016). Both studies also share similar distributions of overweight and obesity. Although the average male BMI was also identical for both studies (27.7 kg/m^2), the mean BF% of males in this study (22.1%) was greater than the mean BF% of the male Californian firefighters (18.8%), and male Virginian (USA) firefighters (21%) (Smith *et al.*, 2020). This was reflected by greater combined prevalence of overweight and obesity characterised by BF% in this study (62.6%) compared with the Californian study (55.6%). This disparity would have been greater if homogenous cut-offs were used for defining overfat and obesity, as this study utilised age-related cut-offs recommended by Gallagher *et al.* (2000) as opposed to the cut-offs used by Choi *et al*. (2016) which were not age-adjusted. Distribution between overfat and obesity categories defined by BF% was again similar between this study and the Californian study. The opposite occurred when comparing combined prevalence using WC, whereby the mean WC of males in this study (92cm) was lower than the Californian firefighters (95.4cm) and the Virginian firefighters (95.5cm) which was reflected in the combined prevalence of 43.1% (this study) and 48.7% (Californian study). Half of the overweight/obese Californian firefighters were classified as obese by WC, which is a greater proportion than found in this study (36%). This suggests that whilst the UK firefighters may carry a greater proportion of body fat, the USA firefighters may have a greater propensity to accumulate body fat centrally.

There remains a paucity of comprehensive overweight prevalence data for female firefighters. Of the obesity studies found, female firefighters in Québec Canada (Gendron *et al.*, 2018), Colorado USA (Li *et al.*, 2017) and Virginia USA (Smith *et al.*, 2020) reported a similar rate of obesity by BMI (12%, 11% and 10% respectively) compared with this study (10.4%), however, obesity prevalence characterised by WC was lower in the Colorado study (5%) compared with this study (15.6%), although the Virginia study reported greater prevalence of female firefighter obesity by WC (20%)

compared with this study. The Colorado female firefighters had a 5% lower mean BF% than the females in this study, however it should be noted that due to firefighting being a male dominated profession, all four studies suffered from small female sample sizes of *n*=78 (UK), *n*=76 (Colorado), *n*=69 (Virginia) and *n*=41 (Québec). More female firefighter adiposity status research is therefore required.

BMI's sensitivity and false negatives

The sensitivity of BMI-based obesity against BF%, WC and WHtR of males in this study ranged from 0.76 to 1.0 which is better than that seen in USA Californian male firefighters: 0.65 to 0.73 (Choi *et al*., 2016). Upon observing the descriptive characteristics of the USA study, the mean height and SD of the males was almost identical to the males of the present study. This indicates that the USA false negative obese firefighters might possess lower skeletal muscle mass (SMM) compared with the obese firefighters in this study, however this cannot be confirmed as SMM was not directly reported in the USA study. The sensitivity of the overweight BMI category was similar between the two studies (this study: 0.88 - 0.99 vs Californian study: 0.91 - 0.97). The first bars of Figures 3.3 and 3.5 show that BF% and WHtR identify a similar false negative error rate of overweight male firefighters generated by BMI, and no female false negatives. The contrasting differential misclassification caused by WC in this study within the males and females may suggest it to be an inappropriate adiposity risk classification measure for UK firefighters. This further reinforces the use of WHtR instead of WC for assessing firefighter abdominal adiposity, which is consistent with a systematic review by Browning, Hsieh and Ashwell (2010) which suggested WHtR to be a more useful clinical screening tool than WC due to personalised cut-offs which are height dependent, thus reducing risk of misclassifying individuals who are shorter/taller in stature. The use of WHtR is further supported by a recent systematic review and dose-response meta-analysis finding that male and female all-cause mortality increased sharply and linearly after the cut-off point of 0.50 (Jayedi *et al*., 2020). Furthermore, a large cross-sectional study of *n*=1462 middle aged Canadian firefighters demonstrated that, compared with other measures of weight/adiposity (BMI, WC and WHR), WHtR had the strongest inverse association with hyperemic velocity time integral (a microvascular function which was predictive of future cardiovascular events in the cohort) (Martin *et al*., 2013), with the authors suggesting WHtR to be the index most strongly correlated with CVD. Martin *et al*. (2013) emphasised the important value of WHtR in terms of seemingly universally applicable cut-offs with no apparent ethnic differences (Martin *et al*., 2013).

Whilst WHtR provides a convenient and strong indication of health risks (Browning, Hsieh and Ashwell, 2010; Martin *et al*., 2013; Jayedi *et al*., 2020), it is unable to detect excess peripheral subcutaneous adiposity. Excess adipose tissue (regardless of anatomical location) increases body weight, which could of course impair firefighting performance. Whilst accurately classifying cardiometabolic health risk is essential, it is also important to obtain a more comprehensive picture of body composition as part of assessing firefighter occupational fitness and risk of musculoskeletal injury. WHtR should therefore not exclusively be relied upon for detection of firefighter adiposity status. Even though BF% provides a more comprehensive assessment of adiposity, it suffers from limitations which are described in detail in Chapter 1. Briefly, as BF% is confounded by FFM it cannot be relied upon to accurately measure FM. A height-adjusted absolute measure of adiposity which is not confounded by FFM is therefore required for this occupational group.

The potentially adverse health implications of false negative errors are clearly of concern, as >10% of firefighters may be incorrectly advised by health professionals who rely upon BMI for classifying risk. This could lead to a false sense of security without sufficient incentive for lifestyle modification, which may not only lead to endangering themselves, but also their colleagues and the public whom they serve.

<u>BMI's specificity and false positives</u>

The specificity of BMI-based obesity against BF%, WC and WHtR of males in this study ranged from 0.84 to 0.90 which is similar to that seen in USA Californian male firefighters: 0.86 - 0.91 (Choi *et al*., 2016). However, when focusing purely on this study's male obesity BMI category (the 3rd bars of Figures 3.3 - 3.5), 35.1% - 64.9% of male firefighters classified obese by BMI were false positive errors, which is similar to the false positive rate of 34.6% - 62.2% seen within this study's male firefighter overweight category (the 2nd bars of Figures 3.3 - 3.5). This is consistent with the previous UK firefighter study by Munir *et al.* (2012) whose results indicate that approximately half of the overweight male firefighters had a healthy WC. A similar false positive rate was also detected in Californian USA firefighters which found 60-62% of male firefighters in the healthy WC and BF% categories to be misclassified as overweight by BMI (Choi *et al*., 2016). Table 3.6 [A] shows that 65% of the male firefighters in this study who were classified as healthy by WC were classified as overweight by BMI, which is similar to a Missouri USA male firefighter study (63%) (Jitnarin *et al*., 2013). It should be noted that the USA studies did not employ the WHtR measure, which, for the male firefighters in this study, substantially reduced the BMI-based overweight false positive error rate to be in closer alignment with the BMI-based false positive error rate identified by BF%. Even so, at first glance of Table 3.4, it would appear that BMI is most closely correlated with WHtR for quantifying overweight prevalence, with less than 7% difference between the two indices. However, the 2nd bar of Figure 3.5 reveals that 38.9% of male firefighters classed as overweight by BMI, actually have a healthy WHtR <0.5. This is consistent with previous firefighter anthropometry studies which have also found high rates of false positive errors, particularly in the overweight classification of firefighters when comparing BMI with waist measure indices (Munir *et al*., 2012; Jitnarin *et al.*, 2013; 2014; Choi *et al.*, 2016; Lessons and Bhakta, 2018). This can be explained by the greater levels of SMM required to effectively perform the physically demanding role of a firefighter, thus increasing total body weight (Jitnarin *et al*., 2013). This is epitomised by 3.6% of the obese BMI category whose WHtRs place them in the healthy range.

A high rate of false positive errors generated by BMI was also detected for the female firefighters. 77.8% of the women in the obese BMI category fell within the lower risk categories for both BF% and WHtR. 72% of the overweight BMI category contained women with a healthy BF%, and 52% of women in the overweight BMI category had a healthy WHtR. To the best of our knowledge there is a paucity of data from other studies which report female firefighter BMI misclassification, therefore comparisons cannot currently be made.

Widespread false positive errors could lead to undue confusion, stigmatisation and potentially result in eating disorders. It is therefore imperative that more valid body composition assessment tools are developed and implemented for firefighters. At present, WHtR for indication of cardiometabolic risk in conjunction with BF% (in the absence of a height-adjusted FM measure) are suggested as the most valid options for assessing firefighter adiposity status. WC and WHtR are proxy measures of central adiposity/abdominal fat (Ashwell and Gibson, 2016), and are more strongly associated with risk factors for cardiovascular and cardio-metabolic disease than BMI (Browning, Hsieh and Ashwell, 2010). Whilst accurately classifying these health risks is essential, it is also important to obtain a more comprehensive picture of body composition as part of assessing firefighter occupational fitness and risk of musculoskeletal injury.

<u>Study strengths</u>

This is the first UK study to comprehensively investigate misclassification of male firefighters by BMI, the first study globally to investigate misclassification of female firefighters by BMI and the first in the UK to quantify the prevalence of overweight and obesity of a population of female firefighters. This is also an early study to utilise WHtR as a method for assessing adiposity status of firefighters. All measurements were taken by a singular experienced researcher using a relatively superior body composition analyser to assess BF% compared with previous studies using less accurate methods including foot-to-foot BIA (Poston *et al*., 2011; Jitnarin *et al*., 2014) and skinfold measures (Choi *et al.*, 2016).

Study limitations

Limitations of this study derived from insufficient racial diversity within the English fire service which precluded assessment of the prevalence of overweight and obesity, and levels of misclassification of ethnicities other than white Caucasian. Also, the purposive sampling strategy of the majority of the female firefighters to ensure a sufficient number could have introduced bias, possibly reducing the representativeness of this study subsample. Whilst a scarcity of UK female firefighters demanded this strategy, further female firefighter studies are required.

A further limitation was that data was not collected for those who decided not to participate and as such, prevents the comparison between their characteristics and the participants. It is therefore unknown whether significant differences exist between participants and non-participants. It should however be noted that those who refused to participate constituted a minor proportion of the target sample.

Another limitation was driven by the free-living environment, whereby some determinants of hydration status were not controlled directly prior to measurement i.e. participants were not instructed to refrain from consuming food or liquids. This decision was made to minimise participant burden and attrition. Whilst a review suggested that BIA is most accurate when measuring healthy people with stable fluid balance (Kyle *et al.*, 2004), BIA may be less sensitive to the volume of fluid recently consumed due to the truncal component only accounting for 10% of absolute body impedance (Bracco *et al.*, 1996). This study's measurement protocol did however attempt to reduce the effect of this potential confounding variable via measurements typically being taken between 11:00 hrs and 16:00 hrs, which goes some way toward reducing diurnal variation. Verbal confirmation of an empty bladder was also obtained from each participant immediately prior to measurement.

Conclusion

When assessing the adiposity of male and female London firefighters, BF%, WC and WHtR identified varying levels of differential misclassification caused by BMI. Sensitivity of BMI for identifying overweight and obesity was better for female firefighters, however, BMI was unable to detect underweight firefighters. Specificity of BMI was very poor for both sexes, generating widespread false positive errors. WC also generated differential misclassification, therefore, WHtR in conjunction with BF% (in the absence of a height-adjusted FM measure) are suggested as the most valid options currently available for assessing firefighter adiposity status and related risk.

Chapter 4. Development of muscle mass and body fat reference curves for UK firefighters

Overview

In this study a novel body composition reference system for UK firefighters was developed by generating centile reference curves illustrating age-related changes in fat mass and skeletal muscle mass of male firefighters. Using body composition and anthropometric data collected for 497 white male firefighters, reference centile curves were generated for BF%, fat mass index (FMI), WHtR and skeletal muscle mass. Comparisons with the equivalent UK general population white male centile curves identified that the firefighters in this study possessed similar amount of body fat and a greater amount of skeletal muscle. Cut-offs for defining overfat and obesity were defined at the 85th and 95th centiles. These centiles were chosen due to relative suitability and good agreement (97%; Kappa 0.86, $p < 0.001$) between the BF% curves and the FMI curves at these centiles. Low muscle and adiposity were defined at the 2nd centile. This system not only overcomes the limitations of commonly used adiposity indexes such as BMI, but also offers a skeletal muscle reference. This can therefore be used as a proxy to indicate firefighters who may possess insufficient muscular strength, which is a vital component of physical fitness not routinely tested in the UK fire services.

4.1. Introduction

To date, BMI has been the primary health risk classification system used to categorise firefighters as being underweight, healthy weight, overweight or obese. Figure 4.1 displays LFB occupational health statistics which shows the average BMI of operational firefighters to be increasing over time.

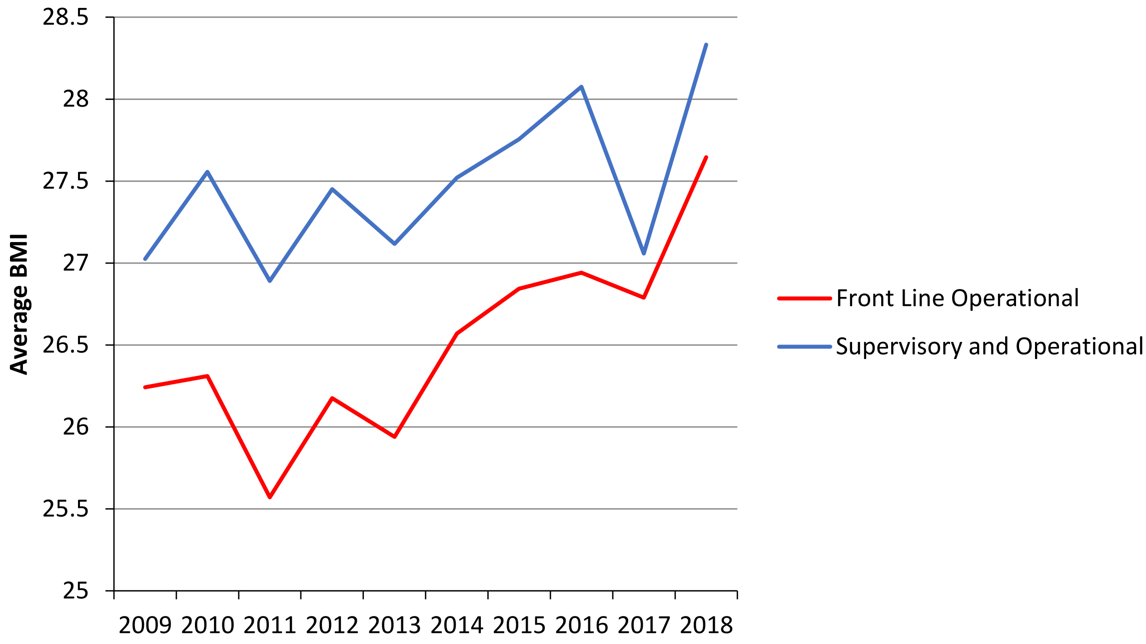


Figure 4.1. LFB average BMI from 2009 to 2018 (unpublished data provided by LFB occupational health).

The validity of BMI for classifying firefighter adiposity status was comprehensively investigated by the study in the previous chapter. This showed BMI to demonstrate poor validity for the classification of UK firefighter adiposity status.

Whilst BF% is a more valid body composition assessment tool than BMI, it is still prone to potentially high rates of misclassification (Rothman, 2008) due to limitations which are described in detail in Chapter 1 (see Figure 1.5). Height adjusted adiposity indices enable more accurate nutritional surveillance over time, providing the ability to elucidate true body composition changes, as opposed to BF% which only provides information on FM changes relative to FFM. WC and WHtR are limited by their inability to measure total adiposity, which is an important consideration when assessing musculoskeletal injury risk and occupational physical fitness (Poston *et al*., 2011). Given the physical nature of firefighting tasks, this is an important consideration that can only be achieved via a more comprehensive assessment of body composition, not exclusively focusing on FM, but also paying attention to skeletal muscle mass (SMM) which, to date has not been assessed in the UK fire service.

Given that SMM and muscular strength are positively correlated (Newman *et al.*, 2003), SMM is likely to be an important marker of firefighter operational readiness. Furthermore, SMM is an independent marker of metabolic health (as described in Chapter 1). Besides metabolic health, age-related muscle loss (sarcopenia) is an emerging public health and clinical concern (Beaudart *et al.*, 2014). This may be of increasing relevance to the fire service considering the recent change in UK policy which sets the national retirement age of firefighters to a minimum age of 60 y. Historically, firefighters could retire after 30 y service which resulted in most personnel retiring in their early fifties. Sarcopenia is the greatest contributor to decreased mobility in older age. It would therefore be prudent to monitor firefighter SMM to not only assess occupational fitness and classify risk of metabolic disease, but to also monitor risk of musculoskeletal injury, as a tight relationship exists between sarcopenia and incidence of osteoporotic fractures (Cederholm *et al.*, 2013). Such surveillance could enable appropriate physical activity and nutritional interventions designed to attenuate this decline, as optimal maintenance of SMM throughout adulthood is key to delaying age-associated muscle loss (Sayer *et al*., 2008).

Total-body SMM is traditionally measured via Dual-energy X-ray absorptiometry (DXA), magnetic resonance imaging (MRI), 24hr creatinine excretion or whole-body K^+ counting (Kim et *al.*, 2006; Shen *et al.*, 2004; Wang *et al*., 2007). The limitations of these methods include invasiveness, procedural duration, financial expense, specialist training requirements and facilities. Bioelectrical impedance analysis (BIA) via segmental whole-body analysis offers a non-invasive, valid and efficient method of assessing both FM and SMM in a field setting. BIA strongly correlates with DXA (Verney *et al*., 2015), and is a highly viable option due to being relatively inexpensive, rapid, and portable (Pietrobelli *et al*., 2004). Segmental BIA analysers can also locate FM and FFM distribution, distinguishing between the limbs and the trunk. This then allows for the calculation of SMM in the limbs which acts as a good proxy for total SMM.

BIA has been used to produce reference charts displaying smoothed centile curves for the assessment of age-related body-fatness in children (McCarthy *et al.*, 2006). The same method was later used to generate child and youth skeletal muscle mass references (McCarthy *et al.*, 2014). This population specific approach has also recently been successfully used for adults in generating age-related FM and SMM references for UK adults over 40 y (Lee *et al.*, 2020).

To date there are no equivalent firefighter-specific body composition references available. The aim of this study was to develop a suite of UK firefighter-specific body composition references.

4.2. Methods

Participants

The study population comprised 497 full-time male firefighters from 28 Greater London fire stations who were recruited on their day shifts from June 2019 to March 2020 during scheduled fire station engagements which the researcher planned in advance. Stations were chosen for inclusion based upon their geographical location, ensuring an even geographical distribution of urban and suburban stations to attain representativeness. The firefighters had the study explained to them in full, and those who chose to participate were provided with a participant information sheet and informed signed consent was obtained from each participant (See Chapter 2). Table 4.1 displays the geographical distribution of the stations and the number of participants from each. This ranged from one to fifty participants. This broad range was attributable to two factors. Firstly, varying numbers of watches were randomly available for inclusion during the study period, e.g. the stations with the lower numbers of firefighters (5 - 20) displayed in Table 4.1 are due to prior commitments such as scheduled skills training, fire inspections etc, thus rendering some watches unavailable. Secondly, if a firefighter from a different fire station happened to be working at the scheduled study station on the day of data collection, they were given the opportunity to participate. This explains the presence of the stations from which only one firefighter participated. Exclusion criteria applied to operational firefighters who were not full-time i.e. those who do not work both day and night shifts, applying to n=8. Centile curves need to be specific to ethnic groups due to inherent body composition differences (Bosy-Westphal and Müller, 2015), therefore exclusion criteria also applied to ethnicities other than white Caucasian, applying to n=27. Figure 4.2 shows the participant flow through the study.

Table 4.1. Fire Station participant postings

Urban fire stations	***n* (%)**
Bethnal Green	50 (10.1)
Edmonton	43 (8.7)
Tottenham	39 (7.8)
Homerton	33 (6.6)
Stratford	20 (4)
Millwall	16 (3.2)
Lambeth	10 (2)
Poplar	9 (1.8)
Stoke Newington	7 (1.4)
Islington	6 (1.2)
Dowgate	5 (1)
Shoreditch	5 (1)
Soho	1 (0.2)
Leyton	1 (0.2)
Leytonstone	1 (0.2)
Total	246 (49.5)
Suburban Fire Stations	***n* (%)**
Dagenham	44 (8.9)
Ilford	39 (7.8)
Enfield	36 (7.2)
Hornsey	35 (7)
Orpington	27 (5.4)
East Ham	25 (5)
Walthamstow	18 (3.6)
Plumstead	18 (3.6)
Plaistow	5 (1)
Hornchurch	1 (0.2)
Wennington	1 (0.2)
Lea Green	1 (0.2)
Southgate	1 (0.2)
Total	251 (50.5)

Stations with *n*=1 participant denotes that particular firefighter's presence at a participating fire station on the day of measurement. They then voluntarily enrolled into the study.

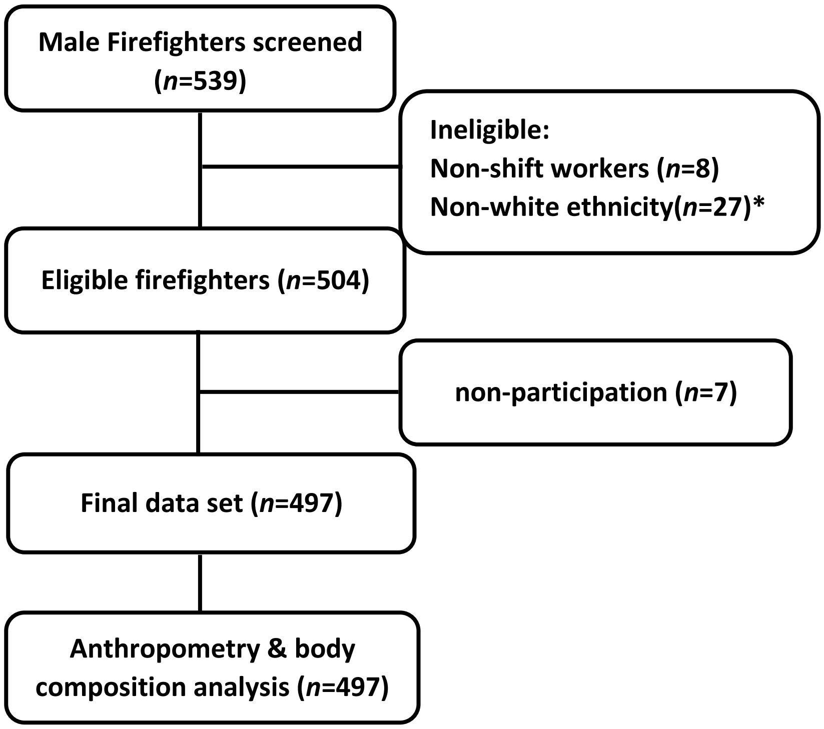


Figure 4.2. Participant flow through the study *all ethnicities were measured but not included in this data set due to inherent body-composition heterogeneity

Anthropometric and body-composition measurements

Chapter 2 describes the measurement protocols followed for obtaining participant anthropometric and body composition data, and how it was converted into the relevant indices. BF (%), appendicular skeletal muscle mass (ASMM) (kg), WHtR, fat mass index (FMI) and skeletal muscle mass index (SMMI) were used in the construction of centile references for this study.

Ethical Approval

This study was approved by the London Metropolitan University School of Human Sciences Research Ethics Committee (See Chapter 2 and appendix 2.2) and the LFB (See appendix 2.1).

Centile curves and statistical analysis

Data was imported to IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). Data was checked for normality. Descriptive statistics were computed for age, BF%, WHtR, WC, ASMM, FMI and SMMI and assigned as continuous variables. Normally distributed data was reported as mean +/- standard deviation (SD). Non-normally distributed data was reported as median +/- interquartile range (IQR). Age groups were assigned as categorical variables and reported as *n* (%). Fire station locations were grouped into urban or suburban categories. Independent samples t-tests were used to test for differences between urban and suburban fire station participants in age and all anthropometric and body composition indices. A scatter plot was generated to assess population age distribution. Smoothed centile curves were generated for SMMI, FMI, WHtR, ASMM and BF% separately using the Cole and Green (1992) method. This summarises the data into three age-specific smooth curves, named *L* (lambda), *M* (mu), and *S* (sigma). Curves *M* and *S* correspond to the medians and body composition/anthropometric coefficient of variations at each age. Curve *L* allows for age dependent skewness in distribution of the body composition/anthropometric measures. Percentile curves were constructed via data importation into LMS Chart-maker light, and the *L*, *M* and *S* curves estimated. Seven centile curves (2nd - 98th) were generated each spaced apart by two-thirds of an SD score. The 85th and 95th centile curves were subsequently calculated for FMI and BF%. Contingency tables were used to calculate the level of agreement between BF% and FMI centiles for defining adiposity status, with the Kappa statistic being calculated (3x3 tables). Mann-Whitney U tests were conducted to investigate anthropometric and body composition differences between a subset of firefighters (n=8) and the rest of the sample. The alpha value for detecting statistical significance was set at $p<0.05$.

4.3. Results

Table 4.2 displays study population characteristics showing no significant differences in anthropometric and body composition variables between urban and suburban fire station-based participants. Participant ages ranged from 21 y – 62 y (mean age: 40.8 y, SD: 8.6 y). Table 4.3 and Figure 4.3 display the study sample age distribution in relation to height, showing the greatest proportion of participants to be aged between 25 y and 55 y. Although less data was obtained for subjects below 25 y and above 55 y, the age-group distribution is consistent with that reported within a UK fire service review which comprised male firefighters from four FRSs (*n*=7,550) (Williams *et al*., 2013), reporting the following age-group distribution: 20-24 y (2.9%), 25-29 y (9.6%), 30-34 y

(15.8%), 35-39 y (16.3%), 40-44 y (20.6%), 45-49 y (22.2%), 50-54 y (10.8%), 55-59 y (1.4%), 60-64 y (0.1%). Figure 4.3 displays a relatively even dispersal of cases within the current study. Table 4.3 also displays mean SMMI, FMI and WHtR values across nine age ranges.

Table 4.2: Study population characteristics

	Total sample (n=497) Mean ± SD	**Urban fire stations (n=246) Mean ± SD**	**Suburban fire stations (n=251) Mean ± SD**	**Urban vs Suburban *p* value**
Age (y)	40.8 ± 8.6	40.4 ± 8.4	41.1 ± 8.8	NS
Height (m)	1.79 ± 0.07	1.79 ± 0.06	1.8 ± 0.07	NS
Weight (kg)	90.3 ± 13.5	90.1 ± 14.1	90.4 ± 12.9	NS
BMI (kg/m^2)[c]	27.7 ± 4.2	27.5 ± 4.1	27.9 ± 4.3	NS
WC (cm)[ac]	92 ± 12.8	92 ± 14.3	92 ± 12	NS
WHtR	0.52 ± 0.06	0.52 ± 0.06	0.52 ± 0.06	NS
BF (kg)	20.5 ± 7.8	20.4 ± 8.1	20.6 ± 7.5	NS
BF%	22.1 ± 5.4	21.9 ± 5.4	22.2 ± 5.4	NS
FMI (kg/m^2)	6.4 ± 2.3	6.3 ± 2.4	6.4 ± 2.3	NS
ASMM (kg)[b]	30.2 ± 3.6	30.3 ± 3.7	30.2 ± 3.6	NS
SMMI (kg/m^2)[b]	9.4 ± 0.9	9.4 ± 0.9	9.4 ± 0.8	NS

[a]*n*=496 due to missing data, [b]*n*=493 due to missing data. [c]Median ± interquartile range.
Abbreviations: BMI: Body mass index, WC: Waist circumference, WHtR: Waist-to-height ratio, BF: Body fat, FMI: Fat mass index, ASMM: Appendicular skeletal muscle mass, SMMI: Skeletal muscle mass index.

Table 4.3. Mean SMMI, FMI and WHtR of participants within each age range

Age (y)	**N**	**%**	**SMMI**		**FMI**		**WHtR**	
			Mean	SD	Mean	SD	Mean	SD
21-24	16	3.2	9.5	0.7	4.6	1.8	0.46	0.04
25-29	42	8.5	9.3	0.8	5.0[a]	2.7[a]	0.48	0.05
30-34	84	16.9	9.6	0.8	5.8	2.0	0.49[a]	0.06[a]
35-39	93	18.7	9.2	0.8	5.9	1.7	0.50	0.04
40-44	85	17.1	9.4	0.9	6.6	2.3	0.52	0.05
45-49	96	19.3	9.4[a]	1.1[a]	6.8[a]	3.1[a]	0.54[a]	0.07[a]
50-54	69	13.9	9.3[a]	1.0[a]	7.0[a]	3.1[a]	0.55[a]	0.06[a]
55-59	8	1.6	8.9	0.4	6.2[a]	1.8[a]	0.51[a]	0.07[a]
60-62	4	0.8	9.4[a]	2.3[a]	8.5[a]	6.1[a]	0.58[a]	0.17[a]

[a]Median and interquartile range. Abbreviations: SMMI: Skeletal muscle mass index (kg/m^2), FMI: Fat mass index (kg/m^2), WHtR: Waist-to-height ratio (cm/cm), SD: Standard deviation.

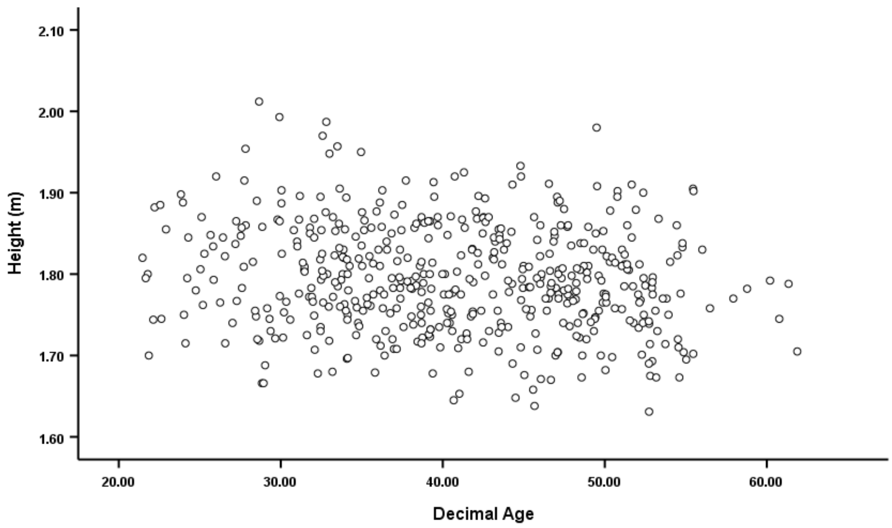


Figure 4.3. Scatter plot depicting age distribution of the study sample in relation to height

<u>Firefighter reference charts</u>

Figures 4.4 – 4.10 display smoothed centile curves which illustrate the age-related 2nd, 9th, 25th, 50th, 75th, 91st and 98th centiles for SMMI, FMI, BF%, WHtR and ASMM. Figures 4.9 and 4.10 also display the 85th and 95th centiles for FMI and BF%. Tables 1-5 in appendix 4.1 display the tabulated corresponding centile cut-off values. Figures 4.11 and 4.12 illustrate centile curve comparisons between this study sample and the UK white male general population from age 40 y for SMMI and FMI respectively.

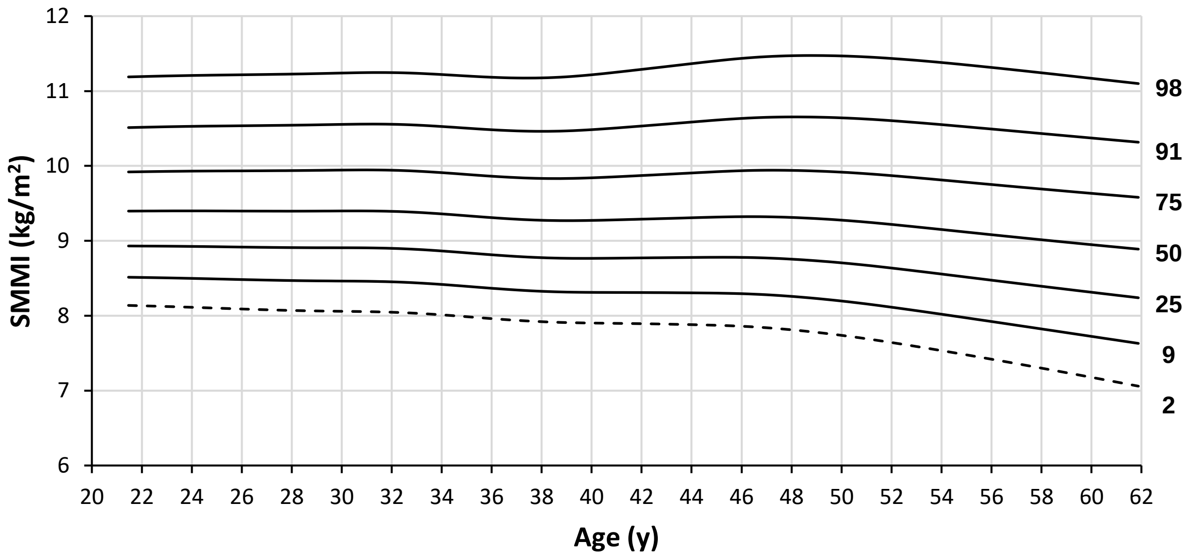


Figure 4.4. Male firefighter age-related skeletal muscle mass index references. The dotted line (2nd centile) defines the cut-off for low SMM.

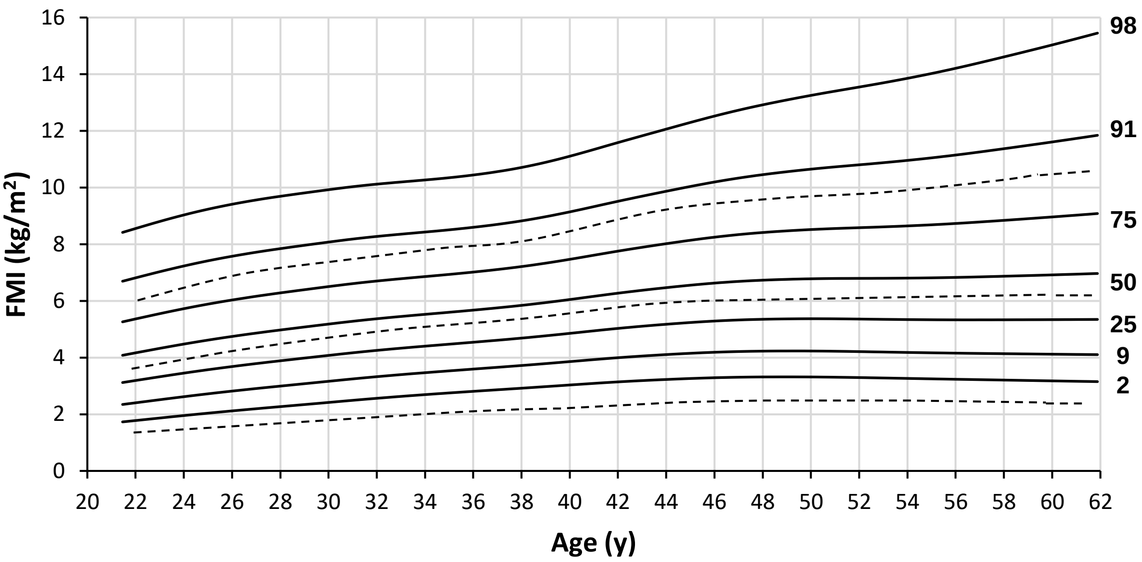


Figure 4.5. The initial male firefighter age-related fat mass index (FMI) reference. Bottom dotted line = preliminary under-fat cut-off, middle dotted line = preliminary overfat cut-off, top dotted line = preliminary obesity cut-off. This reference has since been replaced with Figure 4.9.

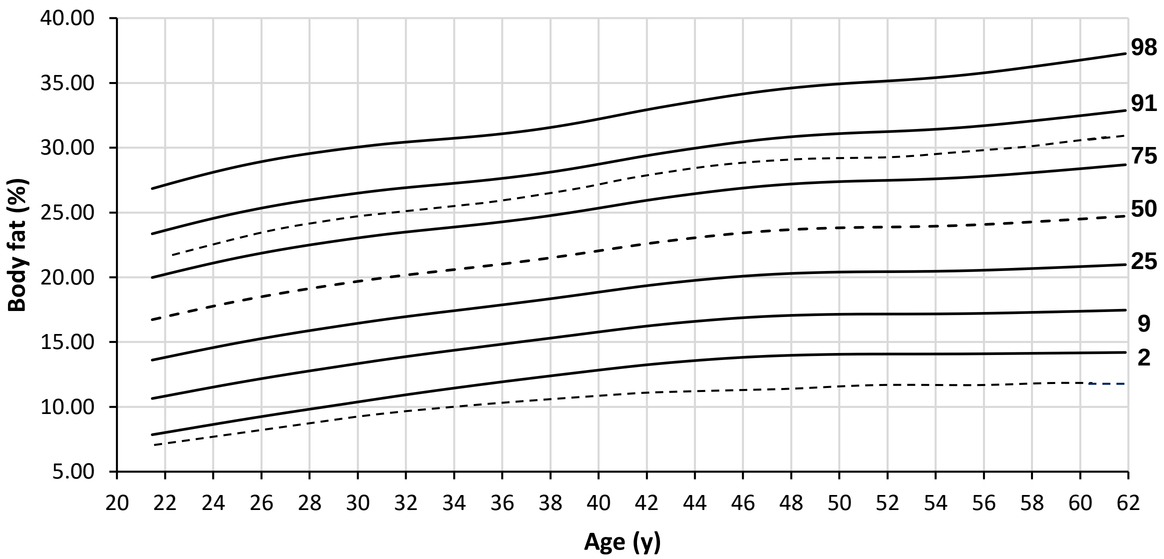


Figure 4.6. The initial male firefighter age-related body fat percentage (BF%) reference. Bottom dotted line = preliminary under-fat cut-off, middle dotted line = preliminary overfat cut-off, top dotted line = preliminary obesity cut-off. This reference has since been replaced with Figure 4.10.

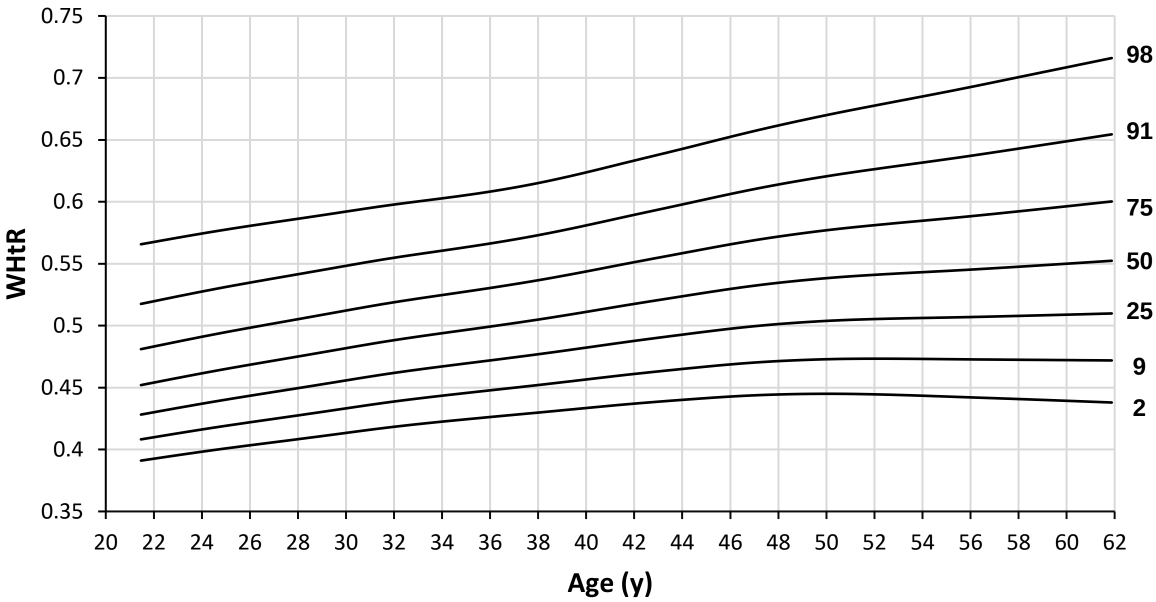


Figure 4.7. Male firefighter age-related waist-to-height ratio (WHtR) reference.

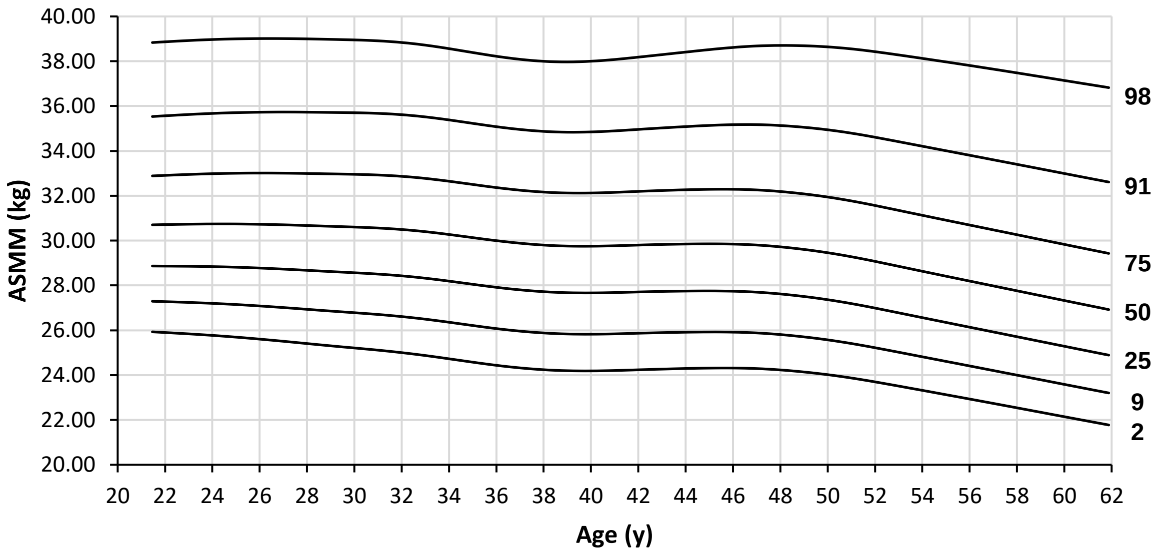


Figure 4.8. Male firefighter age-related appendicular skeletal muscle mass (ASMM) reference.

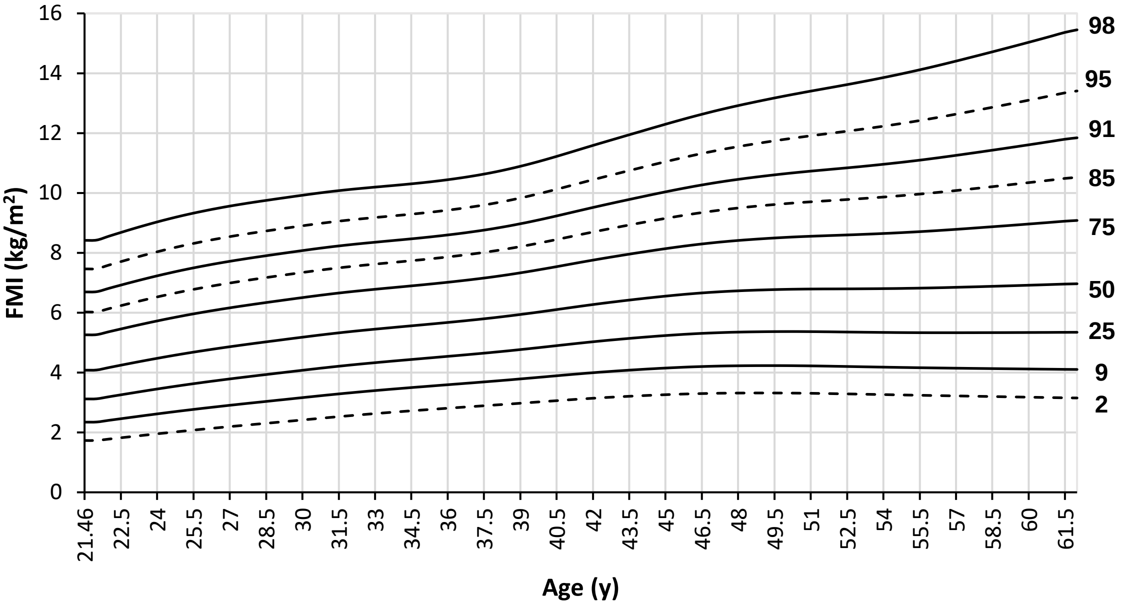


Figure 4.9. The definitive male firefighter age-related fat mass index (FMI) reference. Bottom dotted line = Under-fat cut-off, middle dotted line = Overfat cut-off, top dotted line = Obesity cut-off.

Worked Example: For Figures 4.9 and 4.10, the overfat and obesity cut-off curves were placed at the 85^{th} and 95^{th} centiles due to their high level of agreement (97%, Kappa: .86, $p < .001$) i.e. 97% of firefighters were classified into the same adiposity categories by both FMI and BF% when placing the cut-offs at the 85^{th} and 95^{th} centiles. This approach is more conventional than the novel (initial) approach to applying cut-offs which resulted in them being placed at different centiles (displayed in Figures 4.5 and 4.6, and described in detail on page 119) See page 123 for detailed rationale and justification for using Figures 4.9 and 4.10 as the definitive male firefighter adiposity cut-offs.

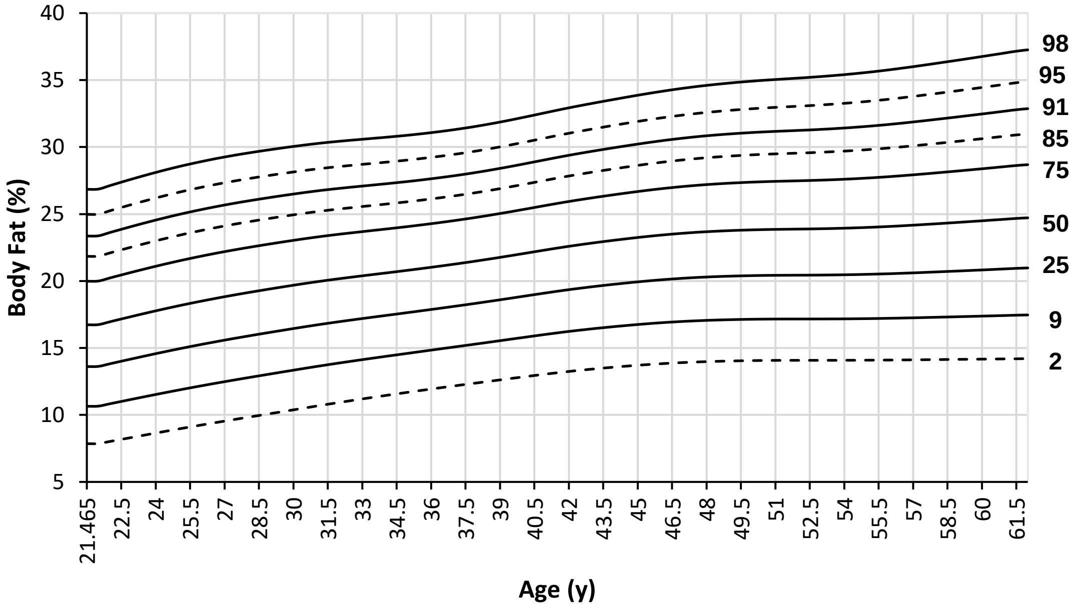


Figure 4.10. The definitive male firefighter age-related body fat percentage (BF%) reference. Bottom dotted line = Under-fat cut-off, middle dotted line = Overfat cut-off, top dotted line = Obesity cut-off.

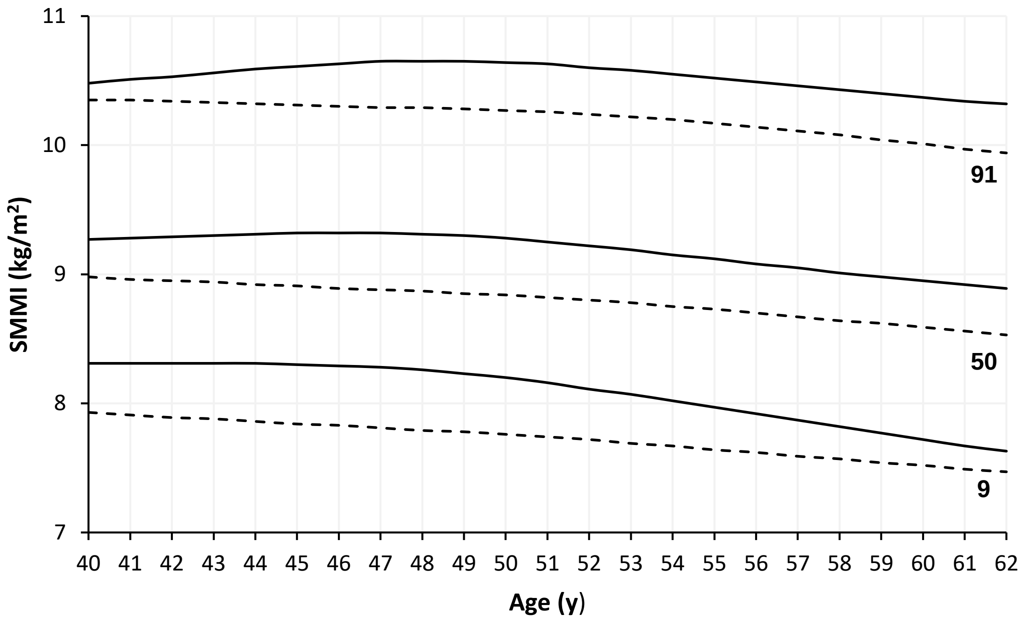


Figure 4.11. Male firefighter age-related skeletal muscle mass index 9th, 50th and 91st centiles (solid curves) with corresponding English white male centiles (dotted curves) between 40 and 62 y (Lee *et al.,* 2020).

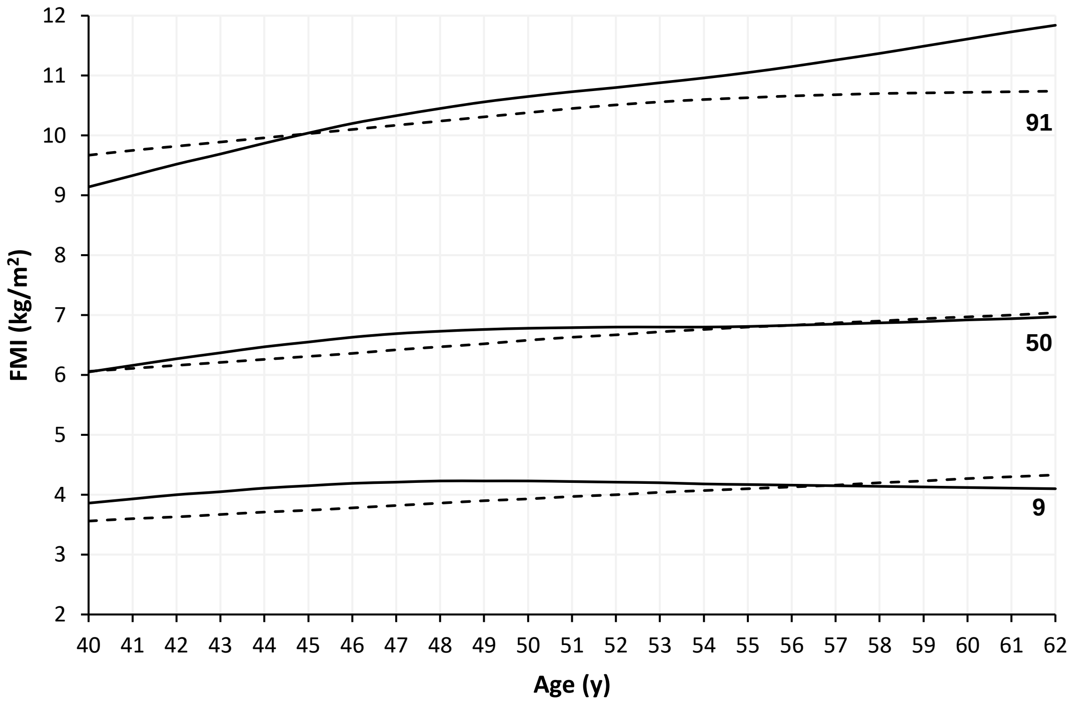


Figure 4.12. Male firefighter age-related fat mass index 9th, 50th and 91st centiles (solid curves) with corresponding English white male centiles (dotted curves) between 40 and 62 y (Lee *et al.,* 2020).

Centile curve trajectories

<u>Skeletal muscle</u>

Figure 4.8 displays the seven ASMM centiles showing a broad distribution, with a range of 17.2 kg, from 21.8 kg at the 2nd centile at 62 y to 39.0 kg at the 98th centile between 25 and 27.5 y. Similarly, the seven corresponding SMMI centile curves shown in Figure 4.4 span a distribution of 4.4 units, ranging from a nadir of 7.1 at the 2nd centile at 62 y to reaching a zenith of 11.5 at the 98th centile between the ages of 47.5 and 50 y. This highlights their main difference from the associated ASMM centiles which represent absolute SMM, and peak in the mid to late twenties (age), thus revealing taller firefighters within the younger age range. This inverse association between age and height is visible from visual inspection of Figure 4.3 and was confirmed as a highly significant very weak correlation (r = -0.152, p = 0.001). Aside from this difference, the SMMI curves follow similar trajectories to the related ASMM curves. Their normalisation for height makes them behave less erratically, however the ASMM curves are useful for making comparisons with SMMI from which useful conclusions can be drawn such as the discovery of taller subjects in the younger age range.

The 50th centile for SMMI displayed in Figure 4.4 shows a stable value of 9.4 for the first decade. Between 32 y and 38 y a decline occurs equating to an average of 0.02 units/y. This is followed by a brief period of stability at 9.3 until 41 y, at which point a very gradual SMMI rebound begins equating to 0.01 units per year, reaching 9.3 at 45 y. This stabilises briefly until 48 y which marks the beginning of a visibly steep decline equating to a mean decline of 0.03 units/y, reaching an SMMI of 8.9 at 62 y. The corresponding ASMM 50th centile (Figure 4.8) suggests this decline to equate to an average of 183 g/y.

<u>Adiposity</u>

The FMI centile curves (Figure 4.9) span a distribution of 13.7 units, ranging from a nadir of 1.7 at the beginning of the 2nd centile curve at 21 y, reaching a zenith of 15.5 at the end of the 98th centile curve at 62 y. The 50th centile begins at FMI 4.1 and steadily increases at a mean rate of 0.1 units/y until reaching 6.6 at 46 y. This curve then levels out, showing a very gradual small total increase of 0.34 units over the following 16 years, equating to an annual mean increase of 0.02 units. Whilst the 25th centile curve follows a similar slight upward trajectory to the 50th centile curve, the 2nd and 9th FMI centile curves show a steady gradual descent from 50 to 62 y.

This contrasts with the BF% chart (Figure 4.10) where all centiles continue to gradually increase until 62 y. The 50th centile begins at 16.7% and steadily increases to intercept 19.7% at 30 y, before continuing upward to reach 22% at 40 y. This curve continues on its trajectory, reaching 23.6% at 47 y which marks the beginning of a more gradual increase toward its zenith of 24.7% at 62 y.

Figure 4.7 displays the WHtR centile curves, showing a broad distribution ranging from 0.39 at the beginning (21 y) of the 2nd centile to 0.72 at the upper end (62 y) of the 98th centile. These curves follow a predictably similar pattern to the FMI centile curves displayed in Figure 4.9. The 50th centile begins at a WHtR of 0.45 at 21 y. This steadily escalates to reach the beginning of the first cardiometabolic disease risk threshold of 0.5 at 35 y. This is exceeded by the age of 39 y and continues on the same trajectory until reaching a WHtR of 0.54 at 49 y, which marks the start of a more gradual increase toward 0.55 at 62 y.

<u>Defining risk</u>

The SMMI and FMI centile charts are intended for use not only as research references, but also as clinical references, to plot and track individual firefighter SMMI and FMI values against the representative reference sample. To identify individuals at the highest health risks in terms of adiposity, cut-offs were defined for classification of firefighters into low-SMM, under-fat, healthy, overfat and obese categories. An initial attempt to define the FMI cut-offs was made using the BF% curves as a reference to help decide where to apply each risk cut-off on the FMI chart. BF% was used for this purpose because body fat percentage ranges for adults in the general population already exist (Gallagher *et al.*, 2000), and were therefore used to initially guide the application of preliminary risk cut-offs to the BF% centiles chart, before translating them to the FMI chart.

<u>Preliminary BF% and FMI cut-offs (displayed in Figures 4.5 and 4.6)</u>

This section of the thesis describes a novel approach for applying cut-offs. This initial attempt was subsequently replaced with the definitive cut-offs displayed in Figures 4.9 and 4.10 (see the next section titled ‘Definitive firefighter reference centile cut-offs’). Figure 4.6 displays the BF% preliminary ‘under-fat’ cut-off curve illustrated by the dotted line below the 2nd centile. This was defined as such due to close relevance with the standard adult male body-fat ranges (BFR) which are displayed in Table 4.4. The curve begins at 7% which is 1% below the BFR under-fat cut-off for 20-40 y. This can be seen to gradually increase, intercepting 11% at around 40 y, followed by a slight increase to around 12% at 50 y before levelling off until 62 y, all of which corresponds with the BFR age-related cut-offs. The preliminary BF% cut-off curve to define overfat firefighters was applied at the 50th centile. This begins at 16.7% at 21 y which is slightly below the BFR overfat cut-off of 20% for 20-39 y. This curve intercepts 19.7% at 30 y, which more closely aligns with the BFR overfat cut-off. This then gradually increases to intercept 22% at 40 y which is identical to the BFR overfat cut-off for

40-59 y, before continuing its trajectory until intercepting 25% at 62 y which is identical to the BFR overfat cut-off for 60-79 y. The preliminary cut-off defining obese firefighters is illustrated by a dotted curve plotted between the 75th and 91st centile curves. This begins at 22% at 21 y which is 3% below the BFR obese cut-off of 25% for 20-39 y. This curve's steady trajectory intercepts 25% at 30 y which is mid-way between 20 and 39 y, illustrating the perfect interception and further validating the chosen preliminary cut-off curve placement (the same happens with the overfat curve at age 30 y, see above). The preliminary obese cut-off curve then climbs to intercept 27% at 40 y, which is 1% below the BFR obese cut-off of 28% for 40-59 y. This curve then increases to reach 28% at 45 y and hovers around this percentage until 52 y when it starts to increase to intercept 30% at 60 y, which perfectly matches the BFR obese cut-off for 60-79 y.

To ascertain how the FMI centiles related to the preliminary BF% cut-off curves, study participants were grouped by age and BF% risk classification. Tables 4.5 and 4.6 display the mean, minimum and maximum FMI scores within each BF% category across two age ranges (Table 4.5) which were then further divided into nine age ranges (Table 4.6). Table 4.5 was first used to examine how FMI scores related to the FMI cut-off curves. This was used as a primary reference aid due to the two age ranges containing a fairly representative number of firefighters within each BF% category, which revealed similar proportions of healthy, overfat and obese firefighters within both age ranges, although FMIs are greater and more variable within the ≥40 y range. Table 4.6 was then used as a subsequent reference aid. As some of its nine age ranges contained relatively small numbers of firefighters within their respective BF% categories, this was used as a rough secondary guide to assess coherence between the newly applied FMI centile cut-off curve and BF% categories.

Table 4.4. Standard adult non-Asian male body fat (%) ranges (BFR)

Age	**Under-fat (%)**	**Healthy**	**Overfat**	**Obese**
20-39	<8	8 - 20	20.1 - 25	>25
40-59	<11	11 - 22	22.1 - 28	>28
60-79	<13	13 - 25	25.1 - 30	>30

Table 4.5. Mean, minimum and maximum FMI scores within each BF% category across two age ranges

Age range (y)	BF% category	*n*	Minimum FMI	Maximum FMI	Mean FMI	SD
21-39	Healthy	90	1.5	5.3	3.83	0.76
	Overfat	102	4.48	7.72	6.01	0.74
	Obese	43	6.31	14.05	8.47	1.48
40-62	Healthy	96	2.25	6.28	4.72	0.89
	Overfat	114	5.29	9.43	7.2	0.91
	Obese	52	8.18	17.76	10.75	2.07

Abbreviations: BF, body fat; FMI, fat mass index.

Table 4.6. Mean, minimum and maximum FMI scores within each BF% category across nine age ranges.

Age range (y)	BF% category	*n*	Minimum FMI (kg/m^2)	Maximum FMI (kg/m^2)	Mean FMI (kg/m^2)	SD (kg/m^2)
21-24	Healthy	11	1.5	4.91	3.56	0.91
	Overfat	4	5.81	7.21	6.33	0.61
	Obese	1	8.83	8.83	8.83	-
25-29	Healthy	18	1.5	4.79	3.46	0.86
	Overfat	19	4.48	6.98	5.69	0.73
	Obese	5	6.61	14.05	8.74	3.01
30-34	Healthy	32	1.88	5.2	3.91	0.7
	Overfat	35	5.03	7.4	6.03	0.65
	Obese	17	6.99	11.91	8.75	1.34
35-39	Healthy	29	2.23	5.3	4.07	0.63
	Overfat	44	4.62	7.72	6.1	0.79
	Obese	20	6.31	11.31	8.14	1.1
40-44	Healthy	38	2.53	6.08	4.65	0.92
	Overfat	32	5.61	8.82	7.2	0.86
	Obese	15	8.18	14.73	10.18	1.66
45-49	Healthy	29	2.25	5.81	4.66	0.85
	Overfat	48	5.29	9.21	7.24	0.99
	Obese	19	8.55	16.97	10.99	2.03
50-54	Healthy	25	3.01	6.28	4.92	0.88
	Overfat	28	5.7	8.68	7.15	0.78
	Obese	16	8.67	17.76	10.7	2.24
55-59	Healthy	3	4.42	5.7	5.07	0.64
	Overfat	4	5.99	7.25	6.53	0.53
	Obese	1	15.67	15.67	15.67	-
60-62	Healthy	1	3.02	3.02	3.02	-
	Overfat	2	7.66	9.43	8.54	1.25
	Obese	1	10.54	10.54	10.54	-

Abbreviations: BF, body fat; FMI, fat mass index.

Figure 4.5 displays the preliminary FMI 'under-fat' cut-off curve illustrated by the dotted line below the 2nd centile. This was applied to match the position of the associated BF% cut-off curve (Figure 4.6). The preliminary FMI cut-off curve to define overfat male firefighters is illustrated by a dotted curve which was applied between the 25th and 50th centile curves. This curve begins at an FMI of 3.6 at age 21 y. This is slightly lower than the mean FMI in the healthy BF% group as displayed in Table 4.5, and slightly higher than the corresponding mean FMI in Table 4.6. This curve steadily escalates to intercept 4.6 at 30 y which is slightly above the minimum FMI in the overfat BF% group, and lower than the maximum FMI in the healthy BF% group in Table 4.5. This interception also aligns well with Table 4.6 by being slightly lower than the maximum FMI in the healthy BF% category within the 30-34 y age range. This curve then maintains a steady trajectory tracking between the 25th and 50th centiles, staying above the age related minimum FMIs in the overfat BF% group, whilst remaining below the maximum FMIs in the healthy BF% group as characterised in Table 4.5. This indicates that the firefighters possessing the greatest FMIs in the healthy BF% group would now be classified as overfat by this FMI cut-off curve. This could be considered appropriate as these firefighters are most likely to be carrying a greater level of FFM which is driving their BF% down into the healthy range, despite the fact they possess high levels of absolute body fat. As such they may be misclassified as false negative errors by conventional BF% cut-offs. Conversely, the firefighters possessing the lowest FMIs in the overfat BF% category are likely to be false positive errors for the opposing reason i.e. they have lower FMIs than the false negative firefighters, however, their relatively low proportion of FFM is driving them up into the overfat BF% category, despite the fact they possess lower levels of absolute body fat compared with firefighters in the upper end of the healthy BF% range. In this instance, low SMM is of greater potential concern than high adiposity. A corresponding alignment was generally observed across the nine age ranges using Table 4.6 as the reference, with the exception of three of the age ranges. This was due to anomaly FMI scores derived from BF% categories containing relatively small numbers of firefighters within them. These anomalies were therefore ignored, and Table 4.5 was referred to for use as a guiding reference. Overall the preliminary FMI overfat cut-off curve indicated good alignment with the BFR for defining overfat male firefighters.

Similar to the initial BF% centiles chart (Figure 4.6), the preliminary FMI cut-off curve defining obesity is illustrated by the dotted curve plotted between the 75th and 91st centile curves (Figure 4.5). This begins at an FMI of 5.6 at 21 y which is almost identical to the mean FMI of 6.0 within the overfat BF% category as displayed in Table 4.5. This curve steadily escalates to intercept 7.3 at 30 y, which is 0.4 below the maximum FMI in the overfat BF% category, and 1.0 above the minimum FMI within the obese BF% category. This curve then maintains a steady upward trajectory intercepting 8.3 at 40 y, which is half-way between the mean and maximum FMIs in the overfat BF% category, and 0.1 above the minimum FMI within the obese BF% category. Between 40 y and 50 y this curve becomes its steepest, intercepting 9.6 at 50 y, which is slightly above the maximum FMI of 9.4 within the overfat BF% category. The preliminary obesity cut-off curve continues on a similar trajectory until intercepting 10.3 at 60 y. The same rationale used in the application of the preliminary overfat FMI cut-off curve was applied to the obesity FMI cut-off curve's location. Additional cross correlation of this curve's values with the corresponding FMI values in Table 4.6 further indicated good alignment of this preliminary cut-off with the BFR for defining obese male firefighters.

<u>Definitive firefighter reference centile cut-offs (displayed in Figures 4.9 and 4.10)</u>

These cut-offs have replaced the preliminary cut-offs in Figures 4.5 and 4.6. Those earlier Figures represent an initial novel attempt for arriving at cut-offs using the widely used BFR (Gallagher *et al*., 2000) as a guiding reference. However, that initial approach was not concerned with whether or not the same firefighters were classified into the same adiposity categories by both indices. This was subsequently considered to be a crucial factor, therefore the decision was made to undertake a series of agreement comparisons between BF% and FMI. The aim was to identify centiles which could be considered suitable to be assigned as cut-offs in defining overfat and obesity, resembling a more conventional approach. It was decided that potential cut-offs needed to show a high level of agreement and an acceptably low rate of misclassification when comparing FMI and BF%. The assessment of agreement was undertaken by identifying the proportion of firefighters falling into the same proposed adiposity classifications by both FMI and BF% at corresponding cut-offs. For example, the 91st and 98th centiles of the BF% and FMI charts were assessed initially. This was decided as a good starting point due to these centiles often being assigned to healthy reference populations in defining overweight and obesity respectively e.g. the child BMI and WC reference charts by Cole, Freeman and Preece (1995) and McCarthy, Jarrett and Crawley (2001) respectively.

The process involved systematically ascertaining if each firefighter's BF% and FMI placed them into the same adiposity classification i.e. if the same firefighter's BF% and FMI scores fell between the 91st and 98th centile curves, this was classed as an agreement. Conversely, if a firefighter's BF% fell between the 91st and 98th centiles but their FMI fell below the 91st or above the 98th centiles (or vice versa), this was classed as a misclassification. Tables 4.7-4.10 display the investigated cut-offs in contingency tables which show the levels of agreement for each attempted comparison. The 85th centile was eventually selected to define overfat firefighters and the 95th centile was selected to define obese firefighters. This was due to (a) the 85th and 95th centiles being of a suitable level to identify those firefighters with high adiposity, (b) the same centile curves have been successfully used for defining overfat and obese 4-20 y olds (McCarthy *et al.*, 2006), (c) A high level of agreement: 97%, Kappa: 0.86 (p<0.001), and (d) the acceptable rate of misclassification which was generated at these centiles acted fairly equivocally in each direction (false positives and false negatives), as opposed to the 91st and 98th centiles which suggested that (i) these centiles were far too conservative which would result in poor sensitivity for detecting overfat and obesity, and (ii) the 91st FMI centile curve lacked sensitivity for detecting the eight firefighters who the 91st BF% centile curve classified as overfat. The 2nd centile was selected to identify under-fat firefighters which is consistent with British growth charts which also use the 2nd centile to define low values (Cole, Freeman and Preece, 1995; McCarthy e*t al.*, 2006). The definitive cut-offs are displayed in figures 4.9 and 4.10.

Table 4.7. Contingency table displaying the level of agreement between BF% and FMI categories using the 91st and 98th centiles to define overfat and obesity.

		FMI category (91st and 98th centiles)			
		Healthy	Overfat	Obese	Total
BF% category (91st and 98th centiles)	Healthy	449	3	0	452
	Overfat	8	22	1	31
	Obese	0	1	13	14
	Total	457	26	14	497

Agreement: 484/497 = 97.4% Kappa = 0.84 (p< 0.001)

Following this initial comparison, the eight firefighters who were classified as overfat by BF% and healthy by FMI were investigated for anthropometric and body composition differences. This revealed them to be an average of 2.5 cm taller than the rest of the sample.

Table 4.8. Contingency table displaying the level of agreement between BF% and FMI categories using the 91st and 98th centiles to define overfat and obesity by BF%, and the 85th and 95th centiles by FMI.

		FMI category (85th and 95th centiles)			
		Healthy	Overfat	Obese	Total
BF% category (91st and 98th centiles)	Healthy	431	21	0	452
	Overfat	2	19	10	31
	Obese	0	1	13	14
	Total	433	41	23	497

Agreement: 463/497 = 93% Kappa = 0.66 (p< 0.001)

Table 4.9. Contingency table displaying the level of agreement between BF% and FMI categories using the 85th and 95th centiles to define overfat and obesity.

		FMI category (85th and 95th centiles)			
		Healthy	Overfat	Obese	Total
BF% category (85th and 95th centiles)	Healthy	427	4	0	431
	Overfat	6	35	4	45
	Obese	0	2	19	21
	Total	433	41	23	497

Agreement: 481/497 = 97% Kappa = 0.86 (p< 0.001)

Table 4.10. Contingency table displaying the level of agreement between BF% and FMI categories using the 50th and 85th centiles to define overfat and obesity.

		FMI category (50th and 85th centiles)			
		Healthy	Overfat	Obese	Total
BF% category (50th and 85th centiles)	Healthy	230	11	0	241
	Overfat	11	168	4	183
	Obese	0	9	64	73
	Total	241	188	68	497

Agreement: 462/497 = 93% Kappa = 0.88 (p< 0.001)

As no comparable SMM cut-offs exist, for these references, low SMM was defined at the 2nd centile which is illustrated in Figure 4.4. Male firefighters possessing extremely low SMM are therefore identified if they fall below the 2nd centile curve on the SMMI chart. This equates to >2 SD below the mean SMMI and is consistent with other British growth charts which also use the 2nd centile to define low values (Cole, Freeman and Preece, 1995; McCarthy e*t al.*, 2006).

4.4. Discussion

In this study novel firefighter-specific body composition references were developed. The charts produced by this study represent the very first firefighter body composition reference centile curves globally. They illustrate the variations and changes in the body compartment proportions across a fire service career and can provide a more detailed body composition assessment against a reference population than other commonly used references such as BMI.

<u>Representativeness of the study population</u>

Firefighters from ethnicities other than white Caucasian were not included in this study due to inherent body composition differences. As these demographics account for 4.3% of the English fire service (Home Office, 2019), obtaining sufficient data to generate ethnicity specific centile references remains unfeasible. With only 6.4% of firefighters in England being female (Home Office, 2019), the same limitation applied for creating sex specific references.

The present limitation of a small sample size for the subjects over 55 y is due to firefighters generally retiring by this age. Indeed, the UK FRS pension review by Williams *et al*. (2013) analysed data on *n*=7,550 male firefighters from four English FRSs, which showed a similar age group distribution to that seen in this study. External validity of the reference centiles is strengthened by this similarity in age distribution along with a mean age of 40.8 y, which is almost identical to the mean age of 41 y across the English fire services (Home Office, 2019), and the median BMI of 27.7 in this study sample being almost identical to the BMI of the average LFB firefighter (27.6 measured in 2018 – see Figure 4.1). Furthermore, the sampling of an even distribution of urban and suburban fire stations within Greater London, renders this sample representative of the wider English firefighting population. The Cole and Green (1992) method accounts for skewness and goes some way to overcoming the less well represented age categories. It therefore provides a representative illustration of body composition differences across the age ranges. As this workforce is an aging workforce being required to work longer to obtain a full pension, the older firefighters will likely represent a greater proportion of the workforce over time.

Centile curves

For all of the centile references in this study, the broad distribution from the 2nd to the 98th centiles may be reflective of varying roles and responsibilities within the firefighting watch structure in terms of managerial or driving responsibilities and associated varying levels of physical activity (Dobson *et al*., 2013), potentially contributing to greater disparities in SMM and adiposity. Furthermore, to date there has been a paucity of fitness testing in UK fire brigades. An occupation which was once highly active has become steadily more sedentary due to increases in computer-based training and advances in fire prevention technology leading to less fires to fight, and ultimately less physical activity (Office of the Deputy Prime Minister, 2004; Choi *et al*., 2011; Home Office, 2020). This is currently being addressed via the introduction of periodic fitness testing which recently began in LFB in 2020. The primary physical fitness assessment is the Chester treadmill test which reflects the VO2 max required of a firefighter. Whilst this tests cardiorespiratory fitness, it is not designed to test muscular strength, which is an essential component of firefighter occupational fitness (Stevenson *et al*., 2017). This further highlights the need for a reference measure of skeletal muscle which can be utilised as a body composition surveillance tool for the assessment of firefighter nutritional status. This would also be useful during periods of weight loss which could result in a loss of SMM (Weinheimer, Sands and Campbell, 2010). In such a scenario, the SMMI reference could be utilised to identify and then reduce SMM loss via appropriate physical exercise and nutritional intervention. At the extreme end of the spectrum, the cut-off defining low muscle mass could be considered as a potential trigger for health professionals to take action in terms of prioritising intervention strategies to increase SMM. Furthermore, if a firefighter falls below this cut-off, consideration could be given to administration of a muscular strength assessment to test the firefighter's ability to undertake firefighting tasks requiring this component of physical fitness safely and effectively.

SMMI centile reference

The age related SMM decline from 48 to 62 y is clearly visible in Figures 4.4, 4.8 and 4.11. The accompanying SMMI centile cut-off values (appendix 4.1, Table 1) show a steady mean decline of 0.03 SMMI units/y. Whilst mean SMMI in this age group is greater than UK white males by a mean of 0.35 units, the rate of decline in this study is steeper than seen in UK white males between 48 and 62 y, which was estimated at a mean rate of 0.024 SMMI units/y (Lee *et al.*, 2020). Appendix 4.1, Table 5 indicates that this translates to a mean decline of approximately 0.6% of absolute ASMM per year from 48-62 y. This is possibly due to the limited number of study subjects over 55 y within this sample, and therefore the following inferences are made with caution. This rate of muscle decline is approaching population-based estimates of sarcopenia usually seen during and after the sixth decade of life (English and Paddon-Jones, 2010; Reid *et al.*, 2014; Koster *et al.*, 2011). Of more potential concern is the conclusion of a review by Mitchell *et al.* (2012), which found that a loss of 1% SMM is associated with a loss of muscular strength of 3-4%, suggesting strength to decline more rapidly, at a rate 2-5 times faster than SMM. The implications of this rate of SMM decline and potentially even greater concomitant losses of muscular strength are potentially concerning for an aging workforce which relies heavily upon muscular strength to successfully perform strenuous life-saving activity whilst minimising risk to themselves and others in hazardous situations. Within this context, the SMMI centile reference curves can be used as a sarcopenic surveillance tool, indicating rates of age-related SMM decline and informing appropriate physical activity and nutritional interventions. Potential aetiology for this suggested expedited decline of SMM in firefighters could be the physiologically adverse combined effects of shift work, sleep interruption and stress. In this context, sleep deprivation could be causing dual pathologies, acting both as a mediator for increased cortisol production resulting in SMM catabolism (Braun and Marks, 2015), whilst simultaneously suppressing testosterone production (Andersen and Tufik, 2008) leading to anabolic resistance (Bremner, 2010). More research is required to confirm the aetiology and physiological mechanisms for the perceived rapid decline in firefighter SMM.

Adiposity

The average FMI from 40-49 y within this sample was 6.7 which is 0.1 units greater than UK white males within the same age range (Lee *et al.*, 2020). Within the 50-54 y age range the average FMI of 7.0 in this sample is the same as 50-54 y UK white males (Lee *et al.*, 2020). Given the established high prevalence of overweight and obesity within the UK general population, these comparisons indicate a similar concerning level of adiposity for UK firefighters. In this instance, the same exposures of firefighting as a highly stressful occupation (Duran, Woodhams and Bishopp, 2018; Rodrigues *et al.*, 2018), combined with shift work and sleep deprivation contributing to the aforementioned SMM decline, could simultaneously be contributing to increased adiposity through a complex combination of pathogenic mechanisms, including increased ghrelin and decreased leptin secretion caused by sleep disturbance (Van Cauter *et al.*, 2008), leading to increased food intake (Spiegel *et al.*, 2004) being possible mechanisms for sleep curtailment being a risk factor for obesity and type 2 diabetes (Van Cauter *et al.*, 2008). This is further associated with the firefighting shift pattern which is characterised by two day shifts followed by two night shifts, as two consecutive nights of restricted sleep (four hours in bed) for young men has been associated with increased ghrelin production of 28%, and reduced leptin production of 18%, leading to a 24% increase in hunger predominantly for energy dense and micronutrient poor foods high in carbohydrate such as starchy foods, high-salt snacks and confectionary (Spiegel *et al.*, 2004). This is further compounded by the fire station food environment which has been characterised as obesogenic (Dobson *et al*., 2013).

Figure 4.9 illustrates the 50th FMI centile for this population increasing at a fairly steady average rate between the ages of 21 and 46 y. From 47 y we see a levelling off of FMI at the 50th centile with a total marginal gain of 0.28 units up to the age of 62 y. As FMI would be expected to increase at a faster rate between these ages, as illustrated by Lee *et al.* (2020), this anomaly could again be attributed to the relatively small sample of over 55 y subjects, and as such the following inference is made with caution. This phenomenon could potentially be related to the fact that older firefighters can still currently retire and collect a full pension at around 50 years of age. Whilst this policy has changed for firefighters recruited after 5th April 2006, who now have to work until 60 y, the majority of firefighters within the older age range were employed on a different contract. This may imply that the personnel who currently decide to remain working beyond 30 y of service/50 y of age are doing so because of superior health/physical fitness, reflected by attenuation of FMI increase. Future generations of firefighters will not have this luxury of choice. The implications of the entire workforce being expected to remain working until the recently imposed minimum retirement age of 60 y could result in the steady deterioration of body composition into the final decade of service unless adequate intervention measures are employed to ameliorate this outcome. The concomitant financial implications of increased LSA via illness, injury and disability would likely disrupt an already financially challenged public sector organisation. When overweight/obesity affects emergency service personnel the stakes are higher than purely financial loss. Impaired physical fitness compromises the personal safety of themselves, their colleagues and that of the public whom they serve (Moore, 2003).

The opposing trajectories of the FMI and SMMI centile curves further highlights a limitation of BMI, being intrinsically unable to detect these important changes in body composition, with the opposing effects of FM gain and SMM loss often cancelling each other out resulting in little weight change. If

BF% is relied upon without FMI, the masking effect could give the false impression of increasing adiposity, whilst the actual cause of increased BF% is in fact a relatively steep decline in SMM. This is depicted in Figures 4.9 and 4.10 by the contrasting trajectories of the FMI and BF% lower centile curves, highlighting a limitation of BF%, which in this instance is masking SMM decline at the lower centiles. Comparison between the FMI and BF% charts at the upper centiles highlights the masking effect to go in the opposite direction, whereby the 75th, 91st and 98th FMI curves show progressively greater divergence from the 50th centile curve. The clear contrast from the corresponding BF% centile curves suggests that a relatively high amount of FFM at the upper centiles is reducing the gradient of the upper BF% centile curves. This was the underlying principle behind the decision to shift the preliminary FMI overfat cut-off curve to just below the 50th centile. Although the corresponding preliminary BF% cut-off was applied at the 50th centile, cross-correlation with Tables 4.5 and 4.6 indicated reduced sensitivity when using the 50th FMI centile as the overfat cut-off. Essentially, the lowering of the preliminary FMI overfat cut-off was justified due to firefighters generally possessing a greater proportion of SMM than the general population. At the obese level, the preliminary FMI and BF% cut-off curves were placed at the same level, as the cross-correlation method using Tables 4.5 and 4.6 showed good alignment between the two indices for defining obesity between the 75th and 91st centiles on both charts.

Definitive cut-offs

The decision to apply the overfat and obesity FMI cut-offs at higher levels than the preliminary cut-offs was partially driven by the desire for the system to avoid generating false positives. This was to avoid the unfair stigma and potential adverse ramifications potentially arising from being labelled as overfat or obese. To counteract the opposite problem which could arise from fairly conservative cut-offs in the form of reduced sensitivity and false negative errors, the FMI 50th centile is proposed as an early warning cut-off which could trigger ‘soft’ intervention without the need for mandatory action. The 50th centile can be justified for this use based upon three principles: (1) this is closer to the established BF% cut-offs which were defined for the adult general population (Gallagher *et al*., 2000), (2) Table 4.10 demonstrates good agreement between the 50th FMI and BF% centiles, showing a low and acceptable rate of misclassification, and (3) this would not be used as a ‘hard’ cut-off with accompanying clinical terms of overfat/obesity. In this context, the 50th FMI centile acts as an early alert system, and the definitive FMI overfat and obesity cut-offs act as a means of identifying high risk individuals.

Whilst BF% centiles were useful for comparison and guidance of the FMI cut-offs, we propose that their utility for risk classification of firefighters is redundant due to the major limitations of percentage measures as comprehensively described in Chapter 1. Similar to the WHtR references, the BF% references are more useful as an academic research tool as opposed to a clinical assessment tool.

When used in conjunction, the FMI and SMMI centiles provide a reference system of superior validity for assessing age-related body composition changes compared with the traditional methods of BMI and BF% assessment. Smoothed centile curves can also be considered as being more reflective of the gradual age-related transitional nature of risk, as opposed to the currently used cut-offs which apply to age groups spanning two decades. The notion of risk suddenly increasing substantially at a specific age is non-sensical, an issue which is overcome via the application of smoothed centile curves.

Overfat/overweight and obesity centile cut-offs are generally applied to healthy-weight reference populations (Cole, Freeman and Preece, 1995; McCarthy, Jarrett and Crawley, 2001; McCarthy *et al.*, 2006). Previous research from Munir *et al.* (2012) and Lessons and Bhakta (2018) suggests that a healthy weight population of firefighters may not currently exist within the UK. As overweight, overfat and obesity were high prevalence for this sample, the cut-off curves defining overfat and obesity had to be applied at a lower level than most British growth charts. Every effort was made to ensure they were applied at appropriate positions for optimal validity.

The WHtR centile reference chart was generated for use as an academic research tool as opposed to a clinical assessment tool. This is because the WHtR health risk cut-offs do not shift with age. This reference is however useful as a nutritional surveillance tool to indicate cardio-metabolic health risk of this occupational group via analysis of the distribution, trajectories and interceptions of the centile curves. When comparing the WHtR chart with the FMI chart using the respective 25th centile curves for comparison, it appears that whilst FMI declines from 47 y, WHtR continues to increase. This observed difference indicates a possible shift in the propensity to store FM, from the relatively benign subcutaneous FM depots to the more pathogenic visceral adipose tissue storage sites. In this context, possible mechanisms could derive from elevated stress and sleep curtailment eliciting insulin dysregulation and increased cortisol secretion promoting triglyceride accumulation mostly in visceral adipocytes, leading to an increase in central adiposity (Hirotsu, Tufik and Andersen, 2015). Further research is required to determine if this observed increase in firefighter central adiposity is of clinical relevance.

The continued accumulation of central adiposity accompanied by the observation that the WHtR of 0.5 is exceeded around midway through the third decade is of concern. This may have important implications considering the fact that firefighters are at significantly increased risk of acute myocardial infarction (MI) due to their occupational exposure to intense heat increasing vascular thrombogenicity (Hunter *et al*., 2017), and do indeed suffer a significantly greater rate of MI (Kales *et al*., 2007), and furthermore are exposed to an occupational environment which has been characterised as obesogenic (Dobson *et al*., 2013). As WHtR provides a simple and inexpensive indicator of intra-abdominal visceral adipose tissue, this measure is recommended as an important risk assessment method to be added to the FMI and SMMI body composition reference charts for indicating cardiometabolic disease risk. This combination of measures also enables the detection of firefighters with a concerning combination of an elevated WHtR and low SMM. This combination may compound their level of risk, as low muscle fitness has been associated with increased metabolic risk (Steene-Johannessen *et al*., 2009) and muscle strength has been positively correlated with insulin sensitivity (Benson *et al*., 2006). At the extreme end of the pathological spectrum, this is characterised by sarcopenic obesity, which could become a widespread problem for an increasingly sedentary occupation which has an aging workforce.

<u>Study Strengths</u>

This study utilised the Tanita MC-780 MA multi-frequency segmental body composition analyser for collecting BIA measurements. This model was developed more recently and is likely to be more accurate than the model used in the most recent and comparable study by Lee *et al.*, (2020) which analysed body composition data obtained from the Tanita BC-418 MA. Because BIA algorithms for the estimation of body composition vary, it is advisable to use these reference centile charts in conjunction with a Tanita MC780 MA system. A few studies have however found only small differences in BF% between different analysers by this manufacturer equating to an FMI difference of 0.3-0.8 units (Hemmingsson, Uddén and Neovius, 2009; Ramírez-Vélez *et al.*, 2016; Lee *et al.*, 2017). This suggests that regardless of the analyser used, a subject would probably fall into the same percentile, considering that the narrowest margin between FMI centiles in this study was observed between the 2nd and 9th centiles which averaged at 0.83 units. Whether the same applies to SMMI whereby the differences between the 2nd and 9th centiles are smaller (averaging 0.44 units) is unclear and therefore requires further research.

<u>Study Limitations</u>

This is a cross-sectional study and therefore makes the assumption that the contemporary young sample of this study population is a valid proxy for their aged sample at a previous time point. This study could therefore be confounded by secular changes such as intergenerational differences reflecting changes in population characteristics as opposed to age-related changes which would be measurable in a longitudinal cohort study. An intergenerational difference in height was indeed identified within this sample. Whilst this is an expected anthropometric change associated with aging (Wannamethee, 2006), and the effect size of r=-0.152 in this study was similar to that of r=0.2 found by a prospective study by Wannamethee (2006), the height difference could just as easily be due to population characteristic differences between the older and younger age groups. Other undetected differences may also exist, which is a common limitation of body composition centile charts including those created by McCarthy *et al*. (2006; 2014). A longitudinal cohort study would be of high logistical burden, relying upon annual measurements of a minimum sample of approximately 500 subjects, taken over several decades. The duration of such a study would likely lead to a high attrition rate rendering this option unfeasible. The cross-sectional design of the current study is a reminder to interpret the centile reference charts with a degree of caution.

The SMMI reference curves were not validated against SMM strength assessment. Whilst this association has been identified in other populations, without directly assessing muscular strength of the subjects in the current study, no firm associations can be made between age related decline in SMM and loss of muscular strength within this reference population. This could have been overcome by strength assessment via handgrip dynamometry, as this method is strongly correlated with lower extremity SMM strength (Lauretani *et al*., 2003) and has been positively correlated with FFM changes as measured by BIA (Dey *et al*., 2009). Although portable, inexpensive and time efficient, the decision was made to not directly measure the handgrip strength of this population. This was to avoid alienating potential participants who may have had concerns regarding their grip strength, which in turn could have led to a reduced participation rate and bias the sample, thus rendering it less representative.

Limitations which applied to the study in Chapter 3, also apply to this study in terms of body composition analysis protocols, whereby participants were not instructed to refrain from consuming food or liquids prior to analysis. Even so, other studies have successfully produced and used body composition centile reference charts without strict measurement procedures (McCarthy *et al.,* 2006; 2014).

Conclusion

These pioneering centile references offer a novel improvement upon the limitations of BMI and BF%, especially when being applied to firefighters, who require greater levels of physical fitness and skeletal muscle than the general population. The Firefighter SMMI centiles indicate that whilst firefighters generally possess more SMM, this may be declining at a faster rate than the UK general population, even at an age when they will still be working. The FMI and WHtR centiles indicate a prevalence of overfat and obesity similar to the UK general population. The references could therefore be utilised both as risk screening tools and individual education intervention tools to show a firefighter their personal level of SMM and FM relative to the reference sample. This could help motivate beneficial behaviour change and improve or maintain body composition. We plan on collecting sufficient data from English FRSs to create a similar suite of references for female firefighters. A coordinated national FRS surveillance approach will also yield additional data for the new male firefighter references to be further refined, which will further enhance their external validity.

Chapter 5: Development of a firefighter dietary assessment tool

Overview

Until now a population specific dietary assessment tool did not exist for UK firefighters. In this study the EPIC-Norfolk food frequency questionnaire (FFQ) was modified to reflect UK firefighter dietary behaviour. The resulting firefighter FFQ (FF-FFQ) amounts to a less burdensome tool which was then validated against 24hr recalls within a sample of 69 firefighters. Correlations between the methods were significant ($p < 0.01$) for energy (r=0.42), carbohydrate (r=0.42), protein (r=0.42), fat (r=0.35), fibre (r=0.34), saturated fatty acids (r=0.36), monounsaturated fatty acids (r=0.32), polyunsaturated fatty acids (r=0.24, p=0.05), vitamin C (r=0.26), calcium (r=0.45), iron (r=0.38) and sodium (r=0.32). Bland-Altman (BA) analyses indicated good agreement between methods for energy and each nutrient, with an average of 96% of cases falling between the limits of agreement. Cross-quartile analysis identified a low mean rate of misclassification (4.2%). In terms of reproducibility, the mean correlation between repeat administrations was 0.7 ($p < 0.01$). BA analyses also indicated good agreement between administrations with >95% of cases falling between the BA limits of agreement indicating good precision. The FF-FFQ demonstrated sufficient validity for its primary uses as both a screening tool to indicate high/low intakes of certain foods, and as a method for measuring dietary changes elicited by an intervention.

5.1. Introduction

There is a strong and ever growing evidence base identifying associations between dietary behaviour and non-communicable disease (Roberts and Barnard, 2005; Kant, 2010), rendering the act of dietary assessment a crucial step toward improving public health outcomes (Fialkowski *et al.*, 2010; Beechy *et al.*, 2012). Methods of assessing diet are utilised to assess both habitual long term and shorter term consumption, and are therefore necessary tools in dietary intervention trials and epidemiological investigation, to help identify associations between dietary behavior and health outcomes in clinical and population settings (Jain, Howe and Rohan, 1996; Fialkowski *et al.*, 2010). Food frequency questionnaires (FFQ), 24hr recalls, and food diaries are the traditional dietary assessment tools at the researcher's disposal (Amorim Cruz, 2002; Thompson *et al.*, 2010). Food diaries involve respondents prospectively recording their dietary intake over several consecutive days which often ranges from three to seven days (Rutishauser, 2005). 24hr recalls are administered by an interviewer asking the respondent to recall all food and beverages consumed over the preceding 24hr hours (Thompson *et al.*, 2010). An FFQ requires the respondent to choose their average intake frequency from a predetermined list of food items. This is retrospective and typically covers the preceding six or twelve months (Thompson *et al.*, 2010).

Strengths and limitations of different dietary assessment methods

Multiple pass 24hr recalls (See methods for description) can be administered with minimal training in a short time period. The strengths include minimal burden placed upon the respondent, and likely increased accuracy of intake due to recent memory recall (Block, 1982). By virtue of the retrospective nature of 24hr recalls, they are free of reactivity bias (modified intake in reaction to a prospective dietary assessment method). They also attempt to minimise underreporting via the multi-pass administration protocol. As such they have been considered as the dietary assessment method of choice for assessing dietary change in obesity. A limitation of this method is that it fails to capture the daily variation in individual diets, thus reducing its ability to reflect habitual diet (Bingham, 1997). This limitation is reduced upon multiple non-consecutive days being recorded (Tucker *et al*., 2013).

The multi-day weighed food diary is generally considered to give a more accurate estimation of habitual diet (Block, 1982), as everything consumed is weighed and recorded by the participant. This places more burden on the participant, and attracts a smaller, unrepresentative sample, thus rendering it impractical for large scale studies (Block, 1982). Although considered as the gold standard for validating other dietary assessment tools (Livingstone and Black, 2003), comparisons are limited for estimating validity, as all dietary assessment tools generate error (Bingham, 1987).

FFQs are retrospective dietary assessment tools which typically require the participant to have good memory, as they are asked their usual consumption over the preceding six or twelve months (Thompson *et al.*, 2010). They are the only dietary assessment method to assess the overall diet as opposed to other methods that are limited to dietary assessment over several individual days, thus being unable to truly capture high levels of intra-individual daily/seasonal variation in dietary behavior (Kristal *et al*., 1992). Unlike 24hr recalls and food diaries, FFQs are can therefore record longer-term intake in just a single administration, whilst placing minimal burden on the respondent (Kroke *et al.*, 1999). The limitations of FFQs have been well established and are reviewed in depth elsewhere (Buyers, 2001). Briefly, they often rely upon portion size conceptualisation rather than recording accurate portion sizes. For longer than sixty five years, portion size conceptualisation has been acknowledged as a source of error in studies quantifying dietary intake (MRC*, 2017*). Participants completing semi-quantitative FFQs often find it difficult to relate their intake to pre-defined reference serving sizes (Friedenreich, Slimani and Riboli, 1992). FFQs are regularly reported to suffer from greater measurement error in terms of misreporting of absolute dietary intakes (Bingham *et al*., 1994), with this error being exacerbated with shorter less comprehensive FFQs (US Institute of Medicine, 2002). They can however provide a good indication of diet quality (Cleghorn *et al.*, 2016) and have shown acceptable validity for ranking dietary intakes, provided they are strategically developed and validated within the population for which they are intended. They are also the least expensive option for large studies, hence they are the most widely utilised (Tucker *et al.*, 2013).

Cleghorn *et al.* (2016) suggested there to be a need for the development of new UK dietary assessment tools that are self-administered, easy to complete, simple to analyse and interpret, and which capture adequate detail appropriate for population health and lifestyle surveys. If the tool's purpose is to provide a good indication of dietary behavior, and is not seeking to accurately assess absolute intakes, short FFQs can be sufficient if they measure dietary intake to the accuracy required (Cummings *et al.*, 1987). In reference to a study by Pietinen *et al.* (1988a; 1988b) which compared a 44-item FFQ with a 273-item FFQ, Willet (1998) suggested there to be a rapidly diminishing marginal gain in information obtained from increasingly detailed FFQs. Thus, there seems to be a useful balance to be found between including adequate detail in an FFQ to minimise measurement error, whilst keeping it short enough to reduce participant burden.

Whilst FFQs are commonly used in epidemiological studies, there is debate whether they are a sensitive enough tool for the detection of important diet-disease relationships (Kristal, Peters and Potter, 2005; Freedman *et al.*, 2006). They are also used within prospective studies to evaluate the effectiveness of interventions which aim to change diet, as well as acting as useful screening tools to identify low and high consumers of certain foods (Cade *et al.*, 2002). This was demonstrated in a recent fire station-based dietary intervention pilot trial by Lessons and Bhakta (2018), who utilised an FFQ to assess dietary changes, and also as an effective qualitative indicator of diet, highlighting potential dietary issues which elicited the appropriate individual nutritional recommendations to be conveyed to each participant by a registered nutritionist.

A common problem which impairs accuracy of all dietary assessment methods is the phenomenon of misreporting.

<u>Misreporting</u>

A ubiquitous problem associated with self-reported dietary data is the under-estimation of food and nutrient consumption which results in intake inaccuracies (Black, 2000). A meta-analysis of seven UK studies produced evidence of subject biases from weighed food diaries, and also from other dietary assessment methods (Black and Cole, 2001). An association has been established between bodyweight status (bodyweight and BMI) and the magnitude of underreporting in studies including a range of body sizes (Johnson *et al*., 1994; Johnson *et al*., 1998). A systematic review of energy balance studies by Livingstone and Black (2003) found that the most robust finding in most of the studies (22 out of 25) was a positive correlation between high BMI and reporting low intakes. Goldberg *et al*. (1991) developed a formula to identify under-reporters, expressed as a ratio of energy intake to basal metabolic rate. Misreporting can be attributed to a multitude of factors including the modification of usual dietary intake, portion size conceptualisation problems, memory issues and subject fatigue (Rebro *et al*., 1998; Lillegaard *et al*., 2007). Worsley *et al*. (1984) found that self-presentation by socially desirable reporting correlated positively to fruit and vegetable consumption and negatively to foods high in fat.

Validation

The validation of an FFQ is essential to assess whether it is measuring what it was designed to measure, or to assess the level of agreement with a 'gold standard' or other dietary assessment methods (Cade *et al.*, 2002). The reference method of multiple 24hr recalls is considered an acceptable method, with a review of FFQ validation studies by Cade *et al.* (2002) finding that 50 (22%) of the studies reviewed used 24hr recalls as the reference measure. There is varying opinion regarding what constitutes a representative number of recalls to be collected. A study by Prentice *et al.*, (2011) found three 24hr recalls to yield suitable consumption estimates. This is consistent with a review by Johnson (2002) who recommended a minimum of three 24hr recalls including one weekend day, because analysis of the UK National Diet and Nutrition Surveys has shown dietary behaviour to alter at weekends (MRC, 2017). Whilst Johnson (2002) suggested 24hr recalls to be the most appropriate method of assessing dietary behaviour in obese subjects, it is important to understand that this is only assessing relative validity against another imperfect dietary assessment method, comparing it with an alternative, but not necessarily more accurate method. The relative validation study can therefore merely indicate whether the two methods give related answers and the extent to which they agree with one-another (Cade *et al.*, 2002). Using 24hr recalls as a reference method in a validation study also benefits from reducing participant burden and gives increased intake precision via recent memory recall (Block, 1982). This method does not suffer from the bias of modified intake (reactivity bias) which is associated with other methods such as weighed food diaries (Black and Cole, 2001).

Pioneering research by Lessons and Bhakta (2018), was the first study to investigate the dietary behavior of UK firefighters. This successfully utilised the EPIC-Norfolk food frequency questionnaire (FFQ) (Bingham *et al*., 2001) in a pilot trial on a small sample of London firefighters. They found the FFQ to be able to detect significant levels of dietary behavioural change when administered pre and post dietary intervention, which was supported by accompanying body composition changes. However, participant feedback identified it as burdensome. Furthermore, it was validated for a different population group, therefore its validity for assessing firefighter diets is unknown.

<u>Study objectives</u>

To develop the first FFQ for UK firefighters, giving careful consideration to finding the balance between sufficient comprehensiveness and minimal participant burden. The relative validity of the newly developed dietary assessment tool was then tested against the reference method of three multi-pass 24hr recalls. The reproducibility of the tool was also tested to evaluate its precision and usefulness for a dietary intervention study.

5.2. Materials and Methods

<u>FF-FFQ development</u>

The firefighter FFQ (FF-FFQ) was designed for dietary assessment within a fire station-based dietary intervention programme. Fire stations can be characterised as time poor environments, with activities such as mealtimes, physical exercise, fire safety inspections and skills training scheduled into each shift. Dietary assessment in this environment therefore needs to strike the balance between sufficient comprehensiveness and minimal burden, and further justifies the choice of dietary assessment method. The FF-FFQ is based upon the comprehensive and thoroughly validated EPIC-Norfolk FFQ (Bingham *et al*., 2001) (see appendix 5.1). This was used effectively in a pilot trial by Lessons and Bhakta (2018) within the target demographic. It was therefore deemed as a good starting point to select food items for the FF-FFQ.

Validated for the diverse population groups living in the UK, the EPIC-Norfolk FFQ was based upon an FFQ used in the USA Nurse's Health Study (Willett *et al.*, 1985; 1988) which was modified to reflect British dietary intakes. Between 1988 and 1990, this was validated against the gold standard reference methods of the sixteen-day weighed food diary and biomarkers on a sample of 160 female adults residing in Cambridge England, aged between 45 and 75 years (Bingham, 1997).

It quantifies a person's typical food intake over the preceding year. Nutrient and food group data can both be obtained from the FFQ. The questionnaire is a two-part, ten-page document, with part 1 displaying a list of 130 food items. Respondents are asked their usual rate of consumption by checking the appropriate frequency box for each food item. The nine frequency options range from 'Never or less than once-a-month' to 'six times per day'. Servings are specified in terms of common servings or units (e.g. one apple, one slice of bread) or household measures (e.g. cup, teaspoon). The FFQ uses average serving sizes for each food item. Part two of the FFQ asks for breakfast cereal choice and brand; the type of fat used for grilling/baking, roasting, frying; and the amount of visible fat around meat that is typically consumed. These questions are linked with pertinent items from part one in order to assist breakfast cereal classification and to quantify intake of fatty acids and total fat. Type of milk and the amount is also asked for in this section.

Before the Epic-Norfolk FFQ could be modified to more specifically reflect the target population's dietary behavior, the Initial step involved administration of the EPIC-Norfolk FFQ to a sample of 150 – 200 LFB firefighters. A sample of this size was deemed to be representative of the wider firefighter population. Fourteen LFB fire stations in the North East area of London were selected from which to recruit participants. An even spread of urban and suburban stations were chosen to further ensure external validity. In June 2019, the fourteen fire stations were visited by the researcher following approval from both the LFB (appendix 2.1) and the London Metropolitan University School of Human Sciences ethics committee (appendix 2.2). Participants were recruited following a verbal explanation of the research to each team of firefighters. Firefighters were included if they were full-time operational staff who worked both day and night duties (shift workers). Exclusion criteria applied to part-time firefighters who only worked day duties, because shift work and the associated sleep deprivation has been associated with altered food choice (Nedeltcheva *et al*., 2009). As the FF-FFQ was being designed to capture the dietary behavior of full-time operational firefighters, these exclusion criteria were justified, and applied to 2.8% of the potential sample (*n*=5). Two eligible firefighters decided not to participate. Written informed signed consent was obtained from 180 participants who each completed one paper-based EPIC-Norfolk FFQ. These were completed confidentially in fire station conference rooms following a brief explanation from the researcher of how to complete the FFQ as accurately as possible. To aid participant portion size conceptualisation (in an attempt to optimise accurate responses), a PowerPoint slide was presented on the conference room training screen. This showed a comprehensive list of foods contained within the FFQ described as 'medium serving', and the corresponding portion sizes which constituted a medium serving (See appendix 5.2). Although detailed portion sizes were described on the FFQ for some foods, for the food items described as 'medium serving' the participants were instructed to refer to the reference list on the screen, and modify their food frequency choices to suit their personal portion sizes e.g. if they consumed eight small roast potatoes instead of the medium serving of four, then they should state that they eat roast potatoes twice as regularly.

Social desirability bias (Worsley *et al*., 1984) was anticipated from an occupational group whose stereotypical image is that of being lean, fit and healthy (Haddock, Poston and Jahnke, 2011), therefore, in a proactive effort to minimise this, care was taken to reassure participants that all information shared with the researcher would remain confidential, and the point was stressed that they would not be judged and there would be no repercussions from their responses. They were also encouraged to complete their FFQ independently so to minimise misreporting caused by social desirability bias toward each other.

Each FFQ was then screened by the researcher, and participants who had completed any sections incorrectly were then confidentially asked if they could clarify the relevant anomaly. This technique was found to be an effective way to minimise mistakes in a study by Tsuchida *et al.*, (1999). A review by Caan *et al.* (1999) found that using a nutritionist to screen for accurate entries on a self-administered FFQ improved agreement with the reference method.

<u>FFQ Modification – part 1</u>

The FF-FFQ was designed to fulfill the primary functions of (i) a screening tool to identify high and low intakes of foods which relate to public health messages, and (ii) for use in a dietary intervention study to detect dietary changes. As an accurate measurement of absolute energy and nutrient intake was not a primary concern, the compromise was made to reduce the number of foods included so to reduce burden in a time poor environment with participants whose motivation levels were largely unknown. A shorter FFQ is justified as long as it measures dietary intake to the accuracy level for which it is required (Cummings *et al.*, 1987). Another consideration contributing to the chosen length of the FF-FFQ was the synchronised administration of a lifestyle and physical activity questionnaire. This amounted to a little under two A4 sides of paper, and was factored into the decision making process, as suggested by Cade *et al.* (2002) in a review of FFQ validation studies.

Firstly, pages 1 and 2 of the EPIC-Norfolk FFQ were discarded. These contained instructions directing how to complete the FFQ. This was deemed unnecessary due to a) the researcher being present to instruct participants, and b) each page featuring intrinsic prompts. The main grid (part 1) of the EPIC-Norfolk FFQ was then modified to more specifically reflect the target population's dietary behavior via a process of eliminating food items which were rarely consumed, and including foods which are not featured in the EPIC-Norfolk FFQ but were commonly reported in the 'additional foods' section.

Table 5.1 displays the results of statistically ranking the food choice frequencies of the 180 firefighters.

Table 5.1. Mean intake frequency and corresponding rankings of 130 Epic-Norfolk FFQ food items, as reported by 180 LFB firefighters.

EPIC-Norfolk FFQ food item	Mean intake frequency	Rank	EPIC-Norfolk FFQ food item	Mean intake frequency	Rank
TEA	5.92	1	FIZZY_DRINKS	2.07	66
INSTANT_COFFEE	5.03	2	COLESLAW	2.05	67
CHICKEN	4.13	3	LOWFAT_YOGURT	2.04	68
EGGS	3.89	4	READYMADE_CAKE	1.99	69
BANANAS	3.87	5	AVOCADO	1.97	70
ONIONS	3.83	6	BROWN_RICE	1.94	71
CARROTS	3.75	7	READYMADE_BUNS	1.94	71
CHOCOLATE_BISCUIT	3.65	8	HOMEBAKED_CAKE	1.93	73
FRUIT_SQUASH	3.63	9	PORK	1.90	74
BROCCOLI	3.55	10	PEARS	1.87	75
TOMATOES	3.55	11	BURGER	1.86	76
APPLES	3.54	12	PIZZA	1.85	77
GREEN_SALAD	3.54	13	SPROUTS	1.84	78
GARLIC	3.47	14	SPIRITS	1.84	79
PEPPERS	3.34	15	PARSNIPS	1.83	80
BUTTER	3.32	16	LAMB	1.81	81
MUSHROOMS	3.25	17	SAVOURY_PIES	1.78	82
CRISPS	3.22	18	LEEKS	1.75	83
BEER	3.21	19	FULLFAT_YOGURT	1.72	84
WHOLEMEAL_BREAD	3.21	20	MARROW	1.69	85
WHITE_BREAD	3.15	21	WHOLEMEAL_PASTA	1.69	86
ORANGES	3.13	22	VEGETABLE_SOUP	1.69	86
CHEESE	3.02	23	OTHER_DRESSING	1.68	88
CEREAL	2.99	24	MELONS	1.68	88
PORRIDGE	2.97	25	FRIED_FISH	1.66	90
BOILED_POTATOES	2.97	25	OTHER_MARGARINE	1.66	91
CHOCOLATE_BARS	2.97	25	BEANSPROUTS	1.66	91
SUGAR	2.95	28	MARMITE	1.65	93
BROWN_BREAD	2.91	29	HOMEBAKED_BUNS	1.64	94
PEAS	2.88	30	LOWCAL_SALAD_CREAM	1.61	95
SPINACH	2.87	31	PEACHES	1.61	95
FRUIT_JUICE	2.86	32	LASAGNE	1.59	97
KETCHUP	2.82	33	LENTILS	1.59	97
BEEF	2.82	34	CRACKERS	1.56	99
NUTS	2.82	35	SINGLE_CREAM	1.55	100
BEANS	2.80	36	SHELLFISH	1.54	101
WHITE_RICE	2.80	37	CRISPBREAD	1.52	102

CHOCOLATES	2.78	38	DAIRY_DESSERT	1.52	102
STRAWBERRIES	2.76	39	FISH_FINGERS	1.49	104
WHITE_PASTA	2.73	40	DECAFF_COFFEE	1.48	105
GRAPES	2.70	41	WATERCRESS	1.48	105
PLAIN_BISCUIT	2.70	42	MILK_PUDDINGS	1.45	107
OILY_FISH	2.69	43	FRENCH_DRESSING	1.44	108
SALAD_CREAM	2.63	44	READYMADE_FRUIT_PIES	1.44	108
SWEETCORN	2.61	45	MEAT_SOUP	1.44	108
CHIPS	2.52	46	COFFEE_WHITENER	1.42	111
BACON	2.50	47	GRAPEFRUIT	1.42	111
WINE	2.50	47	COTTAGE_CHEESE	1.41	113
LOWCAL_FIZZY_DRINKS	2.50	47	POTATO_SALAD	1.39	114
GREEN_BEANS	2.49	50	HARD_MARGARINE	1.39	114
HAM	2.47	51	HOMEBAKED_FRUIT_PIES	1.38	116
CABBAGE	2.41	52	CORNED_BEEF	1.32	117
SAUCES	2.40	53	COCOA	1.32	117
ROAST_POTATOES	2.40	54	DOUBLE_CREAM	1.30	119
POLYUNSAT_MARGARINE	2.39	55	READYMADE_SPONGE	1.30	119
SAUSAGES	2.36	56	LOWFAT_SPREAD	1.30	121
PEANUT_BUTTER	2.32	57	QUICHE	1.26	122
ICE_CREAM	2.30	58	HOMEBAKED_SPONGE	1.23	123
JAM	2.28	59	TINNED_FRUIT	1.21	124
CAULIFLOWER	2.22	60	VERY_LOWFAT_SPREAD	1.20	125
PICKLES	2.15	61	LIVER	1.20	126
WHITE_FISH	2.13	62	TOFU	1.16	127
DRIED_FRUIT	2.13	63	PORT	1.12	128
SWEETS	2.11	64	ROE	1.08	129
BEETROOT	2.07	65	HORLICKS	1.08	129

Mean intake frequencies derived from 180 FFQs. FFQ frequency options were: 1 = Never or less than once/month; 2 = 1-3 per month; 3 = Once a week; 4 = 2-4 per week; 5 = 5-6 per week; 6 = Once a day; 7 = 2-3 per day; 8 = 4-5 per day; 9 = 6+ per day. Items in red were not incorporated into the FF-FFQ.

For a food item to either differentiate between individuals or to contribute toward absolute intake, it must be consumed reasonably regularly by an appreciable proportion of the population (Cade *et al.,* 2002). All food items with a mean intake frequency < 1.5 equated to a rounded average intake of 'never or less than once/month'. All items falling below this cut-off were automatically excluded from the FF-FFQ. Therefore Table 5.1 shows that the vast majority of the excluded food items were simply the lowest ranked (and therefore the least frequently reported). Exceptions to this rule were applied to brown bread, home-baked buns and crispbread, which were also excluded to overcome confusion with similar options, an issue which became apparent during screening and response clarification of the 180 completed EPIC-Norfolk FFQs. Brown and wholemeal bread were confused with one-another, with firefighters choosing brown bread, but when questioned further, it transpired that they were consuming wholemeal bread. The same issue applied to home-baked buns being confused with readymade buns, and crispbread being confused with crackers. A total of thirty food items (23% of the options) were excluded from the part one of the FFQ.

Part two modifications

A question in the second part of the Epic-Norfolk FFQ enabled entry of any '*other' foods* which were not included in the main grid. The '*other' foods* answers from the 180 completed EPIC-Norfolk FFQs were analysed. A judgement was made that no single '*other'* food was reported frequently enough to warrant inclusion in the modified main grid, with the most frequently appearing 'other' food (sweet potato) only appearing on four of the 180 FFQs. It was therefore deemed sufficient to allow the 'any other foods' question toward the end of the FFQ, to capture these foods when reported in the future. The exception to this was takeaway foods, as these appeared on 32% of the 180 EPIC-FFQs in 'other foods'. Due to this high frequency, alongside their potentially detrimental effects on health (Public Health England, 2016), the decision was made to include the question, "How often did you eat takeaway foods, eg. Curry, Chinese, pizza, fish and chips?". Intake frequency options were: Less than once per week; 1 – 3 times per week; 4 – 6 times per week; Daily.

Question 5 on page 9 of the EPIC-Norfolk FFQ was abbreviated to: 'If you usually eat a breakfast cereal other than porridge/Ready Brek, which type? E.g. cornflakes, muesli, etc.' This removed unnecessarily asking 'if' they usually eat a breakfast cereal beforehand, as well as removing the question of 'which brand'. This removal was justified due to the limited amount of research available suggesting that knowing the brand of a particular breakfast cereal does not improve validity (Willett *et al.*, 1988). Questions 8 and 9 on page 10 of the EPIC-Norfolk FFQ were discarded. They referred to frequency of fried food consumption at home and away from home respectively. They were deemed unnecessary because, with the widespread use of low energy spray oils and non-stick cookware not requiring much cooking oil, frying was not necessarily an unhealthy mode of cooking. Questions 11 and 12 were also discarded. They referred to frequency of grilled/roast meat consumption, and how well cooked the meat was, respectively. These questions were included in the EPIC-Norfolk FFQ to test diet-disease associations (Bingham, 1997). As the FF-FFQ is not intended for epidemiological purposes, these questions were removed. Question 16 refers to fruit and vegetable intake. This is repeated, as fruit and vegetable intake is assessed in a different way in part one, and was therefore removed to reduce participant burden. Question 17 was retained but simplified into a less burdensome table for the participant to list dietary supplement usage.

Substantially reducing the main grid of the EPIC-Norfolk FFQ by 23%, along with shortening the second part, and removing the cover & instruction page, reduced it from a ten-page document down to six pages. The balance between comprehensiveness and participant burden was carefully considered, guiding all aforementioned decisions. Subsequent pre-testing of the modified questionnaire suggested that this balance was indeed found.

Adaption of longer FFQs into shorter versions and re-validation is a method of FFQ development practiced by previous researchers (Block, Hartman and Naughton, 1990; Brown and Griebler, 1993; Cleghorn *et al.*, 2016; Bredin *et al.*, 2020). Indeed, a review of FFQ validation studies showed that 45% of the studies conducted between 1980 and 1999 used modified versions of previously developed FFQs (Cade *et al*., 2004). Cade *et al.* (2002) outlined certain considerations to be taken into account when choosing a template FFQ to modify. First of all is to ascertain the original purpose of the FFQ. The EPIC-Norfolk FFQ was intended for use in epidemiological study (Bingham *et al*., 1997). Some of the questions in part two of the questionnaire are clearly for this purpose i.e. 'How well cooked did you usually have grilled or roast meat' is a featured question which has been associated with disease (Svendsen *et al.*, 2012), therefore this, along with other questions were discarded if they did not fulfil the purposes of the FF-FFQ. Secondly, the original target population demographic characteristics need to be considered. In this case they were middle-aged to elderly English people, which, in terms of types of food choice, is not dissimilar to those consumed by English firefighters. Analysis of the 'any other foods question' within the 180 EPIC-Norfolk FFQs did not identify any missing foods regularly enough to suggest that it was outdated and lacking in modern food options, despite the questionnaire originally being created in 1988. This therefore suggests that the FFQ is not out-of-date, which is the third consideration. The Epic-Norfolk FFQ was thus a carefully considered and justifiable template to modify into the FF-FFQ.

General modifications

Aesthetic design

Researcher screening of the 180 completed EPIC-Norfolk FFQs followed by subsequent discussion with respondents helped to clarify mistakes in terms of frequency options sometimes being unintentionally checked within unintended rows. Participant feedback identified the design of the FFQ to be the issue causing the mistakes. The general consensus was that it was difficult to visually differentiate between rows due to the uniform colour. An attempt to mitigate this issue was made by simply alternating the colour of each row.

Food groups, frequency of intake and reference period

Foods were grouped together in a logical and comprehensible manner, following the same sequence as the EPIC-Norfolk FFQ. To further enhance the clustering of traditional food groups, a modification was decided upon to group fruit and vegetables together on the same page, thus fitting more closely with the target demographic's conceptual framework, and aligning with a key consideration of assembling FFQ food lists, as outlined by Cade *et al*. (2002). The EPIC-Norfolk FFQ nine intake frequency options were left unchanged so to allow respondents adequate choice. This also enabled data to be analysed by the accompanying dietary analysis software (see section 2.6).

As one of the purposes of the FF-FFQ was to be used in a dietary intervention study, being able to capture shorter term changes requires asking participants their average intakes over a briefer period than the time frame instructed by the EPIC-Norfolk FFQ. Three months was chosen as the reference period, partly due to the intervention study design. This also reduces burden on the participant due to requiring more recent memory recall, as they will only have to think back over the last quarter of a year, as opposed to the whole year, which is the EPIC-Norfolk reference period. The final version of the FF-FFQ amounted to 100 food items in part 1 of the questionnaire (reduced from 130), followed by a further 12 questions (reduced from 24) in part 2 (see appendix 5.3). This was then successfully pretested on a focus group of nine firefighters, who found it understandable and acceptable in terms of reduced burden compared with the EPIC-Norfolk FFQ. The focus group FF-FFQs were then used to test run the dietary analysis software programme, with the nutrient outputs being subsequently checked by the researcher for mistakes.

Study design and sample

The FF-FFQ was tested for validity and reproducibility in two separate studies using similar sample groups. The two studies were conducted at five LFB fire stations which had also been selected to serve as the control group for a dietary intervention study (see Chapter 7). The control group stations were selected for inclusion within these studies as it was hypothesised that they were less likely to alter their diet over the study period, compared with the intervention group stations. The fire stations were: East Ham, Edmonton, Enfield, Hornsey and Tottenham.

Ethics

The studies received ethical approval from the London Metropolitan University School of Human Sciences ethics committee (See Chapter 2 for details), and were conducted between June and December 2019 during day duties.

Reproducibility study

Firefighters (*n*=126) were recruited at the five LFB fire stations. Eligible participants (full-time operational firefighters) were handed a paper-based FF-FFQ in the fire station conference room at the beginning of the study. After a brief explanation of how to complete the questionnaire, participant attention was guided toward a screen showing medium serving sizes relevant to the FF-FFQ (see appendix 5.2). Once completed, the researcher met with each participant individually to check the FF-FFQ for any mistakes which were then corrected together. The same process was repeated four months later, yielding a total of two completed paper FF-FFQs from each participant.

Validation study

Firefighters (*n*=104) were recruited at four of the five LFB fire stations. The same procedure as the reproducibility study (see above) was carried out, with the addition of a multi-pass 24hr recall (Guenther *et al.*, 1996) being collected from each participant during the initial engagement immediately after checking their FF-FFQ for mistakes. The multiple-pass 24hr recall method was developed by the USA Department of Agriculture to reduce the effect of underreporting that is inherent of self-reported dietary intake (Guenther *et al.*, 1996). It is a staged interview, consisting of five passes (steps) which seeks to capture the previous day's dietary intake. The first step is for the researcher to transcribe a quick list of foods and beverages consumed the previous day. The interviewer then probes for any forgotten foods. The third step is to record eating occasion and time for each food. Then a cycle of more detailed information is recorded including cooking methods, condiments, food brands, amounts and so on. A fifth final probe is then conducted to check if anything else was consumed.

This yielded a total of at least one FF-FFQ and at least one 24hr recall from each participant. Two more 24hr recalls were collected at follow-up station visits in the initial four-month period by the researcher visiting the station or by telephone for participants for whom a third 24hr recall was not obtainable in person. One of the three 24hr recalls recorded dietary intake on a weekend day.

Anthropometry

Participant weight and height were measured to ascertain potential participant anthropometric mean differences between stations. Measurement protocols are described in Chapter 2.

Under-reporters

To identify participants reporting unfeasibly low energy intakes, the Henry equation was used to predict individual basal metabolic rate (BMR) (Henry, 2005). This was then multiplied by 1.1 to calculate estimated individual minimum energy requirements for each participant (EmER) (Goldberg *et al*., 1991). Participants reporting energy intakes below their EmER were considered to be under-reporting. The Goldberg cut-off of 1.1 was chosen because it identifies approximately 75% of under-reporters (MRC, 2017).

Dietary analysis

Printed FF-FFQs were coded utilising the specified format template for the EPIC-Norfolk FFQ (University of Cambridge, 2020), with 1's allocated to the thirty food items which were discarded from the main grid of the EPIC-Norfolk FFQ in the development of the FF-FFQ. The coded FF-FFQs were then processed utilising FETA dietary analysis software (Mulligan *et al*., 2014), which is described in Chapter 2.

The 24hr recall dietary intake data was processed using Nutritics dietary analysis software (Nutritics, 2019), which is described in Chapter 2. The nutrient outputs from the three 24hr recalls were averaged to generate a mean daily nutritional intake for each participant. This study did not include dietary supplement intake in the analyses. The nutrients which were focused on in both studies included energy, carbohydrate, protein, fat, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), fibre (non-starch polysaccharides), sodium, iron, calcium and vitamin C. The micronutrients were chosen based upon their relevance to health and associated public health messages.

Statistical analyses

Data were imported into IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). The distribution of all continuous data was checked for normality. Means and corresponding standard deviations (SD) were used to express normally distributed data, and parametric tests were applied. Medians and interquartile ranges (IQR) were used to express non-normally distributed data, and non-parametric tests were applied. Outliers were identified via visual assessment of box plots before the checking of raw data for collection and/or transcription errors. Descriptive statistics were computed to describe pertinent characteristics of the study sample. Levene's tests were used to assess the variance of participant age, weight and BMI. One-way ANOVAS were then used to investigate differences between fire stations in age, weight and BMI. For the reproducibility study, all nutrient intakes were calculated as median with corresponding interquartile ranges (IQR). The same applied for the validation study, except for carbohydrate, fibre, sodium, iron and calcium which were calculated as mean (SD). For the reproducibility study, Spearman's correlation coefficients and accompanying scatter plots were generated to assess the association between the first and second FF-FFQ for energy and each nutrient of interest. For the Validation study, Spearman's correlation coefficients were generated to assess the association between the two dietary assessment methods for energy, protein, fat, SFA, MUFA, PUFA and vitamin C. Pearson's correlation coefficients were generated to assess the association between the two methods for carbohydrate, fibre, sodium, iron and calcium. All nutrient intakes were adjusted for total energy intake using the nutrient density model, expressing carbohydrate and protein as percentages of total energy, and expressing all other nutrients as intake per 1000 kcal (Willett, Howe and Kushi, 1997). An alpha value of $p < 0.05$ was used to detect significance.

The unadjusted energy and nutrient intakes were grouped into quartiles for each method to estimate the percentage of firefighters cross-classified into the same quartile, the same and adjacent quartiles, and extreme opposite (1st and 4th) quartiles. The predictive capacity of age, BMI and WHtR on low energy intake reporting was investigated using a binary logistic regression model.

Bland and Altman analyses were undertaken for energy and each nutrient to investigate biases and assess the limits of agreement between the first and second FF-FFQ in the reproducibility study, and between the FF-FFQ and 24hr recall in the validation study. In the reproducibility study, for energy and each nutrient, the differences between the means of the first and second FF-FFQ (1st FFFFQ – 2nd FFFFQ) were plotted against the mean of the first and second FF-FFQ [(1st FFFFQ + 2nd FFFFQ)/2]. Judgements on precision of the FF-FFQ were based upon a mean of > 95% of data plots falling within the limits of agreement (mean ± 2SD). In the validation study, for energy and each nutrient, the differences between the means of the FF-FFQ and the 24hr recall (FFFFQ – 24hr recall) were plotted against the mean of the two methods [FFFFQ + 24hr recall)/2]. Following each Bland and Altman analysis, simple linear regression was performed to indicate proportional bias between the two FF-FFQs in the reproducibility study, and between the two methods in the validation study. An alpha value of $p < 0.05$ was used to indicate significant proportional bias.

5.3. Results

Study population (Phase 1)

The initial phase of the study involved the recruitment of firefighters to complete one EPIC-Norfolk FFQ each. Of 187 firefighters invited to participate, 185 agreed, and five were excluded due to being day duty workers. Anthropometric and demographic characteristics of the final study sample are displayed in Table 5.2. They were similar to the 2019 English national fire service average statistics for age (England: 41 y, this study: 39.3 y), female firefighters (England: 6.4%, this study: 5%), ethnic minority firefighters (England: 4.3%, this study: 5.6%) (Home Office, 2019). The mean BMI of 27.6 for this study sample is identical to the 2018 LFB average frontline firefighter (statistic provided by the LFB occupational health service).

Table 5.2: Demographic and anthropometric statistics of the *n*=180 firefighters who completed one EPIC-Norfolk FFQ

Characteristic	Total (*n* = 180)
Male / Female n (%)	171 (95) / 9 (5)
Ethnic minorities n (%)	10 (5.6)
Age (y) (SD)	39.3 (8.9)
BMI (kg/m^2) (SD)	27.6 (3.6)

Abbreviation: BMI, body mass index

Validation Study

<u>Study population</u>

Between June and December 2019, a total of 104 participants from four LFB fire stations were screened to participate in this study, with 102 eligible for inclusion. 2 participants were excluded due to not working night duties (day workers). 69 participants finished the study by completing at least one FF-FFQ and three multi-pass 24hr recalls within a five-month period. The remaining 33 participants completed < three 24hr recalls. This was because they were not present on subsequent study days. Reasons for this include attending an emergency incident, being on leave, training course attendance, temporary detachment to a different fire station, sickness absence, transfer to another fire station or retirement. The final dataset for the validation study comprised 69 participants as illustrated in Figure 5.1. Each participant was posted at one of four LFB fire stations, two of which are classed as inner-city (urban), and the other two being more suburban. There were varying participant numbers from each station (urban stations: *n*=26, 4; suburban: *n*=30, 9). There were no significant differences between stations in age, weight or BMI ($p > 0.05$). Table 5.3 displays demographic and anthropometric characteristics of the study sample, which comprised mainly men (94%), which is representative of the UK fire service (Home Office, 2019).

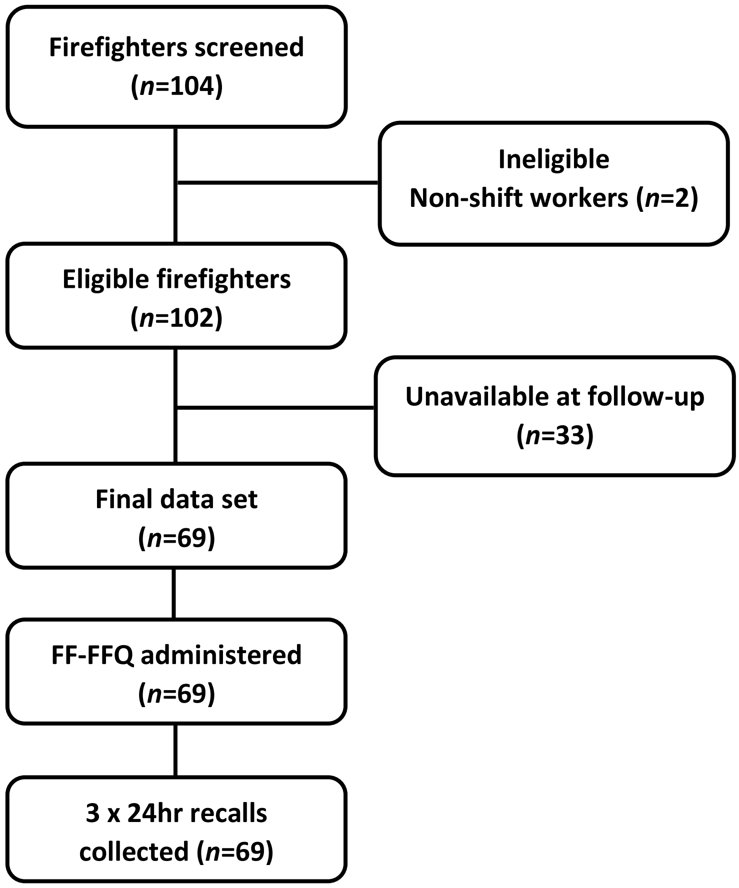


Figure 5.1. Participant flow through the validation study. FF-FFQ: firefighter food frequency questionnaire.

Table 5.3. Demographic and anthropometric characteristics

Characteristic	**Total (*n* =69)**
Male / Female n (%)	65 (94.2) / 4 (5.8)
Ethnic minorities n (%)	6 (8.6)
Age (y)[a]	38.7 (8.2)
Years served (y)[b]	13 (10)
Height (m)[a]	1.78 (0.08)
Weight (kg)[a]	85.5 (12.2)
BMI (kg/m^2)[a]	26.9 (2.7)
WHtR (WC/Height cm)[b]	0.5 (0.08)

Values presented as number of participants (% of sample) or [a]mean (SD) or [b]median (interquartile range). Abbreviations: BMI, body mass index; WC, waist circumference; WHtR, waist to height ratio.

<u>Nutrient intake comparisons between the FF-FFQ and 24hr recall</u>

Table 5.4 displays average energy and nutrient intakes. This indicates widespread underreporting, as energy intake reported by FF-FFQ was an average of 14% below estimated minimum requirements,

compared with the average energy intake measured by 24hr recall being 13% above the minimum requirement. Upon further investigation, 72% of the sample (*n* = 50) had reported energy intakes below this level as measured by FF-FFQ. This equated to 72% of the males (*n* = 47), and 75% of the females (*n* = 3). In comparison, prevalence of underreporting was approximately half as frequent by 24hr recall, with 35% of the sample (*n* = 24) reporting energy intakes below the estimated minimum requirement. This equated to 35% of the males (*n* = 23), and 25% of the females (*n* = 1).

By FF-FFQ, proportions of carbohydrate, protein and fat, in terms of total energy intake were 43.5%, 20.4% and 36.1% respectively. This is below the UK DRV for carbohydrate of (50%) (SACN, 2015), and above the recommended maximum amount for fat (35%) (SACN, 2019). The 24hr recall recorded similar proportions of carbohydrate, protein and fat, in terms of total energy intake: 40.5%, 20.9% and 38.6% respectively. By FF-FFQ, SFA accounted for 11.6% of total energy intake, which is above the maximum recommended amount of 10% (SACN, 2019). 24hr recall recorded a similar proportion of SFA at 10.8% of total energy intake. There was very little difference between the FF-FFQ and the 24hr recall in recording absolute median fibre intakes: 15.9 and 15.7 g/d respectively, which is below the UK recommended average intake of 30g/d (SACN, 2015). Median sodium intakes were also very close between the two methods: 2464 mg/d and 2509 mg/d respectively, which is slightly above the maximum recommended amount of 2400 mg/d (SACN, 2003). Mean calcium intake was slightly above the RNI of 700 mg/d (Committee on Medical Aspects of Food Policy [COMA], 1991) for both methods, although the FF-FFQ measured a greater mean intake (FF-FFQ: 760 mg/d vs 24hr recall: 726 mg/d). Median vitamin C intakes showed the greatest difference between the methods, with the FF-FFQ recording 38% greater median intake than the 24hr recall, both of which were well above the RNI of 40 mg/d (COMA, 1991).

One to three mild outliers were identified for carbohydrate, protein, fat, fibre, SFA, MUFA, calcium, iron and vitamin C. Further investigation indicated that no data collection or transcription errors had been made. The mild outliers were therefore left in the data set.

Correlation coefficients between the FF-FFQ and 24hr recall were mostly moderate and were significant for energy and all analysed nutrient intakes as displayed in Table 5.4. Energy adjustment yielded stronger correlation coefficients for fat, SFA, fibre and vitamin C, but weaker for carbohydrate, protein, MUFA, PUFA, sodium, iron and calcium.

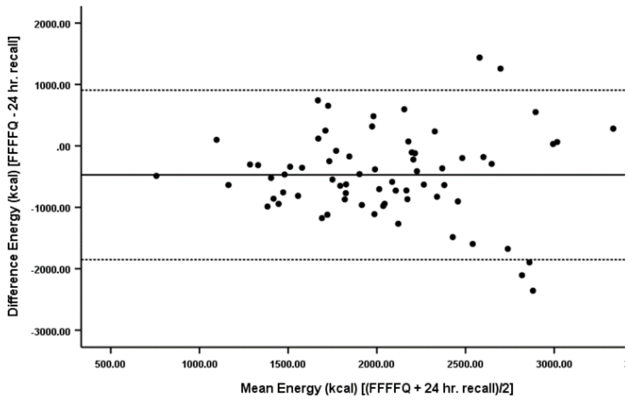
Table 5.5 displays the level of quartile agreement between the two methods, indicating a mean rate of misclassification (extreme opposite nutrient reporting) of 4.2%. Table 5.6 displays the predictive effects of age, BMI and WHtR on low energy intake reporting (LER). This showed no effect of any of the predictor variables on LER when controlling for the other two predictor variables in the model.

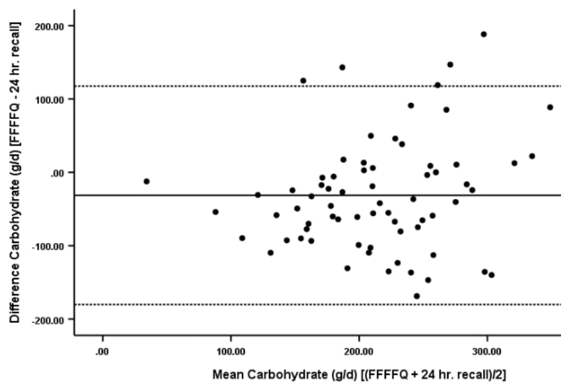
Bland and Altman (BA) analyses were used to detect bias between the mean differences, and to illustrate 95% agreement intervals between the FF-FFQ and 24hr recall for energy, carbohydrate, carbohydrate as a percentage of energy intake, fibre, protein, protein as a percentage of energy intake, fat, SFA, MUFA, PUFA, sodium, iron, calcium and vitamin C. These BA plots are illustrated in Figure 5.2. Appendix 5.4 displays the BA plots in full-size with accompanying descriptions of each. BA analyses indicated good agreement between methods for energy and each nutrient, with an average of 96% of cases falling between the limits of agreement.

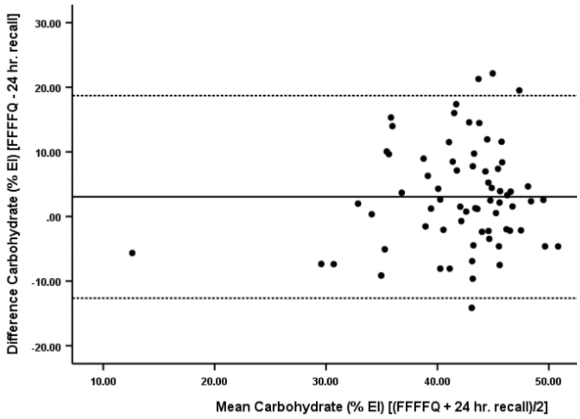
Table 5.4. Energy and nutrient intakes calculated from FF-FFQ vs 24hr recall, and correlations between the two methods.

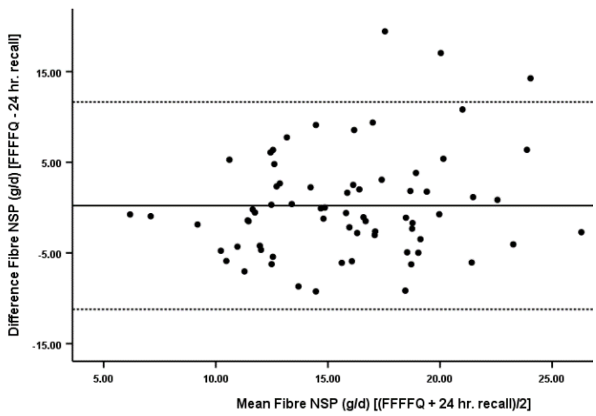
Energy	**FF-FFQ**	**24hr recall**	**Correlation[b]**	
			Unadjusted	**Adjusted[c]**
EI (kcal)	1742 (698)	2250 (744)	0.42	-
EmER (kcal)	1994 (281)	1994 (281)	-	-
EI/EmER (%)	86 (34)	113 (40)	0.43	-
Nutrients				
Carbohydrate (g)[a]	197.6 (76)	228.9 (63.5)	0.42	-
Carbohydrate (% EI)[a]	43.5 (7.4)	40.5 (6.6)	0.35	-
Fibre (g)[a]	15.9 (5.5)	15.7 (4.5)	0.34	0.49
Protein (g)	87.6 (31.2)	119.9 (47.4)	0.42	-
Protein (% EI)	20.4 (3.9)	20.9 (6.5)	0.31	-
Total Fat (g)	67.9 (29.9)	84.8 (38.9)	0.35	0.43
SFA (g)	22.5 (11.4)	26.9 (12.9)	0.36	0.45
MUFA (g)	26.2 (11.6)	28.6 (14.6)	0.32	0.22[d]
PUFA (g)	12.4 (5.6)	12.4 (9.5)	0.24 (*p*=0.05)	0.22[d]
Sodium (mg)[a]	2464 (827)	2509 (824)	0.32	0.27
Iron (mg)[a]	10.6 (3.4)	12 (4.2)	0.38	0.13[d]
Calcium (mg)[a]	760 (274)	726 (240)	0.45	0.27
Vitamin C (mg)	99 (56)	61 (56)	0.26	0.33

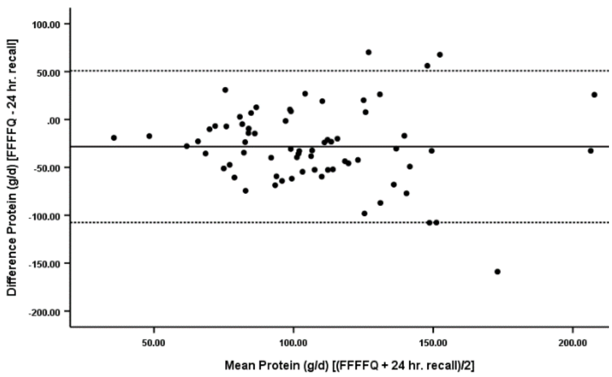
Values presented as median (interquartile range), Spearman's correlation. [a] Values presented as mean (SD), Pearson's correlation. [b]Correlation is significant at the .05 level (2-tailed) for all nutrients analysed. [c]Nutrient intakes adjusted using the nutrient density model [(nutrient/energy)x1000] [d]$p>0.05$. Abbreviations: EI, energy intake; EmER, estimated minimum energy requirement; SFA, saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

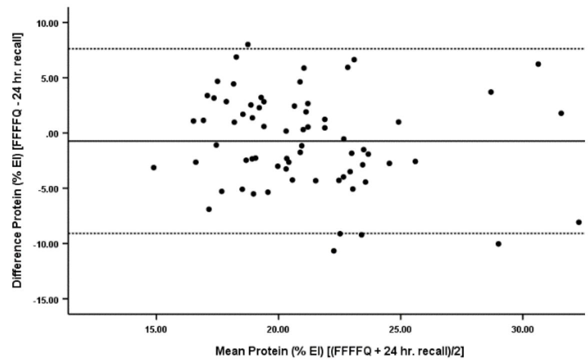

Difference Energy (kcal) [FFFFQ - 24 hr. recall]
Mean Energy (kcal) [(FFFFQ + 24 hr. recall)/2]

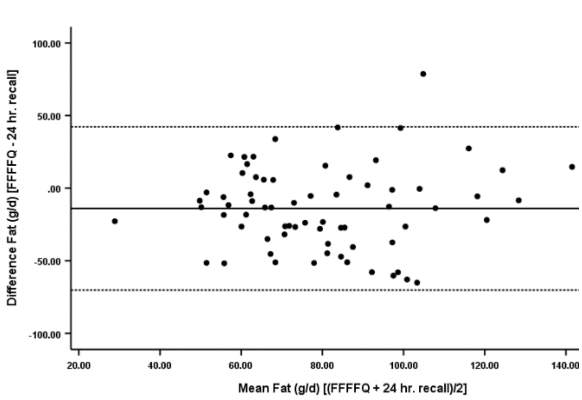

Difference Carbohydrate (g/d) [FFFFQ - 24 hr. recall]
Mean Carbohydrate (g/d) [(FFFFQ + 24 hr. recall)/2]

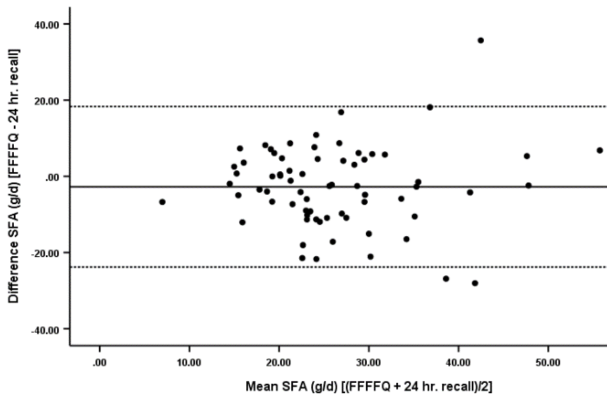

Difference Carbohydrate (% EI) [FFFFQ - 24 hr. recall]
Mean Carbohydrate (% EI) [(FFFFQ + 24 hr. recall)/2]


Difference Fibre NSP (g/d) [FFFFQ - 24 hr. recall]
Mean Fibre NSP (g/d) [(FFFFQ + 24 hr. recall)/2]


Difference Protein (g/d) [FFFFQ - 24 hr. recall]
Mean Protein (g/d) [(FFFFQ + 24 hr. recall)/2]


Difference Protein (% EI) [FFFFQ - 24 hr. recall]
Mean Protein (% EI) [(FFFFQ + 24 hr. recall)/2]


Difference Fat (g/d) [FFFFQ - 24 hr. recall]
Mean Fat (g/d) [(FFFFQ + 24 hr. recall)/2]


Difference SFA (g/d) [FFFFQ - 24 hr. recall]
Mean SFA (g/d) [(FFFFQ + 24 hr. recall)/2]

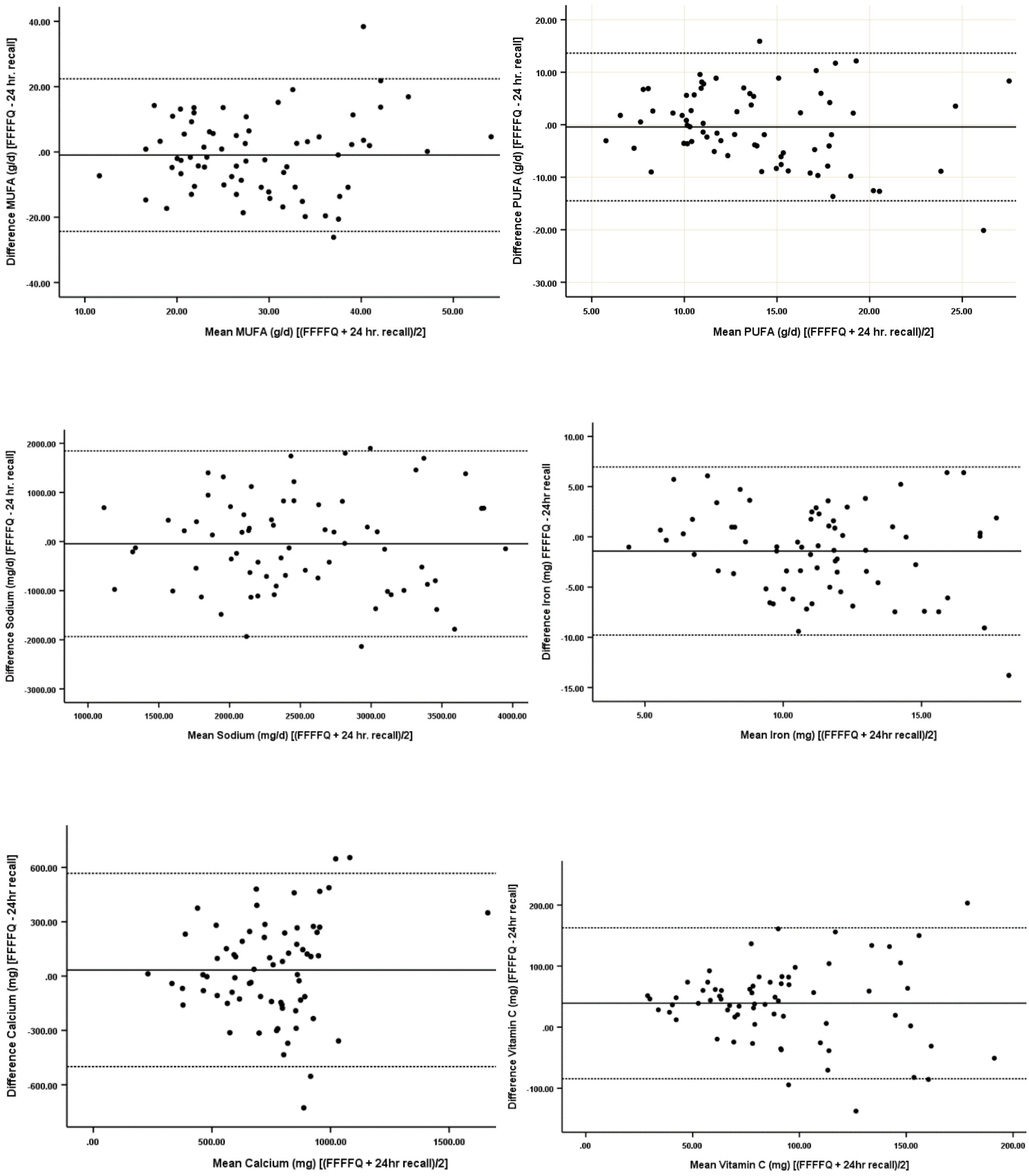


Figure 5.2. Validation study Bland & Altman plots showing levels of agreement between the FF-FFQ and 24hr recalls (Appendix 5.4 provides detailed descriptions of each plot).

Table 5.5. Quartile cross-classification between FF-FFQ and 24hr recall

Nutrient	Level of quartile agreement (%)[a]		
	Same	Same & adjacent	Opposite[b]
Energy (kcal)	41	74	3
Carbohydrate (g)	30	75	1
Protein (g)	32	72	3
Fat (g)	32	70	1
SFA (g)	35	72	6
MUFA (g)	30	75	1
PUFA (g)	17	65	3
Fibre (g)	32	83	7
Sodium (mg)	33	74	7
Iron (mg)	38	72	4
Calcium (mg)	30	71	4
Vitamin C (mg)	41	75	10

[a]Based upon unadjusted data.
[b]Percentage level of agreement in extreme opposite quartiles (1st and 4th quartiles). Abbreviations: SFA, saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

Table 5.6. Variables potentially influencing low energy intake reporting (EI/BMR < 1.1)

Dependent variable: LER (EI/BMR < 1.1)		
	β coefficient	*P* value
Age	0.03	0.43
BMI	-0.04	0.84
WHtR	8.06	0.5

Abbreviations: BMI, body mass index; WHtR, waist-to-height-ratio.

Reproducibility Study

Between June and December 2019, a total of 126 participants from five LFB fire stations were screened to participate in this study, with 121 eligible for inclusion. 5 participants were excluded due to not working night duties (day workers). 72 participants finished the study by completing two FF-FFQs within a five-month period. The remaining 49 participants only managed to complete one FF-FFQ. This was because they were off-duty on the day the researcher visited their fire station to administer the follow-up FF-FFQ. Reasons for this include being on leave, training course attendance, temporary detachment to a different fire station, sickness absence, transfer to another fire station or retirement. The final dataset for the reproducibility study comprised 72 participants as illustrated in figure 5.3. Each participant was posted at one of five LFB fire stations, three of which are classed as inner-city (urban), with the other two being more suburban. Participant numbers at each station varied (urban stations: n=22, 6, 3; suburban: n=16, 25). There were no significant differences between stations in age, weight or BMI ($p > 0.05$). Table 5.7 displays demographic and anthropometric characteristics of the study sample, which comprised mainly of men (94%), which is representative of the UK fire service (Home Office, 2019).

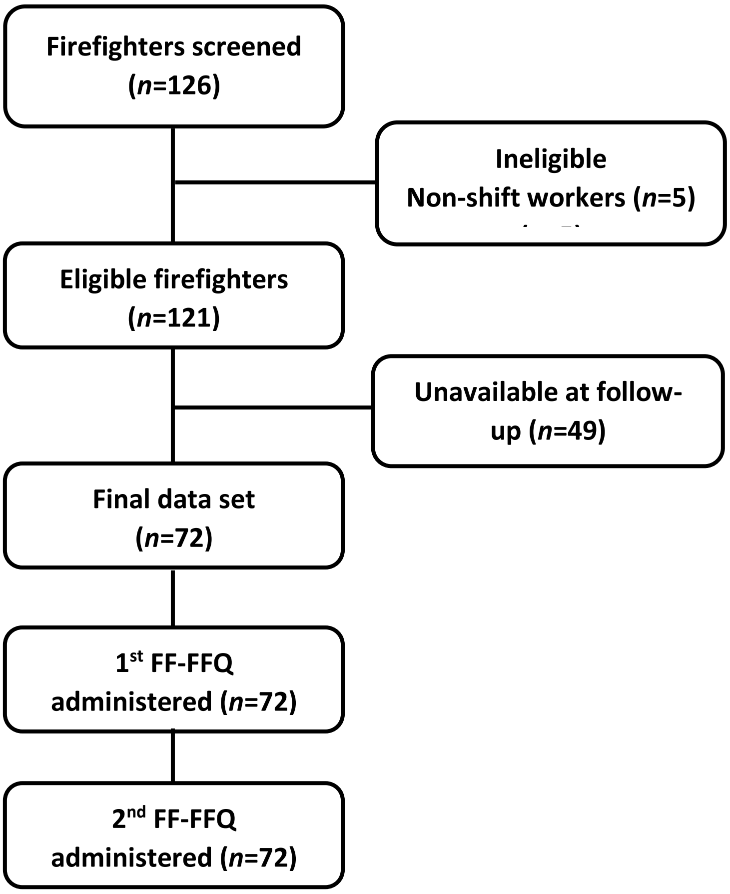


Figure 5.3. Participant flow through the reproducibility study. FF-FFQ: firefighter food frequency questionnaire.

Table 5.7. Demographic and anthropometric characteristics for the reproducibility study population

Characteristic	Total (*n* = 72)
Male / Female n (%)	68 (94.4) / 4 (5.6)
Ethnic minorities n (%)	7 (9.7)
Age (y)[a]	39 (7.9)
Years served (y)[b]	14 (12)
Height (m)[a]	1.79 (0.08)
Weight (kg)[a]	87.2 (12.9)
BMI (kg/m^2)[a]	27 (2.9)
WHtR (WC/Height cm)[b]	0.5 (0.07)

Values presented as number of participants (% of sample) or [a]mean (SD) or [b]median (interquartile range). Abbreviations: BMI, body mass index; WC, waist circumference; WHtR, waist to height ratio.

Nutrient intake comparisons between the 1st and 2nd FF-FFQ

Table 5.8 displays median energy and nutrient intakes. Reported energy intake was an average of 18% below the estimated minimum requirement, indicating widespread underreporting. Upon further investigation, 76% (*n*=55) of the sample had reported energy intakes below this level. This equated to 76% of the males (*n*=52) and 75% of the females (*n*=3).

When averaging the intakes of both FF-FFQs, proportions of carbohydrate, protein and fat, in terms of total energy intake were 45%, 20% and 35% respectively and in alignment with UK national dietary guidelines although 5% below the UK DRV for carbohydrate intake (SACN, 2015). Saturated fatty acids accounted for 12% of total energy intake, which is above the maximum recommended amount of 10% (SACN, 2019). Median fibre intake was 15 g/d which is below the UK recommended average intake of 30g/d (SACN, 2015). Median sodium intake was 2311 mg/d which is within the maximum recommended amount of 2400 mg/d (SACN, 2003), although this is likely to be an underestimation of true sodium intake. Calcium intake was slightly above the RNI of 700 mg/d and vitamin C intake was more than double the RNI of 40 mg/d (COMA, 1991).

Spearman's correlation coefficients between the two FF-FFQs were strong and highly significant for energy and all analysed nutrient intakes as displayed in Table 5.8.

Scatter plots were generated to illustrate the correlation coefficients listed in Table 5.8. Bland and Altman analyses were used to detect bias between the mean differences, and to illustrate 95% agreement intervals between the 1st and 2nd FF-FFQ for energy, carbohydrate, fibre, protein, fat, SFA, MUFA, PUFA, sodium, calcium, iron and vitamin C. An average of 95.1% of the cases fell within the limits of agreement, indicating a good level of agreement. Appendix 5.5 displays the scatter plots and Bland & Altman plots with accompanying interpretations.

Table 5.8: Energy and nutrient intakes calculated from 1st and 2nd FF-FFQs, and correlations between the two measurements

Energy	**1st FFFFQ**	**2nd FFFFQ**	**Correlation[a]**
EI (kcal)	1675 (757)	1679 (796)	0.75
EmER (kcal)	2051 (276)	2051 (276)	-
EI/EmER (%)	82 (41)	82 (33)	0.77
Nutrients			
Carbohydrate (g)	195 (91.7)	179.1 (93.3)	0.80
Fibre (g)	14.6 (8)	15.9 (9.5)	0.71
Protein (g)	83.2 (30.7)	85.6 (35.1)	0.62
Total Fat (g)	66 (30.9)	66.1 (33.6)	0.69
SFA (g)	21.8 (11)	22.7 (13.1)	0.66
MUFA (g)	24.9 (10.9)	25.3 (14)	0.71
PUFA (g)	11.7 (5.7)	13 (6.2)	0.70
Sodium (mg)	2394 (1268)	2227 (1152)	0.74
Iron (mg)	9.7 (4.4)	10.6 (5.2)	0.72
Calcium (mg)	741 (436)	721 (433)	0.55
Vitamin C (mg)	90 (72)	104 (62)	0.69

Values presented as median (interquartile range). [a]Correlation is significant at the 0.01 level (2-tailed) for all nutrients analysed. Abbreviations: EI, energy intake; EmER, estimated minimum energy requirement; SFA, saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

5.4. Discussion

Overview

Except for a small pilot trial by Lessons and Bhakta (2018), UK firefighters have not routinely been exposed to dietary assessment, so it was relatively unknown how a larger sample might react to the proposition. Of 182 participants who were asked to complete the EPIC-Norfolk FFQ, 180 took part. The non-participants therefore constituted a negligible proportion of potential study recruits, thus indicating feasibility for the dietary assessment of this population on a larger scale. In this study, a novel FFQ was developed for UK firefighters (FF-FFQ) and was tested for reproducibility and validity against the reference method of multi-pass 24hr recalls. The FF-FFQ indicated an acceptable level of relative validity against the reference method across a range of nutrients using a variety of analyses. It also showed acceptable reproducibility indicating a good level of precision. This represents the first validation study of an FFQ for UK firefighters.

FF-FFQ Development

In developing the FF-FFQ, the decision to reduce the overall length of the EPIC-Norfolk FFQ yielded favourable feedback from the focus group of firefighters upon whom it was pre-tested. The time taken for the focus group to complete the FF-FFQ was notably shorter compared with the EPIC-

Norfolk FFQ (12 mins vs 18 mins). This also translated to a faster screening process whereby each participant's FF-FFQ was reviewed by the researcher with the relevant participant to clarify any queries. This expedited process therefore enables the user to screen and offer subsequent advice to more firefighters within a shorter timeframe. The reduced FFQ length also translated to an expedited data entry procedure, therefore saving time for both the participant and researcher at each end of the process. The focus group reported that they found the FF-FFQ understandable, unambiguous and easy to complete. This was supported by the FF-FFQ screening carried out by the researcher with each focus group member individually, identifying no mistakes. The successful pre-testing of the FF-FFQ was an important final step to ensuring that it was acceptable and understood for the population for which it is intended, as stipulated by (Cade *et al.*, 2002).

Representativeness of the study population

A total of 180 firefighters completed the EPIC-Norfolk FFQ. Compared with the English national average, the slightly greater proportion of firefighters from an ethnic minority background within this study sample is likely to be a reflection of London's relatively high level of ethnic diversity (ONS, 2019). Overall, this study sample was demographically similar to the English national fire and rescue services (Home Office, 2019). Along with the identical mean BMI of the LFB frontline firefighter (recorded in 2018), this indicates that the study sample of 180 firefighters was representative of both the LFB and the English national fire and rescue services. The even spread of urban and suburban fire stations which were chosen for this study is likely to have contributed to this level of representativeness. The FF-FFQ food list, which was the outcome of this initial study, is therefore externally valid.

Misreporting

In the validation study, the FF-FFQ mean energy intake underestimation was 14% below the estimated minimum feasible intake. This is comparable with a study by Biltoft-Jensen *et al.*, (2009) which found energy intake to be underestimated by 12% in a motivated sample of volunteers. The validation and reproducibility studies indicated a mean rate of energy intake under-reporting (UR) of 74% as recorded by FF-FFQ. This is consistent with a secondary analysis of the UK National Diet and Nutrition Survey data by Rennie *et al*. (2007) which identified prevalence of under-reporting to be between 75 and 88% of subjects.

Smith *et al*. (1994) identified that underreporting can produce substantial over-estimates of intake deficiency. This can significantly decrease when subjects who fall short of the Goldberg cut-off of 1.1 are discarded from the data set. Some previous studies have indeed discarded under-reporters from the data set (Pryer *et al*., 1995; Shortt *et al*., 1997; Drummond *et al*., 1998), however this practice can introduce unknown bias to the sample and can remove subjects of interest (Livingstone and Black, 2003). This contributed to the decision to keep the under-reporters in the data set, along with further justification. Firstly, they constituted a vast majority of the sample. Secondly, due to both dietary assessment methods suffering from similar sources of error and bias, it was judged that attenuation of correlation and agreement between the methods would not be too severely affected by under-reporting. The decision was also driven by the intended purposes of the FF-FFQ i.e. for its use in relative dietary assessment (detecting changes which may have been elicited by an intervention) and as a ranking tool to identify high and low intakes of certain foods. Accurate absolute dietary intakes were therefore not important, in contrast to epidemiological investigation where misreporting is considerably more troublesome (Livingstone and Black, 2003).

Age, BMI and WHtR were found not to be associated with low energy intake reporting in this study, which is consistent with a validation study by Carlsen *et al.* (2010), but contrary to some previous research reporting that age and adiposity can influence low energy reporting (LER) (Pfrimer *et al.*, 2015). In this study, LER also pertained to the 24hr recalls, a method which has previously been identified to suffer from a high prevalence of under-reporting along with positive associations between LER and age, and LER and adiposity (Johansson *et al.*, 2001). Under-reporting as recorded by 24hr recall applied to 35% of the sample in this study, equating to approximately half the level recorded by FF-FFQ, and is comparable with previous studies (Johansson *et al.*, 2001; Schatzkin *et al.*, 2003). This may suggest that whilst the anticipated social desirability bias may partially account for the observed LER, portion size conceptualisation problems may have also been partially responsible. The attempt made to overcome this, using the reference portions PowerPoint presentation slide, may have added to participant burden, which can contribute to subject fatigue. This is consistent with a review by Cade *et al*. (2002) which found that when participants are less than highly motivated, boredom and fatigue can lead to inaccurate responses.

Whilst the relatively short FF-FFQ reference period of three months may have helped reduce misreporting caused by poor memory, three months of memory recall is still more burdensome than twenty-four hours, and therefore may partially account for the energy intake discrepancies seen between the FF-FFQ and the 24hr recalls. This highlights the fact that both the test and reference methods used in this study are retrospective and therefore suffer from the same sources of error and bias. Whilst weighed records/diet records should be the primary reference method of choice, when co-operation of study participants is limited, 24hr recalls may be more appropriate (Hebert *et al.*, 1999), and therefore constituted the only feasible option for this study.

Another source of misreporting which may have contributed to distorted nutrient and energy intake reporting, is the common limitation of FFQs being limited to the foods listed on them. It has been estimated that an available 200,000 commercial foods exist within western supermarkets (Boeing, 2013). This can lead to varied levels of food item substitution on FFQs (Nieman *et al*., 1992).

The 24hr recall method recorded greater absolute intakes than the FF-FFQ, with a difference of 508 kcal between average intakes. The observed underestimation of energy intake by FFQ is consistent with the OPEN study (Schatzkin *et al.*, 2003), and has been found to be greater (676 kcal) in a validation study comparing two similar FFQs (Forster *et al.*, 2014). The median FF-FFQ intake of 1742 kcal/d is similar to validation studies by Procter-Gray *et al.* (2017) and Steinemann *et al.* (2017) whose FFQs recorded energy intake at 1782 kcal/d and 1822 kcal/d respectively. Even though the FF-FFQ underestimated total energy intake (EI), as a proportion of energy, the 24hr recall mean carbohydrate intake was 40.5% of EI, which is 9.5% below the UK recommendation (SACN, 2015). In this case, the FF-FFQ recorded a mean intake of 43.5% which is more comparable to the mean general population intake and DRV of 50% (SACN, 2015). Total fat intakes followed a similar pattern, aligning more closely with UK national recommendations. Mean protein intake (%EI) was similar for both methods and at an expected percentage of EI (20.4% by FF-FFQ; 20.9% by 24hr recall), however, greater intake variability was recorded by 24hr recall. This could be attributed to the open-ended nature of the 24hr recall protocol, whereby participants state their own portion sizes, as opposed to fixed portion sizes for the FF-FFQ. Whilst there exists an auto-correlation of systematic error between the two methods in terms of reliance upon memory and food portion size conceptualisation, the observed disparities between them highlights the fact that the FF-FFQ was validated against an alternative, but not necessarily more accurate dietary assessment method. In this sense, such a validation study can only suggest whether or not the two methods provide related answers. If disagreement exists between the two methods, the study cannot identify which is correct, or whether it accurately records dietary intakes (Cade *et al.*, 2002). The weighed food diary is acknowledged as the gold standard for validating different dietary intake assessment methods (Livingstone and Black, 2003). Even so, comparisons are limited in terms of estimating validity, as every dietary assessment method generates error (Bingham, 1987). Biomarkers of food intake in blood plasma and 24hr urine collections provide accurate validation of dietary assessment methods, but were outside the scope of this study due to their expense. Bingham *et al*. (1997) found biomarkers to correlate better with weighed diaries than 24hr recalls, suggesting weighed diaries may be more accurate. Results between studies are inconsistent, with 24hr recalls indicating greater accuracy (Sawaya *et al*., 1996) and less accuracy (Howat *et al*., 1994; Bathalon *et al*., 2000). Due to the high level of participant burden of weighed diaries, this method was not feasible for this study.

Whilst mean total fibre intake was very close between methods and similar to the UK national average intake (Bates *et al*. 2014), and total sodium intakes were also very close between methods and slightly above the UK recommendation of 2400 mg/d (SACN, 2003), these may be underestimations of true intake, as the low-energy reporting among participants indicates that either the whole diet was under-reported, or selective under-reporting of certain food items led to the low energy intakes, particularly in the FF-FFQ. Conversely, certain foods may have been over-reported by FF-FFQ and/or under-reported by 24hr recall, suggested by the disparity between the methods for vitamin C intake being 38% higher by FF-FFQ. The validation analyses provide an insight by giving an indication of the level of agreement between methods for each nutrient.

Validity of the FF-FFQ

A valid dietary assessment tool is necessary for this population due to a high prevalence of overweight and obesity (Munir *et al.,* 2012; Lessons and Bhakta, 2018), an occupational obesogenic food environment (Dobson *et al*., 2013) and an increased risk of CHD and MI (Hunter *et al*., 2017).

Moderate significant correlations between the two methods ranging between 0.32 and 0.49 were found for energy, carbohydrate, protein, fat, SFA, MUFA, fibre, sodium, calcium and iron. Weak significant correlations were found for PUFA and vitamin C, the latter of which is consistent with a review of FFQ validation studies which found FFQs to correlate better with dietary records than 24hr recalls for recording vitamin C intake (Cade *et al*., 2004). After adjusting for total energy intake, vitamin C improved to a medium strength correlation. Energy adjustment also improved correlations between the methods for fat, SFA and fibre intakes, but produced weaker correlations for carbohydrate, protein, MUFA, PUFA, sodium, iron and calcium. Table 5.4 suggests that macronutrient intakes were recorded in similar proportions by both the FF-FFQ and the 24hr recall after energy adjustment, although the FF-FFQ energy-adjusted macronutrient intakes were slightly closer to recommendations. Energy adjustment in validation studies assumes that, whilst absolute nutrient intakes might differ between methods, people report them in similar proportions (Thompson and Subar, 2017). However, energy adjustment does not necessarily equate to improved correlation, and the varied results in this study are consistent with others (Willett *et al.*, 1985; Flegal and Larkin, 1990). In a validation study by Bohlscheid-Thomas (1997) all correlation coefficients reduced following energy adjustment. In this study, whilst energy adjustment produced similar group means of proportional macronutrient intakes for the two methods, the mixed correlations following energy adjustment infers that individual participants tended to report nutrient intakes in dissimilar proportions for the two methods. This has also been the case in other validation studies (Willett *et al.*, 1985; 1987; Pietinen *et al.*, 1988; Flegal and Larkin, 1990; Forster *et al.*, 2014).

Correlations for energy and nutrient intakes

Correlations between the two methods were significant with moderate correlations for energy intake and all macronutrients. This is consistent with correlations reported in comparable studies. E.g. the correlation between methods for energy intake in this study (0.42) is consistent with a review of FFQ validation studies which found the same correlation coefficient for energy intake (0.42) in studies assessing the diets of men (Cade *et al*., 2004). This correlation for energy intake was stronger than those observed by Procter-Gray *et al.* (2017) (0.27), and Steinemann *et al.* (2017) (0.32). This study's correlation for carbohydrate (0.42) was stronger than Procter-Gray *et al.* (2017) (0.37) and Steinemann *et al.* (2017) (0.24), but weaker than Willett *et al.* (1985) (0.53) and Flegal and Larkin (1990) (0.57). This study's correlation for protein (0.42) was stronger than Willett *et al.* (1985) (0.33), Flegal and Larkin (1990) (0.36) and Procter-Gray *et al.* (2017) (0.37), but weaker than Steinemann *et al.* (2017) (0.46). The correlation for fat (0.35) was the same as Procter-Gray *et al.* (2017), similar to Steinemann *et al.* (2017) (0.37), weaker than Willett *et al.* (1985) and Flegal and Larkin (1990) (0.39), and stronger than Cleghorn *et al.* (2016) (0.22). The improved correlation for energy adjusted fat (0.43) was slightly stronger than Procter-Gray *et al.* (2017) (0.41), but weaker than Willett *et al.* (1985) (0.53).

Similar alignment with comparable studies was also found for all observed micronutrients with the exception of PUFA. This weak correlation may be due to a major limitation of the 24hr recall being unable to capture the daily variation in dietary intake of individuals (Beaton *et al.*, 1979; 1983). When measuring intakes of nutrients which are found within limited or infrequently consumed foods, intraindividual variation can exceed interindividual variation to the extent that many nonconsecutive 24hr recalls are required to stabilise the within-subject estimate of usual consumption (Tucker *et al.,* 2013). For nutrients with high intake variation i.e. vitamin A, twenty one days or more may be required to obtain stable estimates (Hartman *et al.*, 1990). Whilst there is some evidence that increasing the amount of reference method records may lead to improvements to the apparent validity of an FFQ (Potosky, Block and Hartman, 1990), a comparable validation study by Bohlscheid-Thomas (1997) which validated an FFQ against twelve 24hr recalls observed strikingly similar correlations to the current FF-FFQ validation study. Such a high number of 24hr recalls may therefore not necessarily improve correlation, and was not within the scope of this study due to aforementioned participant burden concerns. A comparable validation study found the weakest correlation between their FFQ and 24hr recall to be for oily fish (r = 0.03) (Cleghorn *et al.*, 2016). This is a major dietary source of PUFA (Meyer *et al.*, 2003) and indicates that although the correlation for PUFA was weak within this study, it is stronger than in a comparable study. Conversely, in this study the nutrient showing the strongest correlation was calcium, which is consistent with a review of FFQ validation studies which also found that correlation coefficients were strongest for calcium (Cade *et al*., 2004). Two likely reasons for this are that firstly, unlike PUFA, calcium is generally a micronutrient which features daily in the western diet due to regular dairy consumption. Secondly, unlike the rest of the food items, the FF-FFQ gives portion size options for milk intake. This is consistent with a review of validation studies by Cade *et al.* (2002), which found correlations to be highest when participants were given the option of choosing their portion size. For the rest of the items on the FF-FFQ, fixed portion sizes were specified on the questionnaire for some food items, with others being described as 'medium serving'. Cade *et al.* (2002) found that correlation coefficients ranged between 0.4 and 0.5 when portion sizes were specified, and 0.2 – 0.5 when no portion size was specified. As the majority of items on the FF-FFQ were split between these two categories, the observed correlations in this study are consistent with comparable FFQs. Other than for PUFA, the moderate correlation coefficients between the methods do not fall below the minimum acceptable correlation coefficient of 0.3, as suggested in a review of validation studies by Cade *et al.* (2002).

<u>Agreement between FF-FFQ and 24hr recalls</u>

Cade *et al.* (2002) recommended that, whilst correlation can be helpful in assessing validity, this has been shown to be flawed due to it only measuring the degree to which the two methods are related, and fails to measure the agreement between the two methods. The Bland and Altman method is suggested to be used for this purpose, and was applied to energy and each nutrient in this study. Bland and Altman analyses indicated an acceptable level of agreement for each nutrient, with an average of 96% of cases falling within the limits of agreement. This is consistent with comparable studies (Forster *et al.*, 2014; Bredin *et al.*, 2020), and is a superior level of agreement than indicated in a recent firefighter dietary assessment tool validation study (Sotos-Prieto *et al.*, 2019), furthermore, less evidence of proportional bias between methods was observed from the Bland and Altman plots in this study compared with the three aforementioned studies. This further indicates good agreement between the two methods.

Cross-classification of energy and nutrient intakes between the two methods identified an average extreme opposite quartile disagreement in 4.2% of cases, indicating an acceptable rate of relative disagreement/misclassification comparable with previous validation studies (Bohlscheid-Thomas, 1997; Forster *et al.*, 2014). The average percentage of participants in the 'same' and 'same plus adjacent' categories was 33% and 73% respectively. This is comparable with Bohlscheid-Thomas (1997) who observed a similar rate of cross-classification agreement: 36% and 75% respectively. This indicates that the FF-FFQ produces ranked dietary intakes that are broadly comparable with 24hr recalls, and generates a low rate of misclassification.

The reproducibility study showed strong significant correlations between repeat administrations of the FF-FFQ for energy and all nutrient intakes with a mean correlation coefficient of 0.7, ranging from 0.55 for calcium to 0.8 for carbohydrate. This is similar to comparable reproducibility studies (Pietinen *et al.*, 1988; Bohlscheid-Thomas, 1997), and consistent with a review by Cade *et al*. (2004) which reported a repeatability correlation coefficient range of 0.5 - 0.8, with the highest correlation coefficients found between repeat administrations of an FFQ within a one to six-month time interval. The same review found the strongest repeatability correlations to be for calcium, which was the opposite for this study. Although strong, the relatively lower correlation for calcium may be attributable to the greater variety of portion size choices offered for milk on the FF-FFQ. This was a strength of the validation study, however, may have led to reduced precision in the reproducibility study. Even so, the FF-FFQ indicated a high level of reproducibility, suggesting very good precision of the instrument. This was supported by Bland and Altman analyses for energy and each nutrient. An average of 95.1% of the cases fell within the limits of agreement, with no indication of fixed bias or proportional bias, suggesting a good level of agreement between repeat administrations of the FF-FFQ.

<u>Study Strengths</u>

The representativeness of the study sample indicates a high level of external validity, suggesting wider utility of the FF-FFQ as a valid dietary assessment tool for English fire and rescue services. The paucity of previous studies to quantify firefighter dietary intakes utilised three-day food records to assess firefighter diets in the USA (Hirsch *et al.*, 2018; Johnson and Mayer, 2020). The latter of the two studies suggested that validated methods to assess firefighter dietary intakes would be preferable. Indeed, the FF-FFQ represents such a tool, and is the most comprehensive FFQ validated for firefighters to date. The closest dietary assessment tool to the FF-FFQ was validated for USA firefighters, providing a basic overview of dietary quality by generating a modified Mediterranean diet score (mMDS). This fifteen-item questionnaire was developed by Yang *et al.* (2014) and later validated for use within a firefighter dietary intervention study by (Sotos-Prieto *et al.*, 2019), however it is unable to quantify dietary intakes.

The aforementioned study by Johnson and Mayer (2020) found that firefighter three-day food records identified relatively low intakes of carbohydrate and fibre, along with relatively high intakes of fat and sodium. This is consistent with the relative dietary intakes of this chapter, which is an encouraging sign given their use of what could be considered as a more accurate method of dietary assessment. It also suggests concerning similarities between firefighter dietary intakes within two of the world's most obese nations (OECD, 2017).

For the reference method, this validation study utilised a dietary assessment method which was different to an FFQ. In their review, Cade *et al.,* (2002) found 12% of validation studies to use another FFQ as the reference method, meaning that both the test and reference methods suffered from exactly the same sources of error and bias. Although the 24hr recall is also retrospective, therefore suffering from similar sources of error and bias, the differences between methods renders the study more rigorous compared with validation against another FFQ. Whilst another FFQ chosen as the reference method would naturally result in stronger correlation (especially when the test FFQ was derived from the reference FFQ), Cade *et al.* (2002) does not even acknowledge this as a valid option. This study also benefits from neither method suffering from reactivity bias. Further improving the study was that the multi-pass 24hr recalls were generally conducted in person which is the optimal method of administration (Tucker *et al*., 2013).

The FF-FFQ displays a list of single food items as opposed to grouped food items within the same question. This was an important consideration given the questionable motivation level of the target demographic. Whilst grouping food items was considered as an option for the FF-FFQ to reduce the number of questions with the aim of reducing participant burden, expert consensus was that single items help to differentiate between similar foods. Also, whilst grouped items give the impression of a less burdensome questionnaire, they can actually complicate the process and increase the time and effort for completion (Cade *et al*., 2002).

This study tested the reproducibility of the FFQ, as opposed to 45% of the validation studies in the review by Cade *et al*., (2004) which failed to do so. Assessment of the FF-FFQ's level of precision was therefore carried out. This further validates the FF-FFQ for its intended primary purpose of being used to detect dietary changes within an intervention study. This explicit declaration of its intended purpose is itself another strength of the study, as many studies omit this important fundamental information (Cade *et al.,* 2002).

A variety of analyses were used to assess the validity of the FFQ. These included Bland and Altman analysis for every nutrient of interest in both the validation and reproducibility studies. This assesses the agreement between the methods across the spectrum of intakes (Bland and Altman, 1999) and is preferable to correlation coefficients which are the most common method, used in 90% of the studies reviewed by Cade *et al*. (2002). However, they have been shown to be flawed due to not measuring agreement, only the degree to which the methods/administrations are related (Cade *et* *al.,* 2002). The Bland and Altman method is underutilised, and was used in less than 10% of the studies reviewed by Cade *et al*. (2002; 2004).

Study Limitations

The heterogeneity between differing dietary analysis software packages was a limitation of this study which led to further limitations. Whilst the main nutrients of interest were generated by both FETA software and Nutritics software, food group data was not produced by Nutritics, which rendered food group comparisons unfeasible for this study. A similar limitation also occurred for 'free-sugars' data which was generated by Nutritics but not by FETA. The heterogeneity extended to the food databases which were mapped to the differing software analysis packages. FETA used McCance and Widdowson's 'The Composition of Foods' (5th edition) plus supplemental volumes (Welch *et al*., 2005). Nutritics used the 2015 COFIDS including McCance and Widdowson 7th edition, 2015 nutritional composition database. This is likely to have been a source of systematic error and bias between the methods, possibly attenuating correlation. The FETA software is soon to be updated to the same food databases currently used by Nutritics, which will ameliorate this source of error in the future. A further repercussion of the software heterogeneity was the inability for FETA to process data for dietary supplements. To mitigate this discrepancy, dietary supplements were not entered into the Nutritics dietary analysis software programme during 24hr recall data entry. This further reduces the FF-FFQ's ability to produce accurate absolute nutrient intakes, although, as stated from the outset, the FF-FFQ was not designed for that purpose.

Finally, the sample size for this study was not optimal. Although the minimum recommended sample size of fifty participants for a validation study was exceeded, a larger sample of 100 to 200 as suggested by Cade *et al*. (2002) may have improved statistical power and improved correlation coefficients between the methods. However, the more recent review of FFQ validation studies by Cade *et al*. (2004) showed that validation study sample sizes did not make an appreciable difference to correlation coefficients between the FFQ and reference method.

Conclusion

The FF-FFQ indicated low burden for both the respondents and the researcher, whilst indicating good agreement with 24hr recalls for assessing relative nutrient intakes of firefighters in England. It also showed good reproducibility indicating precision. Although poorer correlation between the methods was observed for vitamin C and PUFA, a variety of analyses indicated good overall relative validity of the FF-FFQ, with the results being comparable to previous published studies. FFQs are most commonly used to rank individuals by their dietary intakes (Dehghan *et al.*, 2012). The FF-FFQ indicated a low rate of misclassification by quartile cross-classification, and along with its precision and good agreement between the methods, the FF-FFQ has demonstrated its valid utility for use as both a screening tool to identify relatively high and low intakes of certain foods, as well as an instrument to identify relative dietary changes elicited by an intervention. This represents the first FFQ validation study for the UK fire and rescue services.

Chapter 6. Mess-manager kitchen-based cookery workshop

Overview

Fire station food culture has contributed to an obesogenic environment. The firefighters responsible for food catering for their teams receive no culinary or nutrition training. This has led to over consumption of meals high in refined carbohydrates, salt and saturated fat. This study describes the design, implementation and evaluation of the feasibility and efficacy of a fire station kitchen-based cookery workshop, designed to ameliorate fire station food environments. A one-day workshop intervention and accompanying cookery book were developed and tested in a controlled trial, demonstrating practical methods of healthy meal preparation along with environmental modification suggestions designed to ameliorate the established obesogenic food environment. This resulted in several key significant ($p < 0.01$) improvements to the mess, including 8 firefighting watches reinstating smaller plates, 10 watches leaving leftovers in the kitchen, 11 watches incorporating wholegrain products and 8 watches switching to making sauces/soups from scratch. No significant changes were reported by the control group ($p > 0.01$). Participant feedback was overwhelmingly positive, with 94% participants reporting an optimal feedback rating.

6.1. Introduction

Prevalence of overweight and obesity in firefighters exceeds that of the general population in both the USA (Poston *et al*., 2013) and the UK (Munir *et al*., 2012; Lessons and Bhakta, 2018). Whilst obesogenic exposures including the effects of shift work and an increasingly more sedentary occupation are contributing factors (Knutson and Van Cauter, 2008; Dobson *et al*., 2013), fire station mess culture has contributed to an obesogenic food environment at USA fire stations (Haddock *et al*., 2011; Jahnke *et al*., 2012; Dobson *et al*., 2013), which is culturally reflected in UK fire stations (Lessons and Bhakta, 2018). Historically, medical assessments of overweight/obese firefighters in both the UK and the USA have resulted in the prescription of physical exercise with very little consideration given to dietary modification (Goheer, 2017). Even when diet and nutrition advice is offered by occupational health nurses, it has little impact (Brown *et al*., 2016). The National Fire Chiefs Council (NFCC) in the UK outlines the importance of physical fitness of UK firefighters (NFCC, 2020), without mention of related standards of nutrition education or monitoring. The firefighter responsible for choosing, purchasing and preparing meals at fire stations does so voluntarily and is simply nominated to be mess-manager by their watch (firefighting team) to carry out this extra duty. There is no culinary or nutrition training involved, with consideration for nutritional content of meals left completely in the hands of the elected mess-manager. This has resulted in a widespread culture of over-nutrition at fire stations and an over consumption of meals high in refined carbohydrates and saturated fat (Haddock *et al*., 2011; Jahnke *et al*., 2012; Dobson *et al*., 2013; Lessons and Bhakta, 2018).

Other factors which potentially contribute to the obesogenic nutrition environment in fire stations have also been identified. These include: irregular meal times caused by emergency callouts (Banes, 2014; Haddock *et al*., 2011; Jahnke *et al*., 2012); excessive portion sizes driven partially by the belief that subsequent potential emergency callouts may interrupt the next meal; and a relatively fast rate of eating (Haddock *et al*., 2011; Jahnke *et al*., 2012). This is also driven by anticipation of an impending emergency callout, and is a habit which contributes to greater weight gain (Gerace and George, 1996). For some of the more health conscious firefighters who would otherwise choose healthier meal options, peer pressure to be part of the mess is often exerted upon them, along with the convenience of having meals prepared for them results in a compromise of their healthy beliefs and resignation to eat what is served by the mess (Haddock *et al*., 2011; Jahnke *et al*., 2012). Customary cakes are regularly supplied to the watch by individuals to mark various occasions including: making a mistake on duty, birthdays, earning extra money via pre-arranged overtime, and well-wishers showing gratitude (Jahnke *et al*., 2012). This has contributed to an endemic culture of overnutrition from refined carbohydrate and saturated fat (Kales *et al.*, 2009; Haddock *et al*., 2011; Jahnke *et al.*, 2012; Banes, 2014). All of these factors were reflected in London fire stations during the UK firefighter pilot study by Lessons and Bhakta (2018) and subsequent extension work.

<u>Cookery skills interventions</u>

A systematic review of nutrition education on related health outcomes identified cooking skills workshops as one of the components yielding greatest impact, influencing decreased BMI (Schembri *et al*., 2015). Whilst there is little evidence attributing the level of effect that cooking skills workshops as a sole intervention have on health outcomes, a qualitative study associated cookery classes with improved cooking skill and nutrition knowledge (Abbott *et al*., 2012). Participants attributed the success of this programme to its social nature as it was conducted in small groups involving subject participation. This is consistent with a review of effective components of nutrition education interventions, finding participatory interventions to have a significant beneficial effect on dietary modification (Sahay *et al*., 2006). This style of active learning may be particularly suited to firefighters who are used to working manually in small cohesive teams. Ranby *et al*. (2011) suggested that learning could be improved when small groups of firefighters engage in intervention activities together.

To date two firefighter interventions have included kitchen-based cookery demonstrations in an attempt to provide firefighters with skills necessary to prepare healthy meal options (Goheer, 2017; Torre *et al.*, 2019). Within the FFIRE study (Goheer, 2017), this was one of the study components receiving a maximum rating of 'very helpful in improving your health' reported by the majority of participants, with eighty-eight percent reportedly trying a new food or new method of food preparation learned during these sessions. This resulted in a fire station food environment change reported by fifty nine percent of respondents with seventy one percent reporting favourable changes extending to their home food environments. Positive feedback from participants was reportedly overwhelming e.g. "This programme has become very helpful to me, and in return to my ten shift mates. My cooking methods have become healthier and being the head cook at work, everybody benefits." (Goheer, 2017). This is consistent with extension work following the UK firefighter intervention pilot trial by Lessons and Bhakta (2018), which elicited similar feedback on a regular basis alongside requests for healthy recipe suggestions for mess-managers. This groundwork has not only reduced initial skepticism from some firefighters, it has furthermore identified a demand for more nutrition education. This satisfies a recommendation which emerged from the PHLAME intervention study (Elliot *et al*., 2007), whereby researchers reflected that initial firefighter skepticism was a barrier to engaging their participation. The reflective advice for future firefighter intervention programmes stated the importance of identifying firefighter and fire station characteristics e.g. shift scheduling, communal activities, teamwork and competition, advising attempts at culture change should focus on a bottom up approach, promoting healthy behaviours in a peer setting, creating a positive atmosphere (Mabry *et al*., 2013). This was an approach adopted by Lessons and Bhakta (2018), which was enabled by the lead researcher's intimate knowledge of cultural and organisational behavior of firefighters, as the researcher spent seventeen years as a full time professional firefighter with the final year spent as a mess-manager. This places the researcher in a unique position to breech aforementioned barriers, build rapport and communicate with study participants in 'their own language'.

When firefighters wish to improve body composition, a common first step is to remove themselves from the mess and to cater for themselves. The mess is however an important corner stone of fire brigade culture which facilitates commensality (Jahnke *et al*., 2012; Dobson *et al*., 2013; Kniffin *et al*., 2015). Commensality has been found to be significantly positively associated with firefighting team performance (Kniffin *et al*., 2015). The fire station mess thus constitutes an important workplace environment which could potentially suffer due to fragmentation. Furthermore, senior LFB management has suggested that, due to mess-managers being paid extra to carry-out their mess duties, it stands to reason that they take responsibility for the preparation of healthy nutritious meals for their colleagues. Thus, a demand has been identified from firefighters, mess-managers and senior management for cookery workshops.

The aim of this study was to create, implement and evaluate a mess-manager kitchen-based cookery workshop.

6.2. Methods

This study was a supplementary component of the prospective cluster-controlled dietary and lifestyle intervention trial (parent study) (see Chapter 7). Mess-managers (firefighters responsible for food catering for their watches) from the red, green and blue watches (shift teams) within the intervention group (seven fire stations) of the parent study were invited to participate whilst on duty. Enrolment was voluntary and handled by telephone or in person, followed by cookery workshop details being sent to participating mess-managers via staff email which provided details of the optional cookery workshops (see appendix 6.1). The intervention group of this study comprised seventeen mess-managers from eighteen invitees, thus one mess-manager declined to participate. Three cookery workshops were held on separate day shifts in October 2019 (one for each of the aforementioned watches). The remaining shift (white watch) were not invited to participate due to insufficient white watch teams within the parent intervention study at that point in time. This amounted to four mess-managers within the intervention group who were uninvited. The control group watches (*n*=13) from the five control group fire stations within the parent study, also served as the control group for this study. The cookery workshops were scheduled to take place after all participating watches had received their first follow-up (one-month post intervention) of the parent study (Chapter 7).

The mess-manager cookery workshops were held on 9th, 11th and 24th October 2019 in the mess (kitchen) of Hornchurch fire station. Six mess-managers from six intervention watches attended on 9th October. Five mess-managers from five intervention watches attended on 11th October. Six mess-managers from five intervention watches attended on 24th October. The final workshop comprised two mess-managers from the same watch (as they both shared the responsibility). The same workshop also included the only female mess-manager within the intervention group.

Ethical approval

This study was authorised by an Assistant Commissioner of the LFB (see appendix 2.1 and Chapter 2) and the London Metropolitan University School of Human Sciences Ethics Committee (see appendix 2.2 and Chapter 2 for details).

Self-reported measures

A nine-item food environment questionnaire was devised by the researcher (see appendix 6.2) to assess the quality of each watch's food environment (mess). This was administered to each watch at baseline and subsequently at each follow-up within the parent study. Table 6.1 displays the nine items alongside evidence-based justification for each. An anonymous participant feedback questionnaire (see appendix 6.3) was also devised by the researcher and administered immediately following the cookery workshop. Along with the rate of enrolment, the feedback questionnaire was designed to assess feasibility of the cookery workshop.

Table 6.1. Mess quality questionnaire items with justification

Mess environment Item	**Justification**
Which size plates are generally used?	(Holt et al, 2016)
Are leftovers kept off the plate or divided up and served on the plate?	(Holt et al, 2016)
Is fruit generally provided to snack on?	As recommended by Public Health England (2016) to reduce risk of CVD and certain cancers.
Is low energy/non-nutritive sweetener provided?	(EFSA, 2011)
Are low sugar/salt products typically provided?	(Johnson et al, 2007; SACN, 2003).
Are whole grains generally used?	(Seal and Brownlee, 2015)
Are sauces and soups generally homemade or readymade?	(Monteiro *et al.*, 2018)
Is oily fish served weekly?	(NHS, 2018)
Are recipes bulked out with vegetables where possible?	As recommended by Public Health England (2016) to reduce risk of CVD and certain cancers.

Mess-manager cookery workshop

The workshop was designed by the researcher who is a registered nutritionist and former firefighter and mess-manager. Workshop content aimed to deliver practical demonstrations based upon transferrable concepts which could be applied to various commonly consumed fire station meals. This conceptual approach was chosen to provide optimal benefit, instead of simply demonstrating several healthy arbitrary meals which may be cooked relatively infrequently. In preparation, the researcher purchased all ingredients required to run the workshop from a local supermarket. Participants arrived at the mess kitchen at 10:30hrs and were greeted with refreshments (tea/coffee). Instead of sucrose, low kcal sweetener was provided for those who preferred sweet tea/coffee. This was done in an attempt to encourage the mess-managers to provide low kcal/non-nutritive sweetener for their watches, as tea and coffee are regularly consumed at fire stations, therefore presenting a key opportunity to reduce the free sugar intakes of their colleagues. This was explicitly explained to the participants during this informal introduction to the workshop, and provided the opportunity for the researcher to highlight the first of several available opportunities for simple environmental modification and choice architecture that mess-managers have at their disposal in order to improve the health of their colleagues. The researcher then reiterated that the aim of the workshop was not to patronise the participants by teaching them how to cook, but instead to impart some basic nutritional concepts which will help improve/maintain the health of their watches. Furthermore, the researcher appreciated that the participants may be able to educate each other in terms of healthy, efficient meal preparation. As such, positive interaction from all participants to share knowledge and experience was encouraged, as was participation in terms of assisting the researcher to prepare the demonstrated meals. This promoted active learning, which has been shown to be more effective than passive learning for improving knowledge acquisition and retention (Angelo, 1993). This approach also took advantage of the team dynamic which is characteristic of the firefighting watch structure, thereby fostering a 'community of practice approach', as characterised by Lave and Wenger (1991) who proposed that daily life is the platform for deep learning, which occurs through interaction with others in family, workplace and education settings. The shared understandings which emerge from cooperation toward common goals is the basis of this 'community of practice approach'.

All recipes which were demonstrated during the workshop were designed by the researcher and feature within a thirty-three-page cookery book entitled 'Healthy mess recipes' which was written by the researcher (see appendix 6.4). The LFB print services department provided hard copies for the researcher to hand out to each mess-manager, which was provided at the conclusion of the workshop. At post-workshop intervention follow-up engagements within the parent study (Chapter 7), watches were asked how many of the recipe book recipes had been attempted by the mess-manager. Recipes within the book and workshop promoted use of whole grains; portion size reduction; inclusion of more fruit and vegetables within meals, reduced intake of free sugars, saturated fat and salt, and promotion of fish whilst reducing red meat intake. Whilst demonstrating each meal, the researcher interspersed the workshop with pertinently timed educational points to reinforce the underlying scientific nutritional concepts which were introduced during the previous group education PowerPoint presentation (see Chapter 7). This was communicated in lay terms to avoid confusion and enhance participant comprehension. The workshop followed the following format (recipe ingredients and cooking methods can be found in appendix 6.4):

1) Introduction: Convey that I am not going to show them how to cook, but hopefully I will impart some basic nutritional concepts which will help maintain the health of their watches.
2) Demonstrate a masala omelete and pass around to taste (p. 5 of Appendix 6.4).
3) Demonstration of making a pasta sauce from scratch, emphasising the free sugars, salt and fat found in most jars. Cook wholemeal pasta (wholegrain promotion) and offer around to taste. (Show portion control utilising standard mess utensils for easy portioning).
4) Explain the importance of switching to wholegrains. Cook mushroom rice as an example of making brown rice more palatable plus adding more vegetables and health promoting spice. Use this opportunity to show correct carbohydrate portion control and to highlight that firefighters only achieve half the recommended fibre intake (see Chapter 5). Pass around to taste. (Show portion control utilising standard mess utensils for easy portioning).
5) Tea break with low kcal sweetener taste test. Reinforce the recommended free sugar limits. Have a fruit bowl to demonstrate healthy snack alternatives.
6) Make sweet potato medallions, promoting them as a healthy alternative to chips. Use this opportunity to administer a blind ketchup taste test utilising 50% reduced sugar and salt ketchup vs regular ketchup.
7) Demonstrate salmon fish cakes, emphasising the importance of incorporating oily fish once per week where feasible and reducing saturated fat as much as possible.
8) Conclude with handing out recipe booklets, participant feedback forms and reinforcing the position of responsibility mess managers have toward the health of their colleagues.

<u>Dietary analysis</u>

Nutrient values displayed within the 'Healthy mess recipes' book were calculated using Nutritics dietary analysis software (Nutritics, 2019), details of which are in Chapter 2.

<u>Statistical analyses</u>

Data were imported into IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). Mess-manager age and length of service were assigned as continuous variables and reported as mean (SD). All mess food environment variables were assigned as dichotomous nominal variables. Fisher's exact tests were used to detect baseline differences between groups. Cochrane's Q tests were carried out for each mess food environment variable to identify a change over time within each group. When a change was detected, post-hoc McNemar tests were undertaken to identify at which point(s) in time the change(s) occurred. Following Bonferroni correction, significance was defined by $p < 0.017$.

6.3. Results

The mean (SD) age of the participating mess-managers was 45.2 (7.0) y, and the mean (SD) length of fire brigade service was 18.9 (6.4) y. Baseline mess characteristics of the study sample are displayed in Table 6.2, showing homogeneity between the intervention and control group. Table 6.3 displays the changes within the intervention group food environments over time, identifying significant improvements in portion control strategies; wholegrain usage and homemade soups/sauces. Table 6.4 displays the changes within the control group food environments over time identifying no significant change. Nine-month data was collected for half of the intervention watches and an insufficient number of control group watches due to the Covid-19 global pandemic. 16 of the participants reported maximum scores (5 out of a possible 5) for both items on their workshop feedback forms. The remaining participant reported 4 out of 5 for both items (see appendix 6.5). Following the mess-manager workshop, intervention group mess-managers reported attempting a median of three recipes from the cookery book.

Table 6.2. Baseline fire station mess characteristics

	Intervention group mess *n*=16 ***n* (%)**	**Control group mess *n*=13** ***n* (%)**
Smaller plates used	0	0
Leftovers in kitchen	2 (13)	4 (31)
Fruit bowl	4 (25)	4 (31)
Low kcal sweetener	0	0
Low sugar/sodium products	1 (6)	2 (15)
Wholegrains	2 (13)	2 (15)
Homemade sauces/soups	4 (25)	3 (23)
Oily fish	2 (13)	1 (8)
Added vegetables	2 (13)	5 (38)

No significant differences were detected between groups.

Table 6.3. Changes in intervention group mess environments (*n*=16)

	Baseline *n* (%)	1 month *n* (%)	Change from baseline	4 months *n* (%)	Change from baseline	9 months (n=8) *n* (%)	Change from baseline[a]
Smaller plates used	0	6 (38)	+6	8 (50)	+8*	4 (50)	+4
Leftovers in kitchen	2 (13)	9 (56)	+7*	12 (75)	+10*	6 (75)	+5
Fruit bowl	4 (25)	5 (31)	+1	6 (38)	+2	3 (38)	0
Low kcal sweetener	0	2 (13)	+2	4 (25)	+4	2 (25)	+2
Low sugar/sodium products	1 (6)	3 (19)	+2	7 (44)	+6	4 (50)	+3
Wholegrains	2 (13)	7 (44)	+5	13 (81)	+11*	5 (63)	+4
Homemade sauces/soups	4 (25)	6 (38)	+2	12 (75)	+8*	5 (63)	+3
Oily fish	2 (13)	2 (13)	0	5 (31)	+3	3 (38)	+2
Added vegetables	2 (13)	3 (19)	+1	3 (19)	+1	2	+1

*Significant difference from baseline. [a]Based upon a different baseline for this subsample.

Table 6.4. Changes in control group mess environments (*n*=13)

	Baseline *n* (%)	One month *n* (%)	Change from baseline	Four months *n* (%)	Change from baseline
Smaller plates used	0	0	0	0	0
Leftovers in kitchen	4 (31)	7 (54)	+3	5 (38)	+1
Fruit bowl	4 (31)	3 (23)	-1	4 (31)	0
low kcal sweetener	0	0	0	0	0
Low sugar/sodium products	2 (15)	3 (23)	+1	3 (23)	+1
Wholegrains	2 (15)	5 (38)	+3	4 (31)	+2
Homemade sauces/soups	3 (23)	4 (31)	+1	5 (38)	+2
Oily fish	1 (8)	3 (23)	+2	2 (15)	+1
Added vegetables	5 (38)	4 (31)	-1	4 (31)	-1

6.4. Discussion

This is the first UK study to assess the feasibility and efficacy of a fire station kitchen-based mess-manager cookery workshop. The one-day workshop proved to be well received, highly feasible and elicited significant improvements in portion control strategies; increased use of wholegrains and homemade soups/sauces.

Feasibility

Ninety four percent of the mess-managers invited to participate in the workshop enrolled in the single session, low intensity workshop. This is a much greater enrolment rate than reported by the most comparable study (FFIRE) which was 16 – 30% (Goheer, 2017). This contrast may be due to the fact that this study's single session cookery workshop took place during work time, as opposed to FFIRE which ran six workshops outside of working hours. This is consistent with previous research finding that intervention programmes which take place outside of working hours present a barrier to participation (Kilpatrick *et al.*, 2017; Sargent *et al.*, 2018). The participating mess-managers were four years older than the average firefighter in England (Home Office, 2019), with around four years more fire brigade service compared with the parent study sample (see Chapter 7). These differences reflect an unofficial time-honoured convention within the LFB whereby more experienced firefighters generally assume/inherit the role of mess-manager (knowledge derived from the researcher's experience within the LFB). This is likely to be due to the fringe benefits associated with the added responsibility, which include a slight pay enhancement along with exemption from some training activities, and exemption from having to work at other fire stations when they have a personnel deficiency. As such, the reasons for assuming the role of mess-manager may not primarily be driven by enjoyment of cooking. When coupled with the absence of nutrition or culinary training, these cultural nuances are likely to have contributed to the established obesogenic food environment within fire stations, and the quick/easy options such as ready-made ultra-processed foods i.e. jars of cooking sauce which are a common feature of fire station mess kitchens. These cultural observations are consistent with USA fire service research highlighting that the fire station food environment is dictated by tradition and particularly resistant to change (Jahnke *et al.*, 2012). This resistance to change may have been somewhat mitigated by the fortunate timing of this study's intervention, which was approved in the midst of organisational cultural transformation which the LFB was undergoing by command of the recently appointed commissioner. The intervention timing also coincided with the recent implementation of mandatory periodic fitness testing for firefighters, all of which may have incentivised participation in a health promotion intervention such as a mess-manager cookery workshop. The factor deemed most important to overcome resistance, was the temporal placement and timing of the workshop, which was subsequent to the parent intervention (see Chapter 7), which built rapport and trust between the mess-manager and researcher, garnering participant enthusiasm for more practical education. Indeed, the high level of enrolment and the overwhelmingly positive participant feedback (see appendix 6.5) was reflective of this cultural shift. This is consistent with the FFIRE study which reported the cookery classes to be the intervention component receiving the most positive feedback (Goheer, 2017). The high level of enrolment, participant engagement and positive feedback from the workshops indicates a highly feasible intervention component.

Baseline mess characteristics

Over 80% of firefighters in the parent study of this intervention (Chapter 7) were mess members. This is a greater proportion of personnel compared with the FFIRE study which reported less than 70% mess membership (Goheer, 2017). The UK full-time firefighter shift system follows a four on, four off pattern (two day shifts followed by two night shifts followed by four days off). This dictates that for the vast majority of firefighters, approximately half of their total dietary intake occurs on duty. The baseline mess food environment characteristics show that there was plenty of scope for improvement across all nine parameters. These obesogenic baseline results are consistent with USA fire station food environments (Haddock *et al*., 2011; Dobson *et al*., 2013) and may account for some of the poor dietary behaviour characterised in Chapter 5, and furthermore may partially explain the high levels of firefighter adiposity which are characterised in Chapters 3 and 4.

Mess modifications

The results indicate that mess-managers were indeed willing to change and simply needed expert guidance to do so in a feasible manner. This is consistent with formative research for a health intervention at a corporate plant, which identified participants to suggest that education on how to cook healthy meals would provide the most feasible and effective nutrition intervention (Wilson *et al.*, 2007). Furthermore, this is consistent with FFIRE which resulted in its cookery workshops attaining a maximum participant feedback rating of 'very helpful' (Goheer, 2017). Energy intake reduction and portion control strategies were an overarching theme of the intervention, which can account for the significantly increased post-intervention reinstatement of smaller plates along with leftovers being left off the plate. This is particularly important for firefighters due to research indicating excessive meal portions to be the cultural norm at fire stations (Haddock *et al*., 2011; Dobson *et al*., 2013). These suggested modifications may also have contributed to the reported decreased energy intake (see Chapter 7), which is consistent with a review of worksite programmes which provided evidence for the efficacy of environmental modifications upon dietary intake improvements (Engbers *et al*., 2005).

Another overarching theme of the intervention was the emphasis placed upon cooking from scratch thereby reducing intake of ultra-processed foods. Sauces/bases for commonly served mess meals such as pasta and curry dishes were the focal point, as a simple pasta sauce cooked from scratch can be applied to many pasta dishes. This was demonstrated live in the workshop to positive feedback, and the several curry dishes included within the supplementary cookery book were also well received and reportedly cooked regularly following the workshop. Again, the speed and simplicity, cost effectiveness and palatability were all factors which can be attributed to this significant improvement, as these factors are common drivers of firefighter food choice (Dobson *et al*., 2013). The general reaction from the participants was surprise at how quick, simple and inexpensively delicious food can be prepared to taste better than a readymade equivalent product.

The most profound improvement was observed in wholegrain usage. The 69% improvement between baseline and post-workshop can be attributed more so toward the workshop, and the low baseline intake is reflective of existing barriers to increasing wholegrain intake among the UK general population, including confusion in terms of which foods constitute wholegrains, how much to consume, the health benefits of whole grain consumption, lack of knowledge on how to prepare wholegrains, acceptance of wholegrain organoleptic properties (i.e. taste and texture) and media propagated negative perceptions regarding starchy carbohydrates (Robinson and Chambers, 2018). Most of these barriers were addressed within the parent intervention classroom setting (Chapter 7), however, the barrier of organoleptic properties is a major hurdle given the importance attributed to taste and texture as drivers of food choice (Clark, 1998), with food appearance also influencing taste perceptions (Hurling and Shepherd, 2003). These barriers were addressed within the kitchen workshop by improving the palatability of wholegrain pasta by cooking it a little longer to give a softer texture (closer to refined pasta texture), followed by coating it in the homemade pasta sauce. A similar process was followed when demonstrating wholegrain brown rice, changing the colour to yellow using turmeric, along with adding flavour and vegetables using cumin seeds and mushrooms (see 'mushroom rice' in appendix 6.4). Both recipes yielded positive participant feedback in terms of organoleptic properties, which may account for the significant increase in post-workshop wholegrain usage.

Although oily fish intake did not change significantly, the non-significant increase in mess' using oily fish is likely due to the final recipe which was demonstrated, which attempted to overcome a common barrier to oily fish consumption, making it taste less potent using herbs and spices. This was also particularly well received, with a comment being received from a workshop participant, "I didn't think that I liked salmon, but that's lovely!". The potential cardio-protective effect of fish derived omega-3 fatty acids was reiterated by the nutritionist during the recipe demonstration by reinforcing the exposure firefighters face in terms of vascular problems and a greater risk of MI. The lack of significant change could be due to taste preference i.e. if just one mess member refuses to eat oily fish, the mess manager is unlikely to serve it on a regular basis. The same issue can apply in the family household environment. The researcher attempted to overcome this at the individual level by recommending tinned oily fish as a light meal for the firefighters who enjoyed oily fish but refrained from consuming it due to family members not wanting it.

Adding vegetables to dishes did not change significantly which is consistent with the parent intervention study results indicating a lack of improvement in this food group (see Chapter 7). This may be due to the predominantly male sample, as there is evidence to suggest that men can find vegetable intake more difficult to improve compared with other food groups (Collins *et al*., 2011) and is consistent with the most comparable firefighter dietary intervention (Goheer, 2017). Implications for practice would be to demonstrate a dish within future workshops which encompasses more vegetables i.e. the bean chilli within the mess cookery book (see appendix 6.4). This could also help to replace some red meat whilst improving phytonutrient and fibre intake.

The observed increase in low sugar/sodium products and low kcal sweetener could be partially attributed to the blind ketchup taste test which elicited a general consensus that the reduced version was more palatable. This employed choice architecture and nudge theory (Thaler and Sunstein, 2008), particularly as table sugar was not available to sweeten teas/coffees consumed throughout the workshop. Although not reaching statistical significance, this resulted in 25% of the mess-managers providing low kcal sweetener for their watches following the workshop, and a 38% increase in the purchase of low sugar/sodium products. This is consistent with the significant dietary improvements observed on an individual basis in the parent intervention study (Chapter 7).

The workshops were a component of the parent study intervention, and due to the timing of the workshop relative to the parent intervention, changes after one month can be attributed to the parent intervention, however, the significant mess environment changes generally occurred post-workshop, suggesting the workshop to have elicited these beneficial changes.

Strengths

This is the first UK study to create, implement, and evaluate the feasibility and efficacy of a fire-station kitchen-based cookery workshop for mess-managers to improve the food environment for firefighters. This adds to a paucity of evidence for firefighter dietary interventions.

The interactive session format in terms of active engagement both verbally and physically may partially account for the overall success of the workshop by utilising active learning. These were suggested as mediating mechanisms for the successful outcomes of the PHLAME intervention trial (Ranby *et al*., 2011), and are likely to have contributed to the successful outcomes of the current study. Tasting the demonstrated food also encouraged participants to 'buy-in' and was a strategy used to successfully overcome the barrier of organoleptic properties (i.e. taste and texture) (Robinson and Chambers, 2018). The recipes were also designed to be low cost and low burden in terms of speed, simplicity and minimal ingredients, all of which is likely to have further encouraged the mess-managers to recreate them due to their suitability to the fire station food environment (Jahnke *et al.*, 2012; Dobson *et al*., 2013). Whilst the median of three recipes having been attempted post-workshop is a positive sign, it should be noted that, following the workshop, one mess-manager was cooking almost exclusively out of the recipe book provided (appendix 6.4) to positive feedback from his watch. Another mess-manager asked for two copies of the book so he could use one at home. These are encouraging signs in terms of the book's utility, suggesting it to be a useful intervention component.

The size of the group which comprised 5-6 mess-mangers per workshop may also have contributed to successful outcomes, as this created rapport, cohesion and a strong group dynamic whereby everyone could be involved and play their part in a community of practice approach which can be an effective method of group learning as characterised by Lave and Wenger (1991). This is consistent with a review of effective components of nutrition education interventions, finding participatory interventions to have a significant beneficial effect on dietary modification (Sahay *et al*., 2006). Participants of a previous cookery class intervention study attributed the success of the programme to its social nature, as it was conducted in small groups involving subject participation (Abbott *et al*., 2012), suggesting that group size may be important. Indeed, small intervention activity groups have been suggested as being beneficial for firefighter learning (Ranby *et al*., 2011). This informed the decision not to exceed six participants per workshop within this study, which ran smoothly and cohesively, producing unanimous positive participant feedback (appendix 6.5).

The combination of attributes possessed by the researcher who ran the session includes extensive experience as a former firefighter, a former mess-manager and a registered nutritionist. This enabled effective communication and empathy with the participants who have the difficult task of catering for a demanding watch. As such, the researcher's nutrition knowledge was tailored to provide practical solutions to very specific challenges faced by mess-managers.

Limitations

The sampling strategy for this study was not random, and instead involved fire stations being assigned by the researcher. The high level of enrolment and low level of active dropout helped decrease selection bias and increase representativeness. Indeed, every effort for obtaining a representative sample was made by ensuring an even spread of urban and suburban fire stations within each group, along with homogeneity of workload in terms of no significant difference in emergency call volume between groups. The cluster-controlled condition was necessary to minimise the chances of group contamination, as was the distance between intervention and control group stations.

Although significance was only reached for four of the nine parameters, all nine were heading in the right direction. The lack of significance could be due to a small sample size for this study. It is important to note that although the sample size was small in terms of number of mess', this translated to approximately ten personnel per mess, therefore the changes which were detected benefited many personnel. Another limitation is the lack of data collected at nine months from baseline which would have provided evidence of intervention durability. This was an extenuating circumstance caused by the Covid-19 global pandemic, therefore future studies with larger sample sizes over a longer duration are required to fully realise the potential long-term impact of mess-manager workshops.

Conclusion

The mess-manager workshop generated overwhelmingly positive participant feedback and showed efficacy for improving the fire station food environment. This study demonstrates that a low intensity, highly feasible worksite cookery workshop is ready for organisational rollout.

Chapter 7. A fire station-based, multi-component, dietary and lifestyle intervention to improve or maintain firefighter health

Overview

This study describes the development, implementation and evaluation of a multi-component fire station-based nutrition and lifestyle intervention comprising a thirty minute 'nutrition and health' PowerPoint presentation (group education) and a twenty minute face-to-face personalised nutrition consultation. Intervention content focused on portion control strategies, promotion of the Mediterranean diet, environmental modification, and education regarding risk factors for nutrition-related non-communicable diseases. The efficacy of the intervention was tested in a cluster-controlled trial. At four months post-intervention, significant improvements were observed (p < 0.01) in daily mean intakes of energy (-244 kcal), total fat (-12 g), saturated fatty acids (-5g), sodium (-311 mg), sugars, preserves and snacks (-19 g). This contributed to concomitant mean body composition improvements in fat mass (-2 kg), BF% (-1.7%), WC (-1.7 cm), weight (-1.7 kg), BMI (-0.5 kg/m2), mood (+0.9) and energy level (+1.2). The intervention group also maintained stable muscle mass during the observed weight loss, compared with the control group increasing in WC (+1.9 cm).

7.1. Introduction

Diet and nutrition have overtaken smoking as the leading cause of non-communicable disease globally (GBD 2015 Risk Factors Collaborators, 2016), and obesity is costing the global economy an estimated 1.573 trillion pounds annually (Tremmel *et al.*, 2017). It has been well established that excess adiposity can be detrimental to the physical health and fitness of humans (Jokinen, 2015). Overweight and obesity is also likely to overburden the NHS as well as the wider economy. This amounted to an NHS cost of £4.2 billion in 2007, as well as indirect costs estimated at £15.8 billion due to approximately 16 million lost working days arising from overweight/obesity associated sick leave (Van Duijvenbode *et al*., 2009; Foresight, 2007). When obesity affects emergency service workers, the stakes are high, as due to impaired physical fitness (Michaelides, 2011; Williford *et al*., 1999) they are compromising personal safety, their colleagues' safety and the public they serve (Moore, 2003).

The overweight and obesity epidemic has not avoided the fire service. Munir *et al*. (2012) investigated overweight and obesity in a cross-sectional sample of UK county firefighters. The proportion of overweight firefighters was measured to be greater than prevalence within the UK general population in 2008, with 65% of firefighters classified as either overweight or obese. A significant rise in obese firefighters of 2% was measured in the same cohort three years later, with the researchers suggesting that obese firefighters could benefit from weight loss advice (Munir *et al*., 2012). Five years later the UK's first fire station based dietary and lifestyle, controlled intervention pilot trial was conducted. This indicated that a low burden and low intensity fire station intervention was highly feasible, could significantly improve dietary behaviour and result in significantly improved body composition of firefighters (Lessons and Bhakta, 2018). Limitations of this study included a small sample size (*n*=38), brief duration (one month), the absence of a control group for measuring dietary intake, and statistical tests which were not able to analyse the interaction between time and group. Questions therefore remain in terms of scalability, durability, robustness and efficacy, all of which warrants further research.

There remains a relatively small evidence base for UK firefighter obesity compared with research conducted in the USA, which has quantified 73-88% of firefighters to be overweight/obese and struggle with maintaining physical fitness, demonstrating significantly less cardiorespiratory fitness and strength than firefighters of a healthy weight (Clark *et al*., 2002; Donovan *et al*., 2009; Tsismenakis *et al*., 2009; Poston *et al*., 2011). This poses a huge problem, as research by Tierney *et al.* (2010) showed aerobically unfit firefighters to be at 90% increased risk of suffering a myocardial infarction (MI) compared with aerobically fit firefighters. Indeed, coronary heart disease (CHD) and MI are the most common causes of on-duty death in the US fire service with a prevalence of 45% (Tierney *et al*., 2010), which is more than double that of on-duty paramedics (11%) and police (22%) (Poston *et al*., 2011). Whilst overweight and obesity are risk factors for CHD and MI, a further job-related exposure has been identified, showing extremely high temperatures experienced by firefighters to impair vascular function and increase risk of thrombogenicity (Hunter *et al*., 2017). This could compound risk, as obese firefighters are less exercise tolerant and more susceptible to heat stress consequences (Donoghue and Bates, 2000; Chung and Pin, 1996). Whilst a combination of exposures elevates risk of firefighter MI and CHD, it becomes all the more necessary to address the modifiable risk factors such as dietary behaviour, overweight and obesity. This may be all the more challenging for this occupational group, as sleep interruption is an integral feature of firefighting shift systems, and has been linked with metabolic dysregulation (Knutsson *et al*., 2007) possibly directly contributing toward obesity and type 2 diabetes (Knutson and Van Cauter, 2008).

Qualitative research by Dobson *et al*. (2013) investigated associations between an obesogenic occupational environment and behavioural drivers of US firefighter overweight/obesity, identifying five themes which contribute to this occupational group suffering one of the greatest overweight/obesity rates. The themes were: a culture of over-consuming energy dense food in excessive portions during mealtimes; sleep interruption from nocturnal emergency calls; a lack of supervisor encouragement regarding physical fitness/fire station gym usage; Sedentary work when not responding to emergencies or engaging in training on the drill ground; and generational influences. To date, several fire station-based nutrition and lifestyle intervention programmes have been conducted in the USA on larger samples of firefighters over longer durations compared with the pilot trial by Lessons and Bhakta (2018). These yielded varying levels of efficacy and are reviewed in Chapter 1. Future interventions could benefit by factoring these themes into a programme. Informal discussions with firefighters who participated in the UK firefighter pilot trial by Lessons and Bhakta (2018) indicated that these same themes are likely driving the overweight/obesity prevalence indicated in UK fire brigades. This notion is reinforced by the researcher's extensive experience of seventeen years as a former full-time firefighter.

Annual health surveillance systems are available for US firefighters (three-yearly for UK firefighters) to monitor BMI, blood pressure, adiposity and cardiovascular fitness. Whilst occupational health providers use these opportunities to identify and counsel overweight and obese firefighters both in the UK and the USA, a recent USA study concluded that, similar to other studies, little benefit is yielded from low intensity weight loss counselling of firefighters, and that further research is required to identify feasible and effective weight management strategies to address firefighter obesity (Brown *et al.*, 2016). Furthermore, 71% of USA firefighters do not follow any specific dietary plan, and 68% of firefighters feel they receive insufficient nutrition information despite 75% of firefighters being interested in learning more about healthy eating (Brown *et al.*, 2016).

The overweight and obesity crisis is on the increase. Over 75% of USA recruits start their careers as overweight/obese (Tsismenakis *et al*., 2009), and evidence indicates that firefighter overweight/obesity prevalence increases over time (Soteriades *et al*., 2005; Glueck *et al*., 1996; Ide, 2000; Davis *et al*., 2002). This evidence base supports the urgent need for interventions of high efficacy to address the modifiable risk factors that excess adiposity poses to firefighters and the public they serve. The high and ever-increasing prevalence of overweight and obesity in the LFB, which is comprehensively characterised in Chapters 3 and 4 needs to be addressed with a feasible, effective and scalable intervention programme tailored for this occupational group. The aim of this study was to test the feasibility and efficacy of a low burden, low intensity nutrition and lifestyle intervention for firefighters. The objectives were to test whether a developed version of the 2017 pilot trial (Lessons and Bhakta, 2018) would improve dietary behaviour and body composition on a larger sample of firefighters over a longer duration.

7.2. Methods

This was a prospective cluster-controlled trial. The sample comprised full-time firefighters from twelve LFB fire stations (seven intervention stations and five control stations). Participants were recruited on their day shifts from June to November 2019 during scheduled fire station engagements which the researcher planned in advance. Stations were chosen for inclusion based upon their geographical location and emergency call volume, aiming for homogenous workload between intervention and control group stations and an even geographical distribution of urban and suburban stations to attain representativeness. Group allocation was pre-selected at the station level (cluster controlled), with the intervention and control groups separated geographically to reduce the risk of group contamination, or in other words, intervention group stations and control group stations were a sufficient distance apart to reduce the risk of participants from different groups meeting and discussing their heterogenous treatment. Participants were therefore blind to group allocation as far as possible. Table 7.1 displays the geographical distribution of stations and the number of study participants from each. This ranged from 2-17 participants depending on attrition and the availability of personnel during the study period due to prior commitments such as scheduled skills training, fire inspections etc. Attrition was due to participant absence at follow-up (as opposed to actively dropping out). Reasons for absence at follow-up included being on leave, on a training course, attending an emergency incident, detachment to another fire station, transfer, on sick leave or retirement. This explains the varying numbers of participants from each station presented in Table 7.1, amounting to a sample size of *n*=89. A post-hoc sensitivity analysis revealed that this sample size was large enough to detect a medium effect size (Cohen's d = .60) with a power of .80 and an alpha error of 5% (two-tailed). Only four participants actively dropped out from the study, thus constituting a negligible proportion of the sample. Exclusion criteria applied to operational firefighters who were not full-time i.e. those who do not work both day and night shifts, applying to *n*=4. Figure 7.1 shows the participant flow through the study.

Table 7.1. Fire Station participant postings

Area description	Intervention stations	*n* (%)
Urban	Bethnal Green	11 (24)
	Millwall	4 (9)
	Homerton	10 (22)
Suburban	Dagenham	8 (18)
	Ilford	7 (16)
	Walthamstow	3 (7)
	Plumstead	2 (4)
	Total	45 (100)
	Control stations	
Urban	Edmonton	4 (9)
	Tottenham	13 (29)
Suburban	East Ham	3 (7)
	Enfield	17 (39)
	Hornsey	7 (16)
	Total	44 (100)

Ethical approval

This study was authorised by an Assistant Commissioner of the LFB (see appendix 2.1 and Chapter 2) and the London Metropolitan University School of Human Sciences Ethics Committee (see appendix 2.2 and Chapter 2). The firefighters had the study explained to them in full, and those who chose to participate were provided with a participant information sheet and informed signed consent was obtained from each participant (See appendices 2.3, 2.4 and Chapter 2).

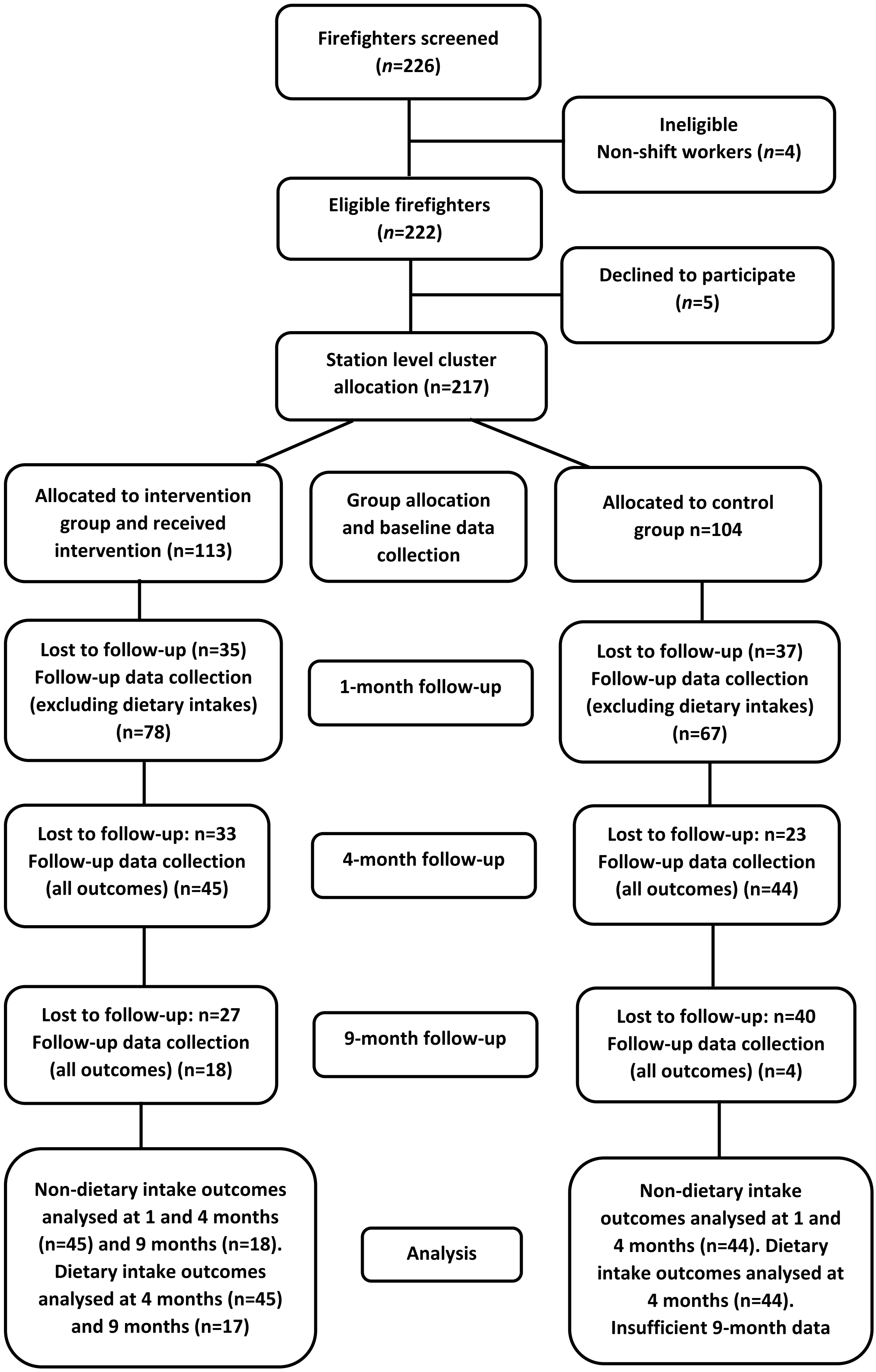


Figure 7.1. Participant flow through the study. Reasons for participant absence at follow-up visits included: being on leave, on a training course, attending an emergency incident, detachment to another fire station, transfer, on sick leave or retirement. Four participants actively dropped out from the study. The study was curtailed for some stations (precluding 9-month data collection) due to the Covid-19 pandemic.

Self-reported measures

A one-page health, lifestyle and occupational history questionnaire (see appendix 7.1) was devised by the researcher and administered to all participants at baseline to ascertain participant ethnicity, professional rank, length of service, dietary and lifestyle behaviour at work and at home, smoking status, underlying health issues, mood and energy levels. Table 7.2 summarises the justification for these questions. An abridged version of the same questionnaire (see appendix 7.2) was administered at all follow-up engagements in an attempt to reduce participant burden. This was similar but omitted questions pertaining to ethnicity, rank, length of service, smoking status, shopping responsibility at home and time of evening meal at fire station and at home.

Assessment of physical activity (PA) was conducted utilising the 'concise physical activity questionnaire' (CPAQ) (Sliter and Sliter, 2014) (see appendix 7.3). This is a four-item measure of general physical activity which was chosen for this study for the following reasons:

i) It encompasses all forms of PA in daily life as opposed to specific PA components such as planned exercise sessions.

ii) It measures PA over the previous month, which is long enough to represent typical PA levels and short enough for accurate PA recall (Sliter and Sliter, 2014).

iii) The items (questions) were designed to be able to measure government PA guidelines which are a component of the general information sheet (see appendix 7.7) in this study i.e. the CPAQ comprises separate items for measuring aerobic and resistance exercise. This attribute thus enables the researcher to identify certain PA deficiencies and subsequent adherence levels to specific individual advice given.

iv) The brevity and ease of administration of the CPAQ minimises participant burden. This is an important attribute considering the battery of measures which participants in the current study were administered.

v) The CPAQ has previously been successfully utilised to measure PA in a sample of 305 USA firefighters. The CPAQ scores were significantly negatively correlated with physical health problems, occupational burnout and absenteeism (Sliter and Sliter, 2014).

The newly validated Firefighter food frequency questionnaire (FF-FFQ) (see Chapter 5 and appendix 5.3) was utilised to assess dietary intakes at baseline, four and nine months. Dietary assessment was not administered at the initial follow-up engagement, as one-month was deemed to be too brief a period between assessments and could overburden participants which could risk participant burnout and attrition. Furthermore, the FF-FFQ reference period is three months, therefore it is logical for a minimum of three months to elapse between administrations. Chapter 5 describes the FF-FFQ and its method of administration in detail. All data collection was conducted and quality assured with one researcher visiting all of the fire stations, and handling the data.

Table 7.2. Justification for the health, lifestyle and occupational history questions in appendix 7.1.

QUESTION	JUSTIFICATION
Years served?	The cumulative effect of nocturnal shifts (>20yrs) has been positively associated with increased obesity rates (Peplonska *et al*., 2015).
Do you smoke?	Shift workers are more likely to smoke compared with non-shift workers (Amelsvoort *et al*., 2006; HSE, 2013).
Are you in the watch mess (meal club)?	Qualitative research has identified a fire station food environment of excessive portion sizes, over-nutrition, ultra-processed foods and nocturnal snacking (Haddock *et al*., 2011; Jahnke *et al*., 2012; Dobson *et al*., 2013).
Who does the food shopping at home?	For assessment of the level of influence the participant has over household food choices. This information helped to inform personalised advice.
Underlying health conditions and/or injuries?	For identification of any dietary or physical activity limitations to appropriately inform nutrition and physical activity recommendations.
Average energy level 1 (lowest)- 10 highest)?	This can affect quantity and quality of energy intake (Tasali *et al*., 2009), as well as physical activity motivation (Atkinson *et al*., 2008).
Average mood level 1 (lowest)- 10 (highest)?	Depressive and anxiety disorders have been associated with shift work (Harrington, 2001).
Time of evening meal at work/at home?	Nocturnal fasting periods of >11 hours have been associated with significant weight loss from reduced energy intake (LeCheminant *et al*., 2013).
Do you snack in the evening after final meal (a) on night shifts? (b) at home?	Sleep deprivation can be accompanied by increased energy intake from snacks (Nedeltcheva *et al*., 2009). This question also helps to inform intervention advice.

Objective measures

Anthropometric and body-composition measurements

The following measurements were recorded for each study participant at baseline, one month, four months, and for a smaller subset of participants at nine months. This enabled assessment of short, mid and long-term changes respectively. The objective measures which were collected/calculated for this study included: height, body weight, body mass index (BMI), body fat percentage (BF%), total body fat (kg), waist circumference (WC), waist to height ratio (WHtR), fat mass index (FMI), skeletal muscle mass index (SMMI). These measures provide a comprehensive picture of body composition via weight category, total adiposity, central adiposity and muscle mass respectively (WHO 2008). All measurements were carried out by the researcher and took place at the relevant participant fire stations during allocated day shifts. Measurement protocols and calculations are described in Chapter 2.

The Intervention

The intervention comprised several main components including: rapport building, a nutrition and health PowerPoint presentation, environmental modification, dietary and lifestyle assessment, anthropometry and body composition analysis and personalised nutrition consultations. Figure 7.2 illustrates the activity flow through the baseline engagement session including typical timings.

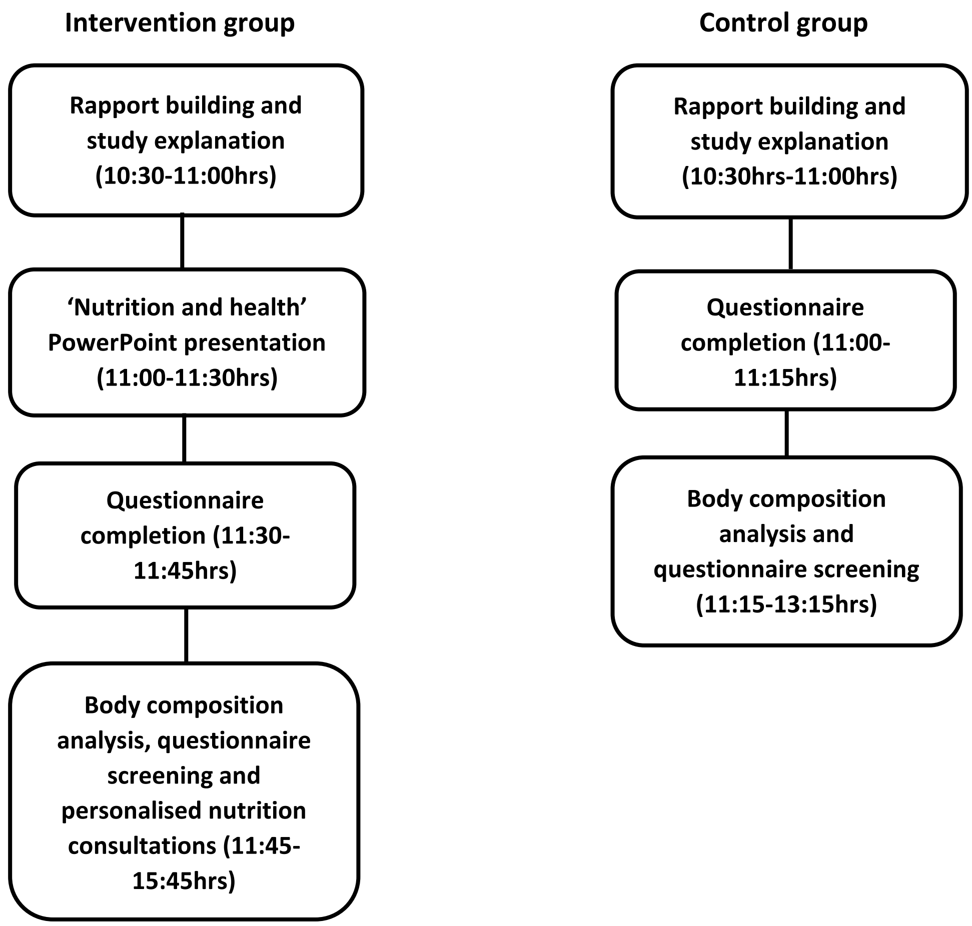


Figure 7.2. Activity flow through the baseline engagement session including typical timings.

Intervention components

Intervention components focused on fire station obesogenic environmental modification alongside evidence-based nutrition, physical activity and lifestyle education in a low-intensity and low burden format. Intervention format and content was designed in alignment with pertinent Cochrane and NICE evidence which is outlined in Table 7.3. Intervention content was also informed by the pilot trial (Lessons and Bhakta, 2018), the researcher's extensive previous exposure to fire-station life along with informal discussions with groups of firefighters to gauge the baseline level of knowledge. For the session to run smoothly and to maximise firefighter participation, building rapport between the researcher and the watch was considered to be an important first step toward a successful session for both intervention and control watches.

Initial rapport building and recruitment

Initial rapport building with the Intervention and control group watches typically involved the researcher arriving at the scheduled fire station at 10:30hrs and introducing himself to the watch, who were generally on a refreshment break in the watch mess at around that time of day. Following the introduction, around thirty minutes was spent reassuring the watch that the study was voluntary, that it was ethically approved and was subject to strict data protection and confidentiality standards, therefore there would be no downside and they could only stand to benefit from participation in the study. This helped to allay potential preconceived suspicion and concern of potential repercussion to themselves. A common complaint from firefighters, both in the LFB and the USA is the false positive error rate of the BMI system (Choi *et al*., 2016). The novel risk classification system to emerge from the centiles study (see Chapter 4) was explained to the watches who seemed to welcome a potential improvement upon the BMI system. This, along with informing them that the overarching aim of the intervention study was to ascertain how a nutritionist could be of optimal use and benefit to the health and wellbeing of firefighters was also a welcome prospect, all of which helped to build important rapport and maximise participant recruitment. This was followed by the group-based education component of the intervention.

(i) Nutrition and health PowerPoint presentation (see appendix 7.4)

A thirty-minute PowerPoint presentation which was created and delivered live by the researcher to teams of firefighters at intervention group fire stations during their day shift at the initial engagement (baseline). Presentation content focused upon dietary behaviours and health related outcomes. Topics which were covered within the presentation included portion control, nutrients and food groups including saturated and unsaturated fat, salt, free sugars, fruit and vegetables, fibre and wholegrains. The non-communicable disease epidemiology, basic mechanisms and outcomes which were covered included cardiovascular disease, obesity, atherosclerosis, coronary heart disease, dyslipidaemia, hypertension, metabolic syndrome, type-2 diabetes, cancer and mental health. The lecture was partially interactive i.e. the researcher punctuated the lecture at key points by asking questions of the watch which were strategically designed to assess the current level of relevant knowledge possessed by the audience. The questions were also designed to promote active learning, which has been shown to be more effective than passive learning for improving knowledge acquisition and retention (Angelo, 1993). This approach also takes advantage of the team dynamic which is characteristic of the firefighting watch structure, therefore fostering a 'community of practice approach', as characterised by Lave and Wenger (1991) who proposed that daily life is the platform for deep learning, which occurs through interaction with others in family, workplace and education settings. The shared understandings which emerge from cooperation toward common goals is the basis of this 'community of practice approach'.

The questions directed toward the watch by the researcher included the following: "Which dietary and lifestyle behaviours would you associate with the accumulation of arterial plaques?" (asked immediately after educating them on the underlying mechanism of atherosclerosis – slide 4); "Which type of fat can contribute to this problem?" (asked after establishing that fatty foods can contribute to atherosclerosis – slide 4); "Which foods do you think this fat comes from?" (asked immediately after the discussion which followed the previous question – slide 4); "If saturated fat should be minimised in the diet, what type of fat should replace it? And which foods contain it?" (asked immediately after the discussion which followed the previous question – slide 4). "What dietary and lifestyle behaviours affect blood pressure?" (asked immediately following educating them on the underlying mechanism and outcomes of hypertension – slides 7-8); "Which dietary and lifestyle behaviours would you associate with the onset of type-2 diabetes?" (asked immediately after educating them on the underlying mechanism and outcomes of insulin resistance – slide 9); "Other than free sugars, there is a staple food which is consumed daily in Asia which may also contribute toward insulin resistance if overconsumed, can you name that food?" (asked immediately after educating them on the definition, metabolism and safe intakes of free sugars – slide 10); "What would be a healthier substitution for white rice?" (asked immediately after the discussion which followed the previous question – slide 10); "Can you name a popular 'diet' which you would consider to provide maximum health benefits?" (asked immediately prior to educating them on the composition of the Mediterranean diet – slide 16); "What changes could be made to the watch mess to help reduce portion sizes and help to avoid overeating?" (asked immediately after educating them on the specific drivers of firefighter obesity – slide 20).

The presentation also described the 2017 pilot trial and the positive feedback and efficacy it yielded (slides 18, 19 and 21) (Lessons and Bhakta, 2018). This was followed by areas of nutritional science that the researcher can help them with by answering any future questions (slide 22). The last two slides explained the rest of the intervention process (slide 23), which involved the administration of three questionnaires (see self-reported measures), followed by body composition analysis and personalised nutrition consultation. The final slide (slide 24) was left up on the presentation screen to aid portion size conceptualisation of the more ambiguous food items within the FF-FFQ (see appendix 5.3/Chapter 5) whilst the participants completed their questionnaires.

(ii) Environmental modification

At key points during the presentation, recommendations were made in order to ameliorate the established obesogenic effects of fire station life (Dobson *et al.* 2013; Haddock *et al.* 2011; Jahnke *et al*., 2012). Examples included: Introducing the concept of reinstating smaller food plates in the fire station mess; Leaving meal leftovers in the kitchen and away from arms-reach; Switching over to whole grains; Introducing the idea of a fruit bowl for snacking as opposed to refined high sugar products; Fire station gym usage whilst on shift. The nutrition related modifications were subsequently reinforced to the watch mess-manager during their personalised nutrition consultation (see iii), via the provision of a paper-based aide memoire (see appendix 7.5) which suggested four simple modifications that could be easily introduced. These were: fruit bowl introduction; Leave leftovers in the kitchen; Consider using smaller plates; Use wholegrains where possible. These suggested modifications were reinforced and built upon further still during mess-manager workshops (see Chapter 6) This extra reinforcement was aimed toward mess-managers in particular due to their greater level of influence over the food environment. This also included guidance regarding substitution of nutrient poor/energy dense foods for healthier alternatives e.g. brown rice instead of white; low kcal/non-nutritive sweetener instead of sucrose; wholemeal bread/tortillas in place of white alternatives; salad with most meals; usage of lower saturated fat, sugar and salt ingredients/meal components wherever possible. Table 7.4 displays supporting evidence for these recommendations.

(iii) Personalised nutrition consultation

This was a one-to-one session between the researcher and each participant in turn, which commenced following questionnaire completion. The session began with baseline anthropometric and body-composition data collection. Questionnaires were then screened for missing data, with any anomalies discussed with the participant before correction. At this point the control group were shown their body composition data whilst the researcher helped them to understand the data. This data was securely saved on GMON software and displayed on the researcher's laptop PC screen (see appendix 7.6 for an anonymous example). This was then emailed to the participant and they were also given a nutrition and lifestyle general information sheet, described in the following section (iv) (see appendix 7.7). A copy was also emailed to them for future/family use.

The intervention group went through the same stages as the control group in terms of data collection and explanation of their body composition. This was then followed by screening of the individual's questionnaires to identify potential for improvement, which was discussed with the participant in terms of feasibility and was then translated into three to six recommendations/goals which were hand-written at the bottom of the individual's general information sheet (GIS) (see appendix 7.7). These constituted personalised, individually tailored goals for each participant to facilitate health improvement and/or elicit body composition improvement. All advice given was in alignment with the Mediterranean diet, which has consistently been associated with improved quality of life and reduced risk of NCDs (Garcia-Fernandez *et al*., 2014; Schwingshackl *et al*., 2017). The Mediterranean diet has also been rated as the most acceptable healthy dietary pattern by USA firefighters (Korre, Sotos-Prieto and Kales, 2017).

Individual levels of intervention were derived from a combination of an individual's body composition risk classifications and self-reported data encompassing diet, lifestyle, sex and age. For example, if the FF-FFQ revealed that a firefighter did not consume oily fish or a fish oil supplement, they had the main health benefits of omega-3 fatty acids explained to them. They were then asked if they knew what constituted oily fish and whether they found it palatable. If they did not, they were recommended to consume a fish oil supplement. If they did find oily fish palatable, they were asked how they might incorporate two servings per week into their diet, thus empowering them to improve their own health. This is a facet of motivational interviewing (mi), a method which has been shown to outperform traditional advice administration for eliciting effective behaviour change in brief encounters of fifteen minutes (Rubak *et al.*, 2005). If their FF-FFQ also indicated they were overconsuming red meat, fish was suggested as a healthy substitution. To avoid overwhelming participants, small, simple dietary and lifestyle changes were suggested by the researcher, as this tried and tested behavioural change strategy has shown efficacy for establishing weight loss (Lally, Chipperfield and Wardle, 2008), possibly due to simpler changes becoming habitual more rapidly (Lally *et al.*, 2010). Once a pragmatic and feasible solution was reached and agreed upon, it was written as a prompt at the bottom of their GIS. All data and subsequent advice/goals were documented, copies of which were kept securely by the researcher (see Chapter 2).

(iv) General information sheet (GIS)

All participants were provided with a GIS (appendix 7.7) which comprised evidence-based information on diet and physical activity recommendations along with sleep improvement strategies, all of which is referenced with supporting evidence in Table 7.4. The information on the sheet was covered in the preceding presentation and therefore reinforced and summarised learning for the intervention group, however this constituted new information for the control group. The only difference between the GIS given to intervention group firefighters and the GIS given to control group firefighters was the area at the bottom of the intervention GIS titled 'Personal advice/Goals', which did not feature on the control group GIS. In addition to a hard copy of the GIS, all participants were also emailed an electronic copy. The same email contained the participant's individual body composition analysis report as well as an educational web link on food portion size guidance (British Nutrition Foundation, 2018). This educational reference contains downloadable PDF files which show how to portion foods relative to hand size as opposed to the more burdensome option of weighing foods. A similar approach was recently employed in a USA study by Johnson and Mayer (2020) for helping firefighters to portion food appropriately. To further encourage optimal fruit and vegetable intake, and to enable firefighters to quantify their intake of fruit and vegetables in terms of portions, a second web link was provided comprising an infographic depicting portion sizes of various types of fruits and vegetables, and the healthy compounds pertaining to each colour fruit and vegetable (BBC good food, 2017). Participants had the two links explained to them during the one-to-one session and were encouraged to refer to the web links in their own time. Additionally, Intervention group participants were given an aide memoir listing healthy snack options (appendix 7.8), and email access to a registered nutritionist (the researcher) following the intervention.

Table 7.3. NICE and Cochrane adult weight management intervention criteria which guided this study's intervention

Intervention component	Evidence based criteria which guided the intervention
Tailored multi-component interventions	-Focus on physical activity and diet in conjunction as opposed to addressing either component exclusively. -Weight management interventions should include strategies to: improve dietary quality and behaviour; reduce energy intake; decrease inactivity and/or increase physical activity. -Should have potential for the intervention to be translated to family members. -Interventions should be personalised and provide ongoing support. Discussions with the individual regarding weight management options, empowering them to decide what may work for them and what is sustainable.
Dietary	-Should focus on dietary improvement and energy intake reduction. Should also combine targeted recommendations, dietary modification, goal setting and family inclusion. -Changes should be tailored to preferred foods, individualised and flexible in approaches to energy intake reduction. The long-term goal should be a balanced diet. -The primary focus for a weight loss approach should be attainment of a negative energy balance of -600 kcal/day, or via low-saturated fat diets, along with professional support and follow-up are advised for long-term weight management.
Physical activity	-Focus should be on activities that easily fit into individuals' daily lives (e.g. walking, dance or cycling), tailoring to individual circumstances and preferences. -Should attempt to foster individual self-belief in a person's ability to change, via verbal persuasion and emphasising positive effects. Continuing support via written materials to be provided in person, by phone, internet or mail.
Outcome measures	-The main weight management intervention outcome measure is overweight or obesity reduction, normally defined as BMI, with body weight being the key measure due to the likelihood of height remaining constant. -It should be remembered that modest weight loss can achieve significant health benefits. 0.5-1 kg of weekly weight loss should be considered as a realistic target, along with a 5-10% total weight loss of baseline body weight over the intervention period. -Diet improvement should be encouraged even in the absence of weight loss, to facilitate other significant health benefits e.g. reduced cancer risk. -The same applies to physical activity for reducing CVD and type 2 diabetes risk.
General	-Interventions should align with government initiatives such as the CMO's physical activity recommendations, the '5-a-day' campaign, and Change4Life. -Interventions should be engaging, enjoyable and be easily accessible for the target audience. -NICE behaviour change guidance is relevant for obesity prevention interventions. Evidence suggests enhanced effectiveness when people: • Feel optimistic/positive about behaviour change • Understand the impact of behaviours on health • Set action specific, time measured goals • Make a commitment to themselves to change • Plan changes in simple steps • Share their goals with others • Prepare for situations or events that may compromise change

(NICE, 2014; Norris *et al*., 2005; Shaw *et al*., 2006; Orozco *et al*., 2008, Swanton, 2008).

Table 7.4. General information sheet (GIS) nutrition advice content with justification

Advice given	Justification
Eat a *minimum* of 5-a-day of various fruit and *veg*. Risk of all-cause mortality (death by any cause) reduces by 14%: 1-3 portions, 29%: 3-5 portions, 36%: 5-7 portions and 42%: 7 or more portions.	As recommended by Public Health England (2016) to reduce risk of CVD and certain cancers. Supplementary advice: Oyebode *et al*. (2014).
Include lots of fibre on your plate. Vegetables, fruits and beans will fill you up instantly.	SACN (2015) recommends a DRV for fibre of 30g/day based upon reduced disease risk.
Protein rich foods will help you to feel fuller for longer, helping reduce the total amount of calories you consume.	Protein ingestion has been associated with increased satiety which may facilitate reduced energy intake (Paddon-Jones et al, 2008).
Take a vitamin D supplement. 10 micrograms per day is recommended.	As recommended by SACN (2016) to protect muscle and bone health.
Reduce/exclude free sugars. Studies are showing free sugars to be a main culprit for the metabolic syndrome, increasing risk factors for cardiovascular disease and type 2 diabetes.	(Johnson *et al*., 2007).
Reduce salt intake. Salt increases blood pressure which increases risk of cardiovascular disease i.e. heart attack and stroke.	As recommended by SACN (2003).
Minimise/exclude junk/ultra-processed food. Read labels, salt and sugar are hiding everywhere!	As recommended by Public Health England (2016).
Avoid over-eating. Studies show that appetite and calorie intake are not related. Eat from a smaller plate, or a smaller container if away from the home. Use the above picture template.	(Holt *et al*., 2016).
Limit alcohol intake to a maximum of 14 units per week (males and females) distributed evenly over ≥ three days.	As recommended by Department of Health (2016).
Not eating or drinking anything except water after 7pm/8pm, until breakfast may improve sleep duration and quality. This is also likely to reduce weight.	(Yamaguchi *et al*., 2013; Antelmi *et al*., 2014).
Centrepiece infographic: The Healthy Eating Plate.	Produced by Harvard School of Public Health. Evidence based advice in an easily accessible form, in alignment with the Mediterranean diet.

Dietary analysis

Nutrient and food groups were chosen for analysis based upon their relevance to the intervention and human health. These included intakes of energy, carbohydrate, protein, fat, saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, fibre, sodium, iron, calcium, vitamin C, sugars, preserves and snacks, vegetables, fruits, fish and fish products.

The dietary analysis software and procedure used to generate mean daily nutrient and food group intakes for each participant is described in detail in Chapter 2 (dietary analysis).

Statistical analyses

Data were imported into IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). The distribution of all continuous data was checked for normality. Non-normally distributed data was log transformed to attain normality. The differences in mean annual emergency call-outs between intervention and control group stations were analysed using the independent samples T-Test. Fire station area description (urban/suburban), sex, ethnicity, job rank, smoking status, mess-membership, home food shopping responsibility, evening snacking at work and at home were assigned as categorical variables and presented as *n* (%). Fire station group call volume, Age, weight, BMI, BF (kg), BF%, WC, WHtR, FMI, SMMI, CPAQ score and all dietary intake data were assigned as continuous variables and presented as mean (SD), with independent samples t-tests used to identify baseline differences between the intervention and control groups in each of these variables. Mood and energy levels were assigned as ordinal variables and presented as mean (SD), with Mann-Whitney U tests used to identify baseline differences between the intervention and control groups in mood and energy. Fisher's exact tests were used to identify baseline relationships between the intervention and control group in mess-membership, home food shopping responsibility, evening snacking at work and at home. Cochrane's Q tests followed by post hoc McNemar tests were undertaken to identify changes over time for each group in evening snacking at work and at home. Mixed-design ANOVAS were carried out to assess the interaction between the intervention and control group over time (baseline, one month and four months) for weight, BMI, BF (kg), BF%, WC, WHtR, FMI, SMMI, CPAQ score and each dietary intake variable. For each of these variables, the mean difference in group change (baseline to four months) was calculated. Independent samples T-tests were then conducted to investigate potential differences between group changes. Mann-Whitney U tests were conducted to investigate mood and energy rating differences between group changes. Post hoc analyses (paired samples t-tests with Bonferroni corrections) were then carried out to identify differences within each group between baseline and one month, and between baseline and four months. Friedman tests were conducted to assess the change over time (baseline, one month and four months) in each group for mood and energy levels. Post hoc analyses (Wilcoxon signed ranks tests with Bonferroni corrections) were then carried out to identify differences within each group between baseline and one month, and between baseline and four months. One-way repeat measures ANOVAS were carried out to assess change over time (baseline, one month, four months and nine months) within the intervention group subset (*n*=18) in weight, BMI, BF (kg), BF%, WC, WHtR, FMI, SMMI, CPAQ score and each dietary intake variable. Post hoc analyses (paired samples t-tests with Bonferroni corrections) were then carried out to assess differences between baseline and nine months for each variable. Friedman tests were conducted to assess the change over time (baseline, one month, four months and nine months) within the intervention group subset (n=18) in mood and energy levels. Post hoc analyses (Wilcoxon signed ranks tests with Bonferroni corrections) were then carried out to assess differences between baseline and nine months in mood and energy levels. An alpha value of $p < 0.05$ was used to identify statistical significance.

7.3. Results

There was no significant difference between the intervention and control group fire stations in terms of mean annual emergency call-out volume: mean (SD) 3017 (947) vs 3712 (1003) respectively ($p > 0.05$). Demographic characteristics of the study sample are presented in Table 7.5, indicating homogeneity across groups in sex, ethnicity, job rank and smoking status. The mean (SD) number of years of service in the fire Brigade was 14.7 (8.2), with no significant difference between the two groups ($p > 0.05$). Table 7.6 displays baseline age, anthropometric, body composition, self-reported physical activity, mood and energy ratings of study participants for whom data was collected at baseline, one and four months. This shows heterogeneity between the two groups, identifying the control group to be of significantly lower weight and adiposity status compared with the intervention group. Both groups had mean BMIs within the 'overweight' classification, however, the mean WHtR of the control group was on the borderline of 'healthy' and 'high risk' whereas the intervention group were around midway through the 'high risk' category.

Table 7.5. Demographic characteristics of study participants

Variable	**Subcategory**	**All (*n*=89) n (%)**	**Intervention (*n*=45) n (%)**	**Control (*n*=44) n (%)**
Sex	Men	86 (97)	44 (98)	42 (96)
	Women	3 (3)	1 (2)	2 (4)
Ethnicity	White	83 (93)	44 (98)	39 (89)
	Other	6 (7)	1 (2)	5 (11)
Job Rank	Firefighter	71 (80)	35 (78)	36 (82)
	JO	11 (12)	6 (13)	5 (11)
	Sub/Stn O	7 (8)	4 (9)	3 (7)
Smoking status	Non-Smoker	81 (91)	40 (89)	41 (93)
	Smoker	8 (9)	5 (11)	3 (7)

Abbreviations: JO, junior officer; Sub/Stn O, Sub Officer or Station Officer. No significant differences were observed ($p > 0.05$).

Table 7.6. Baseline Age, anthropometric, body composition, self-reported physical activity, mood and energy ratings of study participants for whom data was collected at baseline, one and four months.

Variable	**All (*n*=89) Mean (SD)**	**Intervention (*n*=45) Mean (SD)**	**Control (*n*=44) Mean (SD)**	***P* value (Intervention vs Control)**
Age	40.4 (7.8)	41.8 (8.4)	39 (7.0)	NS
Weight (kg)	90.4 (14.7)	93.8 (14.9)	86.9 (13.8)	0.020
BMI (kg/m^2)	28 (3.9)	29 (4.3)	27 (3.2)	0.012
BF%	22.3 (5.5)	24.2 (5.4)	20.4 (4.8)	0.001
BF (kg)	20.7 (8.2)	23.3 (8.9)	18.1 (6.6)	0.001
WC (cm)	92.5 (11.1)	96 (11.2)	89 (9.8)	0.001
WHtR	0.52 (0.06)	0.54 (0.06)	0.50 (0.05)	0.001
FMI (kg/m^2)	6.5 (2.7)	7.2 (3.0)	5.7 (2.2)	0.003
SMMI (kg/m^2)	9.4 (1.5)	9.4 (1.6)	9.3 (1.5)	NS
CPAQ score	16 (8)	14.6 (8.3)	17.0 (7.7)	NS
Mood level (1-10)	6.9 (1.7)	6.5 (1.8)	7.3 (1.5)	0.029
Energy level (1-10)	6.6 (1.5)	6.1 (1.6)	7.1 (1.3)	0.001

Abbreviations: BMI, body mass index; BF, body fat; WC, waist circumference; WHtR, waist-to-height ratio; FMI, fat mass index; SMMI, skeletal muscle mass index; CPAQ, concise physical activity questionnaire.

One and four-month changes

To detect changes over time and between groups in anthropometry, body composition and physical activity, mixed design ANOVAs were conducted, the results of which are displayed in Table 7.9. Table 7.9 also displays the mean differences between the intervention and control group changes (baseline to four months). The significant results warranted post hoc tests to identify changes from baseline, the results of which are displayed in Tables 7.7 and 7.8. These show significant reductions in weight and adiposity status of the intervention group, and significant adiposity increase within the control group. To test changes in mood and energy level ratings (ordinal data), Friedman tests were conducted, which revealed that over the four-month intervention period, mood and energy levels changed significantly for the intervention group ($p < 0.001$), but not for the control group ($p > 0.017$). This warranted post hoc analyses, the results of which are displayed in Tables 7.7 and 7.8, indicating significant improvements in mood and energy within the intervention group but no significant change within the control group.

Nine-month changes

Mitigating circumstances led to insufficient data collection of control group participants, and a smaller subset of data collected for intervention group participants at nine months (*n*=18), which was tested using one-way repeat measures ANOVAs (continuous data), and Friedman tests (ordinal data), the results of which are displayed in Table 7.10. These show significant changes in adiposity, which warranted post hoc tests to identify changes from baseline, the results of which are displayed in the final column of Table 7.7.

Table 7.7. Intervention group changes between baseline, one month, four months and nine months.

Variable	Baseline *n*=45 Mean (SD)	1 month *n*=45 mean (SD)	Change from baseline	4 months *n*=45 mean (SD)	Change from baseline	9 months *n*=18 mean (SD)	Change from baseline[a]
Weight (kg)	93.8 (14.9)	92.9 (14.3)	**-0.9****	92.1 (14.1)	**-1.7****	91.9 (14.5)	-1.5
BMI (kg/m²)	29 (4.3)	28.7 (4.2)	**-0.3****	28.5 (4.3)	**-0.5****	29.1 (4.3)	-0.4
BF%	24.2 (5.4)	23.0 (6.0)	**-1.2****	22.5 (5.8)	**-1.7****	22.9 (5.1)	**-2.1***
BF (kg)	23.3 (8.9)	21.9 (8.9)	**-1.4****	21.3 (9.0)	**-2.0****	22.2 (9.1)	**-1.8***
WC (cm) [b]	96.3 (11.1)	94.8 (10.3)	**-1.5****	94.6 (10.3)	**-1.7****	95.9 (10.3)	-1.2
WHtR [b]	0.54 (0.06)	0.53 (0.06)	**-0.01****	0.53 (0.06)	**-0.01****	0.54 (0.06)	-0.01
FMI (kg/m²)	7.2 (3.0)	6.8 (2.9)	**-0.4****	6.6 (3.0)	**-0.6****	7.1 (3.0)	**-0.5***
SMMI (kg/m²) [c]	9.4 (1.6)	9.5 (1.5)	+0.1	9.5 (1.5)	+0.1	9.6 (1.2)	+0.1
CPAQ score	14.6 (8.4)	17.5 (7.1)	+2.9	16.6 (7.2)	+2.0	16.3 (8.8)	+0.6
Mood rating (1-10)	6.6 (1.8)	7.1 (1.4)	**+0.5****	7.5 (1.7)	**+0.9****	6.8 (2.1)	+0.6
Energy level rating (1-10)	6.0 (1.6)	7.1 (1.2)	**+1.1****	7.2 (1.5)	**+1.2****	6.7 (1.8)	+1.0

[a] Based upon a different baseline for this subset of *n*=18 participants. [b] n=44 due to missing data. [c] n=43 due to missing data. ** Significant at the 0.01 level, * significant at the 0.05 level. Abbreviations: BMI, body mass index; BF, body fat; WC, waist circumference; WHtR, waist-to-height ratio; FMI, fat mass index; SMMI, skeletal muscle mass index; CPAQ, concise physical activity questionnaire.

Table 7.8. Control group changes between baseline, one month and four months.

Dependent Variable	Baseline n=44 Mean(SD)	1 month n=44 mean(SD)	Change from baseline	4 months n=44 mean(SD)	Change from baseline
Weight (kg)	86.9 (13.8)	87.0 (13.8)	+0.1	86.9 (13.9)	0
BMI (kg/m²)	27.0 (3.2)	27.0 (3.2)	0	27.0 (3.3)	0
BF%	20.4 (4.8)	20.1 (5.2)	-0.3	20.7 (5.0)	+0.3
BF (kg)	18.1 (6.6)	17.9 (6.9)	-0.2	18.4 (6.9)	+0.3
WC (cm)	89.0 (9.8)	90.1 (9.9)	**+1.1****	90.9 (10.1)	**+1.9****
WHtR	0.50 (0.05)	0.50 (0.05)	0	0.51 (0.05)	**+0.01****
FMI (kg/m²)	5.7 (2.2)	5.6 (2.3)	-0.1	5.8 (2.3)	+0.1
SMMI (kg/m²)	9.3 (1.5)	9.3 (1.5)	0	9.2 (1.5)	-0.1
CPAQ score [a]	16.9 (7.7)	17.3 (6.0)	+0.4	17.0 (7.2)	+0.1
Mood rating (1-10)	7.4 (1.5)	7.7 (1.6)	+0.3	7.5 (1.6)	+0.1
Energy level rating (1-10)	7.1 (1.3)	7.6 (0.9)	+0.5	7.3 (1.3)	+0.2

[a] n=43 due to missing data. ** Significant at the 0.01 level. Abbreviations: BMI, body mass index; BF, body fat; WC, waist circumference; WHtR, waist-to-height ratio; FMI, fat mass index; SMMI, skeletal muscle mass index; CPAQ, concise physical activity questionnaire.

Table 7.9. Mixed design ANOVA (interaction) *P* values (baseline, 1 month and 4 months) and differences between group mean changes (baseline and 4 months) (*n*=89)

Variable	Interaction between time and group (baseline, 1 month and 4 months) *P* value	Mean difference between group changes (baseline and 4 months)	Difference between group changes (baseline and 4 months) *P* value	Difference between group changes (baseline and 4 months) Effect size[a]
Weight (kg)	0.025	1.78	0.02	-0.50
BMI (kg/m²)	0.028	0.52	0.02	-0.50
BF%	< 0.001	1.9	< 0.001	-0.98
BF (kg)	< 0.001	2.3	< 0.001	-0.87
WC (cm)	< 0.001	3.7	< 0.001	-1.04
WHtR	< 0.001	0.02	< 0.001	-1.12
FMI (kg/m²)	< 0.001	0.7	< 0.001	-0.87
SMMI (kg/m²)	NS	0.2	NS	0.41
CPAQ score	NS	1.9	NS	0.26
Mood rating (1-10)	-	0.8	0.01	0.45
Energy level rating (1-10)	-	1.0	0.003	0.64

[a]Cohen's d. Abbreviations: BMI, body mass index; BF, body fat; WC, waist circumference; WHtR, waist-to-height ratio; FMI, fat mass index; SMMI, skeletal muscle mass index; CPAQ, concise physical activity questionnaire.

Table 7.10. One-way repeated measures ANOVA *P* values identifying changes across time (baseline, 1 month, 4 months and 9 months) within the 9-month intervention group subset (*n*=18).

Variable	Change across time *P* value
Weight (kg)	NS
BMI (kg/m^2)	NS
BF%	0.004
BF (kg)	0.022
WC (cm)	NS
WHtR	NS
FMI (kg/m^2)	0.022
SMMI (kg/m^2)	NS
CPAQ score	NS
Mood rating (1-10) [a]	NS
Energy level rating (1-10) [a]	NS

[a] Friedman test with Bonferroni correction applied. Abbreviations: BMI, body mass index; BF, body fat; WC, waist circumference; WHtR, waist-to-height ratio; FMI, fat mass index; SMMI, skeletal muscle mass index; CPAQ, concise physical activity questionnaire.

Dietary behaviour

Table 7.11 displays self-reported dietary intakes at baseline. The only significant difference detected between the intervention and control groups was in fruit intake, indicating greater intake of fruit within the control group, although both groups were well above the UK RNI for vitamin C of 40 mg/d (COMA, 1991), with the combined fruit and vegetable intake at > 5 portions/day for both groups. However, both groups were consuming below the UK recommended daily fibre intake (SACN, 2015). Both groups reported consuming approximately 6% below the UK government recommended amount of carbohydrate (50%) (SACN, 2015), and both groups were consuming slightly above the recommended maximum amount of dietary fat (35%) (SACN, 2019) and SFA was also slightly above the maximum recommended amount of 10% (SACN, 2019). Mean calcium intake was above the UK RNI of 700 mg/d (COMA, 1991). For sodium intake, both groups were above the maximum recommended amount of 2400 mg/d (SACN, 2003).

Table 7.11. Baseline energy, nutrient and food group intakes of study participants for whom dietary data was collected at baseline and four months.

Variable	All (*n*=89) Mean (SD)	Intervention (*n*=45) Mean (SD)	Control (*n*=44) Mean (SD)	*P* value (Intervention vs Control)
Energy (kcal)	1846 (645)	1857 (616)	1834 (680)	NS
Carbohydrate (g)	200 (79)	200 (75)	201 (84)	NS
Protein (g)	94 (41)	91 (32)	97 (49)	NS
Fat (g)	75 (28)	76 (30)	73 (27)	NS
SFA (g)	26.3 (10.4)	27.4 (11.0)	25.1 (9.6)	NS
MUFA (g)	28.6 (11.2)	29.2 (12.1)	28.0 (10.4)	NS
PUFA (g)	13.6 (5.7)	13.3 (5.6)	13.8 (5.8)	NS
Fibre (g)	15.2 (5.6)	14.9 (5.0)	15.4 (6.1)	NS
Sodium (mg)	2552 (846)	2622 (857)	2481 (838)	NS
Iron (mg)	10.5 (3.5)	10.3 (3.1)	10.7 (3.9)	NS
Calcium (mg)	788 (301)	790 (290)	785 (316)	NS
Vitamin C (mg)	108 (61)	107 (63)	109 (59)	NS
Food groups				
Sugars, preserves and snacks (g)	44.1 (37.2)	47.6 (38.0)	40.5 (36.4)	NS
Vegetables (g)	278 (142)	268 (129)	288 (156)	NS
Fruits (g)	169 (153)	157 (167)	182 (137)	0.048
Fish and fish products (g)	50 (38)	48 (37)	53 (39)	NS

Abbreviations: SFA, saturated fatty acids; MUFA, Monounsaturated fatty acids;
PUFA, polyunsaturated fatty acids. See appendix 7.9 for food group compositions.

Four-month changes in dietary intake

To detect changes in dietary intakes over time and between groups, mixed design ANOVAs were conducted, the results of which are displayed in Table 7.14. Table 7.14 also displays the mean differences between the intervention and control group changes (baseline to four months). The significant results warranted post hoc tests to identify changes from baseline, the results of which are displayed in Tables 7.12 and 7.13, displaying significant changes within the intervention group, and no significant changes within the control group.

Nine-month changes in dietary intake

Mitigating circumstances (the Covid-19 global pandemic) led to insufficient data collection of control group participants, and a smaller subset of data collection for intervention group participants at nine months (*n*=17), which was tested using one-way repeat measures ANOVAs, the results of which are displayed in Table 7.15, indicating significant change over time in consumption of sugars, preserves and snacks. Post hoc analysis revealed this to be significantly lower at nine months compared with baseline, as displayed in the final column of Table 7.12. The forty percent significant reduction in sugars, preserves and snacks from baseline to four months remained at about the same level at nine months, which was a significant reduction of 30 percent from the baseline mean of the nine-month subset of intervention participants.

Table 7.12. Intervention group dietary intake changes between baseline, four months and nine months

Variable	Baseline *n*=45 Mean (SD)	4 months *n*=45 mean (SD)	Change from baseline	9 months *n*=17 mean (SD)	Change from baseline [a]
Energy (kcal)	1857 (616)	1613 (537)	-244**	1654 (564)	+26
Carbohydrate (g)	200 (75)	179 (65)	-21	178 (73)	+5
Protein (g)	91 (32)	84 (30)	-7	82 (29)	0
Fat (g)	76 (30)	64 (26)	-12**	67 (29)	+2
SFA (g)	27.4 (11.0)	22.4 (9.8)	-5**	23.8 (10.1)	+0.3
MUFA (g)	29.2 (12.1)	24.1 (10.1)	-5.1**	25.6 (11.9)	+1.3
PUFA (g)	13.3 (5.6)	11.5 (5.1)	-1.8**	12.1 (5.4)	+0.3
Fibre (g)	14.9 (5.0)	14.8 (6.5)	-0.1	15.1 (6.2)	+1.2
Sodium (mg)	2622 (857)	2311 (1075)	-311**	2409 (1125)	+12
Iron (mg)	10.3 (3.1)	9.8 (3.6)	-0.5	10.2 (3.7)	+0.4
Calcium (mg)	790 (290)	742 (317)	-48	776 (316)	+20
Vitamin C (mg)	107 (63)	98 (55)	-9	95 (45)	0
Food groups					
Sugars, preserves and snacks (g)	47.6 (38.0)	28.4 (29.5)	-19.2**	27.4 (19.1)	-11.8*
Vegetables (g)	268 (129)	258 (150)	-10	247 (115)	-28
Fruits (g)	157 (167)	175 (172)	+18	184 (161)	+48
Fish and fish products (g)	48 (37)	53 (42)	+5	47 (34)	+3

[a] Based upon a different baseline for this subset of *n*=17 participants. *Significant at the 0.05 level. ** Significant at the 0.01 level. Abbreviations: SFA, saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, polyunsaturated fatty acids. See appendix 7.9 for food group compositions.

Table 7.13. Control group dietary intake changes between baseline and four months

Variable	Baseline (*n*=44) Mean (SD)	4 months (*n*=44) mean (SD)	Change from baseline
Energy (kcal)	1834 (680)	1821 (651)	-13
Carbohydrate (g)	201 (84)	200 (83)	-1
Protein (g)	97 (49)	92 (32)	-5
Fat (g)	73 (27)	76 (30)	+3
SFA (g)	25.1 (9.6)	25.2 (12.0)	+0.1
MUFA (g)	28.0 (10.4)	29.5 (12.6)	+1.5
PUFA (g)	13.8 (5.8)	14.6 (6.2)	+0.8
Fibre (g)	15.4 (6.1)	17.1 (6.7)	+1.7
Sodium (mg)	2481 (838)	2507 (1010)	+26
Iron (mg)	10.7 (3.9)	10.9 (3.7)	+0.2
Calcium (mg)	785 (316)	767 (331)	-18
Vitamin C (mg)	109 (59)	116 (58)	+7
Food groups			
Sugars, preserves and snacks (g)	40.5 (36.4)	40.3 (49.4)	-0.2
Vegetables (g)	288 (156)	300 (186)	+12
Fruits (g)	182 (137)	198 (127)	+16
Fish and fish products (g)	53 (39)	50 (39)	-3

*Significant at the 0.05 level. ** Significant at the 0.01 level. Abbreviations: SFA, saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, polyunsaturated fatty acids. See appendix 7.9 for food group compositions.

Table 7.14. Mixed design ANOVA *P* values, displaying time-group interaction for energy, nutrient and food group intakes, and differences between group mean changes (baseline and 4 months) (*n*=89)

Variable	Interaction between time and group (baseline and 4 months) *P* value	Mean difference between group changes (baseline and 4 months)	Difference between group changes (baseline and 4 months) *P* value	Difference between group changes (baseline and 4 months) Effect size[a]
Energy (kcal)	0.014	231	0.03	-0.47
Carbohydrate (g)	NS	20	NS	-0.31
Protein (g)	NS	2	NS	-0.07
Fat (g)	0.001	15	0.001	-0.72
SFA (g)	0.009	5.1	0.007	-0.59
MUFA (g)	0.001	6.5	<0.001	-0.79
PUFA (g)	0.001	2.6	0.002	-0.67
Fibre (g)	NS	1.8	NS	-0.38
Sodium (mg)	0.007	336	0.037	-0.45
Iron (mg)	NS	0.7	NS	-0.24
Calcium (mg)	NS	30	NS	-0.11
Vitamin C (mg)	NS	16	NS	-0.28
Food groups				
Sugars, preserves and snacks (g)	0.004	19	0.034	-0.46
Vegetables (g)	NS	22	NS	-0.17
Fruits (g)	NS	2.6	NS	0.02
Fish and fish products (g)	NS	7	NS	0.19

[a]Cohen's d. Abbreviations: SFA, saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, polyunsaturated fatty acids. See appendix 7.9 for food group compositions.

Table 7.15. One-way repeated measures ANOVA *P* values identifying dietary intake changes across time (baseline, 4 months and 9 months) within the 9-month intervention group subset (*n*=17)

Variable	**Change across time *P* value**
Energy (kcal)	NS
Carbohydrate (g)	NS
Protein (g)	NS
Fat (g)	NS
SFA (g)	NS
MUFA (g)	NS
PUFA (g)	NS
Fibre (g)	NS
Sodium (mg)	NS
Iron (mg)	NS
Calcium (mg)	NS
Vitamin C (mg)	NS
Food groups	
Sugars, preserves and snacks (g)	0.011
Vegetables (g)	NS
Fruits (g)	NS
Fish and fish products (g)	NS

Abbreviations: SFA, saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, polyunsaturated fatty acids. See appendix 7.9 for food group compositions.

Table 7.16 displays other dietary behavior characteristics of the sample, suggesting there to be no difference between the groups in mess membership ($p > 0.05$) at baseline, with 82% (n=37) of the intervention group, and 86% (n=38) being members of their watch mess. No significant change was detected at one or four months for either group ($p > 0.05$).

Table 7.16. Other baseline dietary behavior characteristics of the sample for whom data was collected at baseline, one and four months

Baseline Variable	**Sub-category**	**All (*n*=89)** ***n* (%)**	**Intervention group (*n*=45)** ***n* (%)**	**Control group (*n*=44)** ***n* (%)**	**Intervention vs Control**
Mess membership	Member	75 (84)	37 (82)	38 (86)	NS
	Non-member	14 (16)	8 (18)	6 (14)	
Home food shopping responsibility	Has responsibility	28 (31)	15 (33)	13 (29)	NS
	Someone else buys the shopping	23 (26)	10 (22)	13 (30)	
	Shared responsibility	38 (43)	20 (44)	18 (41)	
Evening snacking at work	Yes	46 (52)	22 (49)	24 (55)	NS
	No	43 (48)	23 (51)	20 (45)	
Evening snacking at Home	Yes	60 (67)	30 (67)	30 (68)	NS
	No	29 (33)	15 (33)	14 (32)	

Evening snacking at work reduced one-month post intervention for the intervention group from a snacking prevalence of 49% at baseline to 36% at one month, as opposed to the control group's evening snacking prevalence at work which increased by 2.3%. This pattern persisted, with the reported changes in both groups carrying forward to four months post-intervention, although no changes were statistically significant ($p > 0.05$). Of the n=18 intervention group participants for whom data was collected at nine months, n=13 (72%) reported not snacking at work in the evening, with the remaining n=5 (28%) reportedly snacking, although this result was non-significant ($p > 0.05$).

Consistent with workplace changes in snacking behavior, evening after-dinner snacking at home followed a similar pattern, whereby the intervention group reduced from a snacking prevalence of 75% at baseline to 44% at one-month (p=0.021), as opposed to the control group who increased from a prevalence of 68% at baseline to 75% at one-month ($p > 0.05$), although this returned to 68% after four months. At four months post-intervention, the intervention group reported a non-significant reduced prevalence of evening snacking at home of 51% compared with baseline (75%) ($p > 0.05$). Of the n=18 intervention group participants for whom data was collected at nine months, n=12 (67%) of them reported home evening snacking at baseline compared with n=7 (39%) at nine months post intervention (p=0.063).

7.4. Discussion

Overview

This study represents the UK's first fire station-based dietary and lifestyle, controlled intervention. The aim of this study was to test the efficacy of the multi-component intervention for improving dietary and lifestyle behaviour, and body composition of firefighters. Whilst the control group's adiposity increased, at one-month post intervention the intervention group had significantly reduced FM without any loss of SMM. Intervention group adiposity continued to reduce further from baseline at four months post-intervention. For the subset of intervention group firefighters for whom nine-month data was collected, this improvement in body composition persisted. Whilst no significant change in physical activity was detected, the reduced adiposity can be mainly attributed to significant reported reductions in dietary energy and fat intake of the intervention group. Furthermore, significant reductions were detected in dietary intakes of saturated fat, sodium, sugars, preserves and snacks, along with significant improvements in evening snacking behaviour. Mood and energy ratings also improved significantly post intervention. Table 7.17 displays where this study stands in the context of published firefighter interventions.

Table 7.17. Published firefighter interventions

Study	Sample and country	Intervention	Duration	Design	Key significant outcomes
PHLAME (Elliot *et al.*, 2007)	N=480 (97% men) USA	Lifestyle intervention: Team-based curriculum (model 1) vs Individual motivational interviewing counselling sessions (model 2) vs usual care (control). Goals: improve energy balance, reduce fat, increase fruit and vegetables and physical activity.	1 year and 4 years follow-up	3-arm cluster randomised	<u>1 year</u> Attenuated weight gain. Dietary behaviour §. Wellbeing (questionnaire). <u>4 years</u> All favourable improvements disappeared.
Fuel 2 Fight (Brown *et al.*, 2016)	N=757 overweight/ obese men USA	health/fitness coordinator; Peer Fitness Trainers; allocated physical training time for all on-duty personnel.	Ongoing Intervention launched in 1996	Prospective cohort (Cross-sectional)	<u>6 months</u> -0.55kg body weight. -3.75 mmHg systolic BP
Low GI & fitness pilot study to reverse MetS	N=10 men, 7 of whom exhibited MetS USA	Weekly dietary education administered by a doctor and a nurse based on the low-GI diet; daily multivitamin and n-3 fatty acid supplementation; meal	12 weeks	Prospective (no control)	<u>12 weeks</u> MetS risk factors reduced from 3.2 to 1.9 risk factors per subject. Prevalence of MetS reduced by

(Carey *et al.*, 2011)		replacement; Daily physical exercise.			57% (from 70% to 30%). <u>6 months</u> MetS risk factors=2.6 per subject.
FFIRE (Goheer, 2017)	N=112 (85% men) USA	Dietary theory and practical education (1 session per month for 6 months).	1 year	Prospective cluster-controlled	Intervention and control groups reported reductions in energy intake, SFA, trans fat, added sugars, non-whole grains and sodium. The intervention group reported a reduction in vegetable intake. Both groups lost 2.3 kg body weight. Control group outperformed intervention group by >2 fold for improvements in BF%, WC and BP.
LFB pilot trial (Lessons and Bhakta, 2018)	N=38 (92% men) UK	Dietary and lifestyle personalised consultation (single session with mid-way support)	1 month	Prospective cluster-controlled	-0.4 kg/m^2 BMI. -0.9% BF. Significant dietary improvements although the control group did not undergo dietary assessment.
(Torre *et al.*, 2019)	N=28 (airport firefighters) Switzerland	Dietary and lifestyle group education (single session), personalised consultation (single session) and a cooking class.	1 year	Prospective intervention (no control)	No significant improvements in dietary behaviour or body composition.
(Waldman et al., 2019)	N=15 (men) USA	Carbohydrate restriction (< 25% of EI) and bodybuilding regime	4 weeks	Prospective intervention (no control)	Increased protein intake. -2.2% BF. Improved cardiorespiratory fitness and muscular endurance. Increased fat oxidation. Decreased carbohydrate oxidation. Reduced BP.
(Sotos-Prieto *et al.*, 2020)	N=48 (90% men) USA	Dietary and lifestyle educational sessions, videos, leaflet, tailored recipes and cooking demonstration, food	6 months	Prospective cluster-controlled	Modest improvement in medium-VLDL cholesterol esters.

		samples and healthy food supermarket discount coupons.			
This study	N=89 (97% men) UK	Dietary and lifestyle group education (single session), personalised consultation (single session), environmental modification.	4 months	Prospective cluster-controlled	-0.5 kg/m^2 BMI. -1.7% and -2 kg BF. -1.7 cm WC. Reductions in intakes of energy, fat, SFA, sodium, sugars, preserves and snacks. Wellbeing indicators also improved.

§ Some significant variables. Abbreviations: BMI, body mass index; BF, body fat; WC, waist circumference; SFA, saturated fatty acids; GI, glycaemic index; MetS, metabolic syndrome.

Feasibility

The vast majority of firefighters invited to participate welcomed the opportunity to benefit from evidence-based nutrition guidance from a trained professional. Those who actively opted out (*n*=5), constituted a negligible proportion of the recruited sample. Those who later actively dropped out (*n*=4) constituted 4% of the final data set. This was due to subject fatigue however this was still considered to be an acceptably low dropout rate. This indicates strong demand for this intervention, which is consistent with USA research reporting 75% of firefighters to be interested in learning more about healthy eating (Yang *et al.*, 2015), and 90% of firefighters being interested in attending "a lecture regarding proper diet and exercise and reducing heart attack risk" (Scanlon and Ablah, 2008). Indeed, the interactive lecture which was integral of this study's intervention focused heavily upon this exact theme and evoked positive interactions with firefighters, potentially contributing to the favourable outcomes discussed later in this Chapter.

This study's high enrolment may also be attributable to the researcher's extensive experience as a former firefighter, thus equipping him with advantageous rapport building and communication skills coupled with an intimate level of knowledge in terms of practicability and feasibility. For example, the level of intervention intensity and participant burden was designed in-part to minimise study opt-out. Furthermore, the intervention and follow-up sessions were scheduled during participant day shifts, as opposed to the FFIRE intervention study (Goheer, 2017) which involved firefighters attending several sessions outside of working hours. FFIRE had a mean enrolment of 23%, and on average firefighters attended 70% of the intervention sessions, compared with this study's enrolment of 98%. The downside of conducting sessions during working hours led to a mean attrition rate of 65 participants per follow-up. Due to the researcher's extensive previous exposure to fire-station life, the absence of a large proportion of participants at follow-up engagements was expected due to the dynamic nature of the London fire brigade which has an obligation to regularly send personnel to other fire stations which have a deficiency of personnel; on training courses and to emergency incidents. Furthermore, absence due to leave being taken, sickness/injury, light duties, transfer and retirement meant that a high attrition rate would be encountered due to this plethora of extenuating circumstances. For the study to withstand this amount of natural loss, a large initial sample was recruited at baseline to ensure sufficient statistical power to detect changes at each time-point. As the crux of the intervention was administered at the initial engagement, the desirable results can mainly be attributed to that initial session. This could suggest that similar results may have occurred for the personnel missed at follow-up, and further supports the intervention being administered within a single session as opposed to multiple sessions, particularly within a time-poor, dynamic and transient workplace which is characteristic of fire stations. Conversely, the USA FFIRE intervention study (Goheer, 2017) which conducted an educational intervention study comprising six sessions over an intervention period of six months suffered an aforementioned poor level of enrolment. However, this was not unusually low, as workplace interventions are generally below 50% enrolment (Robroek *et al.*, 2009), therefore the high participation rate in this study can be regarded as a major study strength. Post intervention, informal conversations between participants and the researcher yielded overwhelmingly positive feedback via personal gratitude expressed verbally directly to the researcher, and via email, examples of which can be seen in appendix 7.10.

<u>Impact on body composition and anthropometry</u>

At one-month post-intervention, mean BF% and WC had reduced by 1.4% and 1.5 cm, which is further than the one-month 2017 pilot trial (Lessons and Bhakta, 2018). Conversely, BMI reduced further in the pilot trial compared with this study. Despite SMM not being measured in the pilot trial, these results show greater preservation of SMM for this study. Indeed, although not reaching significance, mean SMMI increased slightly post-intervention for the intervention group but not for the control group. This is an important finding due to the requirement of adequate muscular strength for firefighters to help resolve strenuous emergency tasks safely and effectively (Stevenson *et al*., 2017). Furthermore, the apparent rapid decline in firefighter SMM between the ages of 48 and 62 y which is indicated in the Chapter 4 study, drew the conclusion that an intervention which preserves SMM for firefighters is very much required for an aging workforce who are not tested for muscular strength or SMM during routine periodic medical or physical fitness tests. The observed preservation of SMM persisted at four and at nine months post-intervention, whilst FM decreased further. Intervention educational content which could have contributed to this preservation, included advice on the GIS emphasizing the importance of undertaking resistance exercise a minimum of twice per week. Furthermore, one of the four CPAQ items assesses muscle strengthening activity. If an intervention group firefighter reported less than two days per week for this item, the researcher (a registered nutritionist with specialisms in public health and sports & exercise) reinforced the health implications of sufficient SMM followed by discussing a personalised strategy to increase this type of physical activity. This further justifies the utilisation of the CPAQ as opposed to, for example, the more strongly validated short-form international physical activity questionnaire (IPAQ-SF) (Lee *et al.*, 2011) which does not feature an item to specifically measure muscle strengthening activity.

The firefighter nutrition intervention trial most comparable with the present study is the FFIRE study (Goheer, 2017). At six-month follow-up, the FFIRE intervention group had reduced BMI by 0.8 kg/m^2. Whilst their reduction is greater than observed in this study, both BF% and WC reductions observed in this study at four-month follow-up were 0.7% and 0.4 cm greater than the reductions reported by FFIRE at six-month-follow-up. This again highlights the beneficial effect of this intervention, not only in terms of FM reduction, but also in terms of SMM preservation, which appears to have been overlooked by comparable studies. Furthermore, greater reductions in adiposity were observed for the FFIRE study control group compared with the FFIRE study intervention group at both six and twelve-month follow-ups. It can therefore be argued that this intervention outperformed FFIRE in terms of body composition improvement.

The PHLAME study (Elliot *et al*., 2007) measured changes from baseline at one year, therefore direct comparisons with this study should be made with caution due to study heterogeneity in terms of timing of follow-up measurements as well as the outcomes which were measured. BMI was the only anthropometric/body composition outcome to be revealed despite PHLAME declaring to measure adiposity via skinfold thickness. It is therefore impossible to assess body composition changes elicited by PHLAME. At one-year post-baseline, BMI increase was significantly attenuated for both PHLAME intervention arms but not for the control arm, therefore it is arguable that the PHLAME intervention was outperformed by this study's intervention.

<u>Impact on dietary behaviour</u>

Energy intake reduction and portion control strategies were an overarching theme of the intervention, which can account for the significantly reduced post-intervention energy intake reported by the intervention group. This is particularly important for firefighters due to research indicating excessive meal portions to be the cultural norm at fire stations (Haddock *et al*., 2011; Jahnke *et al*., 2012; Dobson *et al*., 2013). Reinstating smaller meal plates at the intervention stations was an environmental modification which was initially suggested by the researcher during the group education session along with leaving leftovers in the kitchen and drinking a glass of water immediately prior to each meal. These suggested modifications may also have contributed to the reported decreased energy intake, which is consistent with a review of worksite programmes which provided evidence for the efficacy of environmental modifications upon dietary intake improvements (Engbers *et al*., 2005).

The most comparable firefighter intervention study to comprehensively measure dietary changes was the FFIRE intervention (Goheer, 2017). At six-month follow-up, the FFIRE intervention group reported a significant reduction in energy intake of 363 kcal/d, compared with the intervention group of this study at four-month follow-up: 244 kcal/d significant reduction. However, the FFIRE control group reported an even greater significant reduction of 578 kcal/d, as opposed to this study's control group reporting no significant change.

The significant reduction in total fat intake for this study's intervention group was the main contributor to the concomitant reduction in total energy intake, and is consistent with a systematic review of workplace dietary interventions which identified regular post-intervention dietary fat intake reductions of up to 9% (Mhurchu, Aston and Jebb, 2010). Educational components of the intervention pertaining to fat intake focused upon saturated fat (SFA) reduction. At four-months post-intervention the observed significant reduction in SFA intake (-5 g/d) is consistent with the UK pilot trial (-3.5 g/d) (Lessons and Bhakta, 2018), and comparable with the FFIRE intervention group (6.2 g/d), however, once again the FFIRE control group greatly outperformed its intervention group (Goheer, 2017). The reduction in SFA and total fat intakes recorded in this study translated to a reduction in SFA and total fat as expressed as a percentage of total energy intake, bringing SFA down from 13.3% to 12.5%, and total dietary fat down from 36.8% to 35.7%. This reduction could be particularly important for firefighters due to their increased risk of CHD and MI (Kales *et al*., 2007; Tierney *et al*., 2010; Hunter *et al*., 2017).

The significant reduction in sodium intake for this study's intervention group brought reported intake to below the maximum recommended daily limit. Again, salt reduction was emphasised within the intervention, which may account for this result. The FFIRE intervention group reported a greater reduction in sodium intake, however, once again the control group reported a far greater reduction (Goheer, 2017).

This intervention's greatest emphasis was placed upon free sugars and 'unhealthy snack' reduction. Sugars, preserves and snack intake reduction was the only dietary intake variable to reach significance at 9 months post-intervention within the smaller subsample of seventeen intervention firefighters, indicating that interventional components aimed at reducing intakes of those foods were indeed adhered to. This result is further supported by post-intervention reduction in the amount of intervention group firefighters reporting to snack in the evening after their final meal of the day, although the only significant improvement was detected at one-month post intervention for snacking at home. This could be attributed to advice to avoid snacking on confectionary after the final meal and to consider avoiding energy intake until breakfast the following morning to help lose body fat and potentially improve metabolic health (Hawley, Sassone-Corsi and Zierath, 2020). This dietary improvement is particularly important for firefighters due to sleep deprivation being associated with increased snacking on confectionary (Atkinson *et al*., 2008; Nedeltcheva *et al*., 2009), which is a characteristic endemic of fire stations (Haddock *et al*., 2011; Jahnke *et al*, 2012; Dobson *et al*., 2013). Furthermore, significant improvement in snacking behaviour transcended the fire station, showing the effects of the intervention to translate to home life. This finding is consistent with the FFIRE trial which also reported improvements in the home food environment (Goheer, 2017).

Lack of a significant increase in fruit and vegetable intake was not unexpected given the above average baseline intakes (5.3 portions/d), which is comparable to baseline fruit and vegetable intake reported by UK firefighters in a pilot study (Lessons and Bhakta, 2018) and USA firefighters in the PHLAME trial (Elliot *et al*., 2007). Whilst this study found no significant change, mean vegetable intake was lower and mean fruit intake was higher at post intervention follow-ups. Interestingly, the FFIRE intervention followed the same pattern, however the differences were significant. The reduced vegetable intake is also consistent with this study's predecessor pilot trial (Lessons and Bhakta, 2018), but inconsistent with a review suggesting that dietary interventions generally elicit increased intakes of fruit and vegetables (Mhurchu, Aston and Jebb, 2010). This may be due to the predominantly male sample, as there is evidence to suggest that men can find vegetable intake more difficult to improve compared with other food groups (Collins *et al*., 2011). This may also account for no significant change in total fibre intake. It is of course possible that vegetable intakes were misreported. A review of the design, validation and utilisation of FFQs found that vegetables and related nutrients are particularly difficult to assess using an FFQ (Cade *et al*., 2004). The review suggested that misreporting of vegetables may occur for several reasons such as the double counting of vegetables that may or may not appear within composite meals, or social desirability bias. It is indeed possible that overreporting of these healthy food groups occurred at baseline due to social desirability bias (Worsley *et al*., 1984), which could have subsequently diminished the ability to detect significant change.

<u>Impact on physical activity</u>

Although not significant, reported mean physical activity increased much more so for the intervention group compared with the control group. Similar to fruit and vegetable reporting, baseline physical activity reporting may have been subject to social desirability bias (Worsley *et al*., 1984), thus potentially leading to overreporting which may have reduced any detectable significant differences from baseline. This is likely to be exacerbated in an occupational group who are expected to maintain a relatively high level of physical fitness. Unknown levels of error and bias could also have been generated by the CPAQ which, whilst it has been used to measure the physical activity of firefighters (Sliter and Sliter, 2014), they were based in the USA, therefore this physical activity assessment tool has not been validated for use on UK firefighters. Similar to dietary assessment, the accurate measurement of human physical activity in a free-living environment is difficult (Elia *et al*., 2003). Debate exists in this area of behaviour change, and therefore drawing solid conclusions regarding the impact of physical activity interventions is a recurring challenge (Vuillemin *et al*., 2011). However, a systematic review by Dugdill *et al*. (2008) provided evidence of physical activity improvement via counselling, although this is often of limited efficacy (Whitlock *et al*., 2002; Conn *et al*., 2009).

Another potential reason for a lack of significance could be the fact that the intervention focused more heavily on diet and nutrition than physical activity as it was judged that this was the area of greatest confusion and most in need of being addressed. Furthermore, many firefighters are personal trainers and gym users therefore the emphasis on physical activity may have been lacking within this intervention due to the researcher's perception of it being a reduced need. The crux of the physical activity information was therefore confined to the GIS, which was also given to control group participants. The GIS recommended participants to take thirty minutes of moderate exercise five days per week to obtain health benefits. This may constitute a relatively conservative level of physical activity for an occupational group who are likely, given the nature of the firefighting role, to exercise more than the general population. The same issue was also reported in the PHLAME firefighter intervention, whereby researchers suggested that the physical activity intervention component was not given the emphasis required to elicit significant behaviour change (Elliot *et al*., 2007).

A final potential reason for non-significant improvement could be a prevailing lack of managerial encouragement to use the fire station gym whilst on shift. This has been identified in USA fire stations (Dobson *et al*., 2013) and may be reflected in the LFB. As emergency calls have reduced over time (Home Office, 2020), more administrative work has been placed upon fire crews, which may have marginalised the time, freedom and encouragement given by managers to use the gym on-shift. Despite on-shift gym usage recently becoming a mandatory LFB policy, informal discussions between the researcher and firefighters suggested that this mandate has not been facilitated with the provision of adequate facilities, equipment, time, freedom or encouragement, all of which may have reduced motivation. In an attempt to ameliorate this potential barrier, during the group education (presentation) element of the intervention, the researcher carefully addressed this subject by educating the watch on the qualitative research identifying managerial influence to be one of the themes driving firefighter obesity (Dobson *et al*., 2013). This was done both to raise awareness of this potential barrier and to encourage the officers in the room to prioritise the health of their watch by helping to encourage on-shift gym usage.

Impact on mood and energy levels

This intervention improved reported mood and energy levels significantly, which is consistent with the most comparable intervention study to measure firefighter wellbeing (PHLAME) (Elliot *et al*., 2007). Heterogeneity between the two studies precludes a direct comparison, however, the significant improvement in this study suggests overall wellbeing improvements to be greater than reported in PHLAME. Whilst many physical health promotion benefits may take longer to manifest, research has linked workplace health promotion programmes with more immediate improvements in employee mood, productivity and wellbeing (Mills, 2005). This is especially important due to the occupational exposure of firefighters to high levels of psychological stress (Duran, Woodhams and Bishopp, 2018; Rodrigues *et al.*, 2018).

Study strengths

This study represents the first controlled dietary intervention trial for firefighters in the UK, adding to a sparse evidence base. Furthermore, it was designed as a prospective cluster-controlled trial, which has been identified as a gap in the literature of firefighter interventions (Poston *et al*., 2013). Participants were blinded to group allocation, which resulted in control group participants regularly indicating to the researcher that they believed themselves to be receiving an intervention. This was facilitated by the cluster control condition of separate fire stations, thereby reducing the possibility of control group contamination via awareness of different treatment administered to the intervention group station participants. Furthermore, control group fire stations were generally chosen to be based further away geographically from intervention group stations.

The intervention encompassed active learning and involved interactive group discussion. These were suggested as mediating mechanisms for the successful outcomes of the PHLAME intervention trial (Ranby *et al*., 2011), and are likely to have contributed to the successful outcomes of the current study. Furthermore, the initial rapport built between the researcher and the intervention group watches is likely to have facilitated the positive interactions which followed. This is likely to have been supported by the prior experience of the researcher as a professional firefighter, thereby providing valuable in-depth knowledge and empathy regarding the physiological and psychological stressors faced by firefighters, the practicalities and routines of fire station life, and how all of this interplays with firefighter dietary behaviour.

This study utilised a range of objective measures, and although self-reported measures were required, they included the first ever FFQ to be validated specifically for the dietary assessment of UK firefighters. To the best of the researcher's knowledge this is also the first study to assess the impact of a dietary and lifestyle intervention upon the SMM of firefighters, which resulted in the desirable outcome of reduced adiposity whilst maintaining SMM. Indeed, this intervention arguably outperformed the two most comparable interventions (Elliot *et al*., 2007; Goheer, 2017) across a variety of parameters. This low burden and low intensity intervention yielded high enrolment and low dropout. It was also low cost compared with other intervention modalities such as motivational interviewing (Elliot *et al*., 2007), all of which supports the scalability of this intervention for organisational rollout.

<u>Study limitations</u>

Similar to the FFIRE study (Goheer, 2017), the sampling strategy for this study involved fire stations not being randomised to intervention and control groups, but instead being assigned by the researcher. The high level of enrolment and low level of active dropout helped decrease selection bias and increase representativeness. Indeed, every effort for obtaining a representative sample was made by ensuring an even spread of urban and suburban fire stations within each group, along with homogeneity of workload in terms of no significant difference in emergency call volume between groups. As previously stated, the cluster-controlled condition was necessary to minimise the chances of group contamination, as was the distance between intervention and control group stations. Despite the measures taken to minimise inter-group heterogeneity, and despite the total sample being representative of the LFB in terms of demographic and anthropometric baseline characteristics, at baseline the intervention group possessed significantly more body weight and fat, whilst reporting significantly lower mood and energy levels. Whilst this constitutes a limitation of this study, the firefighters in greatest need of an intervention were the ones who received it.

The low energy intakes recorded by the FF-FFQ are consistent with the FFIRE intervention (Goheer, 2017) and were not unexpected, as discussed in detail in Chapter 5. Briefly, even though absolute dietary intakes were underreported, the FF-FFQ was never designed to accurately measure dietary intake, but instead to be used as a screening tool to identify high and low intake frequencies of certain foods, and also to be used to detect changes elicited by an intervention, both purposes of which it fulfilled. Indeed, due to its purpose of pre-post relative dietary assessment, problems associated with underestimation are theoretically minimised.

Similar to the limitations of the CPAQ which have already been discussed, the ten-point lickert scales used to assess perceived mood and energy levels were not validated for this population group, therefore their validity for accurately assessing these parameters of wellbeing of firefighters is unknown. Even so, the significant improvements in self-reported mood and energy elicited by this intervention were associated with significant dietary and body composition improvements. This is consistent with research finding that improvements in dietary behaviour and body composition are associated with improved mental health (Ellulu *et al.*, 2016; Jacka *et al.*, 2017; Tolkien, Bradburn and Murgatroyd, 2019).

The Coronavirus global pandemic precluded complete data collection at nine months post-intervention. This resulted in yielding an insufficient amount of control group data and a limited amount of intervention group data for this timepoint, therefore no solid conclusions can be drawn regarding intervention impact post-four months. Even so, the significant improvements in the limited subsample of intervention group participants seen at nine months are consistent with those seen at four months, and therefore suggest that the favourable effects of the intervention persisted at nine months. This suggestion is supported by the fact that the participants who were seen before study curtailment were random, as opposed to the remainder of a sample who actively dropped-out. Furthermore, research indicates that habits are formed and behaviour automaticity plateaus on average at around 66 days following the first regular performance (Gardner, Lally and Wardle, 2012), therefore in this study, the significant dietary behaviour changes and concomitant improvements in body composition, mood and energy observed at four-months (120 days) post-intervention arguably became ingrained habitual behaviours, further supporting the durability of the intervention outcomes. Whilst this study was able to detect significant changes in several dietary variables, adiposity and indicators of wellbeing, a future trial with a larger sample size would provide greater statistical power to detect a more modest effect size. An *a* priori sample size calculation will be determined ahead of any future trials.

Conclusion

This study has shown that a low-cost, low-burden and low-intensity worksite dietary and lifestyle intervention comprising group education and personalised nutrition is effective for improving dietary behaviour, body composition and indicators of wellbeing for firefighters. The intervention's high level of feasibility renders it appropriate for organisational rollout.

Chapter 8. General Discussion

8.1. Overview

This chapter discusses the practical applications of how the novel nutritional assessment tools and interventions work together as an integrated system. Intervention strategies are suggested to offer health professionals a practical guide regarding the interpretation of the firefighter centile cut-offs. Several scalability and rollout options are suggested for consideration of UK fire and rescue services (FRSs). The interventions within this thesis arguably outperformed the four most comparable published firefighter nutrition intervention trials. The likely concomitant health improvements are therefore likely to yield a substantially greater return on investment, which has been estimated to be 5:1 yielded by a comparable USA intervention of arguably less efficacy. The general strengths throughout this thesis include original contributions to knowledge, external validity of the assessment tools and interventions for use in other UK FRSs, and the cluster-controlled study design which harnessed teamwork and group cohesion which is characteristic of this occupational group. The general limitations included the unpredictable and dynamic nature of fire stations, which presented some challenges in terms of participant availability. This informed the decision to pre-allocate the clusters to either the intervention or control arm of the study, as opposed to randomisation. Finally, future research directions are discussed, including national level research.

8.1.1. <u>Phase 1. Investigate firefighter misclassification generated by BMI</u>

Chapter 3, entitled 'The validity of BMI for classifying UK firefighter adiposity status', quantified the prevalence of overweight/overfat and obesity in LFB firefighters, achieving its objectives by clearly showing the differing prevalence levels across a variety of indices. It also comprehensively showed the varying levels of misclassification generated by BMI. When comparing the results with results of the most comparable USA firefighter study (Choi *et al*., 2016), combined prevalence of overweight and obesity quantified by BMI was identical for male firefighters (80.4%). However, differences clearly existed between studies in terms of body composition, whereby mean BF% was measured to be higher in this study, however, mean WC was measured to be higher in the USA study. This highlights the complexities of body composition and the limitations of BMI which is intrinsically blind to adiposity and skeletal muscle. Both studies concluded that BMI generated unacceptable levels of misclassification rendering BMI to be an assessment tool of poor validity. The only comparable UK study prior to this was conducted by Munir *et al*. (2012) which solely quantified prevalence of overweight and obesity (using BMI) within a county UK fire brigade at two timepoints. Whilst that study looked at BF% and WC, misclassification and validity of BMI was not investigated, furthermore, the study only assessed male firefighters. As such, the study presented in Chapter 3 is the first in the UK to assess the adiposity of female firefighters, using the largest sample of female firefighters in any study globally. It is also the first female firefighter study globally to assess the levels of misclassification comparing BMI with a range of adiposity indices. The main limitation of the study was that only white firefighters comprised the sample due to a lack of ethnic diversity within the UK fire services (ONS, 2019). This study indicates a concerning level of adiposity for male UK firefighters.

8.1.2. Phase 2. Development of UK firefighter body composition centile charts

The aim of developing a suite of white male firefighter body composition centile references was achieved firstly by collecting sufficient data to generate the charts displayed in Chapter 4. It was estimated that approximately five hundred participants would enable the creation of representative centile curves, along with an even dispersal of ages and a representative sample of firefighters. The sample was indeed deemed as being representative of the wider firefighting population, however, whilst participant age was evenly dispersed, a limitation of the study was a smaller number of firefighters within the lower and upper age ranges, although this is reflective of the UK fire service (Williams et al., 2013). The Cole and Green (1992) method reduces skewness, and there were roughly even numbers of firefighters within the lower and upper age groups, therefore the reference curves were deemed to have achieved their objective of providing a representative reference of firefighter body composition. The main limitation of the study was that insufficient data was available to generate gender and ethnicity specific references, however, this would involve a nationwide study to collect sufficient data for white female firefighters. Due to the lack of racial diversity within the UK FRSs (ONS, 2019), ethnicity specific references remain unfeasible. These were anticipated limitations which were beyond the scope of the current study to overcome, thus they were not objectives of the study. The most comparable body composition references were recently published by Lee *et al*. (2020) for UK white adults over 40 y of age. The references presented in Chapter 4 are the first of their kind for firefighters globally. They provide UK FRSs with an assessment of nutritional status which offers greater validity than the commonly used BMI and BF% classification systems, by overcoming the limitations intrinsic to both.

8.1.3. Phase 3. Development of a firefighter dietary assessment tool

The aim of developing and validating a firefighter dietary assessment tool was achieved in two stages. Firstly, via the dietary assessment of a representative sample of 180 firefighters using the EPIC-Norfolk FFQ (Bingham *et al*., 2001). A strength of this initial stage of the study was the number of FFQs completed which was toward the upper end of the range of respondents recommended for

FFQ validation studies by Cade *et al*. (2002), helping to obtain a representative sample. The second stage of the study involved the validation of the newly developed FF-FFQ against the reference measure of three multi-pass 24hr recalls. Strengths of the validation study included the inclusion of Bland and Altman analysis for testing the agreement between the FF-FFQ and the reference method. Furthermore, the FF-FFQ was tested for reproducibility, demonstrating a high level of precision. Both of these study strengths are often overlooked in FFQ validation studies within the literature (Cade *et al*., 2002; 2004). The FF-FFQ is the first for UK firefighters, and demonstrated an acceptable level of validity within the context of comparable validation studies (Flegal and Larkin, 1990; Procter-Gray *et al.,* 2017; Steinemann *et al.*, 2017), whilst meeting the minimum validation requirements stipulated by Cade *et al*. (2002) in a review of FFQ validation studies. The limitations of the study included the use of a retrospective reference method which suffers from similar sources of error and bias as the FFQ. However, the gold standard for dietary assessment of weighed food diaries (Livingstone and Black, 2003) was not feasible for administration within this population group due to participant burden and attrition concerns. Biomarker nutrient analysis on a subset of participants may have further validated the FF-FFQ, however, this too was unfeasible due to financial restrictions of the current study. Whilst there are a paucity of validated firefighter dietary assessment tools globally, the only comparable instrument is a short fifteen-item screener to assess adherence to a Mediterranean diet, producing a modified Mediterranean diet score (Yang *et al.*, 2014). This is a dietary quality score for USA firefighters as opposed to a comprehensive dietary assessment tool. The FF-FFQ is therefore the most comprehensive validated FFQ for firefighters globally. When utilised within the fire station intervention study (Chapter 7) the FF-FFQ performed very well, enabling efficient and effective dietary screening, and comprehensive detection of significant dietary intake changes over time whilst not overburdening participants.

8.1.4. Phase 4. Creation and implementation of a kitchen-based cookery workshop for mess-managers

The objectives of this study were to design and test the efficacy and feasibility of a fire station mess kitchen-based practical cookery workshop and accompanying healthy recipe cookery book. These objectives were met utilising the high level of nutrition training possessed by the researcher, as well as the valuable experience deriving from the researcher being a former professional mess-manager himself. These strengths facilitated the successful design and organisation of the workshops, which demonstrated high feasibility in terms of the very high study enrollment rate and overwhelmingly positive participant feedback. In terms of efficacy, this controlled intervention study demonstrated that the workshops significantly improved the fire station food environment across several modifiable parameters. A limitation of the study was the small sample of mess-managers which may have reduced statistical power to detect some of the non-significant improvements. Similar to the prior intervention (see section 8.1.5), the nine-month follow-up data collection was reduced due to the Covid-19 pandemic, therefore the long-term sustainable effects of the workshops are unknown, however the limited data which was collected for *n*=8 of the intervention watches suggested that beneficial changes had been maintained. Further research would be required to ascertain the long-term durability of the beneficial environmental modifications elicited by the intervention. The most comparable study is the FFIRE study (Goheer, 2017). Results of the FFIRE intervention showed equivocal/greater improvement for the control group compared with its intervention group. Enrollment and attrition were also poorer for FFIRE compared with the present study. Along with the lower intensity and lower financial expense of the present study, it is arguable that this study outperformed FFIRE both in terms of feasibility and efficacy. Furthermore, this study represents the first fire station-based cookery workshop intervention for the UK fire services.

8.1.5. Phase 5. Development and implementation of a fire station dietary and lifestyle intervention programme

The aim of this study was to develop a feasible fire station-based dietary and lifestyle intervention programme and to test its efficacy in a cluster-controlled trial. This work built upon the pilot trial by the authors (Lessons and Bhakta, 2018), firstly by introducing a group based educational component. This can be considered as a study strength due to the importance of group dynamics characteristic of firefighting watches, which is discussed in greater depth later on in this chapter. Other enhancements upon the pilot trial included the use of the dietary assessment tool validated for UK firefighters, and the sophisticated analysis of body composition utilising a high grade analyser of relatively high accuracy (Verney *et al*., 2015). Previous fire station-based health interventions have generally utilised inferior equipment, and very few of them have utilised a dietary assessment tool validated for firefighters. The exception to this is a firefighter dietary intervention trial named 'Feeding America's bravest' which is yet to be published (Sotos-Prieto *et al.*, 2017), which utilised the modified Mediterranean diet score short questionnaire for firefighters (Yang *et al.*, 2014).

In terms of efficacy for improving dietary behaviour, the intervention (Chapter 7) demonstrated a high level of efficacy compared with the most comparable fire station-based controlled interventions i.e. PHLAME (Elliot *et al*., 2007) and FFIRE (Goheer, 2017). Limitations of the study included a relatively small sample size compared with PHLAME and FFIRE, and a relatively short study duration caused by extenuating circumstances in the form of the Covid-19 global pandemic which precluded complete data collection at the nine-month follow-up. However, the data which was collected at the nine-month mark was consistent with the significant beneficial improvements in dietary intakes, anthropometry and body composition observed at four-months post intervention. A further study strength was the assessment of skeletal muscle, which has been overlooked by previous firefighter intervention studies. This demonstrated that the intervention elicited a significant reduction in mean body fat without loss of muscle. This further demonstrates the efficacy of the intervention, particularly for firefighters who require greater muscular strength and endurance to safely and effectively perform firefighting tasks (Stevenson *et al*., 2017). This represents the first controlled UK firefighter dietary and lifestyle intervention study.

8.2. Practical applications

8.2.1. An integrated system

Each of the preceding chapters documents the necessity and the development of novel tools for the accurate assessment of UK firefighter nutritional status as well as novel dietary and lifestyle interventions for the improvement/maintenance of firefighter health. The studies represent: the world’s first suite of body composition references for UK white male firefighters; the first dietary assessment tool (FF-FFQ) validated for UK firefighters; the UK’s first comprehensive multi-component fire station-based dietary and lifestyle intervention programme.

Whilst the tools and interventions can be used exclusively of one another, they were designed to work in harmony as an integrated system. In a time-poor environment with ever-increasing administrative responsibilities being expected of fire crews, the tools and systems which are the product of this research enable fast and efficient assessment of firefighter nutritional status which is encompassed within a low-intensity, low burden intervention. The temporal order of intervention components were designed to cause minimal disruption to the daily fire station routines, whereby the researcher (a registered nutritionist) would time the group educational component to take place at a time of day when (a) other activities such as mealtimes, gym usage, fire safety inspections or other administrative tasks would not be displaced/disrupted, and (b) at a time of day (11:00 am) when fire crews were more likely to be enthusiastic and less likely to be fatigued. Once this component was finished, the personalised one-to-one consultations required only one firefighter to participate at any given time, allowing the rest of the watch to undertake other duties. Furthermore, the FF-FFQ and body composition reference system now enable a faster assessment of nutritional status, thereby reducing the amount of time necessary to effectively advise each firefighter on a personalised level. The FF-FFQ, CPAQ and general health questionnaire also provide a rich source of information which is easy to analyse at a glance (for a trained nutritionist). For the wealth of dietary, lifestyle and health information yielded from these three questionnaires, the average time for completing all three is approximately fourteen minutes, which further enhances the efficiency of the overall process.

8.2.2. Broad potential intervention strategies

Table 8.1 displays the proposed FMI cut-offs and corresponding broad potential intervention strategies which could be considered by health professionals when using the FMI centile curve references during body composition assessment. WHtR has been included within the Table as an indicator of early health risk because it is recommended as providing an assessment of potentially greater validity than BMI and WC, as suggested by the results of Chapter 3, and as recommended by Ashwell and Gibson (2016).

Table 8.1. FMI/WHtR cut-offs and corresponding suggested broad intervention strategies

FMI centile/WHtR range	**Definition**	**Intervention**
< 2nd	Under-fat	Dietary consultation with a specialist dietician/nutritionist
>2nd and ≤ 50th / < 0.5	Healthy	None
> 50th and ≤ 85th	Early alert	Educating the firefighter that they are above average adiposity; Dietary and physical activity advice; Encourage use of fire service online wellbeing resources.
> 85th and ≤ 95th / 0.5-0.59	Overfat / High risk	Educating the firefighter on the health implications of obesity; Dietary and physical activity advice; Encourage use of fire service online wellbeing resources; Raise awareness of support services and show them that they are close to mandatory improvement.
> 95th and ≤ 98th / ≥ 0.6	Obese / Very high risk	Intensive support; Educating the firefighter on the health implications of obesity; Dietary and physical activity advice; Encourage use of fire service online wellbeing resources; Referral to support services; Mandatory improvement begins.
> 98th / ≥ 0.6	> Class 1 obese / Very high risk	Dangerous level of adiposity therefore consideration needs to be given regarding their fitness for operational duties; Intensive support; Educating the firefighter on the health implications of obesity; Dietary and physical activity advice; Encourage use of fire service online wellbeing resources; Referral to support services; Mandatory improvement required.

Abbreviation: FMI, fat mass index; WHtR, waist-to-height-ratio

8.2.3. Scalability and rollout options

The integrated system was also developed with financial expense in mind, as the emerging financial climate and concomitant financial restrictions placed upon UK FRSs dictates the requirement for efficient and financially viable solutions to complex problems. As such, potential scalability and rollout options are outlined below.

8.2.3.1. Phased rollout

This approach provides a low-cost option, requiring a single registered nutritionist to systematically rollout the intervention across all watches within an FRS. Fire stations/watches identified as having the highest number of cardiovascular risk factors/sickness absences could be addressed initially to help improve the health of those personnel most requiring assistance, before rolling out to other lower risk areas of an organisation, thus adopting a phased approach. To help maintain beneficial intervention effects over the longer term, periodic 'refresher' interventions could be implemented on a rolling basis. This has been suggested as a solution to avoid regression of healthy behaviours which has been observed to occur over the long term following previous fire station-based health interventions (Carey *et al*., 2011; Ranby *et al*., 2011; MacKinnon *et al*., 2010). Furthermore, the bond and trust formed between service users and a health professional is suggested to be a contributing factor in terms of continuity of care resulting in improved health outcomes (Freeman and Hughes, 2010), therefore using the same nutritionist who has gained the trust and professional respect of firefighters over the long term could provide added benefit.

8.2.3.2. Targeted approach

This approach involves targeting the high-risk watches/stations only. As such, the watches identified as being relatively healthy would not benefit from the intervention. Whilst this approach represents the lowest cost option, it must be remembered that firefighters of a healthy weight still benefit from nutrition education. Indeed, nutrition is a continually-evolving discipline with arguably no other area of science more fraught with misinformation which can of course adversely influence dietary beliefs and behaviours, potentially leading to future health being compromised (American Dietetic Association, 2006). As established in earlier chapters, firefighters gain weight at an accelerated rate, therefore overweight and obesity prevention should not be overlooked. Furthermore, throughout the course of the intervention study, many firefighters began consuming oily fish and supplementing with vitamin D as a direct result of the recommendations from the nutritionist. The health benefits from dietary improvements such as these should also not be overlooked, as whilst a firefighter possessing a healthy body composition is at reduced risk of CVD (Donoghue and Bates, 2000; Chung and Pin, 1996; Choi *et al*., 2016), the occupational exposures specific to firefighting, still increase the risk of cardiac events, injury and other NCDs (Smith *et al.*, 2016; Hunter *et al.*, 2017; Kales and Smith, 2017). Optimal/adequate nutritional status in terms of hydration, macro and micronutrient status is likely to reduce the risk of such issues (Hunter *et al.*, 2017; Li *et al.*, 2017; Abdelhamid *et al.*, 2020). This observation is shared by the authors of a recent USA firefighter dietary intake study which identified widespread high intakes of sodium and inadequate intakes of several micronutrients (Johnson and Mayer, 2020). The authors cited Kuehl *et al.* (2013) who recommended education as a means of improving nutrient intakes within firefighter populations. If the targeted approach was the only viable option, or an interim arrangement during a financially challenging period, then this option could be bolstered by also offering the intervention to watches who proactively request the service, which occurred numerous times throughout the study period. Rolling refresher intervention sessions would likely help preserve beneficial intervention effects.

8.2.3.3. Phased rollout or targeted approach augmented with multiple body composition analysers for self-monitoring and feedback to a registered nutritionist

Following initial interventions, multiple analysers could be provided at strategic locations within the fire service for self-monitoring and feeding-back body composition data to a centrally based registered nutritionist. A systematic review by Bankhead *et al*. (2003) reported that screening alone can have a favourable impact upon healthy behaviours. If used in combination with the fire station intervention, this would likely help to sustain beneficial intervention effects over the longer term. In this context, regular body composition analysis could behave as a motivational tool via feedback to individual firefighters as well as a nutritional surveillance system when fed-back to a health professional. As emphasized in Chapter 7, the importance of rapport building and education prior to the delivery of body composition analysers should not be circumvented, as this is a crucial initial step which, if overlooked may lead to resistance, especially within an institution which has been identified as being culturally resistant to change (Jahnke *et al.*, 2012; Torre *et al.*, 2019).

8.2.3.4. National approach

This enables a scalable rollout on a national level. Wellbeing officers employed within UK FRSs can be trained to carry out the programme. This is facilitated by a growing number of registered nutritionists being employed in UK FRS Wellbeing teams around the UK, as they are trained to understand the complexities and evidence-based science underpinning this programme (Association for Nutrition [AfN], 2020).

8.2.4. Mess-manager cookery workshops

The fire station mess kitchen-based practical workshops showed high feasibility and efficacy when undertaken with groups of approximately six mess-managers. This number of participants was informed by previous research outlined in Chapter 6, as well as the researcher's judgement which factored in the size of LFB mess kitchens. This number of mess-managers facilitated an environment conducive to group cohesion, active participation in terms of sharing of ideas/experiences as well as active involvement in the practical aspects of food preparation. This relatively conservative number of personnel (compared with other LFB courses) did not impact adversely on staffing levels and did not create any issues regarding fire cover. It is therefore recommended that periodic workshops are undertaken by a registered nutritionist and offered to mess-managers following the primary intervention. This temporal order of intervention components is important due to the initial primary intervention providing the theoretical knowledge which underpins the mess-manager workshop syllabus content. Once again, mess-managers are more likely to want to participate in the workshop once rapport between themselves and the nutritionist has been built. Furthermore, they are more likely to value the workshop following demonstration of the importance and impact of nutrition upon health. This desire for improvement to the fire station food environment has to come from the mess-managers themselves rather than mandatory imposition of a training course if the fire service is to achieve the desired paradigm and cultural shift toward a healthier worksite food environment. The practical nutritional concepts learned in the workshops will then have a greater chance of being practiced, and the mess cookery book will have a greater chance of being valued and utilised by mess-managers upon returning to their watches. It is proposed that this order of intervention components will produce the greatest efficacy in terms of reproducibility of the food environment improvements reported in Chapter 6.

Whichever option or combination of options is/are adopted by FRSs, it is strongly advised to use the skills and rigorous scientific knowledge of a nutritionist who is registered with the Association for Nutrition (AfN) which regulates the UK Voluntary Register of Nutritionists (UKVRN). The UKVRN is the only register of qualified nutritionists recognised by Public Health England, NHS Choices and NHS Careers. UKVRN registrants are distinguishable by the post nominal letters: ANutr or RNutr ('Registered associate nutritionist' or 'registered nutritionist' respectively). This ensures a high level of evidence based training and mandatory adherence to a strict code of ethical conduct which is designed to protect the end user (AfN, 2020).

8.3. Health improvements

The most widespread fire station-based wellbeing programme globally is the North American 'Wellness Fitness Initiative' (WFI) reviewed in Chapter 1. A large cross-sectional study by Poston *et al*. (2013) (also reviewed in Chapter 1) found that, when compared with fire departments who had not adopted key components of the WFI, the fire departments which adopted WFI components comprised firefighters who exhibited a significantly leaner body composition and who were less likely to suffer from obesity (classified by any weight/adiposity measure). Furthermore, they were less likely to be hypertensive, exhibited greater levels of physical activity, superior cardiorespiratory fitness, considered themselves to be healthier, were less likely to be smokers, reported less anxiety, greater morale and satisfaction with their career, colleagues and employer. Although limited by its cross-sectional design, the study provides evidence of a scalable fire station-based health promotion intervention programme showing significant associations with the health and wellbeing of firefighters. Chapters 6 and 7 of this thesis show significant improvements to markers of firefighter health that go much further in terms of the focus on firefighter diet and nutrition compared with the WFI. Furthermore, this intervention arguably outperformed the most comparable fire station-based interventions by Elliot *et al*. (2007), Carey *et al*. (2011), Goheer (2017) and Torre *et al*. (2019). Further still, the overwhelmingly positive feedback of the intervention system presented in this thesis has received the recognition and governmental support from the Deputy Mayor for fire and resilience in London, the London Assembly at City Hall and parliamentarians at the House of Commons. It has also received non-governmental organisation recognition from the Caroline Walker Trust who awarded the programme coordinator (researcher) the title of 'Nutritionist of the Year 2019'. The programme also recently received recognition from 'Public Sector Catering' who announced the researcher as the winner of their Health and Nutrition Award 2020 'in recognition of good practice in the delivery of a clear health and nutrition strategy, encouraging the concept of eating for health within an organisation'.

8.4. Financial consequences of firefighter obesity

During 2018/19 there were a total of 2,646 firefighter injuries in England (Home Office, 2019). Jahnke *et al*. (2013) found obese firefighters to be 5.2 times more likely to suffer a musculoskeletal injury compared with healthy weight firefighters in a prospective cohort of 347 USA firefighters. A separate USA study by Poston *et al*., (2011) found BMI to be an independent predictor of injury-related absenteeism. After controlling for confounders, the study found that overweight firefighters were 2.6 times more likely to be absent from duty due to injury compared with firefighters of a healthy weight. This odds ratio increased to 2.7 for class 1 obesity and to 4.9 for class 2 and 3 obesity. This translated to estimated annual financial costs of $74 per overweight firefighter, $254 per class 1 obese firefighter and $1,683 per class 2/3 obese firefighter. The authors concluded that these were conservative estimates and were therefore likely to underestimate the true financial burden (Poston *et al.*, 2011).

Kuehl *et al*. (2012) followed this study by undertaking a secondary analysis of data from the PHLAME cohort (Elliot *et al*., 2007). Kuehl and colleagues assessed the frequency of worker's compensation injury claims filed by USA firefighters at baseline. The study found obese firefighters to report back injuries 6% more often than healthy weight firefighters. Indeed, back injuries were the most cited cause of compensation injury claims (35%) followed by knee/lower leg injuries (17%). There was also a significant difference between obese and healthy weight firefighters in terms of visits to a specialist (34% vs 13% respectively). The odds of filing a compensation injury claim were nearly three times greater for obese firefighters. This supports the findings of the study by Poston *et al*. (2011), and a prospective cohort study by Soteriades *et al.* (2008) which identified that each single unit increase in BMI was associated with a 5% increase of firefighter disability. Soteriades and colleagues concluded that fire station-based dietary and physical activity programmes should be supported by fire service leaders. It must be noted that the study by Poston *et al.* (2011) was conducted over one decade ago, therefore the financial impact figures are lower than they would be at the present time due to inflation.

8.4.1. Return on investment (ROI)

A common issue impeding the implementation and progression of health intervention programmes in the fire service is caused by the oversight of administrators who often favour short-term financial savings over longer-term ROI (Korre, Smith and Kales, 2018). However, for FRSs who are willing to adopt a highly feasible intervention programme of high quality, the ROI is likely to be substantial.

Indeed, a USA fire service report commissioned by the IAFF showed significant reductions in firefighter injury claims made by WFI firefighters compared with non-WFI firefighters (17% improvement), as well as fewer lost working days (83% improvement) (IAFF, 2008). Kuehl *et al.* (2013) evaluated the impact of the PHLAME intervention (reviewed in Chapter 1) upon firefighter compensation claims and medical costs. The study found significant reductions in compensation injury claims and medical costs following implementation of the intervention, and also when compared to similar fire departments without the intervention. This equated to an ROI of 4.6, which, considering the intervention's high intensity alongside the necessity of professional expertise involving twelve sessions of motivational interviewing undertaken by professionally trained counsellors, this was a relatively expensive intervention amounting to $600 to $1500 per firefighter depending on which arm of the intervention they were allocated to. It should be noted that the PHLAME study (Elliot *et al*., 2007) is thirteen years old therefore these costs would be far greater at the present time when accounting for inflation. As discussed in Chapter 7, the UK fire station-based dietary and lifestyle intervention programme of this thesis yielded arguably more beneficial results than PHLAME, and incurred a small fraction of the costs attributed to PHLAME, therefore it is suggested that the ROI of this intervention would be of substantially greater magnitude. This of course would require further research to quantify. Kuehl *et al.* (2013) noted that financial savings of the PHLAME intervention were underestimated as they did not include lost working days, pre-arranged overtime costs and backfill in their analysis. Indeed, several other added costs can be incurred from firefighter absence including training course cancellations, accident investigation and other administrative tasks.

8.4.2. Long term sickness absence reduction

Long term sickness absence (LSA) accounts for 75% of total costs associated with sickness absence in the UK (Henderson, Glozier and Elliott, 2005). A recent study by Choi (2017) identified a direct association with firefighter weight loss and reduced LSA, finding that over the course of one year, individual moderate weight loss (5-10% of baseline weight) via healthy behaviours i.e. improved diet and physical activity was associated with a significantly reduced risk of LSA. This amounted to around a 10% and 20% reduced risk compared with firefighters who maintained their weight or firefighters who gained moderate weight respectively. This difference is likely attributable to a reduction in the adverse effects of excess adiposity outlined in Chapter 1, including mental health improvements associated with reduced adiposity (Gariepy, Nitka and Schmitz, 2010; Davillas, Benzeval and Kumari, 2016). Indeed, USA Fire departments with wellness programmes have significantly less firefighters suffering anxiety disorders (Poston *et al*., 2013), And research supports a positive association between healthier dietary choices and improved mental health (Jacka *et al.*, 2017; Tolkien, Bradburn and Murgatroyd, 2019). The significant improvements in indicators of firefighter wellbeing which resulted from this UK firefighter dietary and lifestyle intervention programme will therefore likely yield financial savings which go beyond those associated with physical injury, illness and disability.

8.5. General Strengths

Chapter 3 represents the first study globally to comprehensively investigate the validity of BMI and WC for classifying female firefighter adiposity status, the first study in the UK to do the same for male firefighters, and the first study to quantify the adiposity status of female UK firefighters using a variety of indices. Chapter 4 offers practical solutions to overcome the poor validity of BMI for assessing the nutritional status of firefighters. These solutions represent the first suite of firefighter body composition references globally that will help reduce the widespread misclassification generated by BMI. Chapter 5 represents the first UK firefighter specific dietary assessment tool which enables the efficient, reliable and precise dietary assessment of an occupational group who face a multitude of obesogenic risk factors (Haddock, Poston and Jahnke, 2011; Jahnke *et al.*, 2012; Dobson *et al*., 2013). This performed very well during the intervention study of Chapter 7, and along with the body composition references, is externally valid for use in other UK FRSs. Chapter 7 represents the first UK fire station-based dietary and lifestyle, controlled intervention trial. The high feasibility and efficacy render it a highly viable and efficacious option for UK FRSs to improve/maintain firefighter health. Chapter 6 represents the first UK controlled trial to assess the feasibility and efficacy of a fire station mess kitchen-based practical cookery workshop and accompanying cookery book designed to educate and support mess-managers. This also indicated high feasibility and efficacy, and further enhances the intervention programme.

A major strength of the intervention study was the cluster-controlled study design, which was identified by Poston *et al*. (2013) as a gap in the scientific evidence base of firefighter interventions. The strengths of this study design are discussed in Chapter 7, however, the strengths of maintaining the fire station watch structure whilst delivering the group education component of the intervention go beyond those strengths. Indeed, cohesion and camaraderie are cultural traits of the fire brigade. It has been observed to be so important that it has actually been inversely associated with accident frequency due to familiarity, awareness and fire crew synchronicity improving the safety of firefighters (Driessen, 2002). Furthermore, team cohesion influences the general mood and paradigms of watches at the fire station in terms of enthusiasm, work pace, rest period activities, expectations, decisions and convivial mealtimes. Cohesion is facilitated upon the establishment of expectations, rules and agreements (Driessen, 2002), therefore cohesion is an important determinant of intervention adherence and success (Banes, 2014). The researcher of the present study engaged with many watches during the intervention study. A particularly cohesive watch stood out who were known for their strong interpersonal relationships, epitomising the powerful effect of group influence. This was demonstrated by the whole watch adhering to a ketogenic diet in support of one or two of the other firefighters who were attempting to lose weight. It should be noted that this diet was not advised by the researcher, however, this is a good example of the cohesive strength of some firefighting watches, and is consistent with qualitative research by Jahnke *et al*. (2012) in terms of firefighter cohesion in the fire station food environment.

Whilst it has been demonstrated that intrapersonal motivation is a key determinant of firefighter physical fitness (Staley and Weiner, 2011), the social framework defining individual watches and the fire service imposes multiple levels of influence which may determine behaviours regarding health improvement and disease risk reduction. These intra/interpersonal, organisational and hierarchical influences have been observed to affect firefighter behaviours regarding modifiable risk factors for health (Staley and Weiner, 2011). This was outlined in Chapters 6 and 7 in terms of the more health conscious firefighters often succumbing to the unhealthy influences of their peers at mealtimes (Haddock *et al*., 2011; Jahnke *et al*., 2012), and highlights the importance of harnessing group dynamics, intervening and educating at the group level as well as the individual level (Elliot *et al*., 2007; Torre *et al.*, 2019).

On many occasions during the delivery of the group-based PowerPoint presentation titled 'Nutrition and Health' (see appendix 7.4) within the intervention (Chapter 7), the researcher (presenter) noticed this complex interplay of social dynamics at work. Anecdotally it seemed that the watches who were most engaged and who actively participated in the presentation in terms of asking questions, were the watches who seemed to yield the best outcomes from the intervention. Furthermore, if the firefighter/officer with the greatest influence appeared engaged and interested, their enthusiasm and approval seemed to translate to other members of the watch. These 'influencers' were generally firefighters of a higher rank and/or older firefighters with more experience. Whilst this would require appropriate research to confirm, this anecdotal observation is consistent with research by Staley and Weiner (2011) which identified older firefighters to be more conscious of the importance of risk factors for CVD and MI, which was associated with increased motivation to ameliorate the risk via increased participation in physical exercise programmes. The same study found that the officers in charge who were disinterested in physical training and did not encourage their subordinates to exercise, presented an interpersonal barrier for their healthy behaviours. Within the present study, two polarizing examples of this managerial influence in action are consistent with Staley and Weiner (2011). The positive example was seemingly driven by strong leadership in terms of the clear admiration exhibited for a station officer from his watch. His support, enthusiasm and adherence to the intervention seemed to have a strong influence over his colleagues. This enabled environmental modifications to the watch mess in terms of amelioration of obesogenic behaviours (see Chapter 6). On a group level this may have contributed to some of the most significant improvements in dietary behaviour, anthropometry and body composition observed within the study sample. At the opposite end of the spectrum, a different watch had an officer in charge who was a smoker with obesity and expressed scepticism of the intervention. This leader's decision not to participate may have created a barrier for the watch's mess-manager to participate in the subsequent mess-manager workshop, which resulted in that mess-manager being the only invitee to decline. These polar-opposite examples of managerial influence resulted in opposing intervention effects, illustrating the position of influence held by watch officers regarding the health of their watches.

Until fire station-based intervention programmes for firefighter health improvement/maintenance are fully endorsed by leaders, and until they are incorporated as routine events, the healthy behaviours and benefits derived from interventions will be difficult to maintain in the long term (Carey *et al.*, 2011). Every opportunity for the successful outcome of such programmes should therefore be provided both at the organisational level and the fire station managerial level. At an organisational level, the provision of sufficient allocated time on duty, without interruption of other administrative tasks for personnel to use gym facilities to improve fitness and health was deemed as positive organisational and managerial support by Staley and Weiner (2011). Whilst LFB policy stipulates that time will be allocated for such physical activity, it may often be marginalised in favour of administrative tasks. Although not recorded, this was a common complaint fed back to the researcher by watches during group education sessions.

The efficacy of the intervention system alongside widespread staff acceptance of all intervention components, the desire for accurate assessment of nutritional status and the overwhelmingly positive feedback from firefighters regarding the programme are strong indicators of feasibility. Furthermore, other UK FRSs have approached LFB for information on how to implement the intervention system. This has begun a culture shift in the UK fire service which Jahnke *et al*. (2012) regarded as an institution which is uniquely resistant to cultural change.

Finally, a major strength underpinning the successful execution of all study components was the researcher's extensive experience as a former LFB firefighter and mess-manager in conjunction with being a registered nutritionist with specialisms in public health nutrition and sports & exercise nutrition. Firefighters are considered as industrial athletes (Poston *et al*., 2011), therefore this blend of specialist nutrition training was particularly well-suited to advise this occupational group. This overall combination of attributes and experience enabled effective communication and rapport building with personnel, and furthermore provided a uniquely intimate knowledge of the stressors and demands of firefighting, fire station life and its cultural nuances, shift work and how this all interplays with diet and nutrition.

8.6. General Limitations

The limitations of each individual study are discussed in Chapters 3-7. A general limitation was the unpredictable and dynamic nature of the fire brigade due to the fact that personnel can be mobilised to an incident at any given moment. This presented a challenging environment for a field researcher to operate within, sometimes resulting in incomplete data collection, which Brown *et al*. (2016) also noted as being a limitation resulting in incomplete data sets when conducting fieldwork at fire stations. This was mitigated to a large extent by the researcher carefully planning station engagements to coincide with pre-allocated training days, whereby the fire crew(s) were temporarily unavailable for emergency callouts to facilitate station-based training. When this was not possible, the researcher contacted the relevant LFB personnel department in advance of a station visit to request that the crew(s) be temporarily immobilised to facilitate the intervention/data collection. If this was not possible, the researcher attended the station as scheduled and worked around callouts by waiting for the crew(s) to return to the station following a callout. This involved a certain amount of judgement in terms of gauging the likely duration of an emergency incident. If it was deemed that the watch may be away from the station for a protracted period, the researcher rescheduled the visit for the earliest mutually convenient date. This system of organising and scheduling station engagements resulted in very little study disruption, thereby optimising data collection opportunities, as opposed to Brown *et al*. (2016) whose fire station data collection solely relied upon fire crews not being called out too often or for long periods. As such, their study resulted in inevitable wasted time and missing data. The comparably smoother running of this study was facilitated by a study strength in terms of intimate knowledge of the organisation derived from the researcher's vast experience of the LFB as a former firefighter of seventeen-years of service.

A further limitation was the limited widow of opportunity in which to visit watches. This was firstly due to the time-poor environment whereby the researcher had to fit in around various training activities, administrative duties and mealtimes. To overcome this, the researcher developed intervention and data collection techniques to be as efficient as possible e.g. the FF-FFQ was developed with efficiency in mind to suit the dynamic environment (see Chapter 5). The same principle was applied to body composition analysis and anthropometric measurements, which took no longer than two minutes per firefighter. The resulting low-intensity and low-burden intervention programme is therefore tailored for use in the dynamic environment which is characteristic of fire stations. Not only are fire stations ever increasingly time-poor environments as outlined in Chapter 1, the shift system dictates that any given watch is only on duty two days within every eight-day cycle. This limited the opportunity for the researcher to schedule watches into the study, as a mutually convenient day shift could not always be agreed upon. This therefore resulted in some watches being missed from the study, which is stated in the previous Chapters. The watches missed were however due to random extenuating circumstances i.e. pre-allocated training events, therefore reducing selection bias. These were expected limitations of conducting a fieldwork-based study at operational fire stations.

8.7. Future research directions

National research across the UK FRSs could facilitate the development of white female firefighter body composition references. This would entail the study recruitment of approximately one third of the 1,300 full-time white female firefighters serving in England (Home Office, 2019). The UK white male firefighter reference curves (Chapter 4) could also be further refined with additional white male firefighter anthropometric and body composition data, especially within the younger and older age categories, which would further improve the external validity of the reference charts.

The UK firefighter dietary assessment tool could also be used to collect firefighter dietary intake data on a regional/national level to facilitate investigations into micronutrient intakes. Future research in this area could further our knowledge on firefighter dietary behaviour and add to the emerging evidence base e.g. a recent study by Hershey *et al* (2020) utilised a validated FFQ to investigate associations between firefighter anthocyanin intake, physical activity and lipid profiles. This growing evidence base will hopefully inform targeted nutritional strategies to reduce the heightened risk of CVD observed in firefighters (outlined in Chapter 1).

Firefighter dietary patterns and strategies to help mitigate the adverse metabolic effects of shift work (outlined in Chapter 1) are also avenues worthy of future investigation. Chrono-nutrition and time restricted feeding (TRF) have been suggested as strategies for improved glycaemic control for an overweight and obese population group (Parr *et al.*, 2020), and for the potential prevention of cardiometabolic diseases in high-stress occupations (Waldman, Renteria and McAllister, 2020). It is envisaged that such an intervention would be relatively simple for firefighters to adhere to, and therefore presents a feasible, low-cost research opportunity. Indeed, the results from a recent study of *n*=16 USA firefighters suggested that a six-week TRF intervention reduced markers of oxidative stress, implying TRF to result in some benefits to cardiometabolic health (McAllister, Gonzalez and Waldman, 2020). However, the authors noted that the study limitations of no control group and a small sample which may not be representative, indicates that further research is required in this area of dietary intervention.

8.8. Implications for policy and practice / conclusion

The increased risk of firefighter injury, illness and disability due to a complex combination of occupational exposures, coupled with the high prevalence of overweight and obesity observed in firefighters, increases the urgent need for intervention. An added exposure of the present day is the Covid-19 Coronavirus global pandemic. Given that obese humans may be at greater risk of mortality and morbidity from this highly contagious virus (Kassir, 2020), and that risk of infection increases above a BMI of 25 kg/m^2 (Public Health England, 2020), it has never been more urgent to stage nutritional interventions to reduce risk of poor health outcomes. Firefighters are likely to be at elevated risk of infection due to high prevalence of overweight/overfat and obesity. Furthermore, firefighters are unable to avoid social settings due to the nature of their work, therefore interventions to reduce adiposity may be particularly important for this occupational group. Indeed, a new UK government policy for tackling obesity was recently published in July 2020 due to this very threat and the associated consequences of reduced physical activity and poor nutritional statuses related to lockdown measures implemented in England during 2020 (Department of Health & Social Care, 2020).

In conclusion, UK FRSs are likely to benefit by adopting the multi-component fire station-based dietary and lifestyle intervention system described in Chapters 6 and 7, utilising the UK firefighter body composition references and the UK firefighter dietary assessment tool (Chapters 4 and 5) for the assessment of UK firefighter nutritional status. This system will enable valid risk classification and facilitate the health improvement/maintenance of this essential occupational group.

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Appendix 2.1. London Fire Brigade consent letter

LFB
LONDON FIRE BRIGADE

Hornchurch Fire Station
42 North Street
Hornchurch
RM11 1SH
02085551200 x 17921

To be opened by
Greg Lessons

London Fire Brigade is run by London Fire and Emergency Planning Authority

Date **21st May 2019**
Greg Lessons

Dear Greg ,

Please find the requested authority below

To whom it may concern,

I hereby grant Greg Lessons permission to run a nutrition and lifestyle fire station based intervention programme to benefit the health and wellness of the firefighters.

He may use the data collected for his Ph.D. research which will ultimately serve to benefit the health and wellness of the workforce.

21st May 2019

Colin Digby **on behalf of DAC Perez** , NE Area Commander

Station Commander

Havering Borough

Colin.digby@london-fire.gov.uk

07554333209

Appendix 2.2. London Metropolitan University School of Human Sciences ethical consent letter

LONDON
METROPOLITAN
UNIVERSITY

Tower Building
166–220 Holloway Road
London
N7 8DB

Mr G. Lessons
School of Human Sciences

17.06.19

Dear Mr Lessons,

Research project title: A multi-component dietary and lifestyle worksite intervention to reduce high prevalence of overweight, obesity and acute myocardial infarction risk for UK firefighters.

Thank you for submitting your project for ethical evaluation together with associated documents. Thank you also for submitting revised documentation where amendments were requested. I am now able to confirm a favourable ethical opinion for the above research on the basis described in the research ethics form and supporting documentation.

Approved documents

The final list of documents reviewed and approved is as follows:

Document	**Date approved**
Research proposal	06/06/2019
Ethics application	06/06/2019
Revised Participant Information Sheet/Consent Form	06/06/2019
London Fire Brigade authorisation letter	06/06/2019

Where a variation or substantial amendment to any aspect of the above documentation is required, the updated version(s) must be submitted to the ethics panel for approval. This approval covers the duration of the study.

Wishing you every success with this project.

Yours sincerely,

H. David McCarthy PhD RNutr
Professor of Nutrition & Health
Chair, SHS ethics panel

London Metropolitan University | Tower Building | 166–220 Holloway Road | London N7 8DB
Switchboard: +44 (0)20 7423 0000 | londonmet.ac.uk

Appendix 2.3. Participant information sheet

PARTICIPANT INFORMATION SHEET

Title of Project: Health and wellbeing improvement for LFB Firefighters.

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?

To help you to improve your health and reduce risk of chronic diseases via nutrition education, with help and advice aimed at encouraging healthy practices. Additionally, the controversial BMI system will be adapted to better suit firefighters i.e. it will be amended to prevent firefighters being incorrectly classed as "overweight" when they carry more muscle than the average person.

Why have I been invited to participate?

You have been invited because you are a member at one of the fire stations which were selected for this research.

Do I have to take part?

It is up to you to decide whether or not to take part. Refusal to take part will involve no penalty. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You will not be obliged to follow any recommendations, nobody else will know what advice was given to you and you will never be held to account for following or not following the free advice provided. If you decide to take part you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?

Following a group lecture with the rest of your watch, you will be offered a questionnaire to complete. This will take 10 – 15 minutes and will give the researcher an idea of your dietary and lifestyle habits. Following this, a consultation room will be set up where the researcher will take some basic bodily measurements including height, weight, waist circumference and body composition analysis which involves standing on a set of electronic scales for 20 seconds. The only clothing removal required is that of your shoes and socks during these measurements. All data will be kept confidential. Once these measurements have been collected, the researcher will use these and your questionnaire to offer you the appropriate advice in a relaxed manner with the intention of helping you to improve/maintain your health and minimise risk of chronic diseases. You will have the option of the consultation room door being open or closed throughout. The measurements and advice will last approximately 20 minutes.

What are the possible disadvantages and risks of taking part?
There are no disadvantages or risks of taking part in this study as it is a nutrition education study aimed to provide information on health improvement.

What are the possible benefits of taking part?
You will learn of some of the latest research in nutrition which will help to improve your health and avoid diet and lifestyle related disease. You will be offered some simple dietary adjustments to improve/maintain your health. You will also be given an accurate analysis of your body composition using state of the art equipment. These results will then be explained to you in an easily understandable manner.

Will my data be kept confidential?
All information collected about you will be kept strictly confidential. Access to the data will only be by researchers working on this study. Computer files will be password protected and all data, codes and identifying information will be kept in locked filing cabinets. The findings generated in the course of the research will be kept securely for a period of ten years after the completion of a research project.

What should I do if I want to take part?
If you would like to take part, please complete the consent form.

What will happen to the results of the research study?
The results of this research will be published in a scientific journal. Your identity will not be recognizable from this. If you would like a copy of the published research you can contact the researchers at the phone number or email address given below following completion of the

study. Most importantly, we will use these results to evaluate the usefulness of a nutrition programme for firefighters to improve and maintain their health throughout their career.

Who is organising and funding the research?

This study is being conducted as part of PhD research work at the School of Human Sciences at London Metropolitan University, in collaboration with the LFB.

Who has reviewed the study?

This research has been approved by the London Metropolitan University Research Ethics Committee. If you require more information about this study you can send an email with your questions to the member of the research team Greg Lessons (grl0080@my.londonmet.ac.uk). We would like to thank you in advance for your participation.

DBhakta

Dr Dee Bhakta PhD RD RNutr (public health)
Senior Lecturer in Human Nutrition
London Metropolitan University
166-220 Holloway Road
London N7 8DB
020 7133 4197

Appendix 2.4. Participant consent form

PARTICIPANT CONSENT FORM

CONSENT STATEMENT

1. I understand that my participation is voluntary and that I may withdraw from the research at any time, without giving any reason.
2. I am aware of what my participation will involve.
3. I understand that there are no risks involved in the participation of this study.
4. All questions that I have about the research have been satisfactorily answered.

I agree to participate.

Participant's signature: ________________________________

Participant's name (please print): ________________________________

E-mail: ____________________________

Date: __________

Appendix 4.1. Centile cut-off values Table 1: SMMI Centiles *n*=493

Age	C2	C9	C25	C50	C75	C91	C98
21.465	8.14	8.51	8.93	9.40	9.92	10.51	11.19
22	8.13	8.51	8.93	9.40	9.92	10.52	11.19
23	8.12	8.51	8.93	9.40	9.93	10.52	11.20
24	8.11	8.50	8.93	9.40	9.93	10.53	11.21
25	8.10	8.49	8.92	9.40	9.93	10.53	11.21
26	8.09	8.48	8.92	9.40	9.93	10.54	11.22
27	8.08	8.48	8.91	9.40	9.94	10.54	11.22
28	8.07	8.47	8.91	9.40	9.94	10.54	11.23
29	8.06	8.47	8.91	9.40	9.94	10.55	11.23
30	8.06	8.46	8.91	9.40	9.94	10.55	11.24
31	8.05	8.46	8.91	9.40	9.95	10.56	11.25
32	8.05	8.45	8.90	9.39	9.94	10.56	11.25
33	8.03	8.44	8.89	9.38	9.93	10.54	11.24
34	8.01	8.42	8.86	9.36	9.91	10.53	11.22
35	7.99	8.39	8.84	9.33	9.89	10.50	11.20
36	7.96	8.37	8.81	9.31	9.86	10.48	11.18
37	7.94	8.34	8.79	9.29	9.84	10.47	11.17
38	7.92	8.33	8.78	9.27	9.83	10.46	11.18
39	7.91	8.32	8.77	9.27	9.83	10.47	11.19
40	7.90	8.31	8.77	9.27	9.84	10.48	11.22
41	7.90	8.31	8.77	9.28	9.86	10.51	11.25
42	7.89	8.31	8.77	9.29	9.87	10.53	11.29
43	7.89	8.31	8.77	9.30	9.89	10.56	11.33
44	7.88	8.31	8.78	9.31	9.91	10.59	11.37
45	7.87	8.30	8.78	9.32	9.92	10.61	11.40
46	7.86	8.29	8.78	9.32	9.94	10.63	11.44
47	7.84	8.28	8.77	9.32	9.94	10.65	11.46
48	7.81	8.26	8.76	9.31	9.94	10.65	11.47
49	7.78	8.23	8.73	9.30	9.93	10.65	11.47
50	7.74	8.20	8.71	9.28	9.92	10.64	11.47
51	7.69	8.16	8.67	9.25	9.90	10.63	11.45
52	7.64	8.11	8.64	9.22	9.87	10.60	11.43
53	7.59	8.07	8.60	9.19	9.84	10.58	11.41
54	7.53	8.02	8.56	9.15	9.81	10.55	11.38
55	7.48	7.97	8.52	9.12	9.78	10.52	11.35
56	7.42	7.92	8.47	9.08	9.75	10.49	11.31
57	7.36	7.87	8.43	9.05	9.72	10.46	11.28
58	7.30	7.82	8.39	9.01	9.69	10.43	11.24
59	7.24	7.77	8.35	8.98	9.66	10.40	11.21
60	7.18	7.72	8.31	8.95	9.63	10.37	11.17
61	7.11	7.67	8.27	8.92	9.61	10.34	11.13
61.878	7.06	7.63	8.24	8.89	9.58	10.32	11.10

Table 2: FMI centiles *n*=497

Age	C2	C9	C25	C50	C75	C85	C91	C95	C98
21.46	1.73	2.34	3.12	4.08	5.26	6.02	6.69	7.46	8.42
22	1.78	2.40	3.19	4.17	5.36	6.13	6.81	7.59	8.55
23	1.87	2.51	3.32	4.32	5.55	6.34	7.03	7.82	8.80
24	1.95	2.62	3.45	4.48	5.73	6.53	7.23	8.03	9.03
25	2.04	2.72	3.57	4.62	5.89	6.70	7.41	8.23	9.24
26	2.12	2.82	3.68	4.74	6.03	6.85	7.57	8.39	9.41
27	2.19	2.91	3.79	4.86	6.16	6.99	7.72	8.54	9.56
28	2.27	2.99	3.89	4.97	6.28	7.12	7.84	8.67	9.69
29	2.34	3.08	3.98	5.08	6.40	7.23	7.96	8.79	9.81
30	2.42	3.16	4.08	5.18	6.50	7.34	8.08	8.90	9.92
31	2.49	3.25	4.17	5.28	6.61	7.45	8.18	9.01	10.03
32	2.56	3.33	4.25	5.37	6.70	7.54	8.27	9.10	10.12
33	2.63	3.40	4.33	5.45	6.78	7.62	8.35	9.18	10.20
34	2.69	3.47	4.40	5.53	6.86	7.70	8.43	9.25	10.27
35	2.75	3.53	4.47	5.60	6.93	7.78	8.51	9.33	10.35
36	2.81	3.59	4.54	5.67	7.02	7.86	8.60	9.42	10.44
37	2.86	3.66	4.61	5.75	7.11	7.96	8.70	9.53	10.56
38	2.92	3.72	4.69	5.84	7.21	8.07	8.82	9.67	10.71
39	2.98	3.79	4.77	5.94	7.33	8.21	8.97	9.83	10.89
40	3.03	3.86	4.85	6.05	7.47	8.36	9.14	10.02	11.11
41	3.09	3.93	4.94	6.16	7.61	8.53	9.33	10.23	11.34
42	3.14	4.00	5.03	6.27	7.76	8.70	9.52	10.44	11.59
43	3.19	4.05	5.11	6.37	7.89	8.85	9.69	10.65	11.83
44	3.23	4.11	5.18	6.47	8.02	9.01	9.87	10.85	12.06
45	3.26	4.15	5.24	6.55	8.14	9.15	10.04	11.04	12.30
46	3.29	4.19	5.29	6.63	8.25	9.28	10.20	11.23	12.52
47	3.31	4.21	5.33	6.69	8.34	9.40	10.33	11.40	12.73
48	3.32	4.23	5.35	6.73	8.41	9.50	10.45	11.55	12.92
49	3.32	4.23	5.37	6.76	8.47	9.58	10.56	11.68	13.09
50	3.32	4.23	5.37	6.78	8.52	9.65	10.65	11.80	13.25
51	3.31	4.22	5.37	6.79	8.55	9.70	10.73	11.91	13.40
52	3.29	4.21	5.36	6.80	8.58	9.76	10.80	12.01	13.55
53	3.28	4.20	5.35	6.80	8.61	9.81	10.88	12.12	13.70
54	3.26	4.18	5.34	6.80	8.65	9.86	10.96	12.23	13.85
55	3.25	4.17	5.33	6.81	8.69	9.93	11.05	12.35	14.02
56	3.23	4.16	5.33	6.83	8.73	10.00	11.15	12.49	14.21
57	3.22	4.15	5.33	6.85	8.79	10.08	11.26	12.63	14.41
58	3.21	4.14	5.33	6.87	8.84	10.17	11.37	12.78	14.61
59	3.19	4.13	5.34	6.89	8.90	10.26	11.49	12.94	14.82
60	3.18	4.12	5.34	6.92	8.96	10.35	11.61	13.10	15.03
61	3.16	4.11	5.34	6.94	9.03	10.44	11.73	13.26	15.25
61.88	3.15	4.10	5.35	6.97	9.08	10.52	11.84	13.41	15.45

Table 3: WHtR centiles *n*=496

Age	C2	C9	C25	C50	C75	C91	C98
21.465	0.39	0.41	0.43	0.45	0.48	0.52	0.57
22	0.39	0.41	0.43	0.45	0.48	0.52	0.57
23	0.40	0.41	0.43	0.46	0.49	0.52	0.57
24	0.40	0.42	0.44	0.46	0.49	0.53	0.57
25	0.40	0.42	0.44	0.47	0.49	0.53	0.58
26	0.40	0.42	0.44	0.47	0.50	0.53	0.58
27	0.41	0.42	0.45	0.47	0.50	0.54	0.58
28	0.41	0.43	0.45	0.48	0.51	0.54	0.59
29	0.41	0.43	0.45	0.48	0.51	0.54	0.59
30	0.41	0.43	0.46	0.48	0.51	0.55	0.59
31	0.42	0.44	0.46	0.49	0.52	0.55	0.60
32	0.42	0.44	0.46	0.49	0.52	0.55	0.60
33	0.42	0.44	0.46	0.49	0.52	0.56	0.60
34	0.42	0.44	0.47	0.49	0.52	0.56	0.60
35	0.42	0.45	0.47	0.50	0.53	0.56	0.61
36	0.43	0.45	0.47	0.50	0.53	0.57	0.61
37	0.43	0.45	0.47	0.50	0.53	0.57	0.61
38	0.43	0.45	0.48	0.50	0.54	0.57	0.62
39	0.43	0.45	0.48	0.51	0.54	0.58	0.62
40	0.43	0.46	0.48	0.51	0.54	0.58	0.62
41	0.44	0.46	0.48	0.51	0.55	0.59	0.63
42	0.44	0.46	0.49	0.52	0.55	0.59	0.63
43	0.44	0.46	0.49	0.52	0.55	0.59	0.64
44	0.44	0.47	0.49	0.52	0.56	0.60	0.64
45	0.44	0.47	0.50	0.53	0.56	0.60	0.65
46	0.44	0.47	0.50	0.53	0.57	0.61	0.65
47	0.44	0.47	0.50	0.53	0.57	0.61	0.66
48	0.44	0.47	0.50	0.53	0.57	0.61	0.66
49	0.44	0.47	0.50	0.54	0.57	0.62	0.67
50	0.44	0.47	0.50	0.54	0.58	0.62	0.67
51	0.44	0.47	0.50	0.54	0.58	0.62	0.67
52	0.44	0.47	0.51	0.54	0.58	0.63	0.68
53	0.44	0.47	0.51	0.54	0.58	0.63	0.68
54	0.44	0.47	0.51	0.54	0.58	0.63	0.69
55	0.44	0.47	0.51	0.54	0.59	0.63	0.69
56	0.44	0.47	0.51	0.55	0.59	0.64	0.69
57	0.44	0.47	0.51	0.55	0.59	0.64	0.70
58	0.44	0.47	0.51	0.55	0.59	0.64	0.70
59	0.44	0.47	0.51	0.55	0.59	0.65	0.70
60	0.44	0.47	0.51	0.55	0.60	0.65	0.71
61	0.44	0.47	0.51	0.55	0.60	0.65	0.71
61.878	0.44	0.47	0.51	0.55	0.60	0.65	0.72

Table 4: BF% centiles *n*=497

Age	C2	C9	C25	C50	C75	C85	C91	C95	C98
21.465	7.85	10.64	13.61	16.73	19.98	21.84	23.36	24.97	26.84
22	8.02	10.83	13.82	16.95	20.23	22.09	23.62	25.24	27.12
23	8.33	11.18	14.20	17.37	20.67	22.56	24.10	25.73	27.63
24	8.65	11.53	14.57	17.77	21.10	23.00	24.55	26.20	28.11
25	8.95	11.86	14.93	18.15	21.50	23.41	24.96	26.62	28.54
26	9.25	12.18	15.27	18.50	21.86	23.78	25.34	27.00	28.92
27	9.54	12.48	15.59	18.83	22.19	24.11	25.67	27.34	29.26
28	9.82	12.78	15.88	19.13	22.49	24.41	25.97	27.63	29.55
29	10.10	13.06	16.17	19.41	22.77	24.68	26.24	27.90	29.81
30	10.38	13.34	16.45	19.68	23.04	24.94	26.49	28.14	30.05
31	10.66	13.62	16.72	19.94	23.28	25.18	26.72	28.36	30.26
32	10.93	13.88	16.96	20.17	23.49	25.38	26.92	28.55	30.43
33	11.20	14.13	17.20	20.39	23.69	25.56	27.09	28.71	30.58
34	11.45	14.37	17.42	20.59	23.87	25.74	27.26	28.87	30.73
35	11.69	14.60	17.65	20.80	24.07	25.92	27.43	29.04	30.89
36	11.93	14.84	17.87	21.02	24.28	26.13	27.63	29.23	31.08
37	12.17	15.07	18.11	21.25	24.51	26.35	27.86	29.45	31.30
38	12.39	15.31	18.35	21.50	24.76	26.61	28.11	29.71	31.56
39	12.62	15.54	18.60	21.76	25.04	26.89	28.41	30.01	31.87
40	12.84	15.78	18.85	22.04	25.33	27.20	28.73	30.34	32.21
41	13.05	16.02	19.11	22.32	25.64	27.53	29.06	30.69	32.57
42	13.25	16.23	19.35	22.59	25.94	27.84	29.39	31.03	32.93
43	13.42	16.43	19.57	22.83	26.20	28.12	29.68	31.34	33.26
44	13.57	16.60	19.76	23.05	26.45	28.38	29.96	31.63	33.57
45	13.71	16.75	19.94	23.25	26.68	28.63	30.22	31.91	33.87
46	13.82	16.88	20.09	23.42	26.89	28.86	30.46	32.17	34.15
47	13.91	16.98	20.21	23.57	27.06	29.05	30.67	32.40	34.39
48	13.98	17.06	20.30	23.68	27.20	29.20	30.84	32.59	34.61
49	14.03	17.11	20.36	23.76	27.30	29.33	30.98	32.74	34.78
50	14.06	17.14	20.40	23.82	27.38	29.42	31.09	32.86	34.92
51	14.07	17.16	20.42	23.85	27.44	29.49	31.17	32.96	35.04
52	14.08	17.16	20.43	23.88	27.48	29.55	31.24	33.05	35.15
53	14.08	17.17	20.44	23.90	27.53	29.61	31.32	33.15	35.27
54	14.08	17.17	20.47	23.94	27.60	29.70	31.42	33.26	35.41
55	14.09	17.19	20.50	24.00	27.69	29.81	31.55	33.41	35.58
56	14.10	17.22	20.55	24.08	27.80	29.94	31.70	33.58	35.78
57	14.11	17.25	20.61	24.17	27.93	30.09	31.87	33.78	36.00
58	14.13	17.29	20.68	24.27	28.07	30.26	32.07	34.00	36.25
59	14.15	17.33	20.75	24.38	28.22	30.44	32.26	34.22	36.50
60	14.17	17.38	20.82	24.50	28.38	30.62	32.47	34.45	36.76
61	14.18	17.42	20.90	24.61	28.54	30.81	32.68	34.68	37.02
61.878	14.20	17.47	20.97	24.72	28.69	30.98	32.87	34.89	37.26

Table 5: ASMM (kg) centiles *n*=493

Age	C2	C9	C25	C50	C75	C91	C98
21.465	25.93	27.29	28.87	30.70	32.89	35.53	38.83
22	25.90	27.28	28.86	30.71	32.91	35.57	38.87
23	25.84	27.24	28.85	30.73	32.95	35.63	38.92
24	25.77	27.20	28.84	30.74	32.98	35.67	38.97
25	25.69	27.15	28.81	30.74	33.00	35.71	39.00
26	25.61	27.08	28.77	30.73	33.01	35.73	39.01
27	25.51	27.01	28.73	30.70	33.01	35.73	39.01
28	25.41	26.93	28.67	30.67	32.99	35.73	39.00
29	25.31	26.86	28.62	30.64	32.98	35.72	38.98
30	25.21	26.78	28.57	30.60	32.96	35.70	38.95
31	25.11	26.70	28.51	30.56	32.93	35.67	38.91
32	25.00	26.61	28.43	30.49	32.87	35.62	38.84
33	24.87	26.49	28.32	30.40	32.77	35.52	38.72
34	24.73	26.36	28.19	30.27	32.65	35.38	38.56
35	24.58	26.21	28.05	30.13	32.50	35.23	38.39
36	24.44	26.07	27.92	30.00	32.37	35.08	38.22
37	24.32	25.96	27.80	29.88	32.25	34.96	38.09
38	24.24	25.88	27.72	29.80	32.16	34.87	38.00
39	24.20	25.83	27.68	29.76	32.12	34.84	37.97
40	24.19	25.82	27.67	29.75	32.12	34.85	38.00
41	24.20	25.84	27.68	29.77	32.15	34.89	38.08
42	24.24	25.87	27.71	29.80	32.19	34.96	38.18
43	24.27	25.89	27.73	29.83	32.23	35.03	38.30
44	24.29	25.91	27.75	29.85	32.27	35.09	38.41
45	24.31	25.92	27.75	29.85	32.29	35.14	38.52
46	24.32	25.92	27.74	29.84	32.29	35.17	38.62
47	24.29	25.88	27.70	29.80	32.26	35.17	38.68
48	24.23	25.81	27.62	29.72	32.19	35.13	38.71
49	24.14	25.70	27.51	29.60	32.08	35.05	38.69
50	24.02	25.57	27.36	29.46	31.94	34.94	38.64
51	23.87	25.41	27.19	29.28	31.77	34.79	38.55
52	23.70	25.22	26.99	29.07	31.57	34.61	38.43
53	23.51	25.02	26.78	28.85	31.35	34.41	38.28
54	23.32	24.82	26.56	28.63	31.13	34.21	38.13
55	23.13	24.61	26.35	28.41	30.91	34.01	37.97
56	22.93	24.41	26.14	28.19	30.69	33.81	37.81
57	22.74	24.20	25.92	27.98	30.48	33.60	37.65
58	22.54	24.00	25.71	27.76	30.26	33.40	37.48
59	22.34	23.79	25.50	27.54	30.05	33.20	37.31
60	22.14	23.59	25.29	27.33	29.83	32.99	37.14
61	21.95	23.38	25.07	27.11	29.62	32.79	36.97
61.878	21.77	23.20	24.89	26.92	29.43	32.61	36.82

Appendix 5.1. EPIC Norfolk FFQ

FOOD FREQUENCY QUESTIONNAIRE

This questionnaire asks for some background information about you, especially about what you eat.

Please answer every question. If you are uncertain about how to answer a question then do the best you can, but please do not leave a question blank.

1. **YOUR DIET LAST YEAR**
For each food there is an amount shown, either a "medium serving" or a common household unit such as a slice or teaspoon. Please put a tick (✓) in the box to indicate how often, **on average**, you have eaten the specified amount of each food **during the past year**.

EXAMPLES:

For white bread the amount is one slice, so if you ate 4 or 5 slices a day, you should put a tick in the column headed "4-5 per day".

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
BREAD AND SAVOURY BISCUITS (one slice or biscuit)	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
White bread and rolls								✓	

For chips, the amount is a "medium serving", so if you had a helping of chips twice a week you should put a tick in the column headed "2-4 per week".

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
POTATOES, RICE AND PASTA (medium serving)	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Chips				✓					

For very seasonal fruits such as strawberries and raspberries you should estimate your average use when the fruits are in season, so if you ate strawberries or raspberries about once a week when they were in season you should put a tick in the column headed "once a week"

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
FRUIT (1 fruit or medium serving)	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Strawberries, raspberries, kiwi fruit			✓						

2

Please estimate your average food use as best you can, and please answer every question - do not leave ANY lines blank. PLEASE PUT A TICK (✓) ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
MEAT AND FISH (medium serving)	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Beef: roast, steak, mince, stew or casserole									
Beefburgers									
Pork: roast, chops, stew or slices									
Lamb: roast, chops or stew									
Chicken or other poultry eg. turkey									
Bacon									
Ham									
Corned beef, Spam, luncheon meats									
Sausages									
Savoury pies, eg. meat pie, pork pie, pasties, steak & kidney pie, sausage rolls									
Liver, liver paté, liver sausage									
Fried fish in batter, as in fish and chips									
Fish fingers, fish cakes									
Other white fish, fresh or frozen, eg. cod, haddock, plaice, sole, halibut									
Oily fish, fresh or canned, eg. mackerel, kippers, tuna, salmon, sardines, herring									
Shellfish, eg. crab, prawns, mussels									
Fish roe, taramasalata									
	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day

Please check that you have a tick (✓) on EVERY line

3

PLEASE PUT A TICK (✓) ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
BREAD AND SAVOURY BISCUITS (one slice or biscuit)	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
White bread and rolls									
Brown bread and rolls									
Wholemeal bread and rolls									
Cream crackers, cheese biscuits									
Crispbread, eg. Ryvita									
CEREALS (one bowl)									
Porridge, Readybrek									
Breakfast cereal such as cornflakes, muesli etc.									
POTATOES, RICE AND PASTA (medium serving)									
Boiled, mashed, instant or jacket potatoes									
Chips									
Roast potatoes									
Potato salad									
White rice									
Brown rice									
White or green pasta, eg. spaghetti, macaroni, noodles									
Wholemeal pasta									
Lasagne, moussaka									
Pizza									
	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day

Please check that you have a tick (✓) on EVERY line

PLEASE PUT A TICK (✓) ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
DAIRY PRODUCTS AND FATS	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Single or sour cream (tablespoon)									
Double or clotted cream (tablespoon)									
Low fat yogurt, fromage frais (125g carton)									
Full fat or Greek yogurt (125g carton)									
Dairy desserts (125g carton)									
Cheese, eg. Cheddar, Brie, Edam (medium serving)									
Cottage cheese, low fat soft cheese (medium serving)									
Eggs as boiled, fried, scrambled, etc. (one)									
Quiche (medium serving)									
Low calorie, low fat salad cream(tablespoon)									
Salad cream, mayonnaise (tablespoon)									
French dressing (tablespoon)									
Other salad dressing (tablespoon)									
The following on bread or vegetables									
Butter (teaspoon)									
Block margarine, eg. Stork, Krona (teaspoon)									
Polyunsaturated margarine (tub), eg. Flora, sunflower (teaspoon)									
Other soft margarine,dairy spreads (tub), eg. Blue Band, Clover (teaspoon)									
Low fat spread (tub), eg. Outline, Gold (teaspoon)									
Very low fat spread (tub) (teaspoon)									
	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day

Please check that you have a tick (✓) on EVERY line

PLEASE PUT A TICK (✓) ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
SWEETS AND SNACKS (medium serving)	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Sweet biscuits, chocolate , eg. digestive (one)									
Sweet biscuits, plain, eg. Nice, ginger (one)									
Cakes eg. fruit, sponge, home baked									
Cakes eg. fruit, sponge, ready made									
Buns, pastries eg. scones, flapjacks, home baked									
Buns, pastries eg. croissants, doughnuts, ready made									
Fruit pies, tarts, crumbles, home baked									
Fruit pies, tarts, crumbles, ready made									
Sponge puddings, home baked									
Sponge puddings, ready made									
Milk puddings, eg. rice, custard, trifle									
Ice cream, choc ices									
Chocolates, single or squares									
Chocolate snack bars eg. Mars, Crunchie									
Sweets, toffees, mints									
Sugar added to tea, coffee, cereal (teaspoon)									
Crisps or other packet snacks, eg. Wotsits									
Peanuts or other nuts									
SOUPS, SAUCES, AND SPREADS									
Vegetable soups (bowl)									
Meat soups (bowl)									
Sauces, eg. white sauce, cheese sauce, gravy (tablespoon)									
Tomato ketchup (tablespoon)									
Pickles, chutney (tablespoon)									
Marmite, Bovril (teaspoon)									
Jam, marmalade, honey (teaspoon)									
Peanut butter (teaspoon)									
	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day

Please check that you have a tick (✓) on EVERY line

6

PLEASE PUT A TICK (✓) ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
DRINKS	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Tea (cup)									
Coffee, instant or ground (cup)									
Coffee, decaffeinated (cup)									
Coffee whitener, eg. Coffee-mate (teaspoon)									
Cocoa, hot chocolate (cup)									
Horlicks, Ovaltine (cup)									
Wine (glass)									
Beer, lager or cider (half pint)									
Port, sherry, vermouth, liqueurs (glass)									
Spirits, eg. gin, brandy, whisky, vodka (single)									
Low calorie or diet fizzy soft drinks (glass)									
Fizzy soft drinks, eg. Coca cola, lemonade (glass)									
Pure fruit juice (100%) eg. orange, apple juice (glass)									
Fruit squash or cordial (glass)									
FRUIT **For seasonal fruits marked *, please estimate your average use when the fruit is in season**									
Apples (1 fruit)									
Pears (1 fruit)									
Oranges, satsumas, mandarins (1 fruit)									
Grapefruit (half)									
Bananas (1 fruit)									
Grapes (medium serving)									
Melon (1 slice)									
* Peaches, plums, apricots (1 fruit)									
* Strawberries, raspberries, kiwi fruit (medium serving)									
Tinned fruit (medium serving)									
Dried fruit, eg. raisins, prunes (medium serving)									
	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day

Please check that you have a tick (✓) on EVERY line

7

PLEASE PUT A TICK (✓) ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE LAST YEAR								
VEGETABLES Fresh, frozen or tinned (medium serving)	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Carrots									
Spinach									
Broccoli, spring greens, kale									
Brussels sprouts									
Cabbage									
Peas									
Green beans, broad beans, runner beans									
Marrow, courgettes									
Cauliflower									
Parsnips, turnips, swedes									
Leeks									
Onions									
Garlic									
Mushrooms									
Sweet peppers									
Beansprouts									
Green salad, lettuce, cucumber, celery									
Watercress									
Tomatoes									
Sweetcorn									
Beetroot									
Coleslaw									
Avocado									
Baked beans									
Dried lentils, beans, peas									
Tofu , soya meat, TVP, Vegeburger									
	Never or less than once/month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day

Please check that you have a tick (✓) on EVERY line

8

YOUR DIET LAST YEAR, continued

2. Are there any **OTHER** foods which you ate more than once a week? Yes ☐ No ☐
If yes, please list below

Food	Usual serving size	Number of times eaten each week

3. What type of milk did you most often use?
Select one only
Full cream, silver ☐
Skimmed/blue ☐
Dried milk ☐
Other, *specify* ________
Semi-skimmed, red/white ☐
Channel Islands, gold ☐
Soya ☐
None ☐

4. How much milk did you drink each day, including milk with tea, coffee, cereals etc?
None ☐
Quarter of a pint ☐
Half a pint ☐
Three quarters of a pint ☐
One pint ☐
More than one pint ☐

5. Did you usually eat breakfast cereal (excluding porridge and Ready Brek mentioned earlier)?
Yes ☐ No ☐

If yes, which brand and type of breakfast cereal, including muesli, did you usually eat?
List the one or two types most often used

Brand *e.g. Kellogg's*	Type *e.g. cornflakes*

6. What kind of fat did you most often use for frying, roasting, grilling etc?
Select one only
Butter ☐
Lard/dripping ☐
Vegetable oil ☐
Solid vegetable fat ☐
Margarine ☐
None ☐
If you used vegetable oil, please give type eg. corn, sunflower ________

7. What kind of fat did you most often use for baking cakes etc?
Select one only
Butter ☐
Lard/dripping ☐
Vegetable oil ☐
Solid vegetable fat ☐
Margarine ☐
None ☐
If you used margarine, please give name or type eg. Flora, Stork ________

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8. How often did you eat food that was fried at home?

Daily ☐ 1-3 times a week ☐ 4-6 times a week ☐
Less than once a week ☐ Never ☐

9. How often did you eat fried food away from home?

Daily ☐ 1-3 times a week ☐ 4-6 times a week ☐
Less than once a week ☐ Never ☐

10. What did you do with the visible fat on your meat?

Ate most of the fat ☐ Ate as little as possible ☐
Ate some of the fat ☐ Did not eat meat ☐

11. How often did you eat grilled or roast meat? ☐☐ times a week

12. How well cooked did you usually have grilled or roast meat?

Well done /dark brown ☐ Lightly cooked/rare ☐
Medium ☐ Did not eat meat ☐

13. How often did you add salt to food while cooking?

Always ☐ Rarely ☐
Usually ☐ Never ☐
Sometimes ☐

14. How often did you add salt to any food at the table?

Always ☐ Rarely ☐
Usually ☐ Never ☐
Sometimes ☐

15. Did you regularly use a salt substitute (eg LoSalt)? Yes ☐ No ☐

If yes, which brand? ________________

16. During the course of last year, on average, how many times a week did you eat the following foods?

Food type	**Times/week**	**Portion size**
Vegetables (not including potatoes)	☐☐	medium serving
Salads	☐☐	medium serving
Fruit and fruit products (not including fruit juice)	☐☐	medium serving or 1 fruit
Fish and fish products	☐☐	medium serving
Meat, meat products and meat dishes (including bacon, ham and chicken)	☐☐	medium serving

10

17. Have you taken any vitamins, minerals, fish oils, fibre or other food supplements during the past year? Yes ☐ No ☐ Don't know ☐

If yes, please complete the table below. If you have taken more than 5 types of supplement please put the most frequently consumed brands first.

Vitamin supplements	**Average frequency** Tick **one** box per line to show how often on average you consumed supplements									
Name and brand Please list full name, **brand** and strength	**Dose** Please state number of pills, capsules or teaspoons consumed	Never or less than once a month	1-3 per month	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day

Thank you for your help

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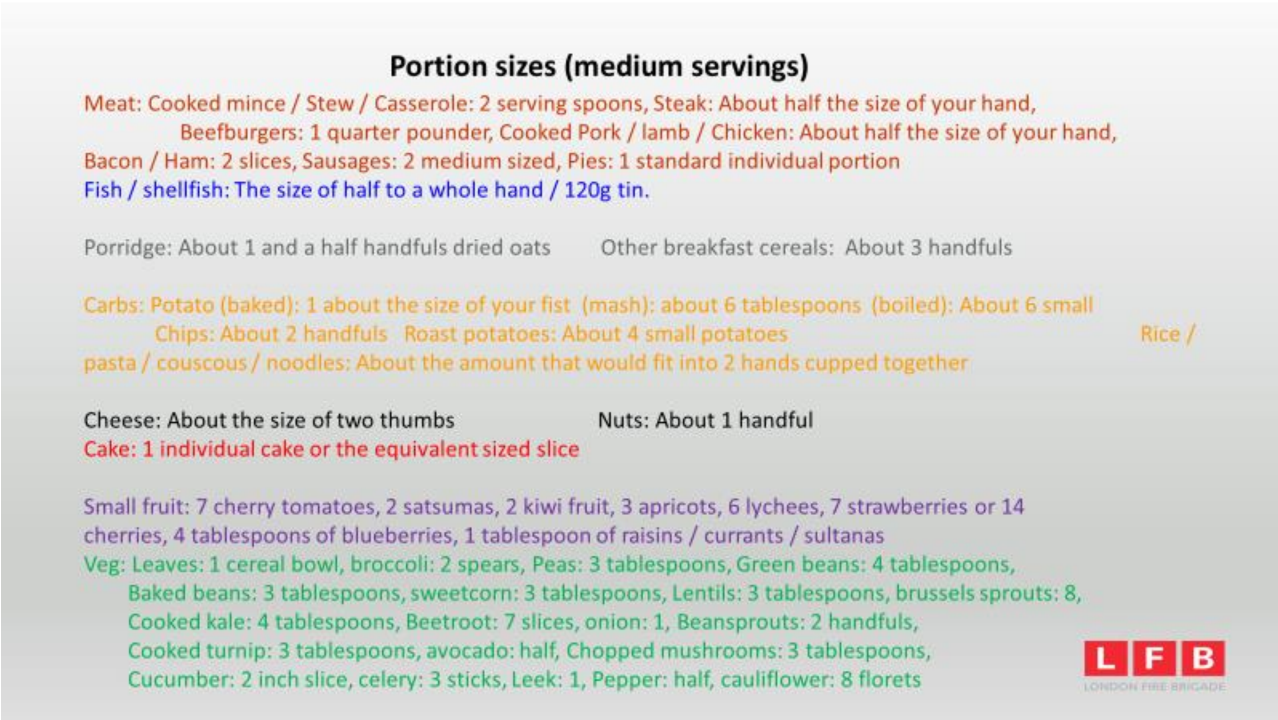
Appendix 5.2. FF-FFQ medium serving size PowerPoint slide aide memoire



Appendix 5.3. Firefighter Food Frequency Questionnaire (FF-FFQ)

Firefighter Food Frequency Questionnaire (FF-FFQ)

**Please estimate your average food use as best you can, and please answer every question –
do not leave ANY lines blank. PLEASE PUT ONE TICK ON EVERY LINE**

FOODS AND AMOUNTS	AVERAGE USE OVER THE LAST 3 MONTHS								
MEAT AND FISH (medium serving)	Never or less than once/month	1-3 per mnth	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Beef: roast, steak, mince, stew/casserole									
Beef burgers									
Pork: roast, chops or stew									
Lamb: roast, chops or stew									
Chicken or other poultry e.g. turkey									
Bacon									
Ham									
Sausages									
Savoury pies, e.g. Meat pie, pork pie, pasties, steak & kidney pie, sausage rolls									
Fried fish in batter, as in fish and chips									
Other white fish, fresh or frozen, e.g. Tuna, cod, haddock, plaice, sole, halibut									
Oily fish, fresh or canned, eg. Salmon, mackerel, sardines, kippers, herring									
Shellfish, e.g. Crab, prawns, mussels									
BREAD AND SAVOURY BISCUITS (One slice or biscuit)									
White bread and rolls									
Wholemeal bread and rolls									
Cream crackers, cheese biscuits									
CEREALS (one bowl)									
Porridge, Readybrek									
Breakfast cereal such as cornflakes, muesli etc.									

	Never or less than once/month	1-3 per mnth	Once a week	2-4 per week	5-6 per week	Once a day	2-3 Per day	4-5 per day	6+ per day

Please check that you have one tick on EVERY line

PLEASE PUT ONE TICK ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE OVER THE LAST 3 MONTHS								
POTATOES, RICE AND PASTA (medium serving)	Never or less than once/month	1-3 per mnth	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Boiled, mashed, instant or jacket potatoes									
Chips									
Roast potatoes									
White rice									
Brown rice									
White or green pasta, e.g. Spaghetti, macaroni, noodles									
Wholemeal pasta									
Lasagne, moussaka									
Pizza									
DAIRY PRODUCTS AND FATS									
Single or sour cream									
Low fat yogurt, fromage frais (125g carton)									
Full fat or Greek yogurt (125g carton)									
Dairy desserts (125g carton)									
Cheese e.g. Cheddar, Brie, Edam (medium serving)									
Eggs as boiled, fried, scrambled, etc. (one)									
Low cal, low fat salad cream (tablespoon)									
Salad cream, mayonnaise (tablespoon)									
Other salad dressing (tablespoon)									
The following on bread or vegetables (teaspoon)									

Butter, salted/unsalted									
Polyunsaturated margarine, e.g. Flora, Vitalite sunflower spread									
Soft margarine, including olive oil based & dairy spreads, e.g. Utterly Butterly, Bertolli									
	Never or less than once/month	1-3 per mnth	Once a week	2-4 per week	5-6 per week	Once a day	2-3 Per day	4-5 per day	6+ per day

Please check that you have one tick on EVERY line

PLEASE PUT ONE TICK ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE OVER THE LAST 3 MONTHS								
SWEETS AND SNACKS (medium serving)	Never or less than once/month	1-3 per mnth	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Biscuits (chocolate) e.g. Digestive (one)									
Biscuits (plain) e.g. Nice, ginger (one)									
Cakes e.g. Fruit, sponge (home baked)									
Cakes e.g. Fruit, sponge (ready made)									
Buns, pastries e.g. Croissants, doughnuts									
Ice cream, choc ices									
Chocolates, single or squares									
Chocolate snack bars e.g. Mars, Crunchie									
Sweets, toffees, mints									
Sugar added to tea, coffee (teaspoon)									
Sugar added to cereal (teaspoon)									
Crisps, e.g. Wotsits (medium packet)									
Peanuts or other nuts									
SOUPS, SAUCES AND SPREADS									
Vegetable soups (bowl)									
Sauces, e.g. White sauce, cheese sauce, gravy (tablespoon)									
Tomato ketchup (tablespoon)									

Pickles, chutney (tablespoon)									
Marmite, Bovril (teaspoon)									
Jam, marmalade, honey (teaspoon)									
Peanut butter (teaspoon)									
DRINKS									
Tea (cup)									
Coffee, instant or ground (cup)									
Wine (glass)									
Beer, lager or cider (half pint)									
Spirits, e.g. Gin, whiskey, vodka (single)									
Low calorie or diet fizzy soft drinks (glass)									
Fizzy soft drinks, e.g. Cola, lemonade (glass)									
Pure fruit juice (100%) e.g. orange, apple juice (glass)									
Fruit squash or cordial (glass)									
	Never or less than once/month	1-3 per mnth	Once a week	2-4 per week	5-6 per week	Once a day	2-3 Per day	4-5 per day	6+ per day

Please check that you have one tick on EVERY line

PLEASE PUT ONE TICK ON EVERY LINE

FOODS AND AMOUNTS	AVERAGE USE OVER THE LAST 3 MONTHS								
FRUIT AND VEGETABLES Fresh, frozen or tinned (medium serving)	Never or less than once/month	1-3 per mnth	Once a week	2-4 per week	5-6 per week	Once a day	2-3 per day	4-5 per day	6+ per day
Apples (1 fruit)									
Pears (1 fruit)									
Oranges, satsumas, mandarins (1 fruit)									
Bananas (1 fruit)									
Grapes (medium serving)									
Melon (1 slice)									
Peaches, plums, apricots (1 fruit)									
Strawberries, raspberries, kiwi fruit									
Dried fruit, e.g. raisins, prunes									
Carrots									
Spinach									
Broccoli, spring greens, kale									

Brussels sprouts									
Cabbage									
Peas									
Green beans, broad beans, runner beans									
Marrow, courgettes									
Cauliflower									
Parsnips, turnips, swedes									
Leeks									
Onions									
Garlic									
Mushrooms									
Sweet peppers									
Beansprouts									
Green salad, lettuce, cucumber, celery									
Tomatoes									
Sweetcorn									
Beetroot									
Coleslaw									
Avocado									
Baked beans									
Dried lentils, beans, peas									
	Never or less than once/month	1-3 per mnth	Once a week	2-4 per week	5-6 per week	Once a day	2-3 Per day	4-5 per day	6+ per day

Please check that you have one tick on EVERY line

YOUR DIET OVER THE LAST 3 MONTHS, continued

How often did you eat takeaway foods, eg. Curry, Chinese, pizza, fish and chips?

Less than once a week		1 – 3 times a week	
4 – 6 times a week		Daily	

If there are any other foods which you ate more than once a week, please list below:

Food	Usual serving size	No. of times eaten each week

What type of milk did you most often use? For animal milks, please tick **one box** for fat content:

MILK TYPE	Full cream/whole	Semi-skimmed	Skimmed	Channel/Jersey
1% fat	☐	☐	☐	☐
Cow	☐	☐	☐	
Goat	☐		☐	

Soya, sweetened ☐ Soya, unsweetened ☐

Nut based, e.g. almond, hazelnut ☐ Rice milk ☐ Oat milk ☐

Other (please specify) [ ]

How much milk do you drink each day, including milk with tea, coffee and cereals etc?

None	☐	Three quarters of a pint	☐
Quarter of a pint	☐	One pint	☐
Half a pint	☐	More than one pint	☐

If you usually eat a breakfast cereal other than porridge/Ready Brek, which type?

Type: e.g. cornflakes, muesli, etc [ ]

What kind of fat did you most often use for frying, roasting, grilling etc?

Butter	☐	Solid vegetable fat	☐
Lard/dripping	☐	Baking/cooking liquid	☐
Vegetable oil	☐	Margarine	☐
None	☐		

If you used **vegetable oil**, please give type e.g. corn, sunflower: [ ]

What kind of fat did you most often use for baking cakes etc?

Butter	☐	Solid vegetable fat	☐
Lard/dripping	☐	Baking/cooking liquid	☐
Vegetable oil	☐	Margarine	☐
None	☐		

If you used **margarine**, please give type e.g. Flora, Stork: [ ]

What did you do with the visible fat on your meat?

Ate most of the fat ☐ Ate some of the fat ☐ Ate as little as possible ☐ Did not eat meat ☐

How often did you add salt to food while cooking?

Always ☐ Usually ☐ Sometimes ☐ Rarely ☐ Never ☐

How often did you add salt to any food at the table?

Always ☐ Usually ☐ Sometimes ☐ Rarely ☐ Never ☐

Did you regularly use a salt substitute (eg LoSalt)? Yes ☐ No ☐

Please list any supplements you have taken over the past 3 months e.g. vitamins, minerals, fish oils, protein etc.

Supplement	**Dose** (number of pills, teaspoons, scoops etc.)	**Average frequency** (daily, weekly etc.)

Appendix 5.4. Validation study Bland & Altman plots

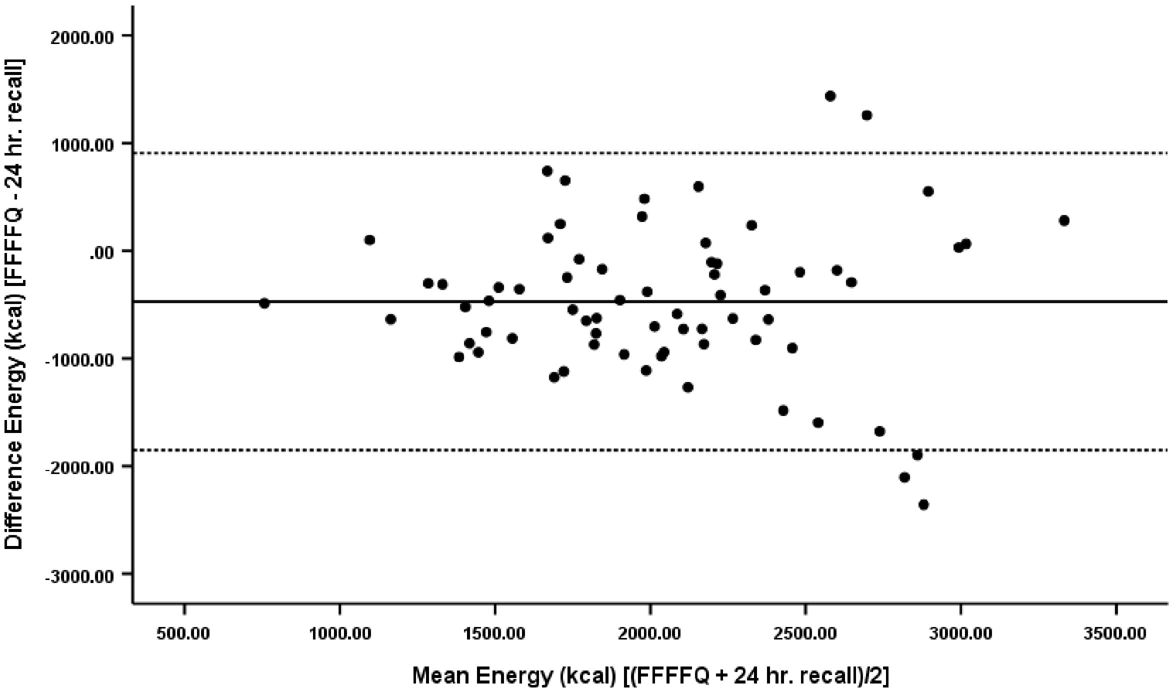


Figure 1. Bland and Altman Plot for mean daily energy intake, indicating broad limits of agreement (dotted lines). The mean difference in energy intakes between the FFFFQ and 24 hr. recall (solid line) (-472 kcal/d), revealed a fixed bias, with the 24 hr. recall recording greater intakes than the FFFFQ. Upon a visual inspection of the plot, there seemed to be a potentially greater disparity between methods at mean energy intakes >2500 kcal/d. Simple linear regression was performed to further assess whether mean energy intake significantly predicted the difference recorded in energy intakes between the FFFFQ and the 24 hr. recall. The results of the regression did not reach statistical significance, $R^2 = 0.001$, $F(1, 67) = 0.051$, $p = 0.822$. Mean energy intake did not significantly predict the difference in energy between the two methods, $\beta = -0.038$, $t = -0.226$, $p = 0.822$, indicating no proportional bias between them. Several cases fell outside the limits of agreement ($n = 5$), indicating a poor level of agreement between the FFFFQ and the 24 hr. recall for recording energy intake.

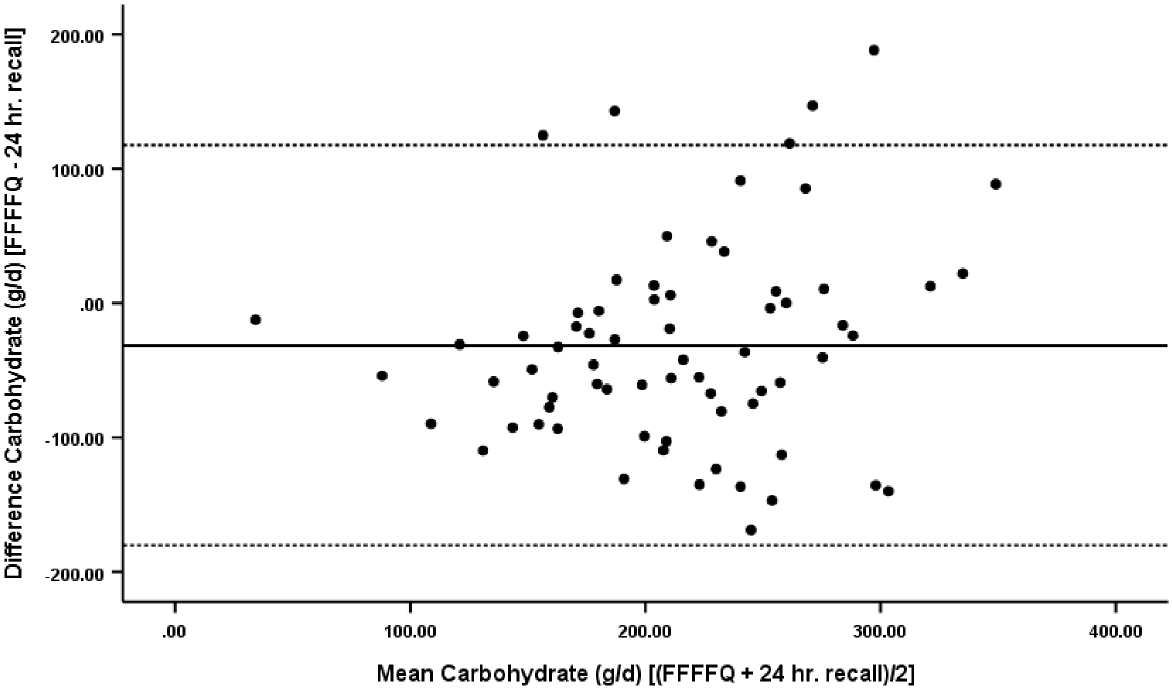


Figure 2. Bland and Altman Plot for mean daily carbohydrate intake, indicating reasonably broad limits of agreement (dotted lines). The mean difference in carbohydrate intakes between the FFFFQ and 24 hr. recall (solid line) (-31 g/d), revealed a relatively small fixed bias, with the 24 hr. recall recording greater intakes than the FFFFQ. Upon a visual inspection of the plot, there seemed to be a potentially greater disparity between methods (progressively greater divergence from the mean difference) as mean carbohydrate increased. Simple linear regression was performed to further assess whether mean carbohydrate intake significantly predicted the difference recorded in carbohydrate intakes between the FFFFQ and the 24 hr. recall. The results of the regression did not reach statistical significance, $R^2 = 0.038$, $F(1, 67) = 2.66$, $p = 0.108$. Mean carbohydrate intake did not significantly predict the difference in carbohydrate between the two methods, $\beta = 0.252$, $t = 1.631$, $p = 0.108$, indicating no proportional bias between them. Several cases fell outside the limits of agreement ($n = 5$), indicating a poorer level of agreement between the FFFFQ and the 24 hr. recall for recording carbohydrate intake.

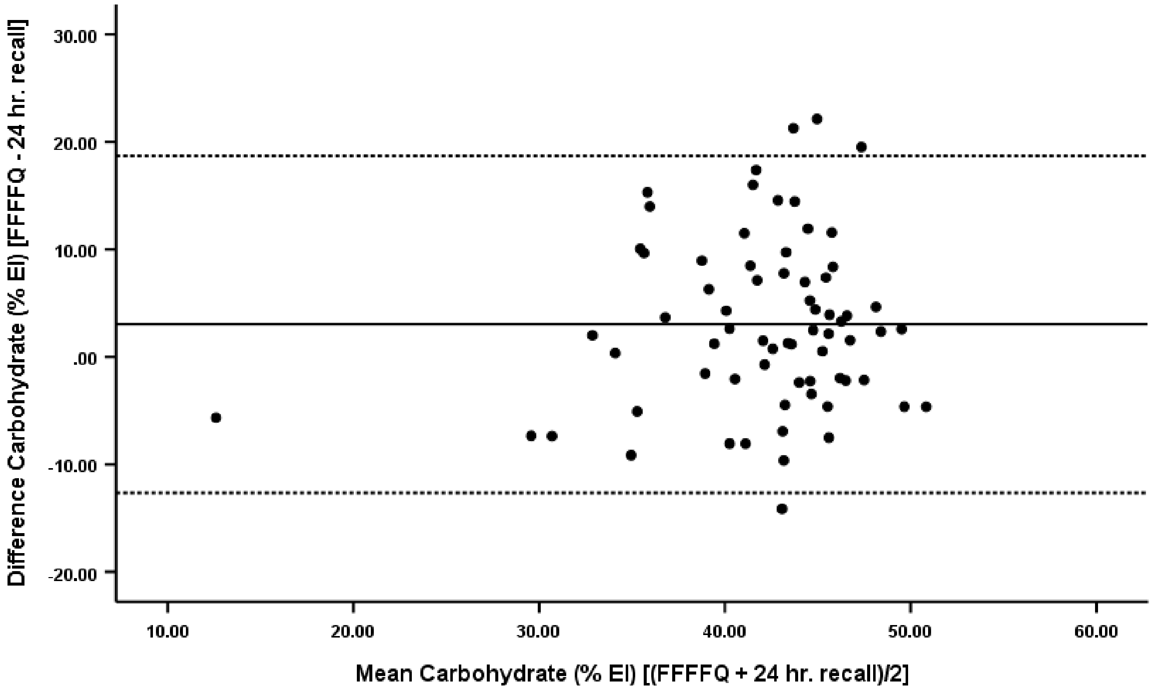


Figure 3. Bland and Altman Plot for mean daily carbohydrate intake expressed as a percentage of total energy intake (% EI), indicating relatively narrow limits of agreement (dotted lines). The mean difference in carbohydrate (% EI) between the FFFFQ and the 24 hr. recall (solid line) was relatively marginal (3 %), with the FFFFQ recording greater intakes than the 24 hr. recall. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean carbohydrate (% EI) significantly predicted the difference recorded in carbohydrate (% EI) between methods. The results of the regression did not reach statistical significance, R^2 = 0.016, $F(1, 67)$ = 0.078, p = 0.303. Mean carbohydrate (% EI) did not significantly predict the difference in carbohydrate (% EI) between methods, β = 0.176, t = 1.038, p = 0.303, further indicating no proportional bias between the FFFFQ and 24 hr. recall. Although 5.8% of the cases fell outside the limits of agreement (n = 4), they remained in close proximity to the limits, which were relatively narrow (2 SD from the mean difference = 15.7 %), compared with the relatively broad limits of agreement for absolute carbohydrate intake (2 SD from the mean difference = 149 g/d) as displayed in Fig 24. This indicates an acceptable level of agreement between the FFFFQ and 24 hr. recall for recording carbohydrate (% EI). It also suggests that the poor agreement displayed in Figure 2 (absolute carbohydrate intake) is probably a function of the FFFFQ's underlying underestimation of total energy intake (table 4 (main text); Figure 1), having a repercussive proportional effect on total carbohydrate intake measurement.

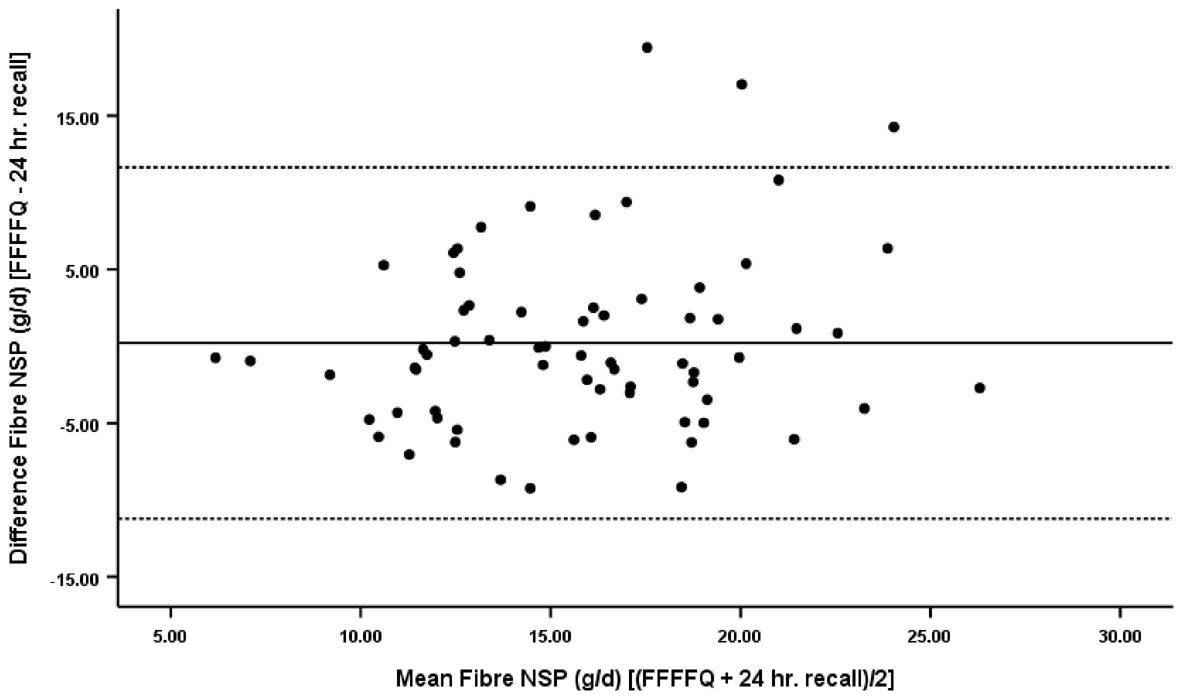


Figure 4. Bland and Altman Plot for mean daily fibre intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in fibre intakes between the FFFFQ and 24 hr. recall (solid line) was marginal (0.2 g/d). No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean fibre intake significantly predicted the difference recorded in fibre intakes between methods. The results of the regression did not reach statistical significance, $R^2 = 0.04$, $F(1, 67) = 2.801$, $p = 0.099$. Mean fibre intake did not significantly predict the difference in fibre between the two methods, $\beta = 0.284$, $t = 1.674$, $p = 0.099$, further indicating no proportional bias between them. More than 95% of cases remained between the limits of agreement ($n = 66$), indicating a good level of agreement between the FFFFQ and 24 hr. recall for recording fibre intake.

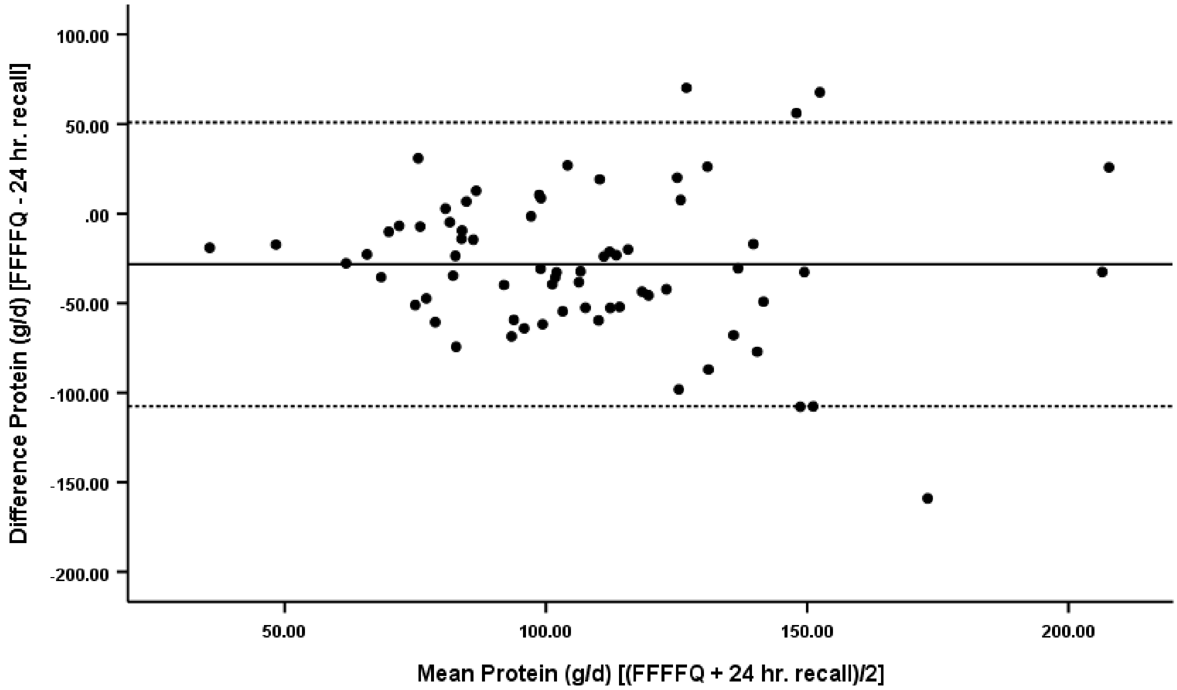


Figure 5. Bland and Altman Plot for mean daily protein intake, indicating broad limits of agreement (dotted lines). The mean difference in protein intakes between the FFFFQ and 24 hr. recall (solid line) (-28.3 g/d), revealed a fixed bias, with the 24 hr. recall recording greater intakes than the FFFFQ. Upon a visual inspection of the plot, there seemed to be a potentially greater disparity between methods, with progressively greater divergence from the mean difference above a mean intake of 120 g/d. Simple linear regression was performed to further assess whether mean protein intake significantly predicted the difference recorded in protein intakes between the FFFFQ and the 24 hr. recall. The results of the regression did not reach statistical significance, $R^2 = 0.012$, $F(1, 67) = 0.79$, $p = 0.377$. Mean protein intake did not significantly predict the difference in protein between the two methods, $\beta = -0.136$, $t = -0.889$, $p = 0.377$, indicating no proportional bias between them. Several cases fell outside the limits of agreement ($n = 4$), indicating an acceptable level of agreement between the FFFFQ and the 24 hr. recall for recording protein intake.

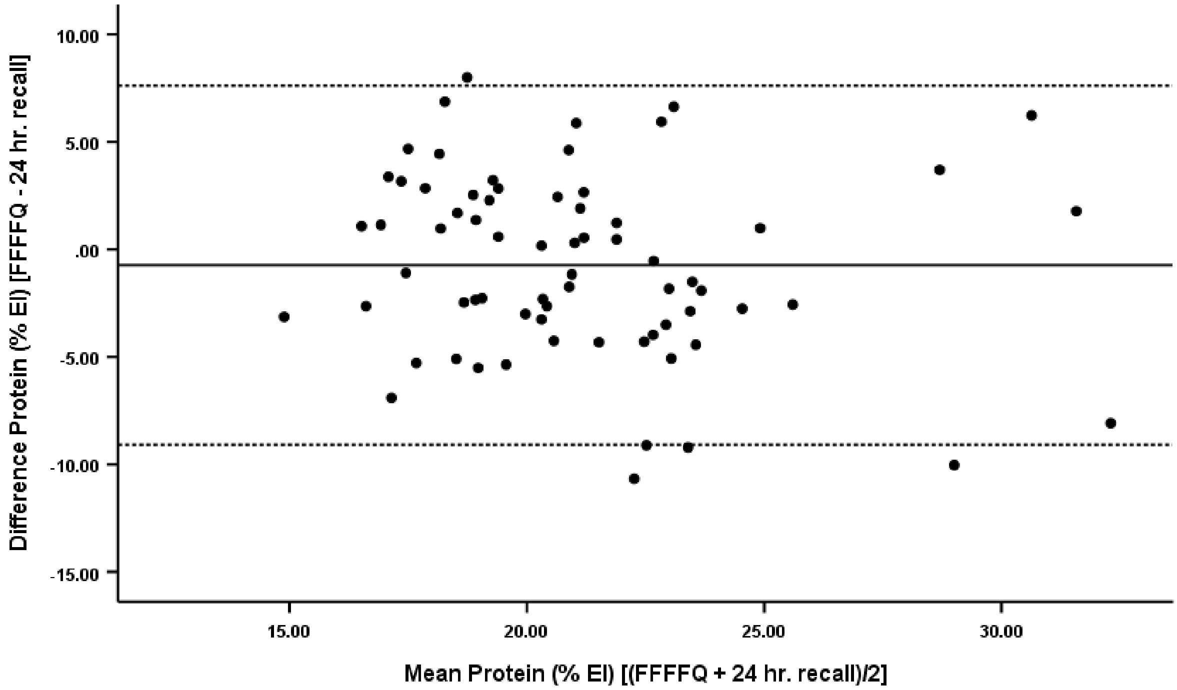


Figure 6. Bland and Altman Plot for mean daily protein intake expressed as a percentage of total energy intake (% EI), indicating reasonably narrow limits of agreement (dotted lines). The mean difference in protein (% EI) between the FFFFQ and the 24 hr. recall (solid line) was marginal (0.7 %). No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean protein (% EI) significantly predicted the difference recorded in protein (% EI) between methods. The results of the regression did not reach statistical significance, $R^2 = 0.027$, $F(1, 67) = 1.877$, $p = 0.175$. Mean protein (% EI) did not significantly predict the difference in protein (% EI) between methods, $\beta = -0.201$, $t = -1.37$, $p = 0.175$, further indicating no proportional bias between the FFFFQ and 24 hr. recall. Although < 5 % of the cases fell outside the limits of agreement (n = 3), two cases fell on the lower limit boundary, which were relatively narrow limits (2 SD from the mean difference = 8.3 %), compared with the relatively broad limits of agreement for absolute protein intake (2 SD from the mean difference = 79 g/d) as displayed in Figure 5. This indicates a borderline acceptable level of agreement between the FFFFQ and 24 hr. recall for recording protein (% EI). It also suggests that the slightly poorer agreement indicated in Figure 5 (absolute protein intake) is probably a function of the FFFFQ's underlying underestimation of total energy intake (table 4 main text; Figure 1), having a repercussive proportional effect on total protein intake measurement.

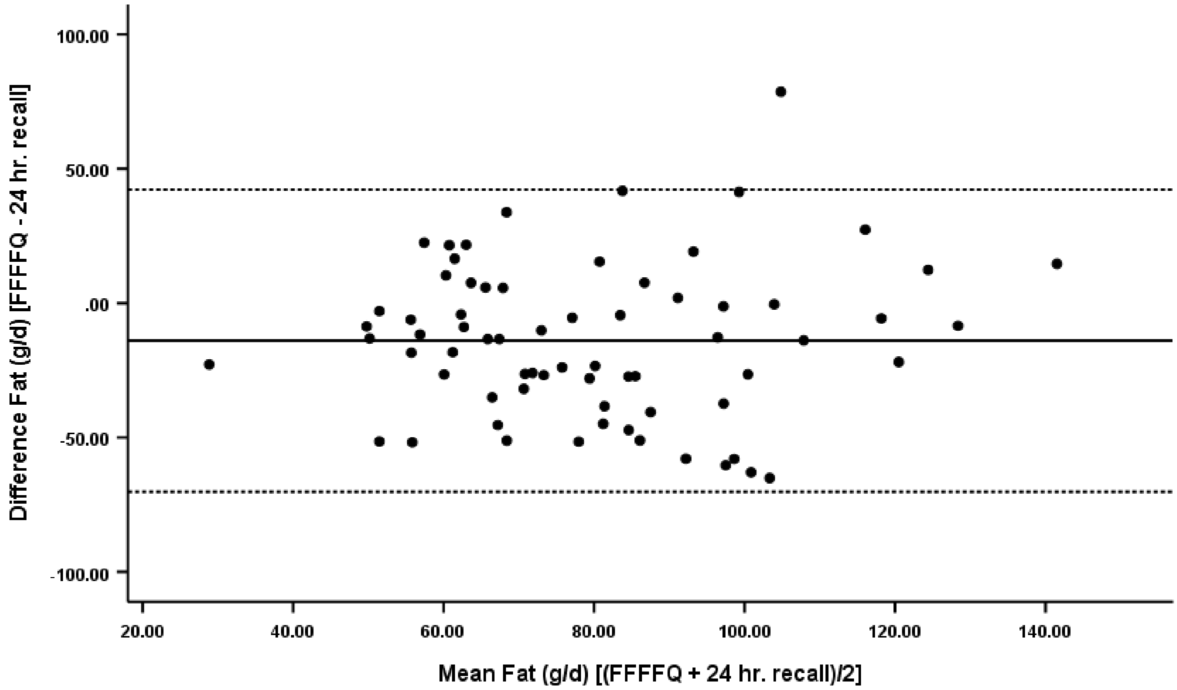


Figure 7. Bland and Altman Plot for mean daily fat intake, indicating reasonably broad limits of agreement (dotted lines). The mean difference in fat intakes between the FFFFQ and 24 hr. recall (solid line) (-14 g/d) revealed a fixed bias, with the 24hr. recall recording greater intakes than the FFFFQ. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean fat intake significantly predicted the difference recorded in fat intakes between methods. The results of the regression did not reach statistical significance, $R^2 = 0.04$, $F(1, 67) = 0.283$, $p = 0.597$. Mean fat intake did not significantly predict the difference in fat between the two methods, $\beta = 0.086$, $t = 0.532$, $p = 0.597$, further indicating no proportional bias between them. More than 95% of cases remained between the limits of agreement ($n = 68$), indicating a good level of agreement between the FFFFQ and 24 hr. recall for recording fat intake.

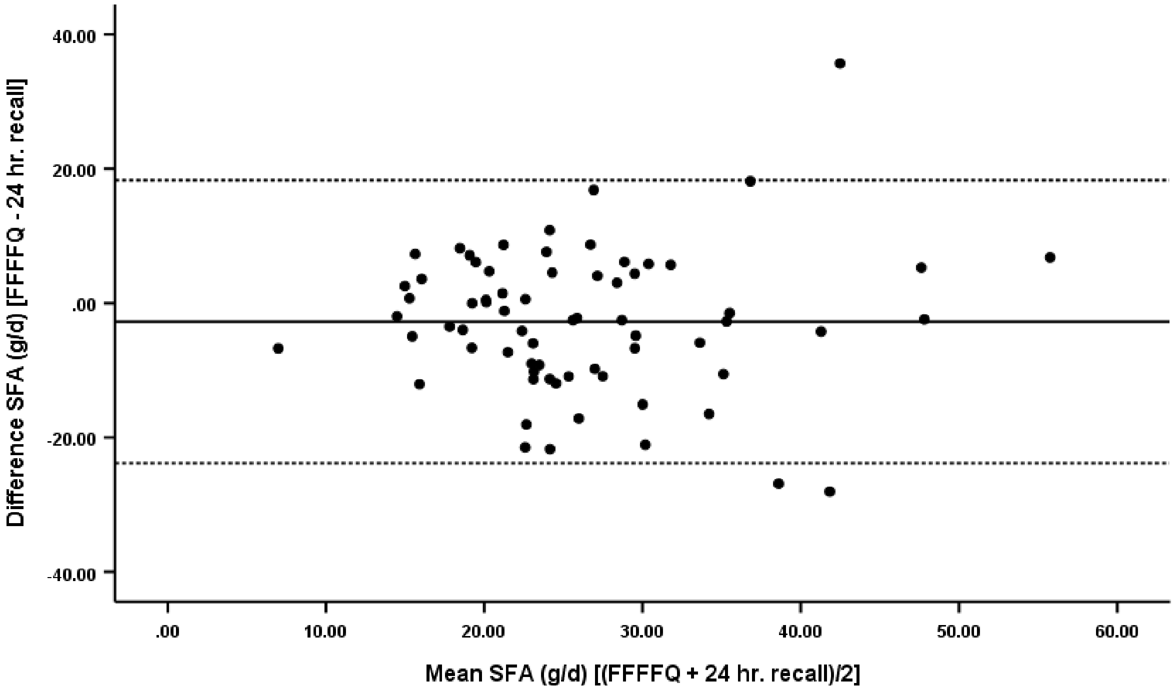


Figure 8. Bland and Altman Plot for mean daily SFA intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in SFA intakes between the FFFFQ and 24 hr. recall (solid line) (-2.8 g/d) revealed a relatively small fixed bias, with the 24 hr. recall recording greater intakes than the FFFFQ. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean SFA intake significantly predicted the difference recorded in SFA intakes between methods. The results of the regression did not reach statistical significance, $R^2 = 0.001$, $F(1, 67) = 0.084$, $p = 0.772$. Mean SFA intake did not significantly predict the difference in SFA between the two methods, $\beta = 0.044$, $t = 0.290$, $p = 0.772$, further indicating no proportional bias between them. More than 95% of cases remained between the limits of agreement ($n = 66$), indicating a good level of agreement between the FFFFQ and 24 hr. recall for recording SFA intake.

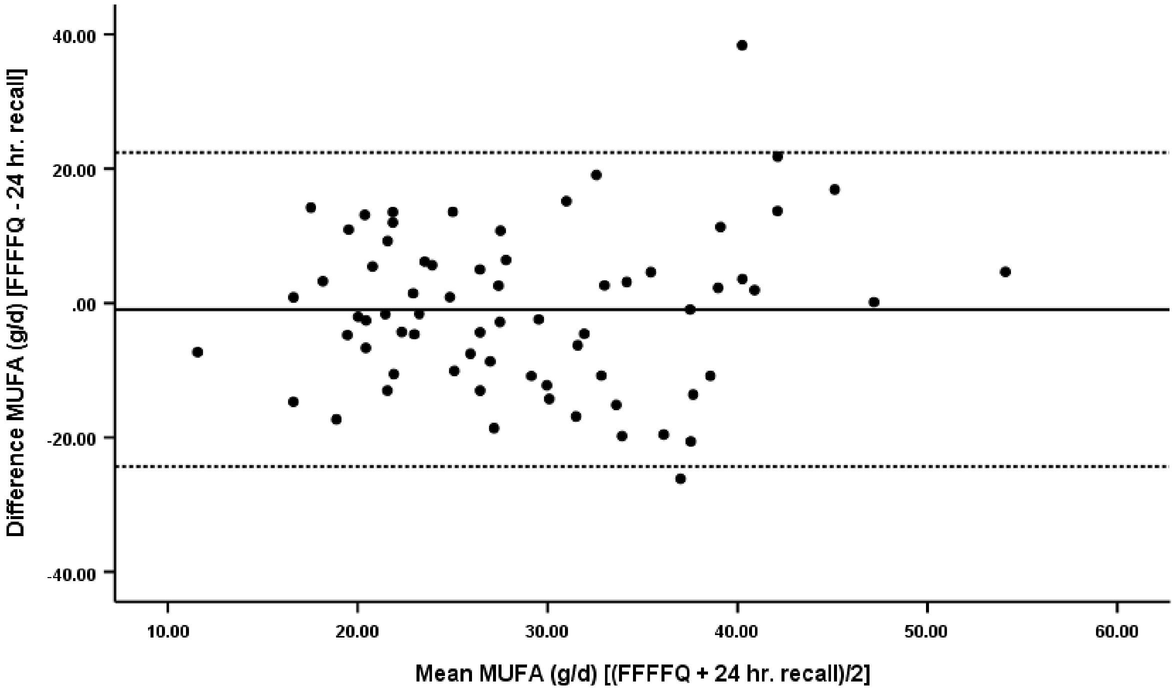


Figure 9. Bland and Altman Plot for mean daily MUFA intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in MUFA intakes between the FFFFQ and 24 hr. recall (solid line) (-0.1 g/d) was marginal. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean MUFA intake significantly predicted the difference recorded in MUFA intakes between methods. The results of the regression did not reach statistical significance, $R^2 = 0.011$, $F(1, 67) = 0.734$, $p = 0.395$. Mean MUFA intake did not significantly predict the difference in MUFA between the two methods, $\beta = 0.146$, $t = 0.857$, $p = 0.395$, further indicating no proportional bias between them. More than 95% of cases remained between the limits of agreement ($n = 67$), indicating a good level of agreement between the FFFFQ and 24 hr. recall for recording MUFA intake.

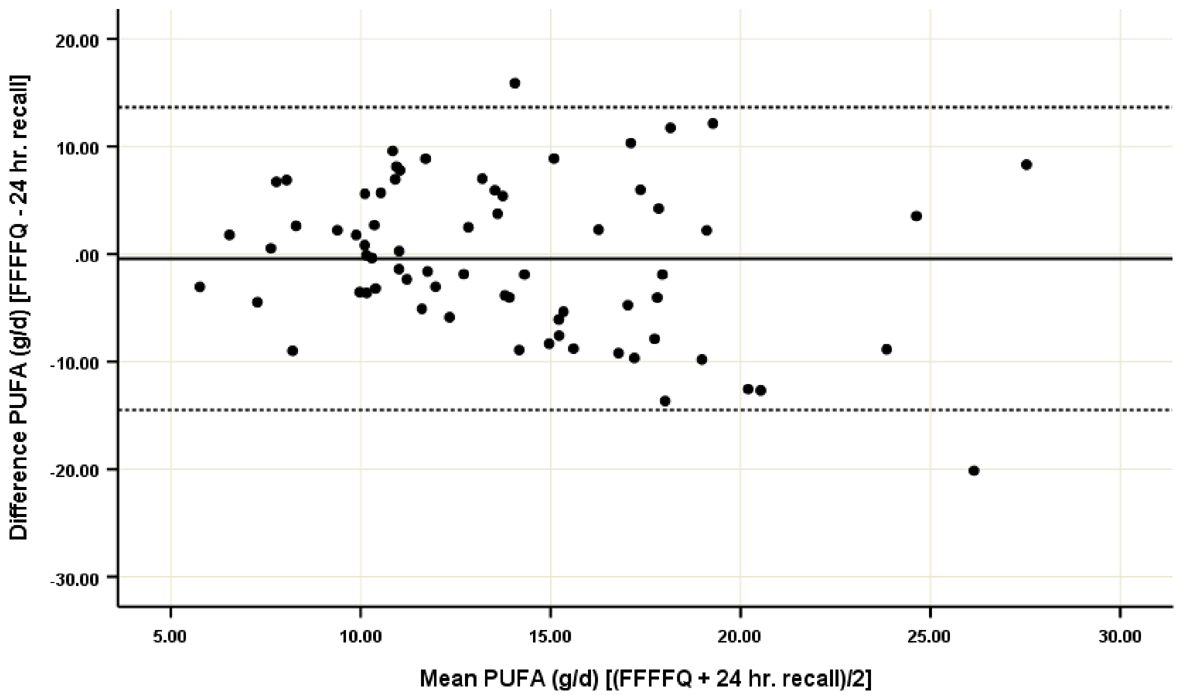


Figure 10. Bland and Altman Plot for mean daily PUFA intake, indicating broad limits of agreement (dotted lines). The mean difference in PUFA intakes between the FFFFQ and 24 hr. recall (solid line) (-0.4 g/d) was marginal. Upon a visual inspection of the plot, there seemed to be a potentially greater disparity between methods, with progressively greater divergence from the mean difference above a mean intake of 15 g/d. Simple linear regression was performed to further assess whether mean PUFA intake significantly predicted the difference recorded in PUFA intakes between methods. The results of the regression suggested that mean Mean PUFA intake explained 6% of the variance, $R^2 = 0.06$, $F(1, 67) = 4.042$, $p = 0.048$. Mean PUFA intake significantly predicted the difference in PUFA between the two methods, $\beta = -0.369$, $t = -2.011$, $p = 0.048$, indicating some proportional bias between them. This warranted further visual inspection of the Bland and Altman plot. This revealed, at mean intakes below 15 g/d, 26% of the participants recorded greater PUFA intakes via 24 hr. recall ($n = 18$), vs 36% of the participants recording greater intakes of PUFA via FFFFQ ($n = 25$). Even so, there was a smaller deviation from the line of equality at these smaller intakes, and with > than 95% of cases remaining between the limits of agreement ($n = 67$), no fixed bias, and what can be considered as an acceptable level of proportional bias, a good level of agreement was indicated between the FFFFQ and 24 hr. recall for recording PUFA intake.

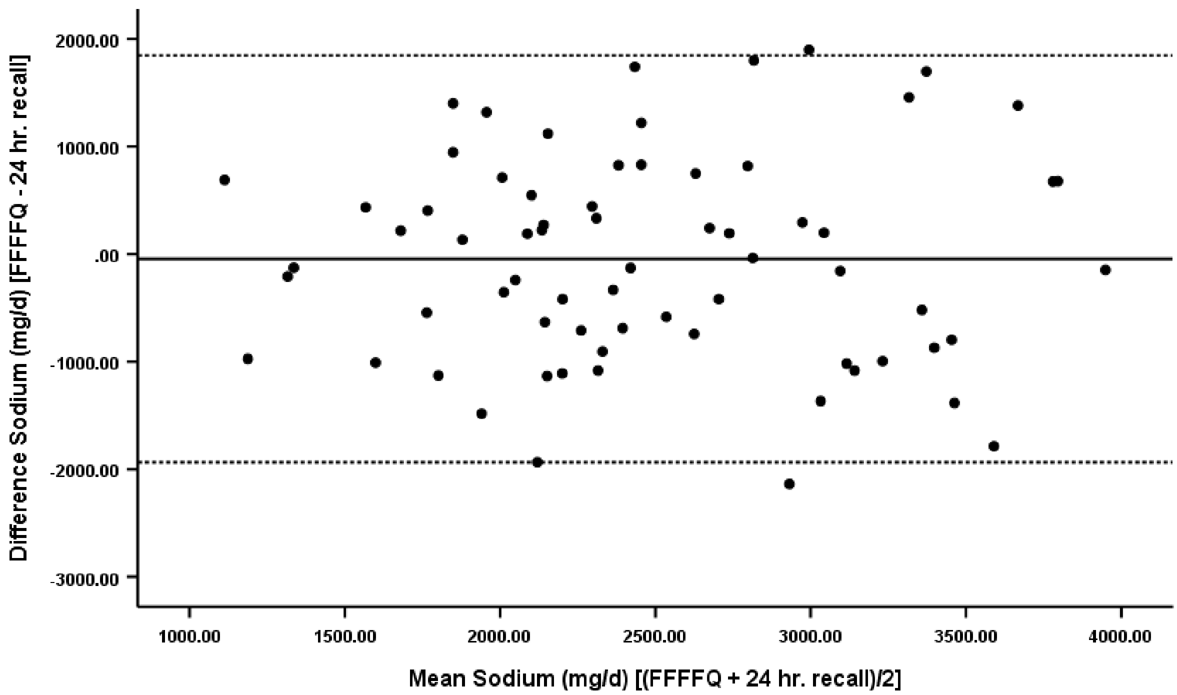


Figure 11. Bland and Altman Plot for mean daily sodium intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in sodium intakes between the FFFFQ and 24 hr. recall (solid line) (-45 mg/d) was marginal. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean sodium intake significantly predicted the difference recorded in sodium intakes between methods. The results of the regression did not reach statistical significance, $R^2 = 0$, $F(1, 67) = 0.001$, $p = 0.971$. Mean sodium intake did not significantly predict the difference in sodium between the two methods, $\beta = 0.006$, $t = 0.037$, $p = 0.971$, further indicating no proportional bias between them. More than 95% of cases remained between the limits of agreement ($n = 67$), indicating a good level of agreement between the FFFFQ and 24 hr. recall for recording sodium intake.

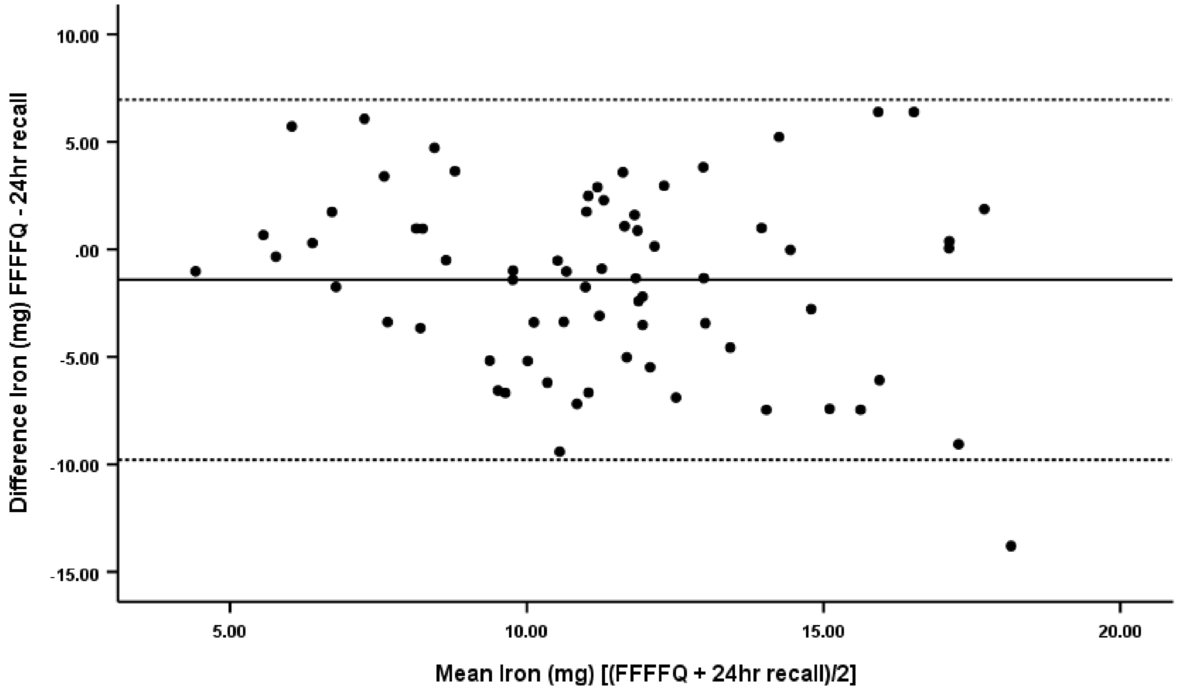


Figure 12. Bland and Altman Plot for mean daily iron intake, indicating fairly broad limits of agreement (dotted lines). The mean difference in iron intakes between the FFFFQ and 24 hr. recall (solid line) (-1.4 mg/d) revealed a relatively small fixed bias, with the 24 hr. recall recording greater intakes than the FFFFQ. Visual inspection of the plot indicates that the FFFFQ may record slightly greater intakes than 24hr recall at mean intakes below 9 mg/d. Simple linear regression was performed to further assess whether mean iron intake significantly predicted the difference recorded in iron intakes between methods. The results of the regression did not reach statistical significance, $R^2 = 0.05$, $F(1, 67) = 3.19$, $p = 0.08$. Mean sodium intake did not significantly predict the difference in sodium between the two methods, $\beta = -0.29$, $t = -1.79$, $p = 0.08$, indicating no proportional bias between them. More than 95% of cases remained between the limits of agreement ($n = 68$), indicating a good level of agreement between the FFFFQ and 24 hr. recall for recording iron intake.

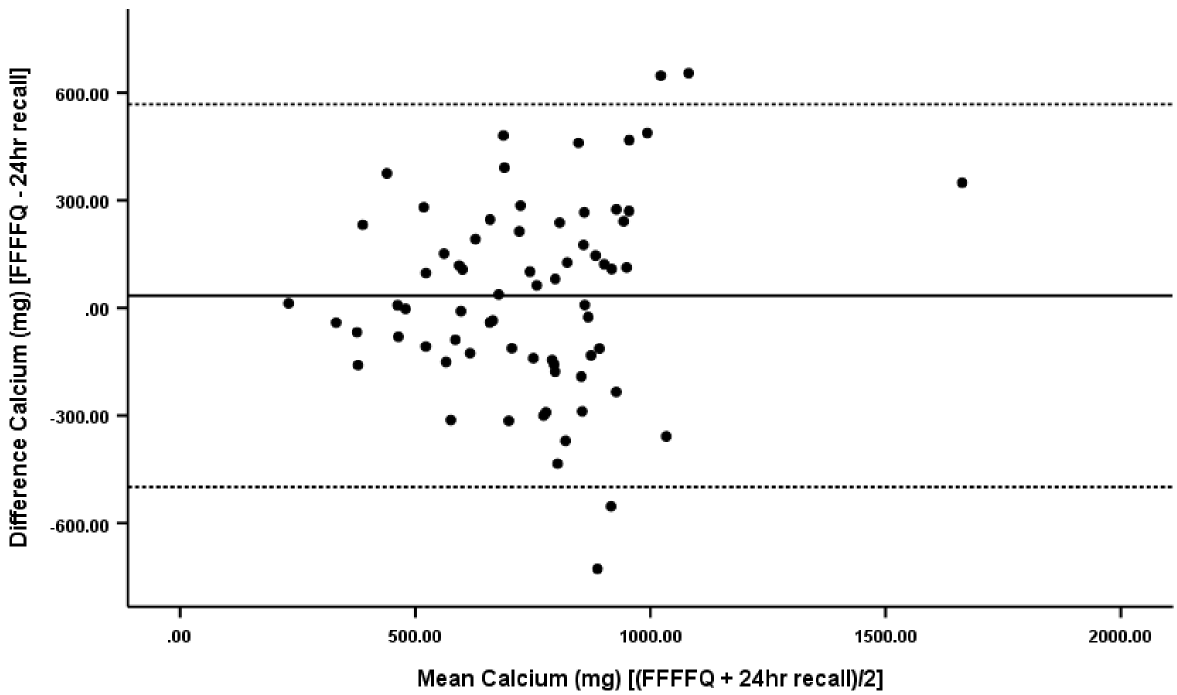


Figure 13. Bland and Altman Plot for mean daily calcium intake, indicating broad limits of agreement (dotted lines). The mean difference in calcium intakes between the FFFFQ and 24 hr. recall (solid line) (33.9 mg/d) was marginal. Upon a visual inspection of the plot, there seemed to be a potentially greater disparity between methods, with progressively greater divergence from the mean difference. Simple linear regression was performed to further assess whether mean calcium intake significantly predicted the difference recorded in calcium intakes between methods. The results of the regression did not reach statistical significance, $R^2 = 0.02$, $F(1, 67) = 1.52$, $p = 0.22$. Mean calcium intake did not significantly predict the difference in calcium between the two methods, $\beta = 0.19$, $t = 1.23$, $p = 0.22$, indicating no proportional bias between them. The vast majority of cases remained between the limits of agreement ($n = 65$), indicating an acceptable level of agreement between the FFFFQ and 24 hr. recall for recording calcium intake.

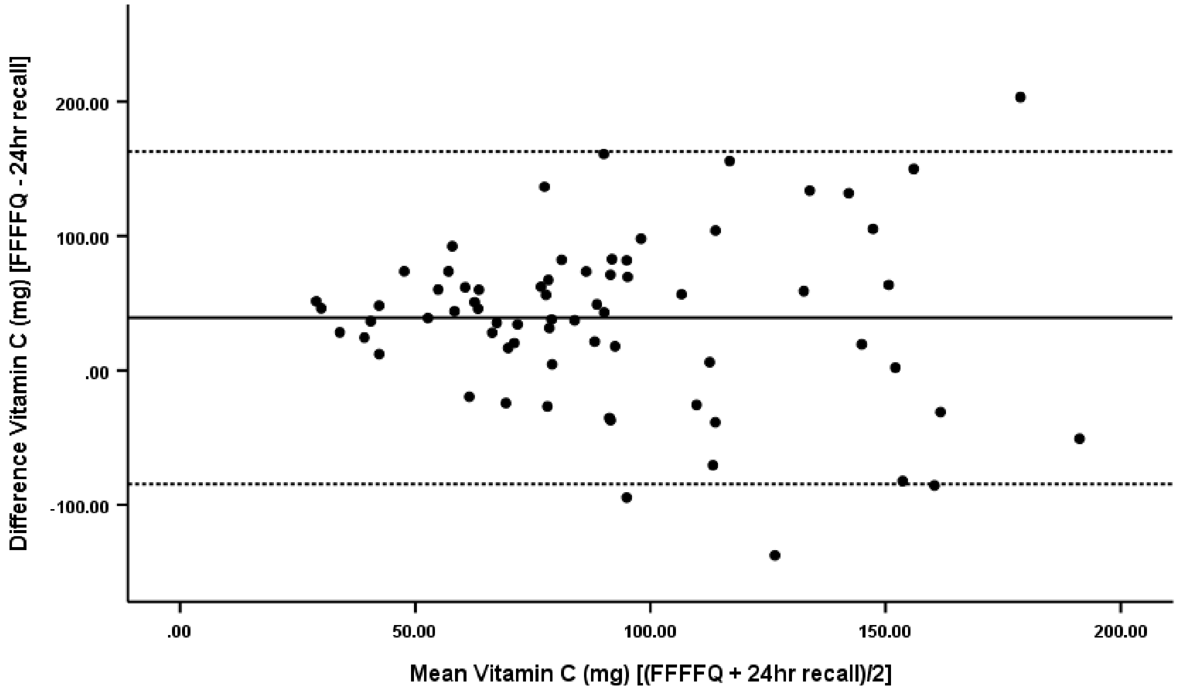


Figure 14. Bland and Altman Plot for mean daily vitamin C intake, indicating broad limits of agreement (dotted lines). The mean difference in vitamin intakes between the FFFFQ and 24 hr. recall (solid line) (39 mg/d) revealed a fixed bias, with the FFFFQ recording greater intakes than the 24hr recall. Upon a visual inspection of the plot, there seemed to be a potentially greater disparity between methods, with progressively greater divergence from the mean difference. Simple linear regression was performed to further assess whether mean vitamin C intake significantly predicted the difference recorded in vitamin C intakes between methods. The results of the regression did not reach statistical significance, $R^2 = 0.002$, $F(1, 67) = 0.15$, $p = 0.7$. Mean vitamin C intake did not significantly predict the difference in Vitamin C between the two methods, $\beta = -0.08$, $t = -0.39$, $p = 0.7$, indicating no proportional bias between them. More than 95% of cases remained between the limits of agreement ($n = 66$), indicating a good level of agreement between the FFFFQ and 24 hr. recall for recording vitamin C intake.

Appendix 5.5. Reproducibility study scatter plots and Bland & Altman plots

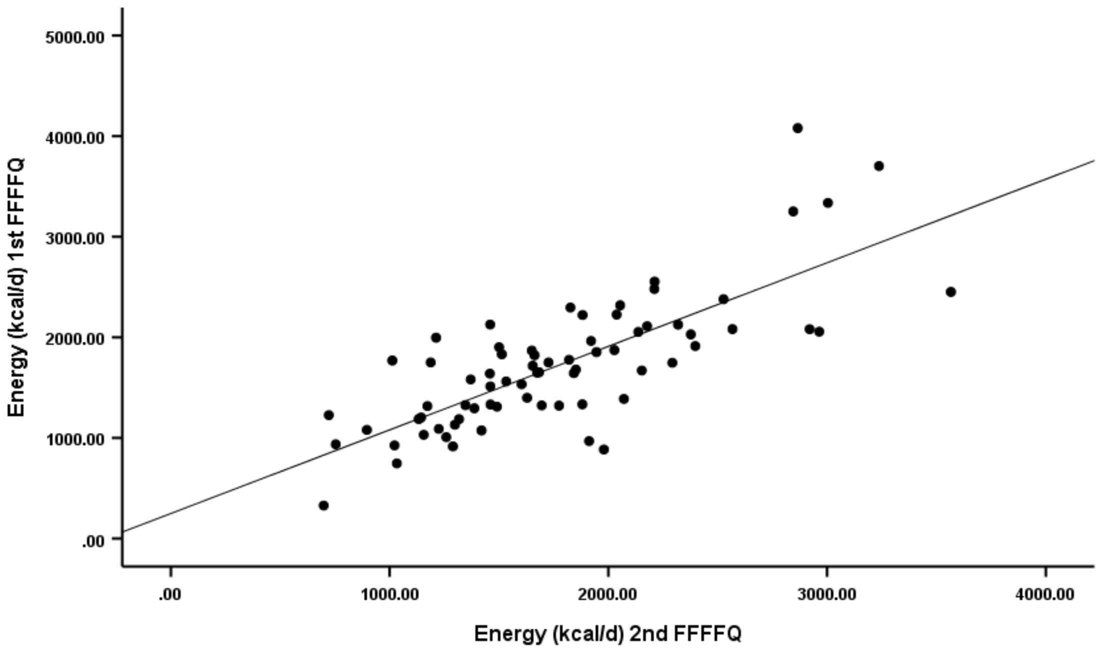


Figure 1. Scatter plot displaying a strong and highly significant correlation between energy intakes measured by the 1st and 2nd FFFFQ.

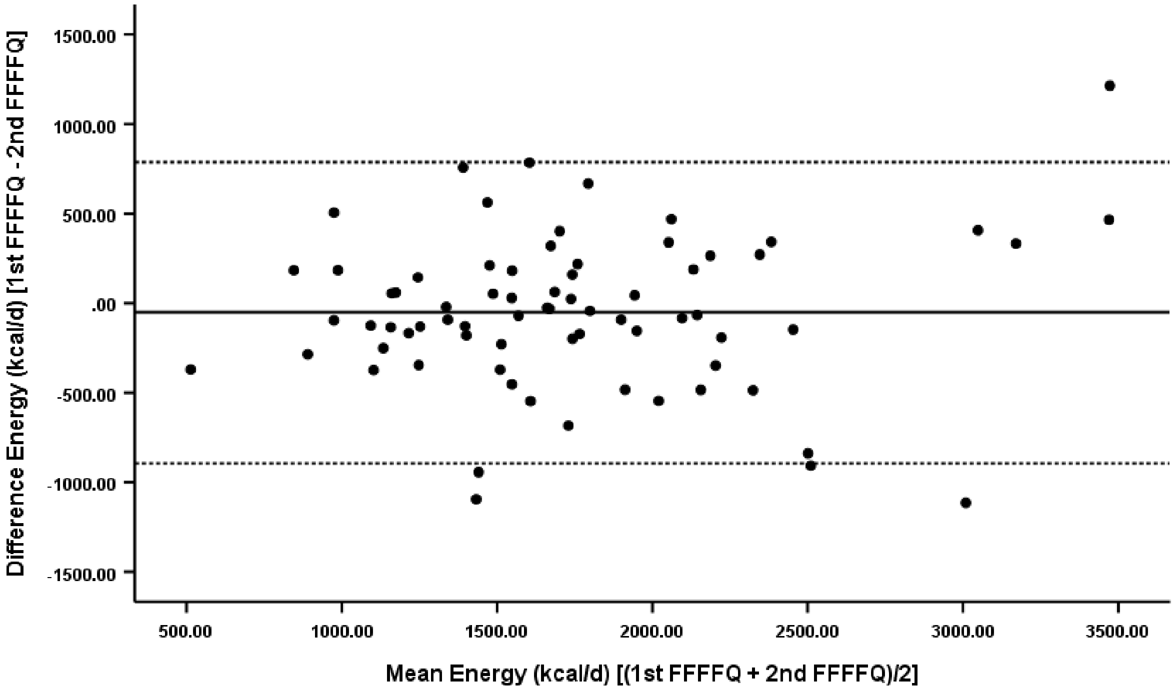


Figure 2. Bland and Altman Plot for mean daily energy intake, indicating reasonably broad limits of agreement (dotted lines). The mean difference in energy intakes between FFFFQs (solid line) was relatively marginal (-50 kcal/d), with the 2nd FFFFQ recording higher intakes than the 1st FFFFQ. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean energy intake significantly predicted the difference recorded in energy intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.036$, $F(1, 70) = 2.59$, $p = 0.112$. Mean energy intake did not significantly predict the difference in energy between questionnaires, $\beta = 0.084$, $t = 0.979$, $p = 0.331$, further indicating no proportional bias between the 1st and 2nd FFFFQ. A small minority of cases fell outside the limits of agreement ($n = 5$), indicating an acceptable level of agreement between the 1st and 2nd FFFFQs for energy intake.

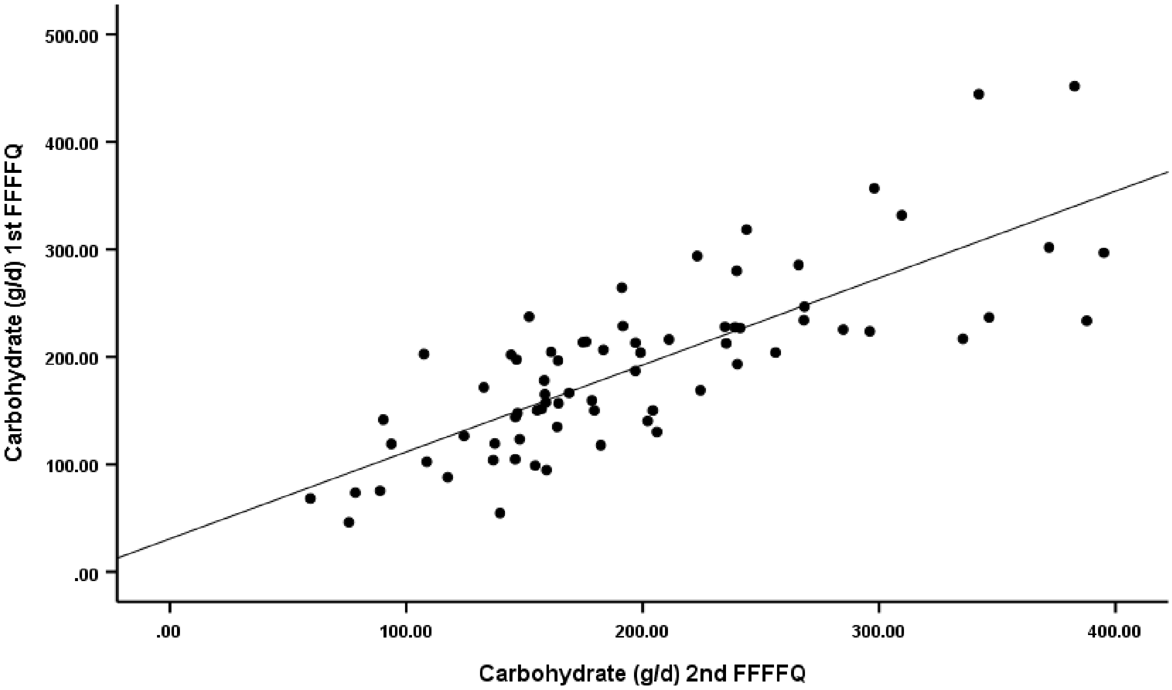


Figure 3. Scatter plot displaying a strong and highly significant correlation between carbohydrate intakes measured by the 1st and 2nd FFFFQ.

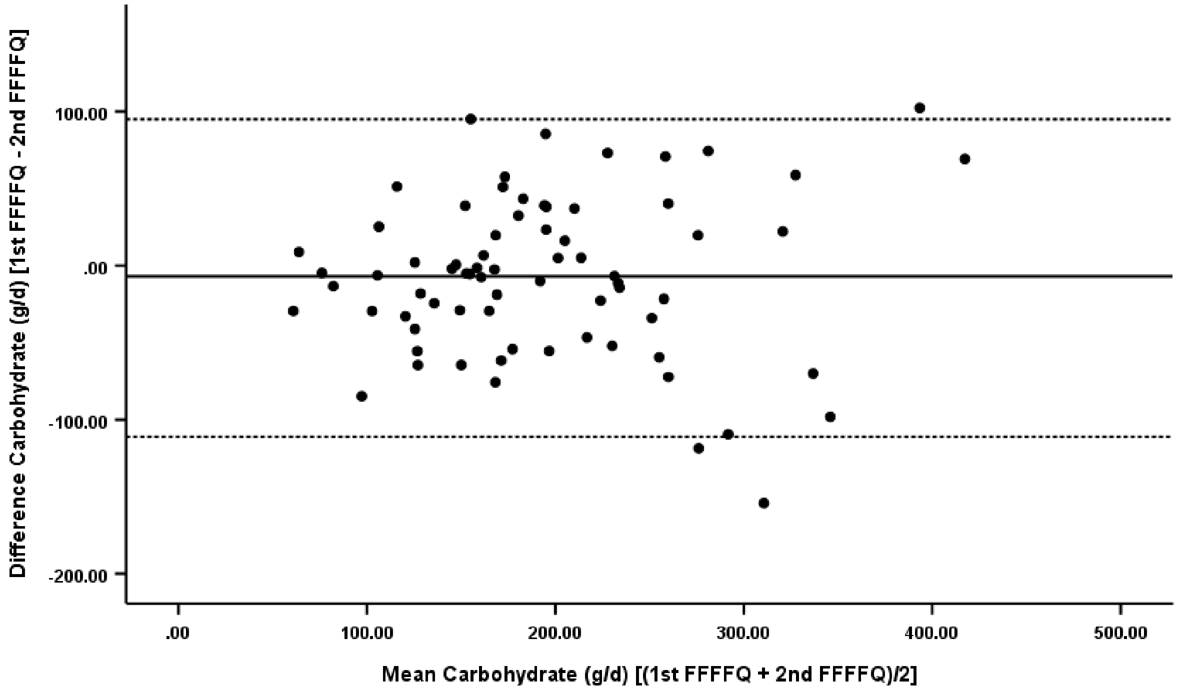


Figure 4. Bland and Altman Plot for mean daily carbohydrate intake, indicating reasonably broad limits of agreement (dotted lines). The mean difference in carbohydrate intakes between FFFFQs (solid line) was relatively marginal (-7 g/d), with the 2nd FFFFQ recording higher intakes than the 1st FFFFQ. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean carbohydrate intake significantly predicted the difference recorded in carbohydrate intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.002$, $F(1, 70) = 0.145$, $p = 0.705$. Mean carbohydrate intake did not significantly predict the difference in carbohydrate between questionnaires, $\beta = 0.031$, $t = 0.380$, $p = 0.705$, further indicating no proportional bias between the 1st and 2nd FFFFQ. Less than 5% of cases fell outside the limits of agreement ($n = 3$), confirming a good level of agreement between the 1st and 2nd FFFFQs for carbohydrate intake.

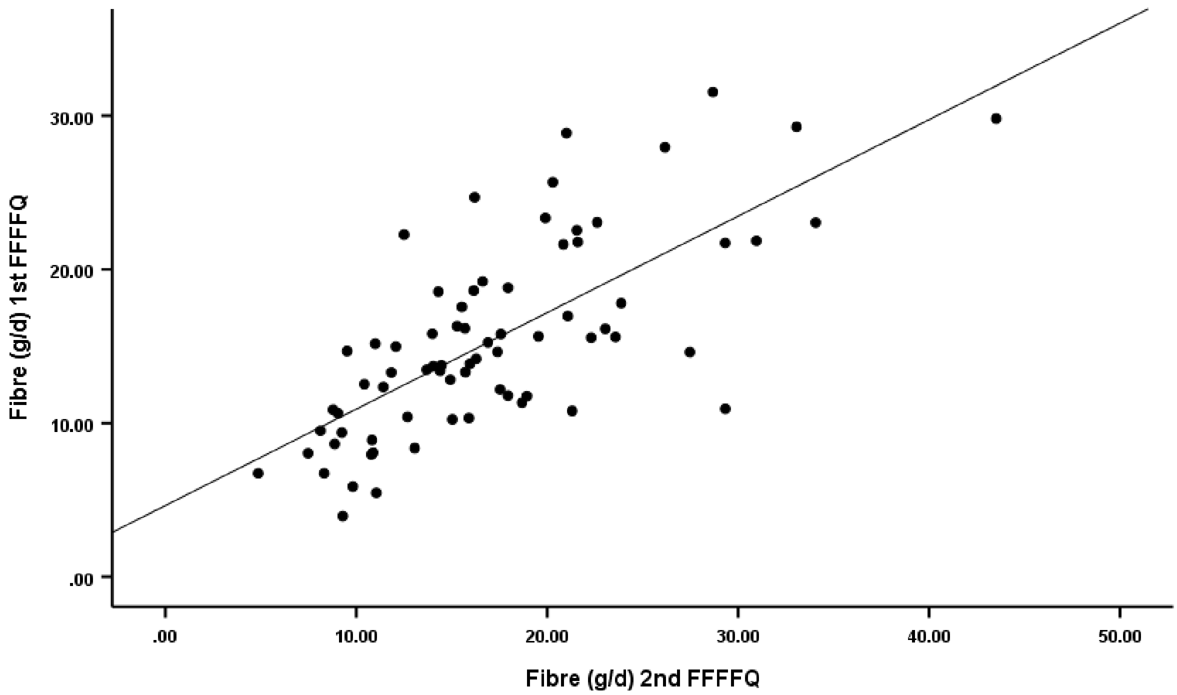


Figure 5. Scatter plot displaying a strong and highly significant correlation between fibre intakes measured by the 1st and 2nd FFFFQ.

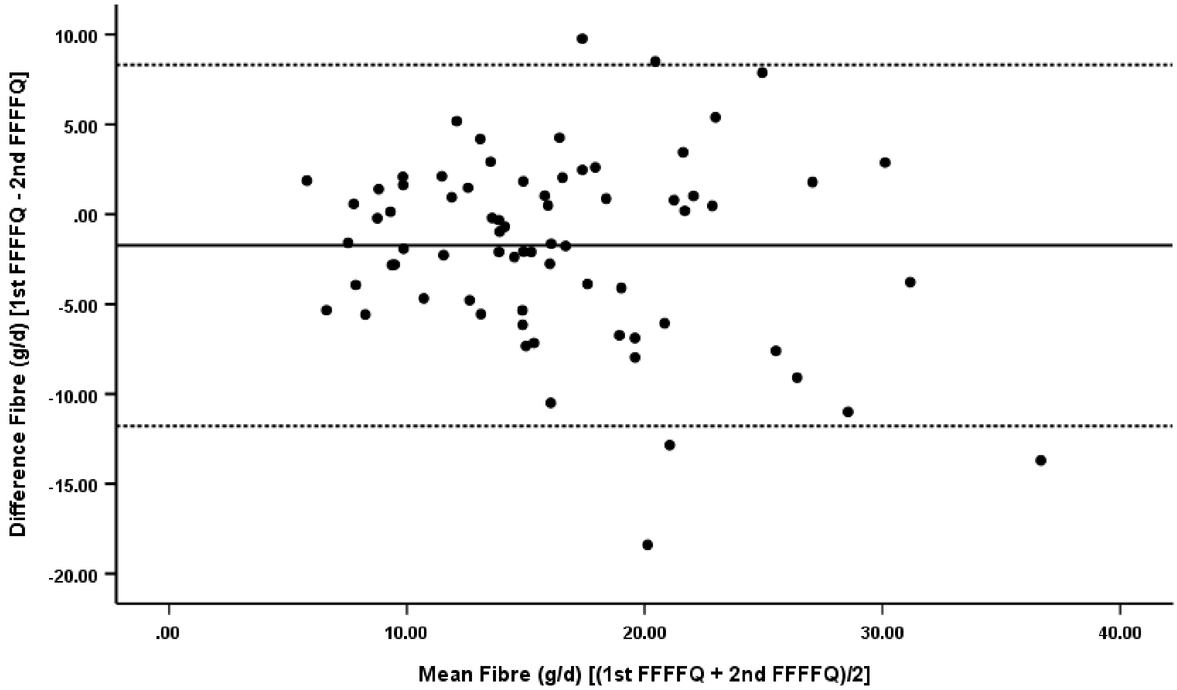


Figure 6. Bland and Altman Plot for mean daily fibre intake, indicating broad limits of agreement (dotted lines). The mean difference in fibre intakes between FFFFQs (solid line) was relatively marginal (-1.7 g/d), with the 2nd FFFFQ recording higher intakes than the 1st FFFFQ. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean fibre intake significantly predicted the difference recorded in fibre intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.036$, $F(1, 70) = 2.59$, $p = 0.112$. Mean fibre intake did not significantly predict the difference in fibre between questionnaires, $\beta = -0.155$, $t = -1.609$, $p = 0.112$, further indicating no proportional bias between the 1st and 2nd FFFFQ. A small minority of cases fell outside the limits of agreement ($n = 5$), indicating an acceptable level of agreement between the 1st and 2nd FFFFQs for fibre intake.

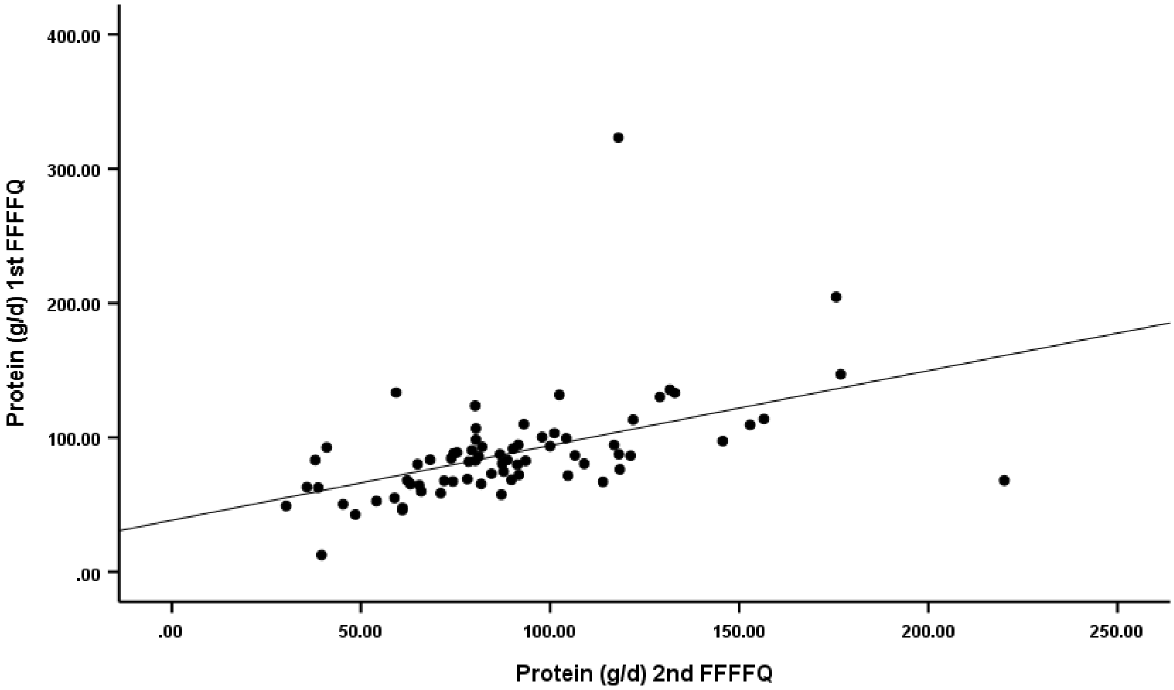


Figure 7. Scatter plot displaying a strong and highly significant correlation between protein intakes measured by the 1st and 2nd FFFFQ.

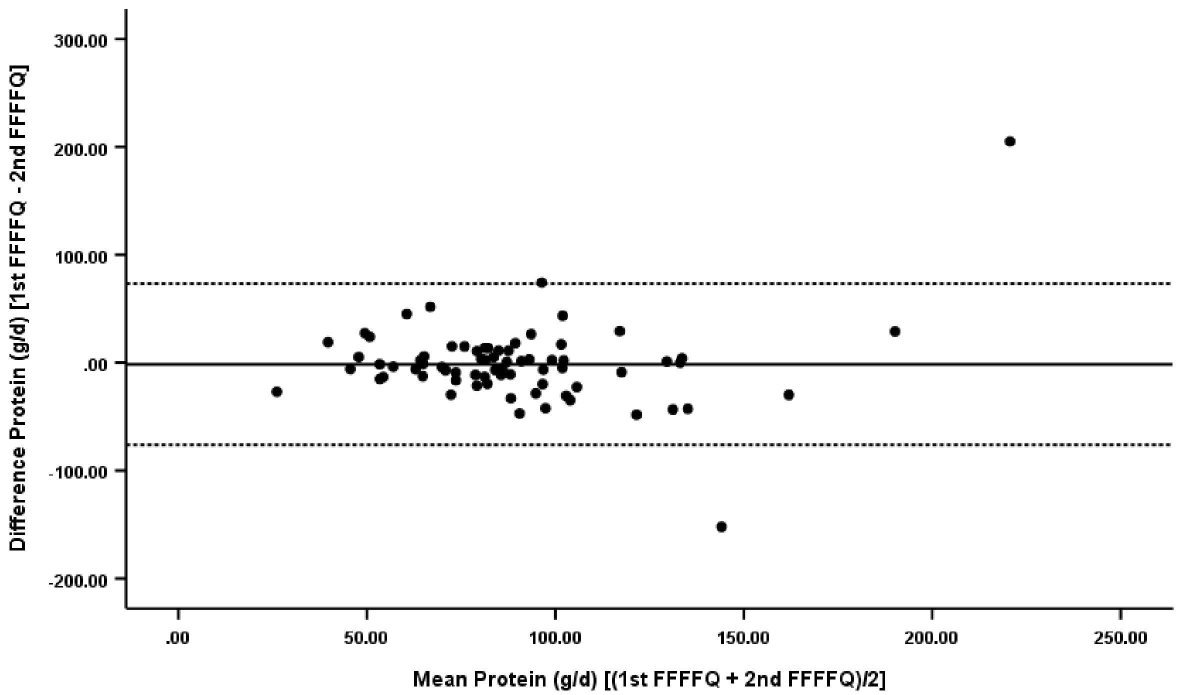


Figure 8. Bland and Altman Plot for mean daily protein intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in protein intakes between FFFFQs (solid line) was marginal (-1.5 g/d). No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean protein intake significantly predicted the difference recorded in protein intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.022$, $F(1, 70) = 1.547$, $p = 0.218$. Mean protein intake did not significantly predict the difference in protein between questionnaires, $\beta = 0.173$, $t = 1.244$, $p = 0.218$ further indicating no proportional bias between the 1st and 2nd FFFFQ. Less than 5% of cases fell outside the limits of agreement ($n = 2$), confirming a good level of agreement between the 1st and 2nd FFFFQs for protein intake.

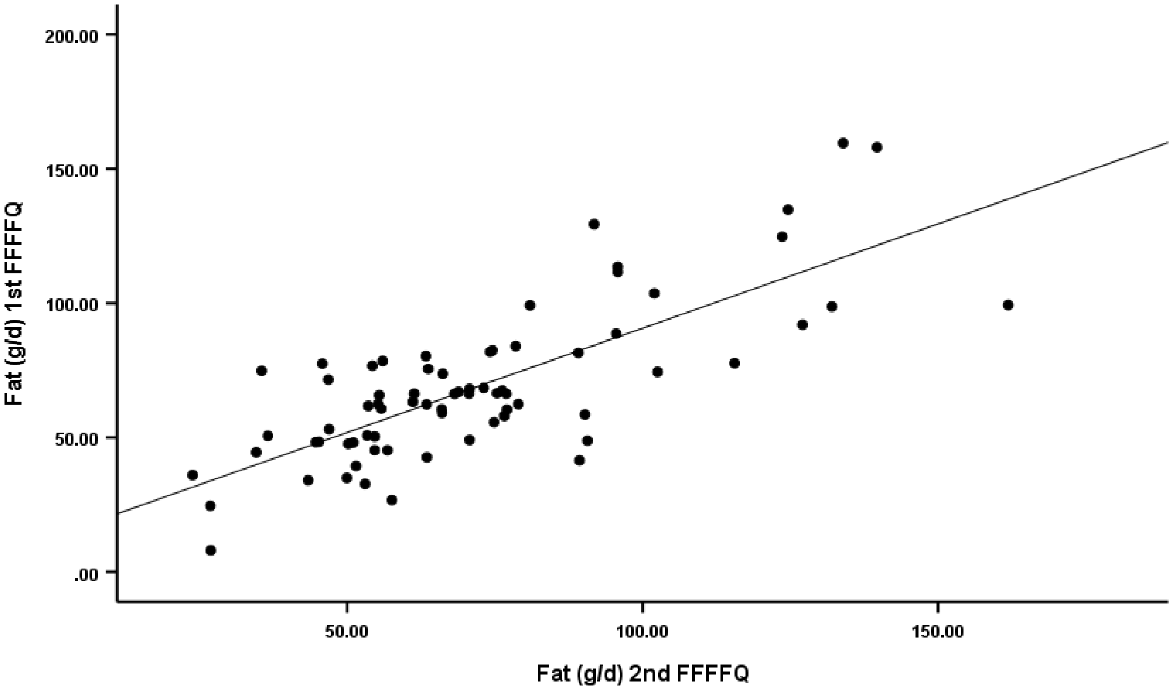


Figure 9. Scatter plot displaying a strong and highly significant correlation between total fat intakes measured by the 1st and 2nd FFFFQ.

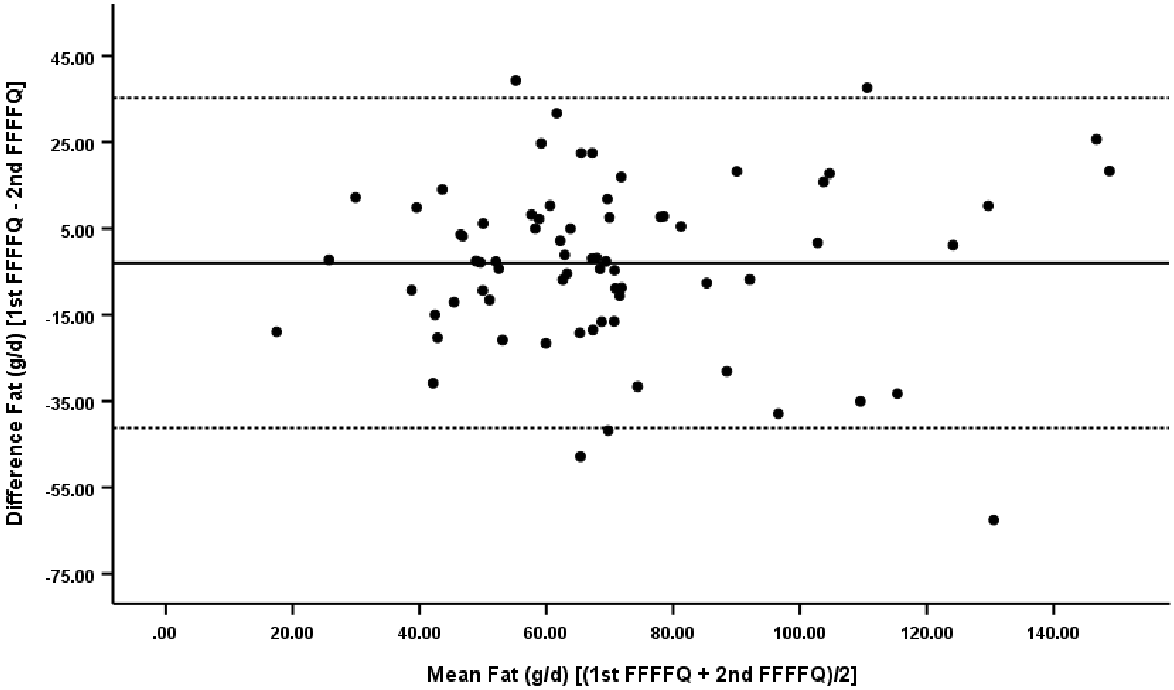


Figure 10. Bland and Altman Plot for mean daily total fat intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in fat intakes between FFFFQs (solid line) was relatively marginal (-3 g/d), with the 2nd FFFFQ recording higher intakes than the 1st FFFFQ. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean fat intake significantly predicted the difference recorded in fat intakes between questionnaires. The results of the regression did not reach statistical significance, R^2 = 0.001, $F(1, 70)$ = 0.04, p = 0.842. Mean fat intake did not significantly predict the difference in fat between questionnaires, β = 0.017, t = 0.2, p = 0.842, further indicating no proportional bias between the 1st and 2nd FFFFQ. A small minority of cases fell outside the limits of agreement (n = 5), indicating an acceptable level of agreement between the 1st and 2nd FFFFQs for fat intake.

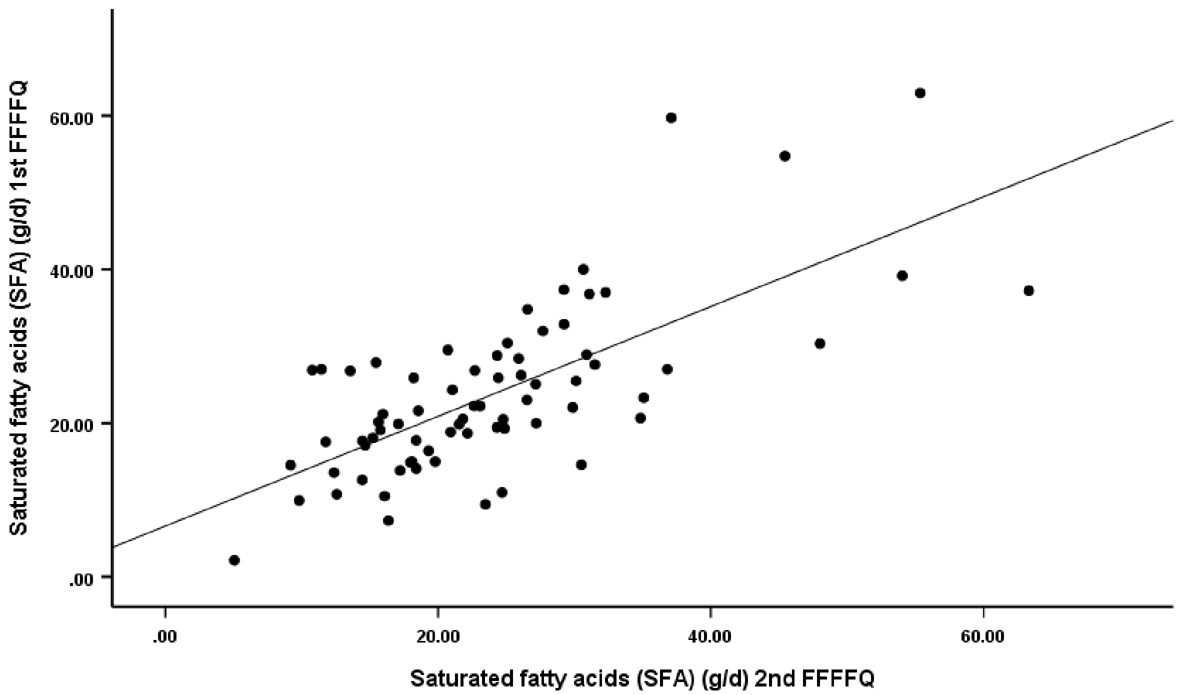


Figure 11. Scatter plot displaying a strong and highly significant correlation between SFA intakes measured by the 1st and 2nd FFFFQ.

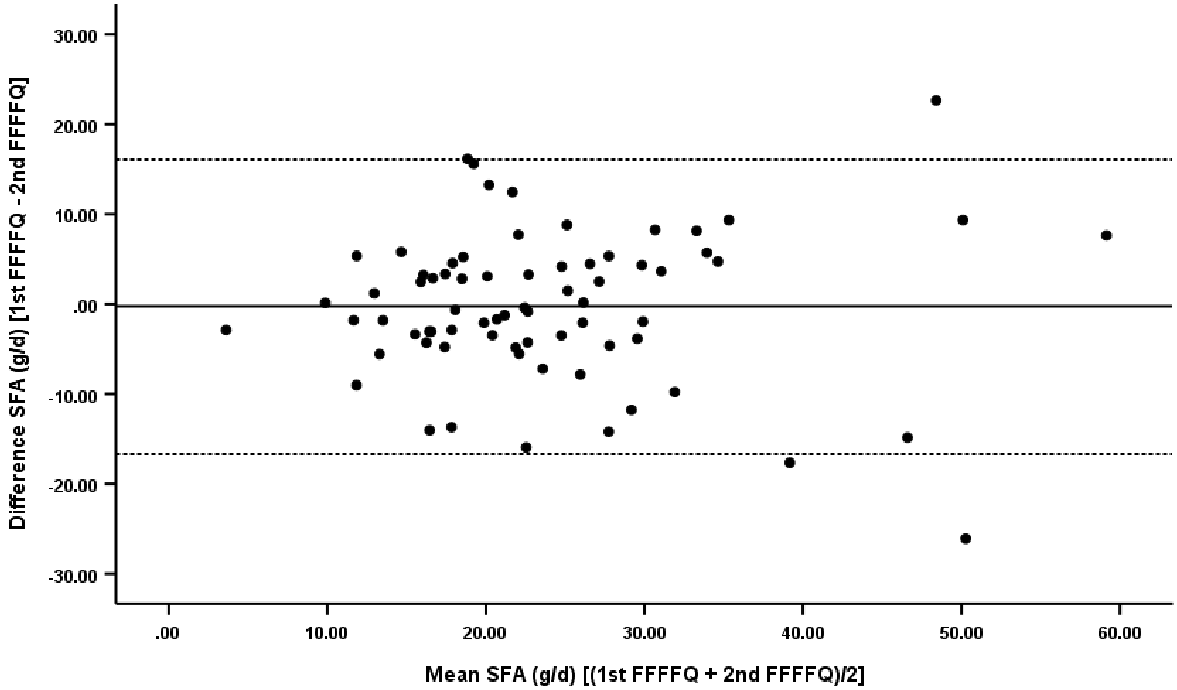


Figure 12. Bland and Altman Plot for mean daily SFA intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in SFA intakes between FFFFQs (solid line) was marginal (-1.5 g/d). No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean SFA intake significantly predicted the difference recorded in SFA intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.00$, $F(1, 70) = 0.02$, $p = 0.887$. Mean SFA intake did not significantly predict the difference in SFA between questionnaires, $\beta = 0.014$, $t = 0.143$, $p = 0.887$, further indicating no proportional bias between the 1st and 2nd FFFFQ. Less than 5% of cases fell outside the limits of agreement ($n = 3$), confirming a good level of agreement between the 1st and 2nd FFFFQs for SFA intake.

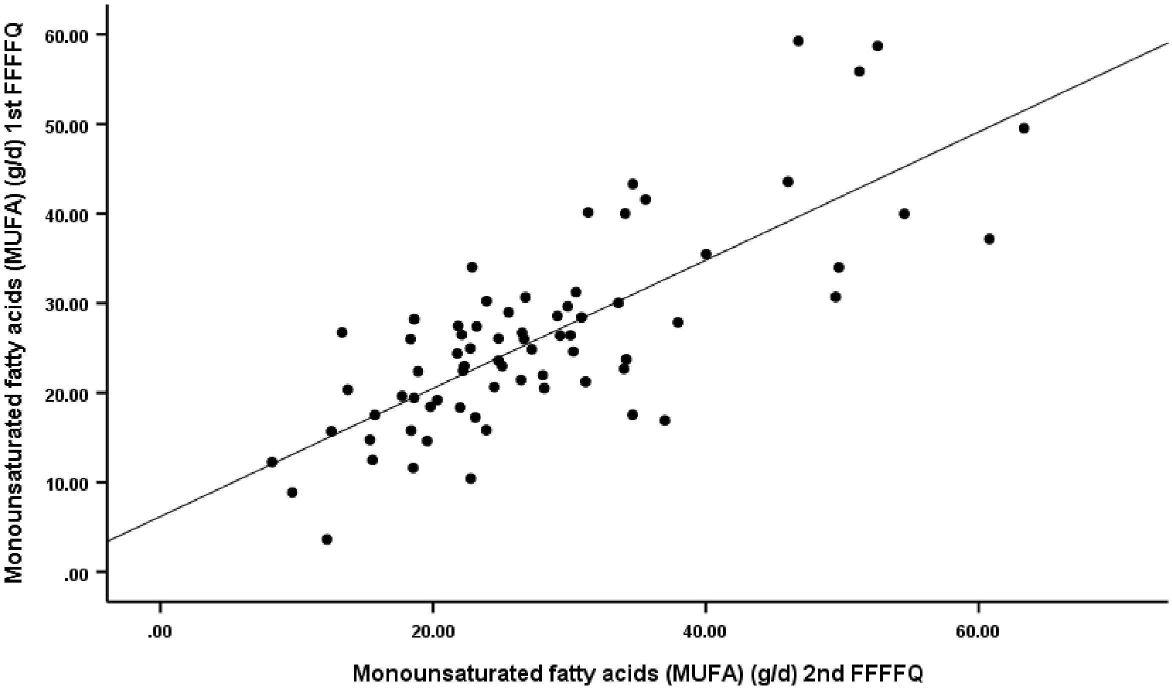


Figure 13. Scatter plot displaying a strong and highly significant correlation between MUFA intakes measured by the 1st and 2nd FFFFQ.

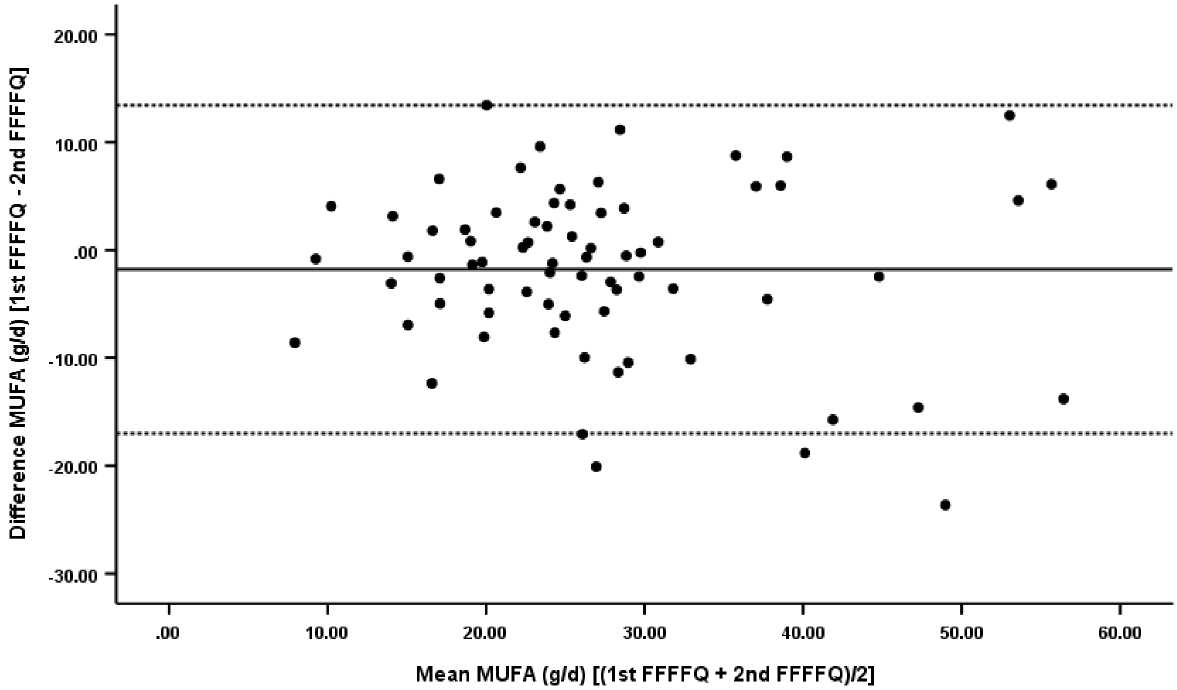


Figure 14. Bland and Altman Plot for mean daily MUFA intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in MUFA intakes between FFFFQs (solid line) was relatively marginal (-1.8 g/d), with the 2nd FFFFQ recording higher intakes than the 1st. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean MUFA intake significantly predicted the difference recorded in MUFA intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.012$, $F(1, 70) = 0.876$, $p = 0.353$. Mean MUFA intake did not significantly predict the difference in MUFA between questionnaires, $\beta = -0.081$, $t = -0.936$, $p = 0.353$, further indicating no proportional bias between the 1st and 2nd FFFFQ. Less than 5% of cases fell outside the limits of agreement ($n = 3$), confirming a good level of agreement between the 1st and 2nd FFFFQs for MUFA intake.

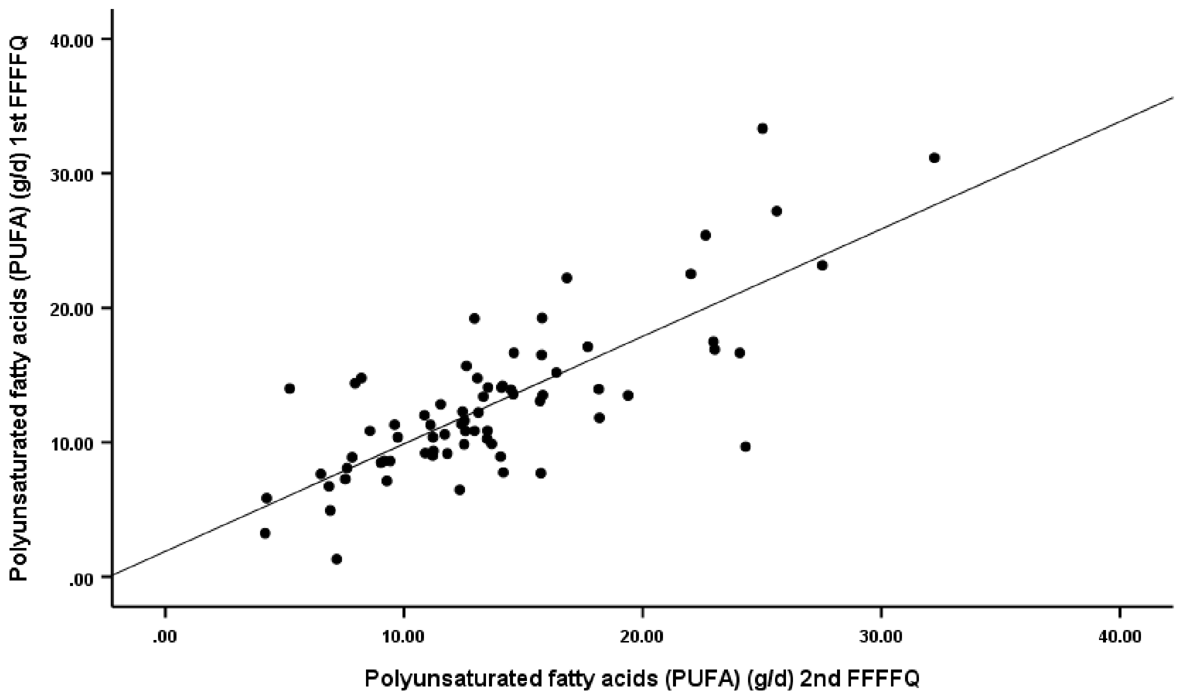


Figure 15. Scatter plot displaying a strong and highly significant correlation between PUFA intakes measured by the 1st and 2nd FFFFQ.

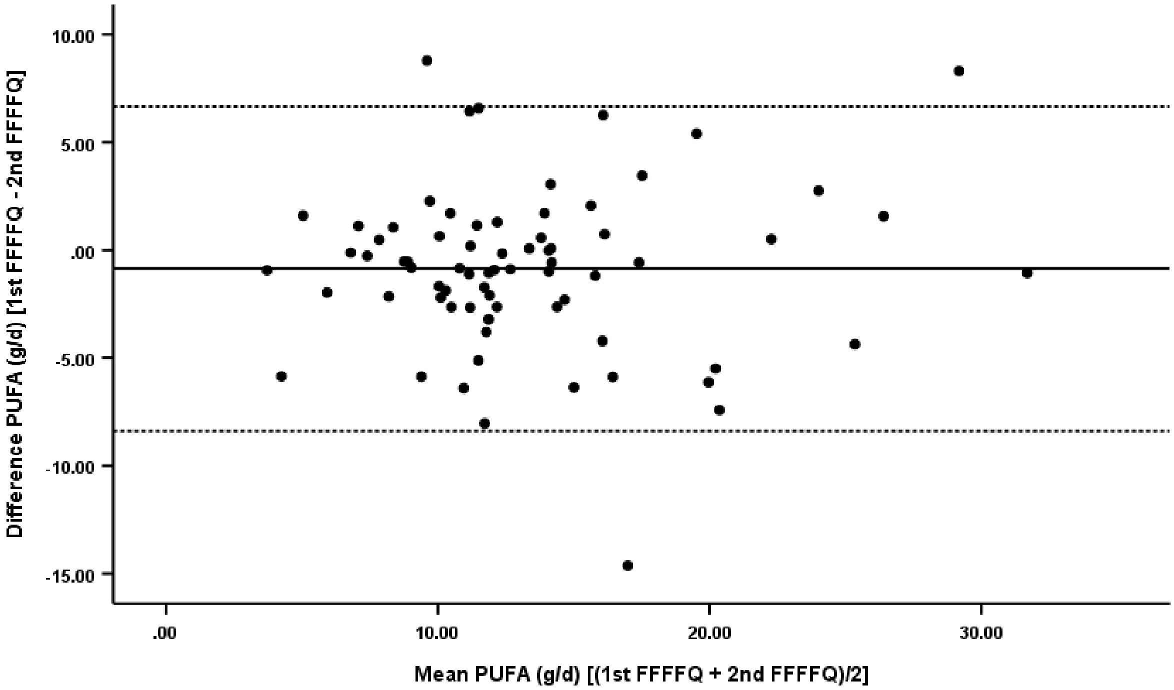


Figure 16. Bland and Altman Plot for mean daily PUFA intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in PUFA intakes between FFFFQs (solid line) was relatively marginal (-0.9 g/d), with the 2nd FFFFQ recording higher intakes than the 1st. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean PUFA intake significantly predicted the difference recorded in PUFA intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.002$, $F(1, 70) = 0.126$, $p = 0.724$. Mean PUFA intake did not significantly predict the difference in PUFA between questionnaires, $\beta = -0.030$, $t = -0.355$, $p = 0.724$, further indicating no proportional bias between the 1st and 2nd FFFFQ. Less than 5% of cases fell outside the limits of agreement ($n = 3$), confirming a good level of agreement between the 1st and 2nd FFFFQs for PUFA intake.

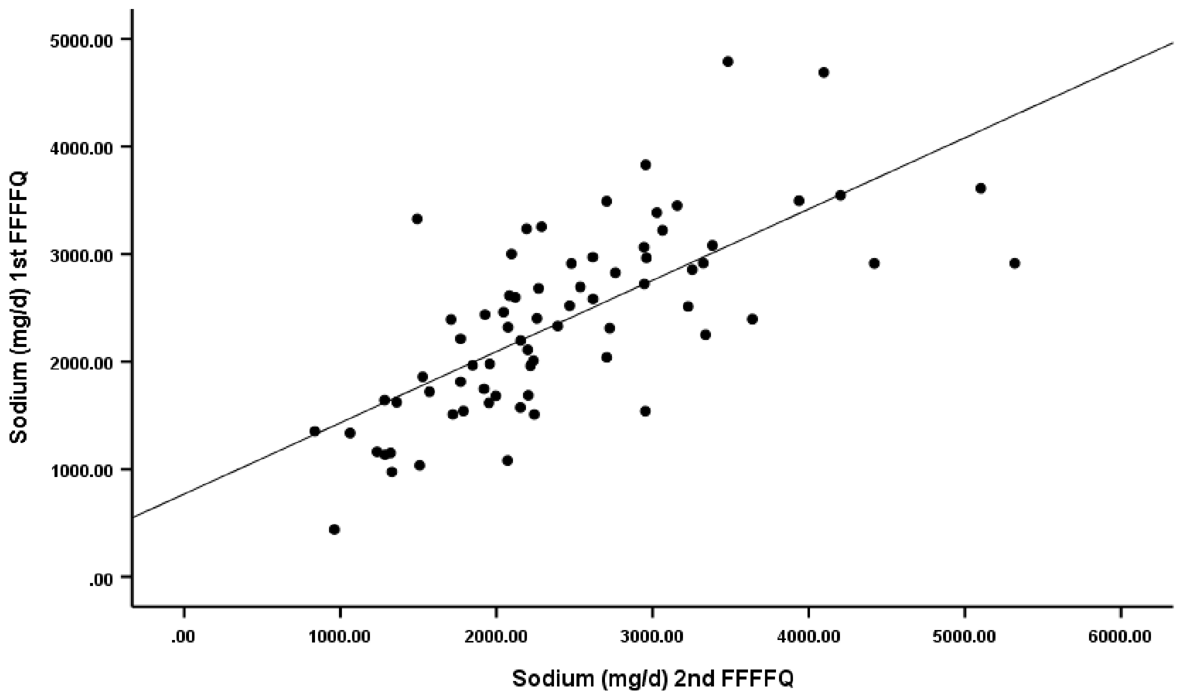


Figure 17. Scatter plot displaying a strong and highly significant correlation between sodium intakes measured by the 1st and 2nd FFFFQ.

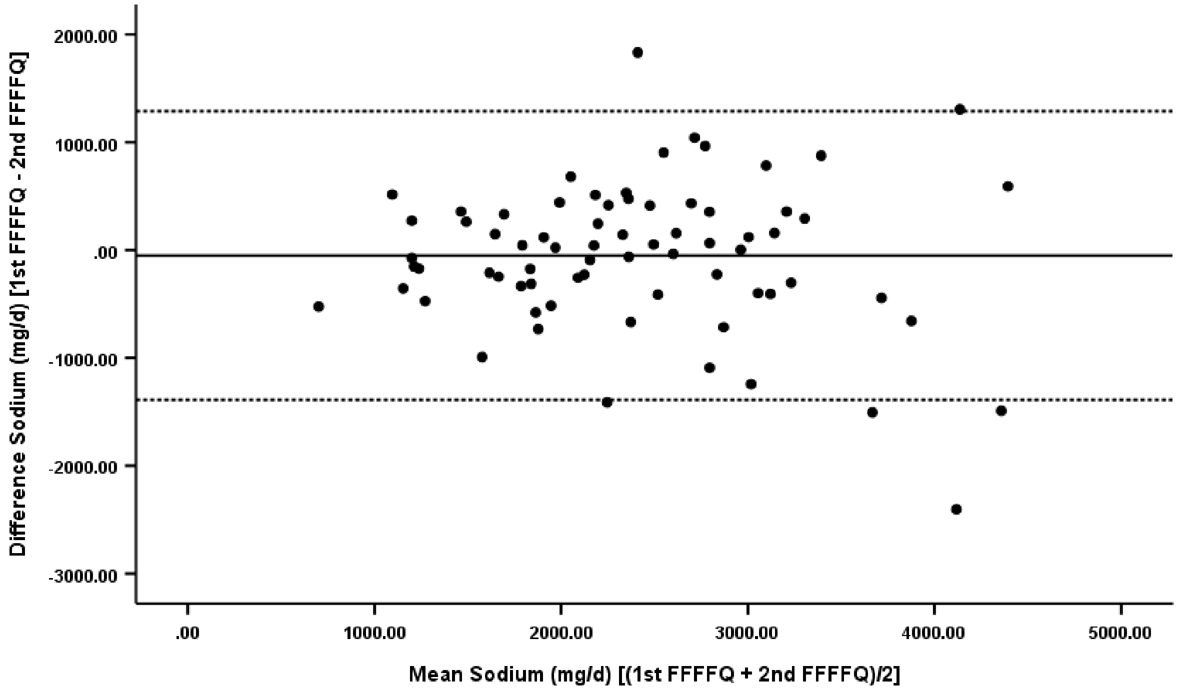


Figure 18. Bland and Altman Plot for mean daily total sodium intake, indicating relatively broad limits of agreement (dotted lines). The mean difference in sodium intakes between FFFFQs (solid line) was marginal (-50 mg/d). No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean sodium intake significantly predicted the difference recorded in sodium intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.008$, $F(1, 70) = 0.580$, $p = 0.449$. Mean sodium intake did not significantly predict the difference in sodium between questionnaires, $\beta = -0.075$, $t = -0.761$, $p = 0.449$, further indicating no proportional bias between the 1st and 2nd FFFFQ. A small minority of cases fell outside the limits of agreement ($n = 5$), indicating an acceptable level of agreement between the 1st and 2nd FFFFQs for sodium intake.

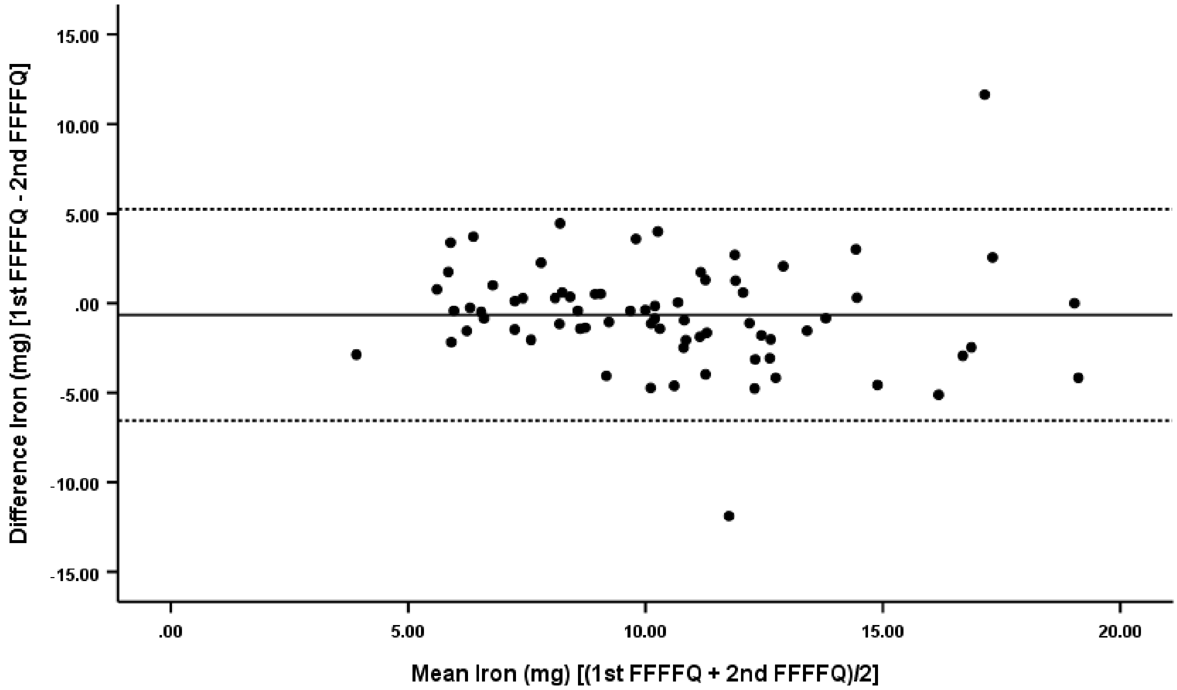


Figure 19. Bland and Altman Plot for mean daily iron intake, indicating fairly broad limits of agreement (dotted lines). The mean difference in iron intakes between FFFFQs (solid line) was relatively marginal (-0.7 mg/d), with the 2nd FFFFQ recording slightly higher intakes than the 1st. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean iron intake significantly predicted the difference recorded in iron intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.01$, $F(1, 70) = 0.62$, $p = 0.44$. Mean iron intake did not significantly predict the difference in iron between questionnaires, $\beta = -0.083$, $t = -0.79$, $p = 0.44$, further indicating no proportional bias between the 1st and 2nd FFFFQ. Less than 5% of cases fell outside the limits of agreement ($n = 2$), confirming a good level of agreement between the 1st and 2nd FFFFQs for iron intake.

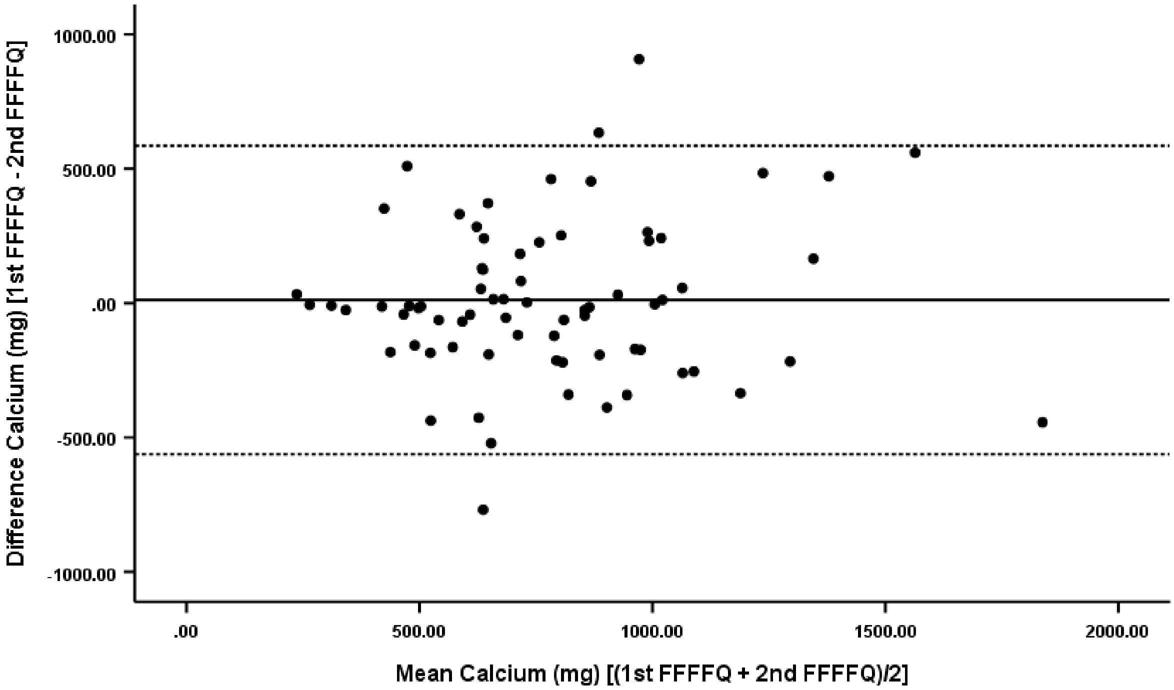


Figure 20. Bland and Altman Plot for mean daily calcium intake, indicating fairly broad limits of agreement (dotted lines). The mean difference in iron intakes between FFFFQs (solid line) was marginal (11.7 mg/d), with the 1st FFFFQ recording slightly higher intakes than the 2nd. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean calcium intake significantly predicted the difference recorded in calcium intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0.007$, $F(1, 70) = 0.51$, $p = 0.48$. Mean calcium intake did not significantly predict the difference in calcium between questionnaires, $\beta = 0.08$, $t = 0.71$, $p = 0.51$, further indicating no proportional bias between the 1st and 2nd FFFFQ. Less than 5% of cases fell outside the limits of agreement ($n = 3$), confirming a good level of agreement between the 1st and 2nd FFFFQs for calcium intake.

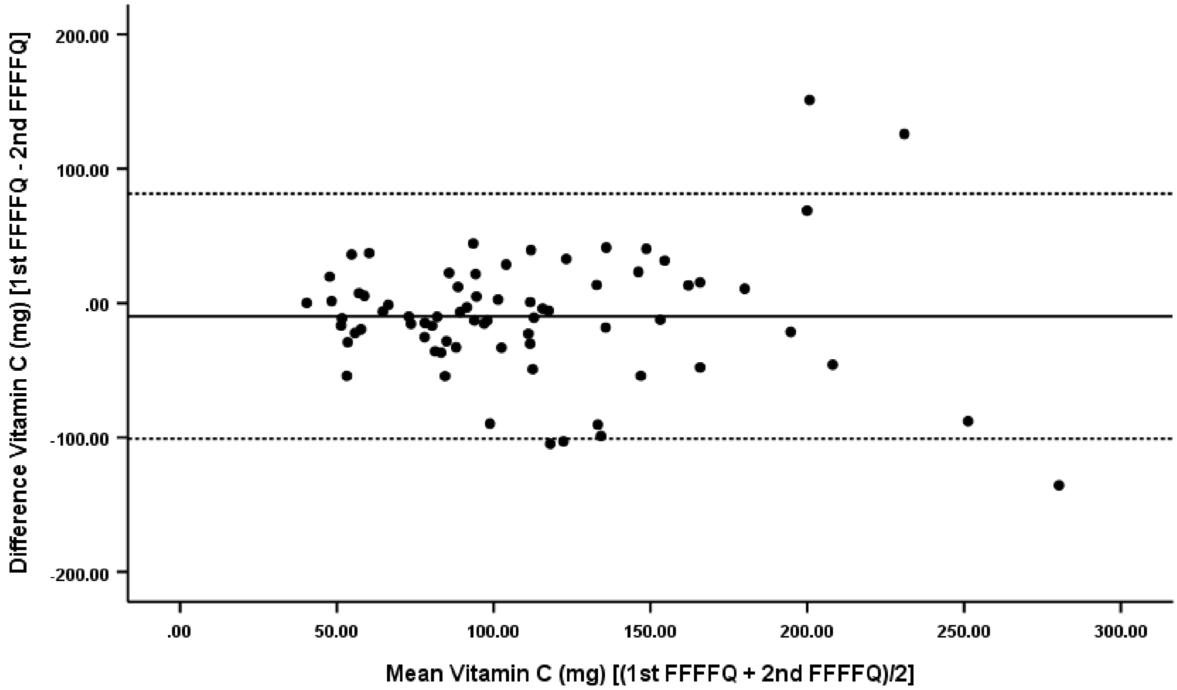


Figure 21. Bland and Altman Plot for mean daily vitamin C intake, indicating fairly broad limits of agreement (dotted lines). The mean difference in vitamin C intakes between FFFFQs (solid line) was relatively marginal (-9.8 mg/d), with the 2nd FFFFQ recording slightly higher intakes than the 1st. No clear evidence of proportional bias is visible from this plot. Simple linear regression was performed to further assess whether mean vitamin C intake significantly predicted the difference recorded in vitamin C intakes between questionnaires. The results of the regression did not reach statistical significance, $R^2 = 0$, $F(1, 70) = 0$, $p = 1$. Mean vitamin C intake did not significantly predict the difference in vitamin C between questionnaires, $\beta = 0$, $t = 0$, $p = 1$, further indicating no proportional bias between the 1st and 2nd FFFFQ. The vast majority of cases fell outside the limits of agreement ($n = 5$), confirming an acceptable level of agreement between the 1st and 2nd FFFFQs for vitamin C intake.

Appendix 6.1. Staff recruitment email

From: LESSONS, GREG
Sent: 04 September 2019 20:42
To: [redacted]
Cc: [redacted]
Subject: Mess manager workshop

Hi [redacted],

Following our phone chat the other day, I have arranged your release from duty to attend a mess-manager workshop.

The release covers the entire day so no need to report to your base station. Just arrive at F39 Hornchurch's mess for a 10:30 hrs start. The entire session will be finished by 16:30 hrs (at the latest).

Details:
Date: Thursday 24th October

Venue: F39 Hornchurch (mess)

Clothing: Standard workwear

Start time: 10:30 hrs

Finish time: 16:30 hrs (at the latest)

Lunch arrangements: You are welcome to eat the food prepared during the session. Alternatively, there are plenty of nearby shops and restaurants

Further info:
As a follow-up to the recent nutrition presentation, you are invited to attend a mess-manager nutrition workshop. The idea for this came from several mess-managers requesting something more practical. The session will include ways of implementing some of the concepts which were suggested during the nutrition presentation, and is simply a demonstration of how nutrition theory can be applied to the mess. It is by no means attempting to teach anyone how to cook. Moreover, it is a practical way of providing simple ideas which can make a big difference to people's health. There will also be opportunity to share ideas and experiences. The session will be held at F39 Hornchurch's mess in a group of around five people.
If you have any problems/issues with attending, please ensure you inform me asap. Otherwise I will look forward to seeing you on what is intended to be an informative and enjoyable day.

Kind regards,
Greg

Greg Lessons *BSc MSc ANutr*

Hornchurch Fire Station,
42 North Street,
Hornchurch RM11 1SH
Direct line: 07388 370451

Registered with the Association for Nutrition - http://www.associationfornutrition.org
Protecting the public and promoting high standards in evidence-based science and professional practice of nutrition

AfN ANutr REGISTERED ASSOCIATE NUTRITIONIST

London Fire Brigade
For advice about how to stay safe from fire and other emergencies, please go to london-fire.gov.uk/Safety
The information in this email may contain confidential or privileged materials. Please read the full email disclaimer notice at london-fire.gov.uk/EmailDisclaimer
The Brigade is committed to using personal data in a responsible and transparent way. To find out more visit london-fire.gov.uk/privacy

Appendix 6.2. Fire station Mess food environment questionnaire

Which plates are generally used?	Small	Large
Are leftovers kept off the plate or divided up and served on the plate?	Off	Served
Is fruit generally provided to snack on?	Yes	No
Is low energy/non-nutritive sweetener provided?	Yes	No
Are low sugar/salt products typically provided?	Yes	No
Are whole grains generally used?	Yes	No
Are sauces and soups generally homemade or readymade?	Homemade	Readymade
Is oily fish served weekly?	Yes	No
Are recipes bulked out with vegetables where possible?	Yes	No

Appendix 6.3. Mess manager kitchen workshop feedback form

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

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Thank you for your participation

Appendix 6.4. Healthy mess recipes cookery book

Healthy Mess Recipes

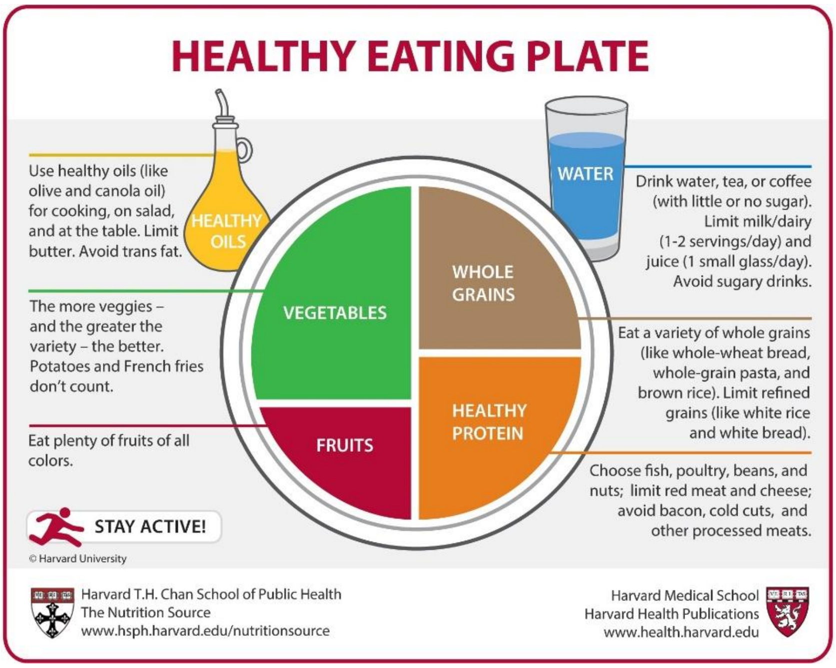
LONDON METROPOLITAN UNIVERSITY

LFB
LONDON FIRE BRIGADE

The recipes in this booklet are healthy based upon portion size, free sugars, salt, saturated fat and refined carbohydrate reduction. Where possible they are also high in fibre and important micronutrients.

For more healthy recipes and for other health related information please use LFB WellWorks and Workplace.

Greg Lessons, RNutr



It is recommended to fry in refined rape-seed/olive oil, using the minimal amount. Nutrition values are given in terms of a single serving for one person. For info on portion sizes please visit: https://www.nutrition.org.uk/healthyliving/find-your-balance/portionwise.html

BREAKFAST / STAND-EASY

Eating breakfast helps control blood sugar

Seeded Porridge

Serves 1

- **2 heaped tablespoons (40g) wholegrain rolled oats**
- **1 tablespoon milled seeds (flax/pumpkin/sunflower/chia)**
- **300 ml water or low-fat milk**
- **Handful (100 g) of frozen berries and/or chopped banana**

Put oats and water/milk into a small saucepan and give a quick stir. Place on a high heat and bring to the boil. Reduce heat immediately to a simmer and stir in the seeds. Simmer for as long as necessary (1-5 mins) to achieve the desired consistency. Empty contents into bowl and top with fruit.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated fat (g)	Sugar (g)	Salt (g)	Fibre (g)
347	**51**	**8.8**	**9.3**	**1**	**15**	**0.02**	**11**

Overnight Oats

Serves 4

- **100g wholegrain rolled oats**
- **1 grated apple**
- **200g yogurt (reduced fat and no added sugar)**
- **150g frozen berries**
- **100ml water**

Combine all ingredients in a mixing bowl, stir until thoroughly mixed. Cover bowl with cling-film and leave in fridge overnight.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
165	**26**	**9**	**2.4**	**0.4**	**8.9**	**0.05**	**3.4**

Masala Omelette

Serves 1

- **2 free range eggs**
- **¼ onion diced**
- **¼ green pepper diced**
- **1 tomato chopped**
- **1 garlic clove crushed**
- **½ green finger chili finely chopped**
- **¼ teaspoon cumin powder**
- **¼ teaspoon coriander powder**
- **½ teaspoon garam-masala powder**

Crack the eggs into a mixing bowl. Add the garlic, chili, cumin, coriander, garam-masala and tomato. Whisk the mixture until thoroughly mixed. Add a little oil to a medium sized frying pan and place on a medium heat. When pan is hot, fry the onion and pepper for 2 minutes. Pour the omelette mixture into the hot pan and cook for another 2 minutes. Finish by placing the pan under a hot grill for a further 1 - 2 minutes.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
293	**8**	**15**	**21**	**4**	**6.4**	**0.43**	**3.2**

Black bean brunch

Serves 4

- **8 free range eggs**
- **2 x 380g cartons of organic black beans in water**
- **Dried chili flakes (as much as is preferred)**
- **Small bag of baby plum/cherry tomatoes**
- **1 avocado sliced**
- **1 small bag of baby leaf spinach**

Place a large frying pan on a medium – high heat with 1 tablespoon of oil. Once the pan is hot, crack the eggs around the pan. As soon as the last egg is in, empty the contents of the 2 black bean cartons (including the water) around the eggs. Sprinkle the desired amount of chili flakes and then place the tomatoes around the pan. Cover with a lid until the eggs are cooked to your liking. Serve on a bed of spinach and top with chopped avocado.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
541	**29**	**34**	**28**	**5.8**	**3.3**	**0.64**	**17**

Scrambled egg vegetable hash

Serves 4

- **6 free range eggs whisked**
- **1 onion chopped into 1 cm^2 chunks**
- **1 pepper chopped into 1 cm^2 chunks**
- **Small bag of cherry tomatoes cut into halves**
- **Small box of mushrooms sliced**
- **8 slices of wholegrain toast**

Place a large frying pan on a medium – high heat with 1 tablespoon of oil. Once the pan is hot, add the onion, pepper, mushrooms and stir-fry until browned. Add the tomatoes and eggs, and stir fry until the scrambled eggs are cooked. Serve on top of the toast.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
466	**37**	**24**	**23**	**3.8**	**9.1**	**1.2**	**8.4**

Tuna wraps

Serves 4

- **8 wholemeal flour tortillas**
- **4 cans of tuna in spring water**
- **2 tablespoons of light mayonnaise**
- **Small can of sweetcorn**
- **1 bag of baby plum tomatoes cut into halves**
- **2 red onions chopped**
- **1 cucumber**
- **Bag of baby leaf spinach**
- **Chili infused extra virgin olive oil (optional)**

Drain the tuna and place in a large mixing bowl with mayonnaise and sweetcorn. Mix thoroughly and put to one side. Slice the cucumber lengthways into eight sections and then chop into small chunks width ways. Combine the cucumber with the onion and tomato and dress the salad with the recipe on page 8. Construct the tortillas with the tuna mix, chopped salad, spinach and a drizzle of chili infused olive oil.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
549	**53**	**41**	**17**	**2.5**	**12**	**1.2**	**8.9**

Chicken fajitas

Serves 4

- **8 wholemeal flour tortillas**
- **4-5 chicken breasts cut into strips**
- **2 large brown onions sliced**
- **3 peppers sliced**
- **1 romaine lettuce sliced**
- **2 tblsp Fajita seasoning**

Brown the onion and pepper in a large frying pan whilst simultaneously frying the chicken in a separate frying pan on a medium heat. Half way through cooking, add the fajita mix to the chicken stirring both pans regularly. Once the chicken is cooked through portion out the chicken, onion and pepper onto 4 plates. Serve with lettuce and the tortillas for wrapping.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
570	**51**	**52**	**15**	**2.3**	**13**	**1.6**	**9.8**

Vinaigrette salad dressing

Serves 4

- **2 tablespoons extra virgin olive oil**
- **4 teaspoons balsamic vinegar**
- **2 teaspoons wholegrain mustard**
- **2 garlic cloves**

Crush the garlic into a mug. Add the remaining ingredients and stir until thoroughly mixed.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
93	**1.1**	**0.5**	**9.5**	**1.3**	**0.8**	**0.2**	**0.5**

Quinoa, egg & salmon salad

Serves 4

- **1 bag of baby leaf spinach**
- **1 small cucumber chopped**
- **1 large avocado chopped**
- **4 pickled beetroot chopped**
- **1 red onion sliced**
- **1 large can of salmon**
- **8 free range eggs**
- **1 cup quinoa**
- **1 small bag baby plum tomatoes halved**

Boil the eggs in a saucepan for 6-7 minutes and then place in cold water. Put the quinoa in a saucepan and cover in hot water (so the water is 5mm above the quinoa). Bring to the boil, reduce the heat and simmer for 10 mins. Take off the heat and leave aside for a few more mins. Drain the salmon, mash up with a fork and separate into 4 equal portions, then set aside. Combine the spinach, cucumber, tomatoes, avocado and quinoa in a large mixing bowl and dress with the recipe on page 8. Portion the contents of the bowl onto 4 plates, top with beetroot, onion and salmon. Peel the eggs, cut into halves and place atop the salad.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
503	**25**	**43**	**24**	**5.3**	**10**	**1.3**	**6.4**

Pea, leek & onion soup

Serves 3

- **1 onion diced**
- **1 leek thinly sliced**
- **175g peas**
- **2 tbsp fresh parsley chopped**
- **450 ml of very low salt vegetable stock**
- **1 small baking potato (200g) peeled and diced**

Heat 2 tsp oil in a pan on a medium heat. Sauté the onion and leek for 5 min or until softened. Stir in the potato and stock and season with black pepper. If using fresh peas, add them at this stage; if using frozen peas, add them in 10 mins time. Bring the mixture to the boil, reduce the heat, cover and simmer for 15-20 mins, until the vegetables are tender, stirring occasionally. Remove from the heat and then purée the soup using a hand-held blender or in a food blender, until smooth. Stir in the parsley and serve.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
162	**24**	**5.7**	**3.5**	**0.3**	**7.9**	**0.02**	**6.3**

DINNER

Chicken & sweet potato traybake

Serves 4

- **6 chicken thighs**
- **6 chicken drumsticks**
- **2 red onions, cut into wedges**
- **1 bulb of garlic**
- **4 medium sweet potatoes, unpeeled and cut into wedges**
- **2 rosemary sprigs**

Preheat oven to 220°C. Break the garlic up into cloves and place in the bottom of a large roasting tin with the onion. Add the chicken pieces, potato, rosemary and some black pepper. Drizzle with oil, then bake for 45 minutes. Baste the chicken in its juices half way through the cooking time.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
479	**50**	**31**	**16**	**4.1**	**25**	**0.39**	**7.3**

Chicken/king prawn soba noodles

Serves 4

- **3 bundles of soba noodles (1 x 250g pack)**
- **2 bags raw king prawns or 3-4 chicken breasts sliced**
- **1 red pepper sliced**
- **1 green pepper sliced**
- **2 onions sliced**
- **8 closed cup mushrooms sliced**
- **4 garlic cloves finely chopped**
- **2” of ginger finely chopped**
- **2 finger chilies finely chopped**
- **4 tsp reduced salt soy sauce**
- **4 tsp of sesame oil**
- **4 spring onions chopped**

Boil the noodles in a large pan for 2 mins. Drain in a sieve, rinse under cold water and set aside. Heat 1 tablespoon of oil in a large frying pan and stir fry the onion, garlic and ginger for 2 mins. Add the chicken and cook for a further 2 mins before adding the pepper, mushrooms and chili. Once the chicken is cooked add the noodles, soy sauce and sesame oil, stir frying for another 2 mins on a high heat. If using prawns, cook the veg first, then stir fry the prawns until they turn pink before adding the noodles, soy sauce and sesame oil

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
518	**55**	**40**	**14**	**1.4**	**14**	**1.8**	**5.1**

Easy chicken fried rice

Serves 2

- **1 egg**
- **1 onion diced**
- **2 tsp sesame oil**
- **2 garlic cloves finely chopped**
- **Half a pepper finely chopped**
- **2 tsp reduced salt soy sauce**
- **2 tsp tomato & chilli chutney**
- **2 chicken breasts finely sliced**
- **1 microwave bag of wholegrain brown rice (250g)**

Sauté the onion and garlic in 1 tsp of hot oil for 2 mins in a frying pan. Add the chicken and stir fry for a further 2 mins before adding the pepper. Once the chicken is almost cooked, add the rice, chutney, soy sauce, sesame oil and stir fry for another 2 mins. Create a space in the centre of the pan and crack the egg in. Move the egg around until it is partially cooked and then stir everything in together.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
509	**37**	**49**	**17**	**3.1**	**7.2**	**1.1**	**4**

Jerk chicken & baked sweet potato

Serves 4

- **4 tsp Dunns River jerk paste**
- **4 sweet potatoes**
- **12 skinless chicken thighs**
- **Large pack of asparagus**
- **Large pack of cherry tomatoes**

Coat the chicken thighs evenly with jerk paste. Bake the chicken and sweet potato in the centre of a 200°C preheated oven for 45 mins.

Serve with grilled cherry tomatoes and asparagus.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
550	**33**	**68**	**14**	**3.6**	**21**	**1.1**	**6.2**

3-bean veg chilli

Serves 4

- **1 onion chopped**
- **4 carrots chopped**
- **Bag of celery chopped**
- **1 green pepper chopped**
- **1 red pepper chopped**
- **250 ml veg stock (low salt)**
- **2 tsp chilli flakes**
- **2 tsp chilli powder**
- **1 tsp cumin powder**
- **1 tsp paprika**
- **1 tsp dried oregano**
- **2 garlic cloves crushed**
- **1 cm ginger finely chopped**
- **400g can red kidney beans**
- **400g can chickpeas**
- **400g can black beans**
- **400g can chopped tomatoes**

Fry onion, celery and carrots in 1.5 tablespoons oil for 5 min. Add 250ml veg stock, green and red pepper. Add all herbs & spices and cook for a further 5 min. Stir in the chopped tomatoes and simmer for 40 mins. Add all beans and cook for a further 10 mins.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
350	**46**	**17**	**6.5**	**0.8**	**18**	**0.8**	**21**

Salmon fish cakes

Serves 4 (8 fish cakes)

- **800g skinless and boneless salmon fillets**
- **Small bunch of coriander chopped**
- **Chilli flakes (as much as preferred)**
- **10 cm piece of ginger peeled and finely chopped**

Finely chop half the salmon and chop the other half into larger (1cm) pieces. Mix all of the salmon with the other ingredients on a chopping board and season with black pepper. Separate the mix into 8 even portions and form into patties. Fry on a medium-high heat in a little oil for 2 mins each side.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
505	**1.9**	**42**	**36**	**6**	**0.5**	**0.33**	**1.6**

Lentil Stew

Serves 8

- **2 large onions chopped**
- **4 garlic cloves crushed**
- **6 celery sticks chopped**
- **6 carrots chopped**
- **Small box of mushrooms chopped**
- **500g lentils**
- **Tinned chopped tomatoes (2 x 400g tins)**
- **Vegetable stock 1 litre**
- **3 tbsp balsamic vinegar**
- **3 tbsp tomato puree**
- **3 teaspoons turmeric**
- **Heaped tablespoon of dried chili flakes**
- **½ teaspoon black pepper**
- **½ teaspoon coriander seeds**
- **½ teaspoon cinnamon**
- **1 cm grated ginger**

Place a large saucepan/pot on a medium heat. Once 2 tablespoons of oil is hot add the onions, garlic, ginger, celery, carrots and mushrooms and mix together. Place lid on pan and cook gently, stirring occasionally. 10 mins later add the turmeric, dried chilli flakes, coriander seeds, pepper and cinnamon. Mix together, replace lid and cook for a further 10 mins. Add the tomatoes, lentils, tomato puree, stock and balsamic vinegar. Mix together, replace lid, bring to the boil, reduce heat and simmer for 40 mins stirring occasionally. If the stew starts to become dry, add water along the way. Serve with spring onion and coriander on top. Goes well with wholegrain brown rice or wholewheat pasta.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
340	**51**	**19**	**4.1**	**0.8**	**15**	**0.5**	**9.5**

Chicken and vegetable stew

Serves 8

- **1 Whole chicken**
- **2 leeks chopped**
- **4 carrots chopped**
- **3 parsnips chopped**
- **1 turnip chopped**
- **Half a green cabbage sliced**
- **Half a butternut squash & 2 potatoes peeled and chopped**
- **1 box of mushrooms & 2 large onions chopped**
- **Bag of mixed vegetables & 1 can of borlotti beans**
- **2cm of ginger & 6 cloves of garlic chopped**
- **1 tbsp Oregano, 1 tbsp dried Thyme & 1 tbsp fennel seeds**
- **2 tsp tarragon & 2 tsp ground mace**
- **2 tsp of basil pesto & 3 tsp crushed chillies**

Fill a large saucepan with enough water to cover the chicken. Boil the chicken for 20 mins or until it easily pulls away from the bones, then remove from the water and put to one side. In a separate pot, sauté the onion, ginger and garlic in a little oil for 4 mins, followed by adding all of the vegetables. Add enough water from the chicken pot to cook the veg. Simmer until the veg is softened. Add the pesto and all herbs & spices and season. Blend the contents of the veg pot then simmer for a further 5 mins with the lid on. Add water from the chicken pot as you go, keeping the consistency to the thickness desired. Add the beans, the bag of veg and the pulled chicken meat to the pot and continue to simmer for 5 mins, adding more water from the chicken pot if required.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
429	**38**	**37**	**11**	**2.6**	**18**	**0.4**	**15**

Sea Bass Curry

Serves 4

- **1 large onion chopped**
- **2 cm ginger grated**
- **3 garlic cloves crushed**
- **3 tbsp curry powder**
- **1 can of chickpeas drained**
- **Handful of coriander, chopped**
- **2 x 400g cans of low salt chopped tomatoes**
- **4-5 frozen skinless and boneless sea bass fillets**
- **Chilli (optional)**

Place a frying pan with a lid on a medium heat. Once 1 tbsp of oil is hot, sauté the onion for 4 mins, then stir in the ginger, garlic and curry powder followed by the tomatoes and chickpeas. Add a few grinds of black pepper and simmer with the lid off for 8-10 mins. Bury the frozen sea bass fillets in the sauce, place the lid on the pan and simmer for 20 mins, gently stirring occasionally (be careful not to break the fillets up too much). Add chilli as desired to increase the heat of the dish. Stir in half of the coriander half-way through and garnish the dish with the other half after plating up. Serve with wholegrain brown rice.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
349	**22**	**41**	**9**	**1.5**	**12**	**1.2**	**6.8**

Chilli & Garlic Sea Bass

Serves 2

- **2 sea bass fillets**
- **8 king prawns**
- **2 garlic cloves crushed**
- **4 garlic cloves sliced**
- **1 medium heat chilli pepper sliced**
- **1 medium onion chopped**
- **Half a bell pepper chopped**
- **Several mushrooms sliced**
- **1 bag of mixed grains (ready cooked)**
- **2 tsp reduced salt soy sauce**

Marinate the raw prawns in the crushed garlic whilst the rest of the meal is prepared. Get a wok on a medium heat. Once 1 tsp of oil is hot sauté the onion for 4 mins. Stir in the bell pepper and mushrooms, stirring occasionally. Place a non-stick frying pan on a medium to hot heat. Once 1 tsp of oil is hot sauté the chilli and sliced garlic for 2 mins. Add the sea bass fillets skin side down in the non-stick pan and cook for 5 mins turning once. As soon as the fish is flipped, place the sliced chilli and garlic atop the sea bass skin to prevent it burning. Whilst the sea bass is cooking, add the bag of mixed grains to the wok along with the soy sauce, stir frying to heat the rice through. Plate up the grains with the sea bass on top (skin side up so it remains crispy). Stir fry the prawns in the sea bass pan for 2 mins until thoroughly pink in colour.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
452	**36**	**33**	**18**	**2.7**	**7.8**	**1.2**	**6.5**

Kedgeree

Serves 2-3

- **2-3 eggs**
- **2-3 haddock fillet pieces**
- **1 large onion diced**
- **1 tsp turmeric**
- **1tsp coriander powder**
- **2 tsp curry powder**
- **150g easy cook long grain rice (raw)**
- **2 bay leaves**
- **Handful of fresh coriander/parsley**
- **1 pint of skimmed/semi-skimmed milk**

sauté the onion in 1 tsp of hot oil for 5 mins in a frying pan with a lid. Stir in the turmeric, coriander and curry powder coating the onion. Stir in the rice with 400ml of boiled water and bring to the boil. Reduce the heat, place the lid on the pan and simmer for 10 mins (do not remove the lid). Remove from the heat and rest for a further 10 mins (do not remove the lid). Meanwhile, boil the eggs in a saucepan for 6 mins before submerging in a bowl of cold water. Meanwhile, fill another frying pan with the milk and bay leaves, place on a medium heat. Once the milk begins to steam, submerge the haddock in the milk and poach the fish for 10 mins. Peel the eggs, chop the coriander/parsley and put to one side. Once the fish is cooked, remove from the pan and remove the skin. Gently fold the haddock and coriander/parsley into the rice. Serve with an egg on top either halved or quartered.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
381	**46**	**34**	**6.2**	**1.6**	**5.1**	**0.4**	**3.1**

Jamaican chicken curry on the bone

Serves 8

- **12 chicken thighs (skinless)**
- **12 chicken drumsticks (skinless)**
- **6 medium brown onions diced**
- **8 garlic cloves crushed**
- **4 scotch bonnet chilies finely chopped**
- **2 tablespoons of chicken gravy granules**
- **1.5 litres of reduced sodium chicken stock**
- **4-5 medium white potatoes peeled and cut into 1” cubes**
- **Madras curry powder**
- **1 tablespoon of chicken seasoning**

Marinate the chicken in chicken seasoning and curry powder overnight in the fridge. Boil the potatoes for 20 mins. In the meantime fry the onions in an extra large saucepan/pot using 2 tablespoons of oil. Whilst the onions are cooking, coat them in some curry powder and stir. Once the onions are softened, add the chicken. Once this is sealed on all sides, add the garlic, scotch bonnets and stock. By now the potatoes will be ready so drain them and stir them into the pot along with the gravy granules. Simmer on a low heat for 45 mins stirring occasionally. Serve with brown basmati rice.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
458	**34**	**51**	**12**	**3.3**	**8.9**	**1.5**	**5.6**

Thai panang chicken curry on the bone

Serves 8

- **12 chicken thighs (skinless)**
- **12 chicken drumsticks (skinless)**
- **4 brown onions finely sliced**
- **3 red peppers sliced**
- **2 packs of tenderstem broccoli**
- **80g panang/Thai red curry paste**
- **3-4 bird eye chilies finely chopped**
- **300g reduced fat coconut milk**
- **100g reduced fat peanut butter**
- **40ml fish sauce**
- **4 teaspoons of ground turmeric**
- **12 dried kaffir lime leaves**
- **1.5 tablespoons of sugar**
- **700 ml boiled water**

To make the stock, mix the coconut milk with the boiled water (in a large measuring jug). Add the peanut butter, turmeric, fish sauce and sugar. Whisk/mix until smooth and set aside. Fry the onion and pepper in an extra large saucepan/pot using 2 tablespoons of oil. Once softened, add the chicken, broccoli, chili and curry paste. Mix well and seal the chicken on all sides. Once sealed, add the stock and stir in the lime leaves. Allow to simmer for 45 mins stirring occasionally. Serve with brown basmati rice or mushroom rice (page 19).

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
478	**19**	**53**	**20**	**5.9**	**14**	**1.3**	**6**

Aubergine curry

Serves 8

- **4 large aubergines**
- **3 tsp fennel seeds**
- **8 tsp ground coriander**
- **1 tsp turmeric**
- **1 tsp chilli powder**
- **6 cm piece of ginger finely grated**
- **1 bulb garlic crushed**
- **4 cans chopped tomatoes**
- **Small bag chopped corriander**

Cut aubergine into large wedges. Shallow fry to soften on a medium heat until brown on both sides. Set wedges aside and add the fennel, chilli, coriander and turmeric to the pan. Let the oil foam a little with the spices before adding the ginger and garlic. Stir fry for 1 min before stirring in the tomatoes and allowing the mixture to simmer. Reintroduce the aubergines and simmer for a further 20 mins. Serve with wholegrain brown basmati / mushroom rice (see page 23). Garnish with coriander.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
110	**11**	**4.4**	**3.9**	**0.5**	**8.9**	**0.1**	**6.6**

Mushroom rice

Serves 8

- **8 heaped serving spoons of cooked brown basmati rice (cold)**
- **2 teaspoons of cumin seeds**
- **Small punnet of mushrooms sliced**
- **2 teaspoons of ground turmeric**

Heat 2 tablespoons of oil in a large frying pan. Once the oil is hot, add the cumin seeds and fry for 1 min. Add the mushrooms and stir to coat in the seeds. Once the mushrooms are almost cooked, add the rice and the turmeric, stir frying on a high heat until the rice has a uniform yellow colour and is cooked through.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
149	**32**	**3.4**	**0.5**	**0**	**7.1**	**0.32**	**1.2**

Seafood pasta

Serves 4

- **1 onion chopped**
- **2 garlic cloves chopped**
- **400g tin chopped tomatoes**
- **Half a low salt chicken stock cube**
- **300g wholewheat spaghetti cooked (al dente)**
- **240g frozen mixed seafood (defrosted)**
- **Handful fresh basil, coriander or parsley**
- **1 tsp paprika**
- **Dried chili flakes**

Heat 1 tablespoon of oil in a wok or large frying pan. Add the onion and soften. Stir in the paprika, chili and garlic and cook on a medium heat for 1 min. Stir in the tomatoes and crumbled stock cube. Bring to the boil and then reduce the heat to a simmer, stir in the seafood and cook for a further 3 min ensuring it is heated through, stir in the cooked pasta and cook until heated through. Add ground black pepper and serve garnished with fresh herbs.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
392	**56**	**23**	**5.8**	**0.8**	**9.5**	**1.3**	**12**

Italian pasta sauce

Serves 8

- **3 medium brown onions chopped**
- **8 garlic cloves finely chopped**
- **2-4 hot chilies**
- **1.5 kg Italian sieved tomato passata**
- **2 tablespoons of dried basil**
- **Several grinds of black pepper**

Heat 1.5 tablespoons of oil in a medium sized saucepan. Once hot, add the onion and cook until browned. Add the chili and cook for a further 2 mins. Add the garlic and stir fry for one minute more before pouring in the passata and mixing it all together. Stir in the basil and pepper and simmer for 20 mins stirring occasionally. Serve atop wholemeal pasta. Turn into bolognaise using lean minced beef or seafood pasta using your favourite seafood.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
96	**15**	**3.6**	**1.7**	**0.2**	**9.4**	**0.23**	**3.8**

Spiced sweet potato medallions

Serves 8

- **10 sweet potatoes scrubbed clean**
- **3 teaspoons of Cajun spice**
- **1 tablespoon of red wine vinegar**

Preheat oven to 180°C. Cut the potatoes into 3cm medallions and place in a roasting tin. Cover the tin contents in the red wine vinegar,1 tablespoon of oil and the Cajun spice. Mix so that the potatoes are covered in the oil, vinegar and Cajun spice. Roast for 1 hour at 180° turning half way.

This side dish is a healthy alternative to chips.

Energy (kcal)	CHO (g)	Protein (g)	Fat (g)	Saturated Fat (g)	Sugar (g)	Salt (g)	Fibre (g)
214	**46**	**2.9**	**0.8**	**0.4**	**25**	**0.48**	**5.4**

Healthy snack ideas

- Fruit
- Low fat, low sugar (around 5% sugar is ok) Greek/natural yoghurt with fresh or frozen berries
- Half a handful of raw nuts with a little dried fruit
- Low sugar, low salt and low-calorie popcorn (Most supermarkets sell this)
- Vegetable sticks and Hummus (Peppers, carrots, celery sticks, cucumber etc.)
- 2 squares of dark chocolate (the higher the cocoa content the healthier. Try not to exceed this amount per day)
- Rice cake and peanut butter

Appendix 6.5. Mess-manager workshop participant feedback

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Great ideas + strategies to help make a healthier Mess. Everything explained very well - why particular things are healthier and the benefit of certain techniques. I think this should be done on a semi regular basis so the dishes are constantly updated to ensure continued interest from the watch.

Thank you for your participation

Thank you very much

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Eating is a vital part of firebrigade life. and heathy eating is so important. Most mess managers have no training in cooking. So struggle to provide nutritious meals. The overall health of firefighters will benefit from this style of course.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

This course was very usefull and gives ar insight into how small changes can eimprove nutritional intake.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

I thought Gregs workshop was extremely invaluable, an excellent knowledge put into laymens terms and demonstrated practically. At least 4 refresher courses per year!

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

VERY HELPFUL, FEW SIMPLE IDEAS ON OILS, WHOLEWHEAT AND BROWN FOODS.

COSTINGS WOULD BE VERY HELPFUL IN EITHER THE RECIPE BOOK OR WORKSHOP TO GIVE ROUGH IDEA ON BUDGETS.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Really good day. Lots of useful information.
Good to see impact on other watches
and able to talk to other mess managers
about changes made to their mess.
Taking away some good ideas.
Cheers Greg!

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

MORE RECIPES WOULD BE GREAT. REFRESHER COURSES AS NUTRITION EVOLVES.

LOOKING FORWARD TO TAKING SOME OF GREGS IDEAS BACK TO THE WATCH.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Great to have some impat on

sdemore healthy ways to eat

+ what oil's to cook with.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

I FOUND THE WORKSHOP VERY INFORMATIVE, I TOOK AWAY SOME GOOD IDEAS TO USE AT THE FIRE STATION & ALSO ON A PERSONAL LEVEL. THE RECIPE BOOK WILL COME IN VERY USEFUL.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Very helpful and really well delivered.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Informative! good to share with other mess mangers and the pros and cons of runnig a mess Great Ideas on what to use and what helthy options are avaliable

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

SHARE RECIPES FROM OWN MESS IN FOLLOW UP. WITH ADVICE ON HOW TO IMPROVE.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

REGULAR REFRESHER COURSES. :)

EXCELLENT COURSE WITH LOTS OF USEFULL INFORMATION PLUS THE RECIPE BOOK IS VERY HELPFULL

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

SUPERB COURSE, GREG WAS VERY KNOWLEDGABLE AND INFORMATIVE. A GOOD DAY!

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Very good day - interesting to see what other stations are doing - more ideas of what to cook - Healthy and on a budget.

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Great idea for a course, its actually nice as a mess manager to have a platform to share ideas. I think the key for cooking on stations is easy/quick dishes, cheap & healthy. Knowing recipes that do this makes it easier to be healthy. When are we coming back?

Thank you for your participation

Mess manager kitchen workshop feedback

How useful did you find the workshop overall?

Not at all	Somewhat	50/50	Very useful	Extremely useful
1	2	3	4	5

What is the likelihood that you will put some of the ideas which were shared today into practice?

Unlikely	Possibly	likely	very likely	Definitely
1	2	3	4	5

Please offer any comments / suggestions on how this could be improved:

Very useful day. Would be good to have regular course to enhance knowledge and experience.

Thank you for your participation

Appendix 7.1. Firefighter Health and Lifestyle Questionnaire

Name: ……………………………….. Sex: M F Age: …… Years served: …….

Ethnicity (optional): …………………………………………… Rank: ………………

Fire station………………………………….... Watch………. Do you smoke? YES NO

Are you in the watch mess? YES NO Who does the food shopping at home?

………………………………………………………………………………………

Do you have any injuries or underlying health conditions?

………………………………………………………………………………………

………………………………………………………………………………………

On a scale of 1 – 10, with 1 being low mood and 10 being perfectly content, how would you rate your general mood over the last three to four months?

1 2 3 4 5 6 7 8 9 10

Time of evening meal (a) at fire station? …………….. (b) at home?......................

Do you snack in the evening after final meal (a) on night shifts? .... (b) at home?.....

On a scale of 1 – 10, with 1 being low energy and 10 being high energy, how would rate your average daily energy level over the last three to four months?

1 2 3 4 5 6 7 8 9 10

Appendix 7.2. Follow-up Health and Lifestyle Questionnaire

Name: …………………………………………………………..

Fire station………………………………….... Watch……….

Are you in the watch mess? YES NO

On a scale of 1 – 10, with 1 being low mood and 10 being perfectly content, how would you rate your general mood over the last three to four months?

1 2 3 4 5 6 7 8 9 10

Do you snack in the evening after final meal (a) on night shifts? .... (b) at home?..…

On a scale of 1 – 10, with 1 being low energy and 10 being high energy, how would rate your average daily energy level over the last month?

1 2 3 4 5 6 7 8 9 10

Appendix 7.3. Concise Physical Activity Questionnaire (Sliter and Sliter, 2014).

Please think about the past month. During that time, approximately **how many days per week** did you engage in each of the following types of physical activity **for at least 20 consecutive minutes?**

Example 1. If you walk to work and it takes you 10 minutes each way, that would NOT count because the minutes were not consecutive.

Example 2. If you walk to work and it takes you 20 minutes each way, then that would count as performing light physical activity that day. You walked for at least 20 consecutive minutes that day.

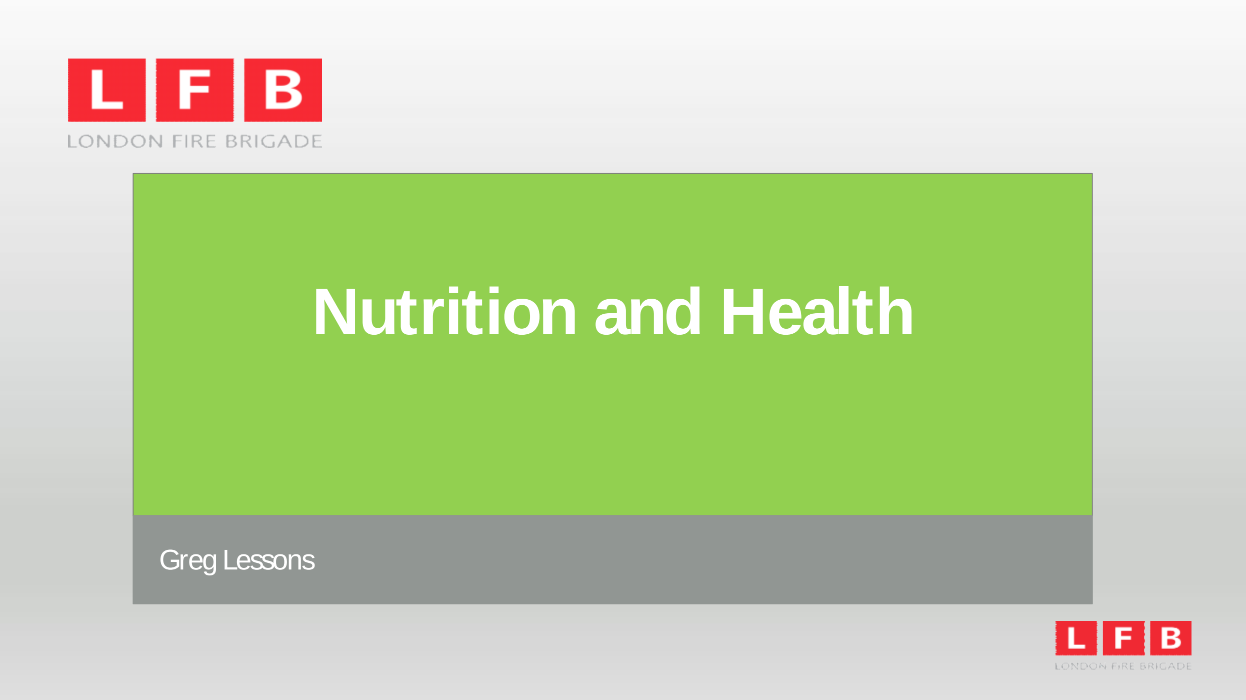
1. Light aerobic activity (e.g.: Shopping, housework, leisurely walking)
………… days per week

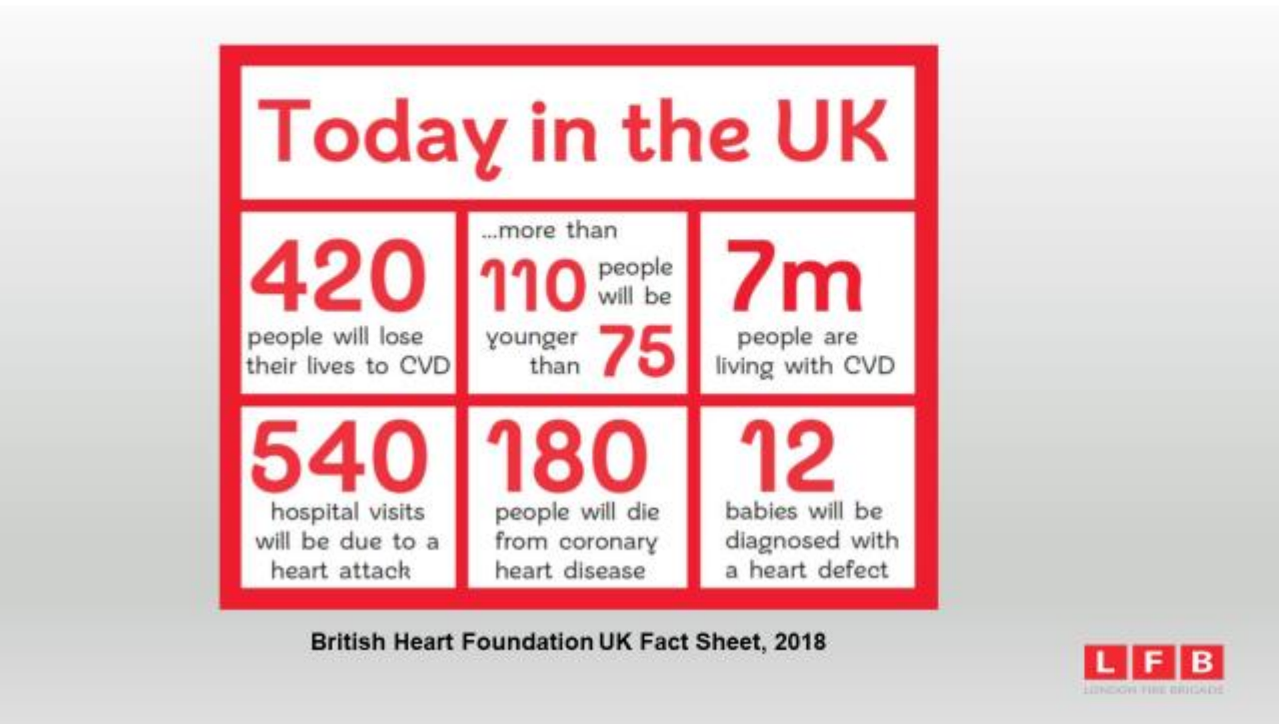
2. Moderate aerobic activity (e.g.: Brisk walking, bicycling, tennis)
………… days per week

3. Vigorous aerobic activity (e.g.: Jogging/running, swimming laps, skipping)
………… days per week

4. Muscle-strengthening activity (Ex: Lifting weights, pilates, yoga)
…………. Days per week

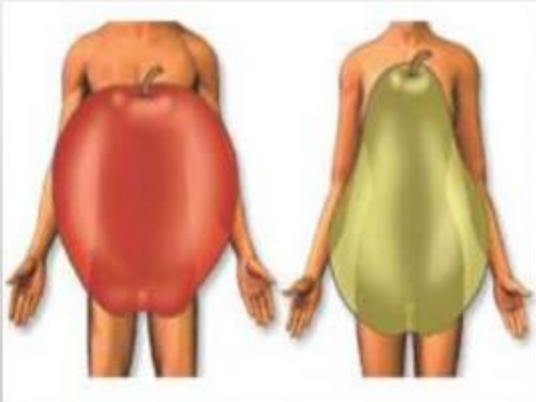
Appendix 7.4. ‘Nutrition and health’ PowerPoint presentation for firefighters



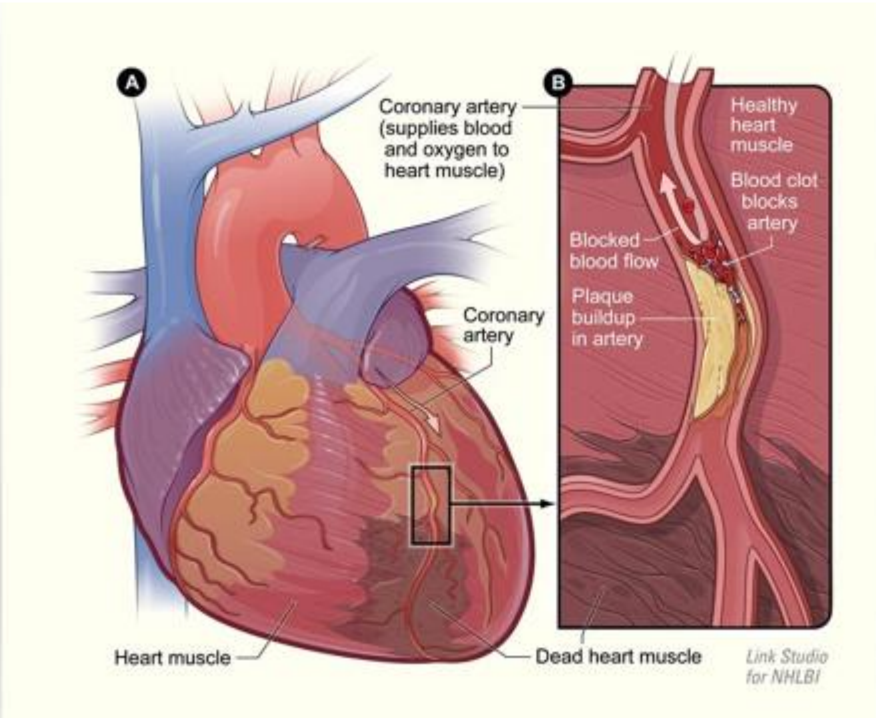


Being overweight/obese harms health

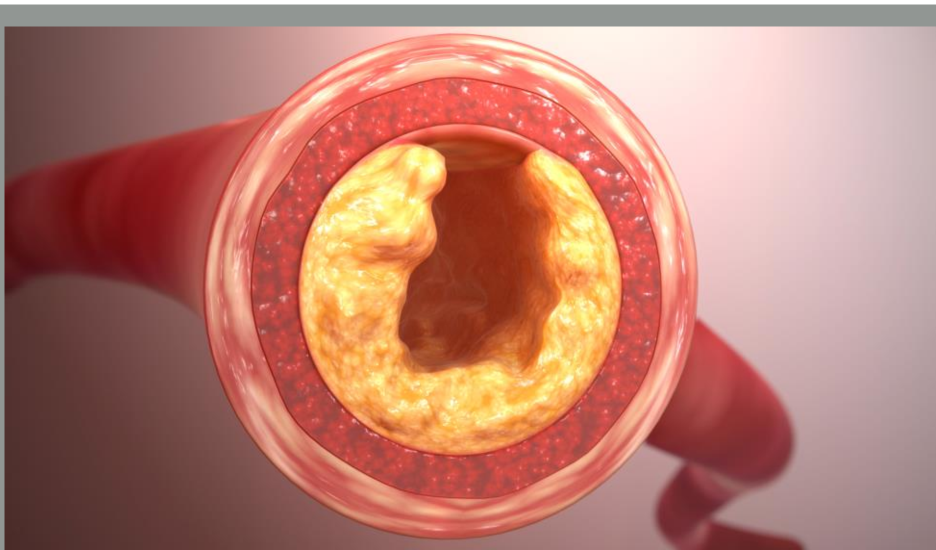
Heart disease
Stroke
Type 2 diabetes
Cancer
Liver disease
Kidney disease
Asthma
Chronic musculoskeletal disorders
Osteoarthritis
Back pain
Sleep apnoea
Reproductive complications
Gallbladder disease
Alzheimer's disease
Dementia
Depression



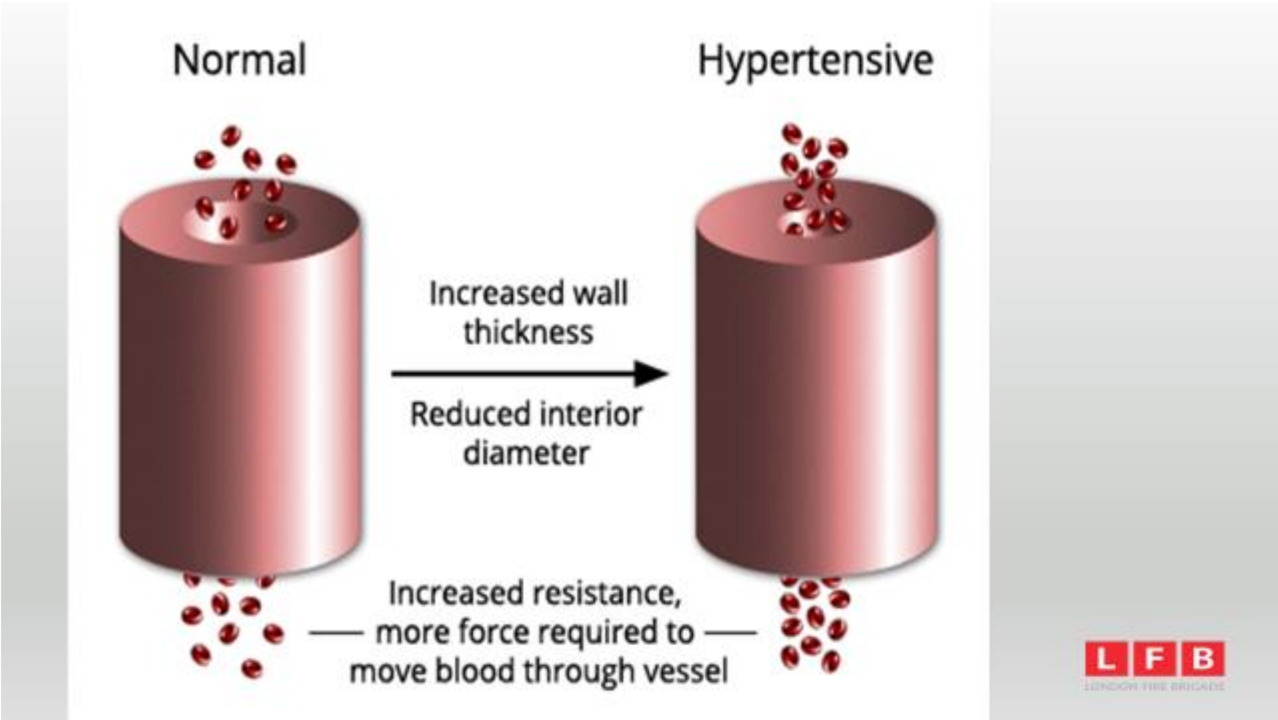
Risks increase above a BMI of 23

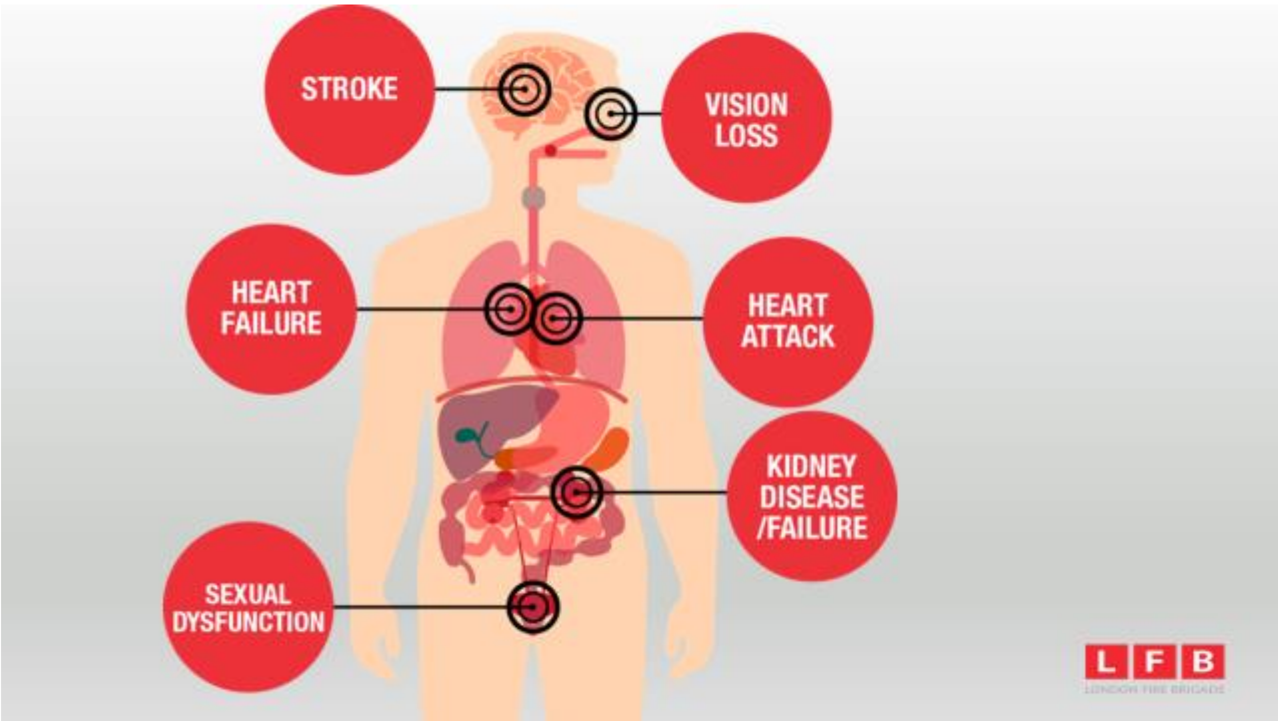


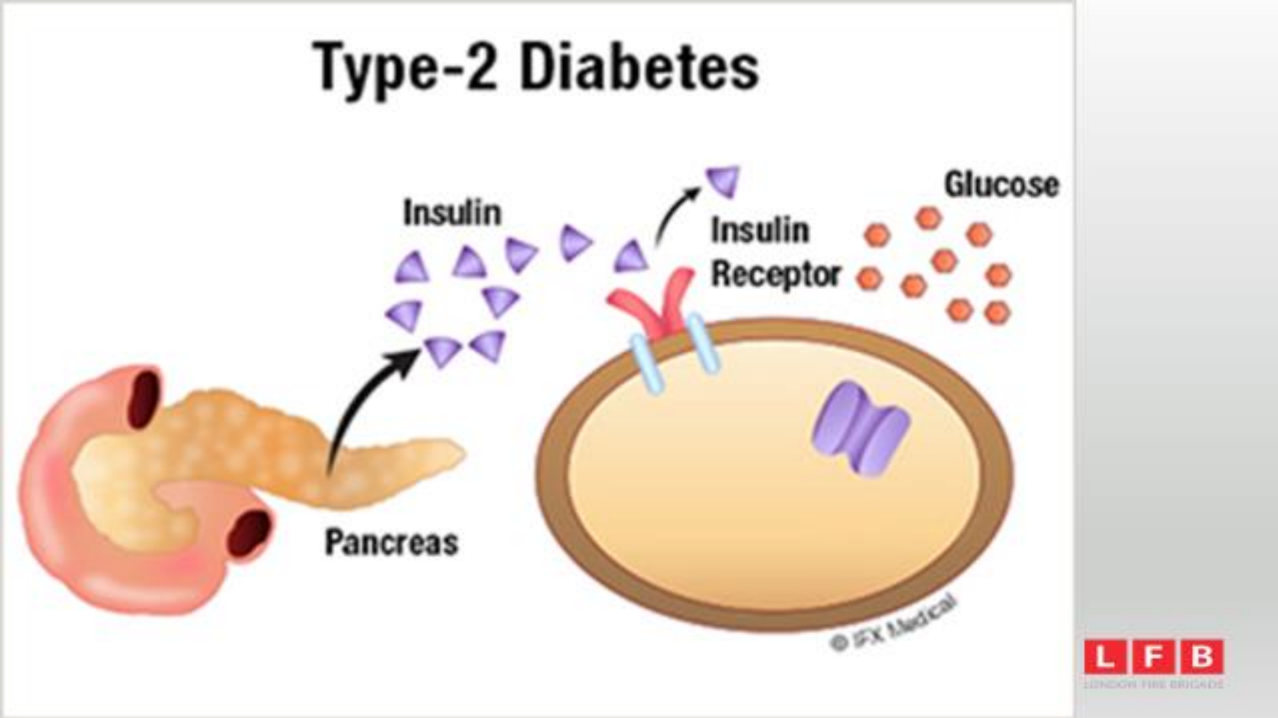
hyperlipidemia (high fats in blood, can be cholesterol, triglycerides, or both)

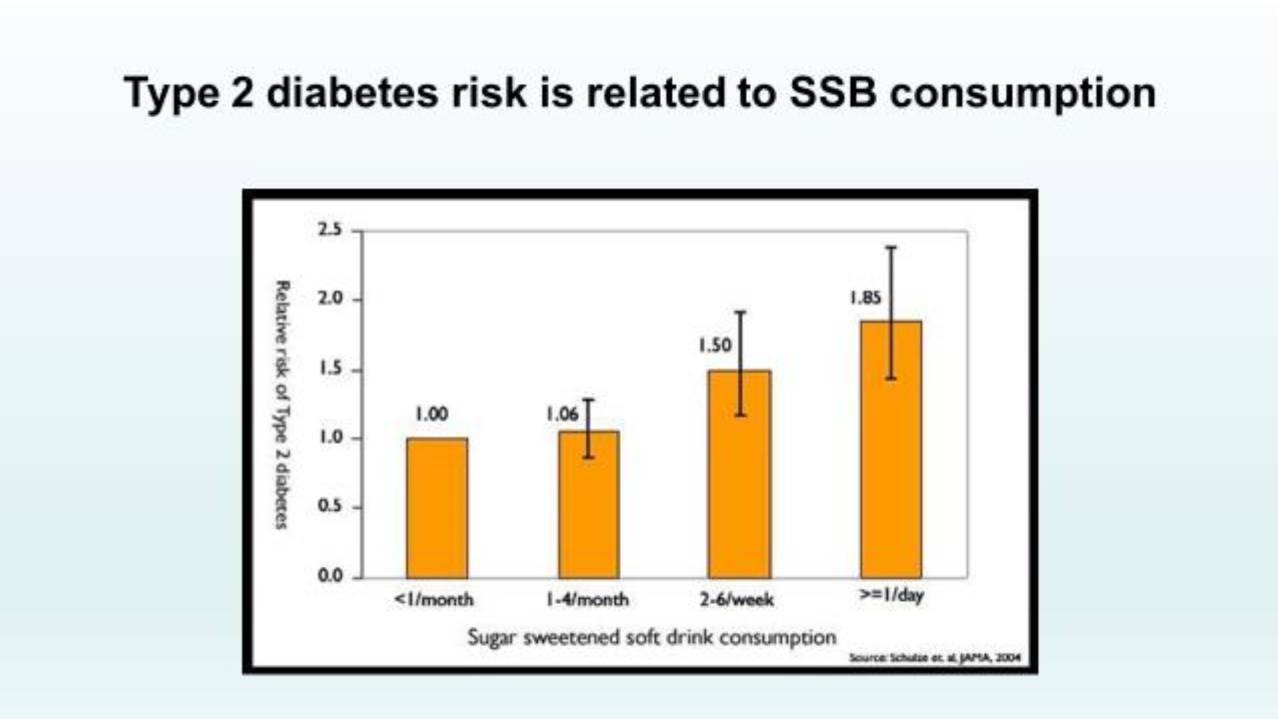


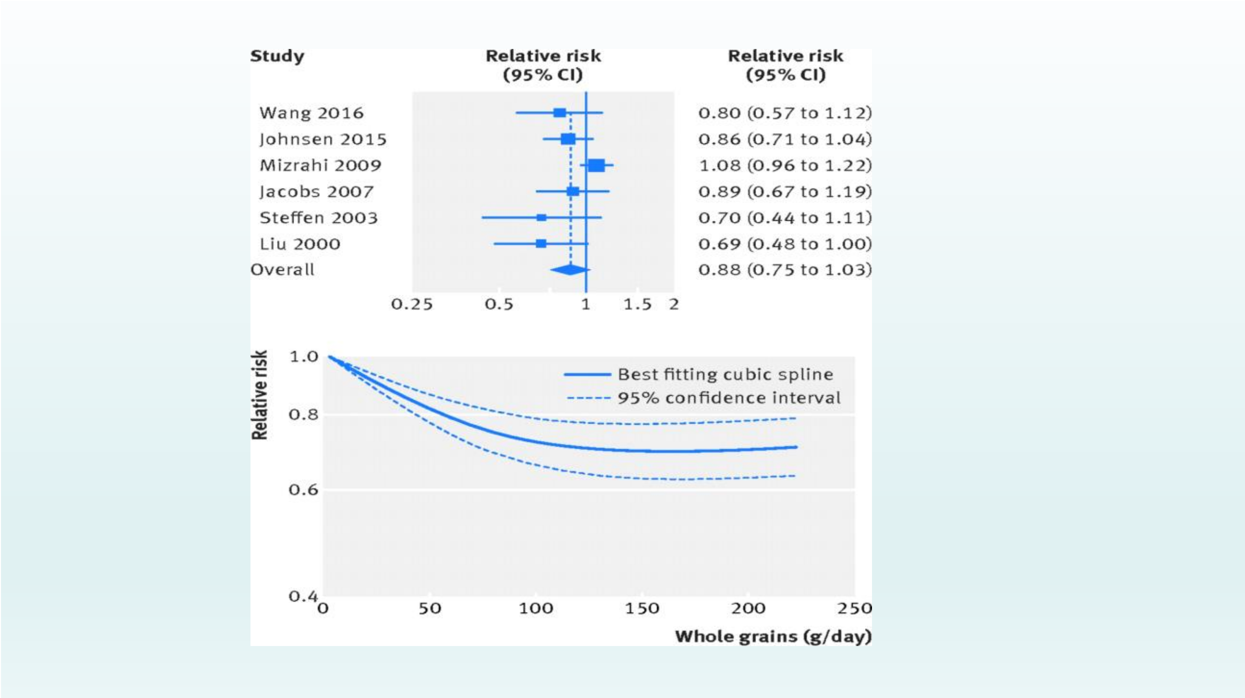
Cardiovascular atherosclerosis – coronary heart disease (CHD)

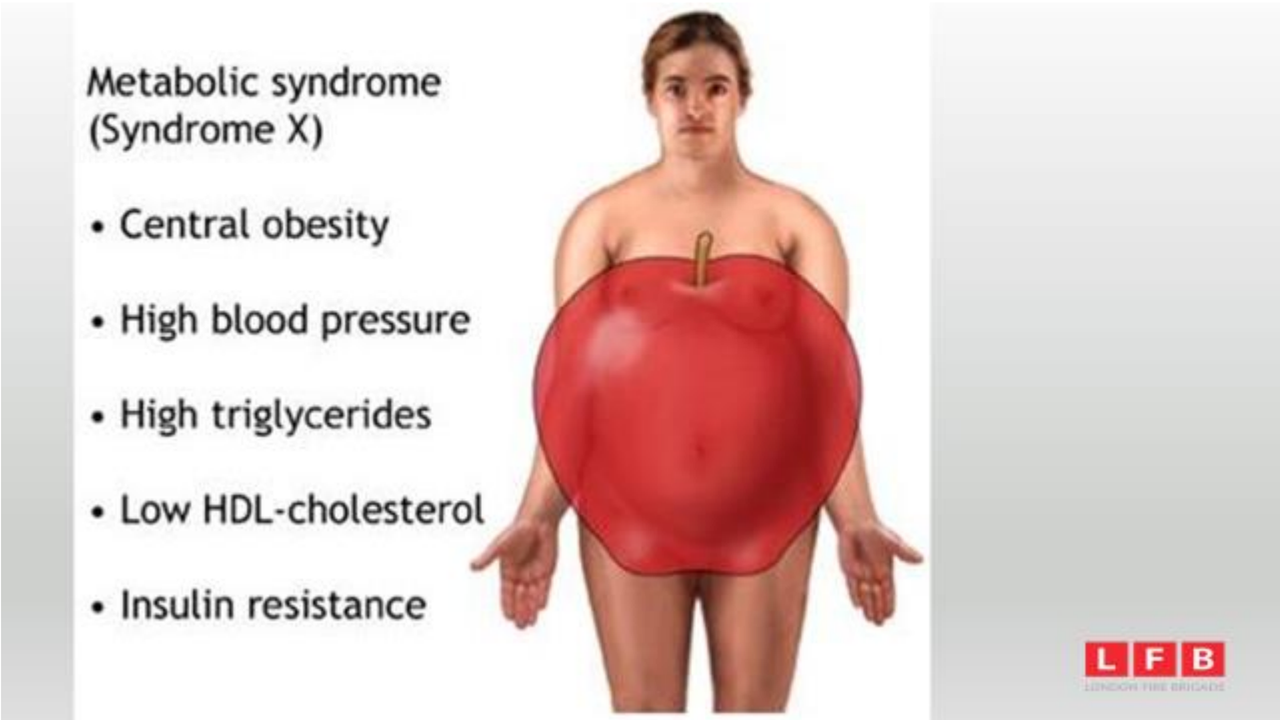

Normal
Hypertensive
Increased wall thickness
Reduced interior diameter
Increased resistance, more force required to move blood through vessel


STROKE
VISION LOSS
HEART FAILURE
HEART ATTACK
KIDNEY DISEASE /FAILURE
SEXUAL DYSFUNCTION

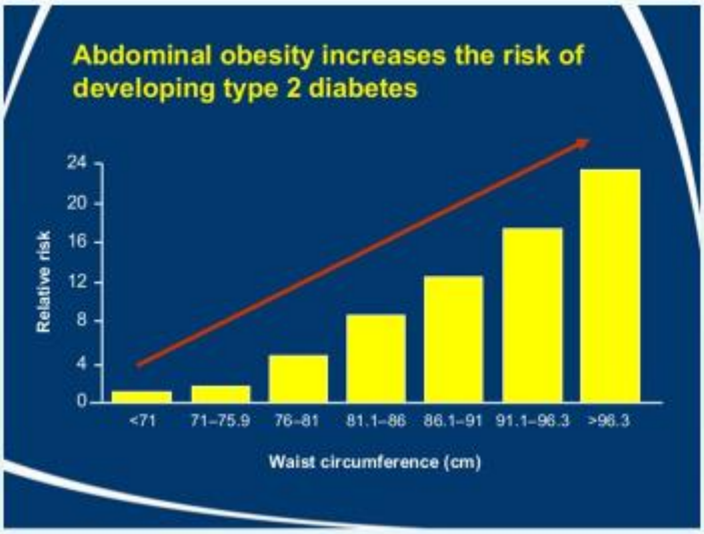

Type-2 Diabetes
Insulin
Insulin
Receptor
Glucose
Pancreas
© IFX Medical
LFB


Type 2 diabetes risk is related to SSB consumption
Relative risk of Type 2 diabetes
2.5
2.0
1.5
1.0
0.5
0.0
1.00
1.06
1.50
1.85
<1/month
1-4/month
2-6/week
>=1/day
Sugar sweetened soft drink consumption
Source: Schulze et. al, JAMA, 2004


Study
Relative risk (95% CI)
Relative risk (95% CI)
Wang 2016 0.80 (0.57 to 1.12)
Johnsen 2015 0.86 (0.71 to 1.04)
Mizrahi 2009 1.08 (0.96 to 1.22)
Jacobs 2007 0.89 (0.67 to 1.19)
Steffen 2003 0.70 (0.44 to 1.11)
Liu 2000 0.69 (0.48 to 1.00)
Overall 0.88 (0.75 to 1.03)
0.25 0.5 1 1.5 2
Relative risk
1.0
0.8
0.6
0.4
Best fitting cubic spline
95% confidence interval
0 50 100 150 200 250
Whole grains (g/day)


Metabolic syndrome
(Syndrome X)
• Central obesity
• High blood pressure
• High triglycerides
• Low HDL-cholesterol
• Insulin resistance
LFB

Type 2 diabetes risk is strongly related to waist circumference and abdominal obesity



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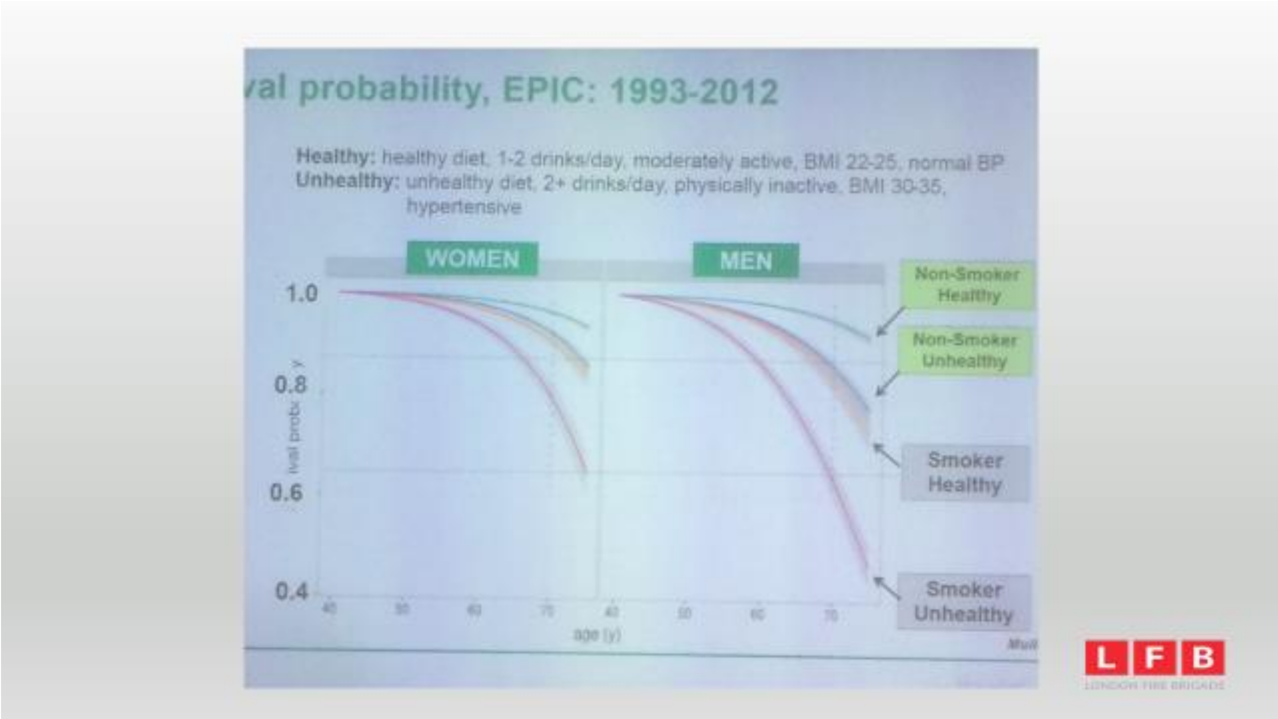
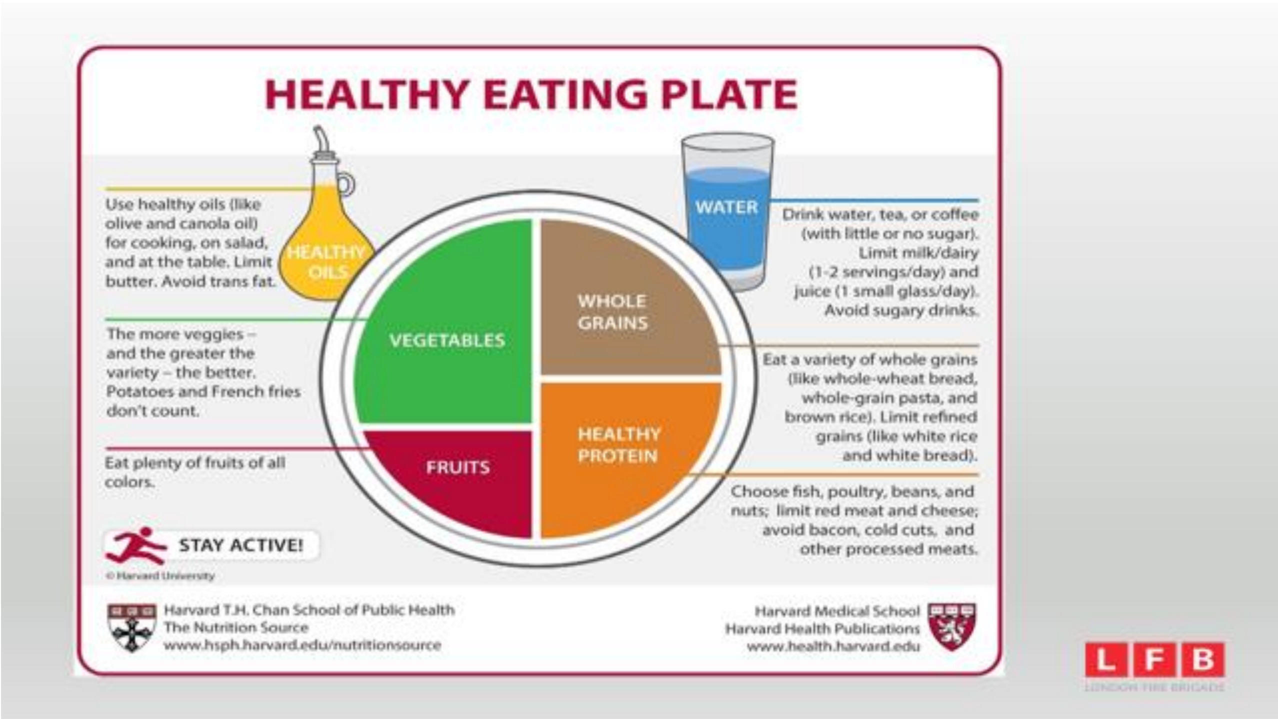


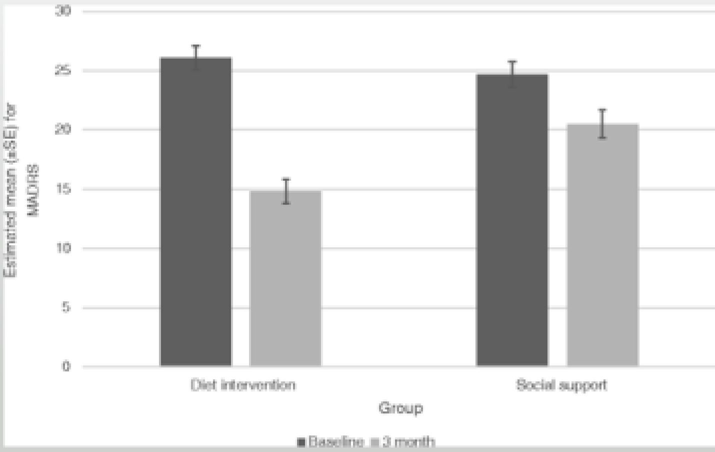
val probability, EPIC: 1993-2012
Healthy: healthy diet, 1-2 drinks/day, moderately active, BMI 22-25, normal BP
Unhealthy: unhealthy diet, 2+ drinks/day, physically inactive, BMI 30-35, hypertensive
WOMEN
MEN
1.0
0.8
0.6
0.4
Non-Smoker Healthy
Non-Smoker Unhealthy
Smoker Healthy
Smoker Unhealthy
LFB



HEALTHY EATING PLATE
Use healthy oils (like olive and canola oil) for cooking, on salad, and at the table. Limit butter. Avoid trans fat.
HEALTHY OILS
The more veggies – and the greater the variety – the better. Potatoes and French fries don't count.
Eat plenty of fruits of all colors.
VEGETABLES
FRUITS
WHOLE GRAINS
HEALTHY PROTEIN
WATER
Drink water, tea, or coffee (with little or no sugar). Limit milk/dairy (1-2 servings/day) and juice (1 small glass/day). Avoid sugary drinks.
Eat a variety of whole grains (like whole-wheat bread, whole-grain pasta, and brown rice). Limit refined grains (like white rice and white bread).
Choose fish, poultry, beans, and nuts; limit red meat and cheese; avoid bacon, cold cuts, and other processed meats.
STAY ACTIVE!
© Harvard University
Harvard T.H. Chan School of Public Health
The Nutrition Source
www.hsph.harvard.edu/nutritionsource
Harvard Medical School
Harvard Health Publications
www.health.harvard.edu
LFB

A randomised controlled trial of **dietary improvement for adults with major depression** (the 'SMILES' trial)

BMC Medicine 2017 **15**:23



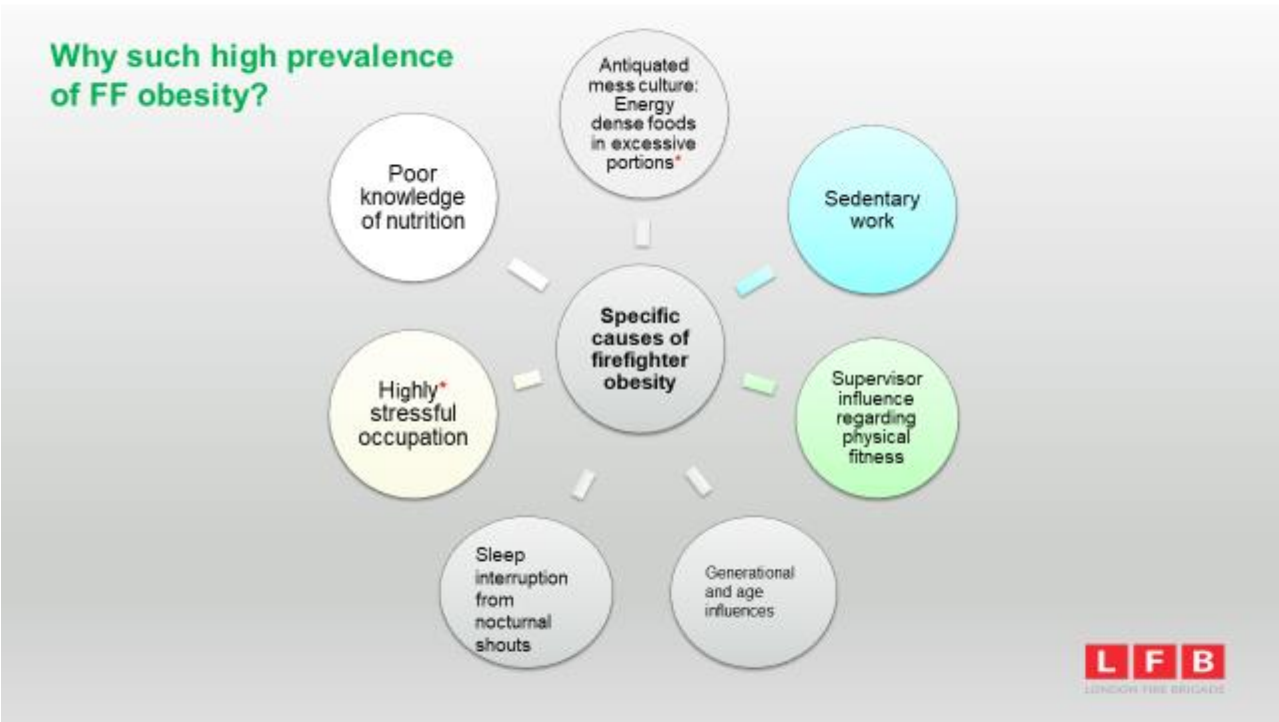
significant reductions in depression symptoms as a result of dietary intervention, outperforming pharmacotherapy and psychotherapy.

Participants

Control group Harold Hill fire station 19 participants *	Intervention group Hornchurch fire station 21 participants *

Recruited via staff email.
Pilot trial ran February to March 2017


Preliminary research
Initial Findings
Very poor lifestyle choices
70% of the sample overweight or obese *
Lack of awareness and confusion around nutrition*
LFB


Why such high prevalence of FF obesity?
Antiquated mess culture: Energy dense foods in excessive portions*
Sedentary work
Supervisor influence regarding physical fitness
Generational and age influences
Sleep interruption from nocturnal shouts
Highly* stressful occupation
Poor knowledge of nutrition
Specific causes of firefighter obesity
LFB

Results after 1 month

- A significant mean reduction in BMI and body fat percentage for the intervention group, with no significant reduction for the control group, outperforming similar USA trials.
- A significant reduction in calories consumed (- 413) for intervention participants.*
- Significant reduction in consumption of unhealthy fats, sugars and highly processed foods indicating improved dietary knowledge and practice.
- **4 Hornchurch firefighters (20%) crossed over into more desirable risk categories for waist circumference. General wellbeing (mood), sleep quality and energy level improvement.***

LFB LONDON FIRE BRIGADE

Additional support

- Omega 3 fatty acids
- Iron defeciency
- Pre/post natal nutrition
- Protein for muscle growth
- Ketogenic diet
- Intermittent fasting
- Dietary strategies
- Individual appointments

?

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3 Step process

Dietary and lifestyle assessment via tickbox questionnaire → Body composition analysis → Individual nutritional recommendations

100% CONFIDENTIAL

LFB
LONDON FIRE BRIGADE

Portion sizes (medium servings)

Meat: Cooked mince / Stew / Casserole: 2 serving spoons, Steak: About half the size of your hand, Beefburgers: 1 quarter pounder, Cooked Pork / lamb / Chicken: About half the size of your hand, Bacon / Ham: 2 slices, Sausages: 2 medium sized, Pies: 1 standard individual portion

Fish / shellfish: The size of half to a whole hand / 120g tin.

Porridge: About 1 and a half handfuls dried oats   Other breakfast cereals: About 3 handfuls

Carbs: Potato (baked): 1 about the size of your fist (mash): about 6 tablespoons (boiled): About 6 small Chips: About 2 handfuls Roast potatoes: About 4 small potatoes Rice / pasta / couscous / noodles: About the amount that would fit into 2 hands cupped together

Cheese: About the size of two thumbs   Nuts: About 1 handful

Cake: 1 individual cake or the equivalent sized slice

Small fruit: 7 cherry tomatoes, 2 satsumas, 2 kiwi fruit, 3 apricots, 6 lychees, 7 strawberries or 14 cherries, 4 tablespoons of blueberries, 1 tablespoon of raisins / currants / sultanas

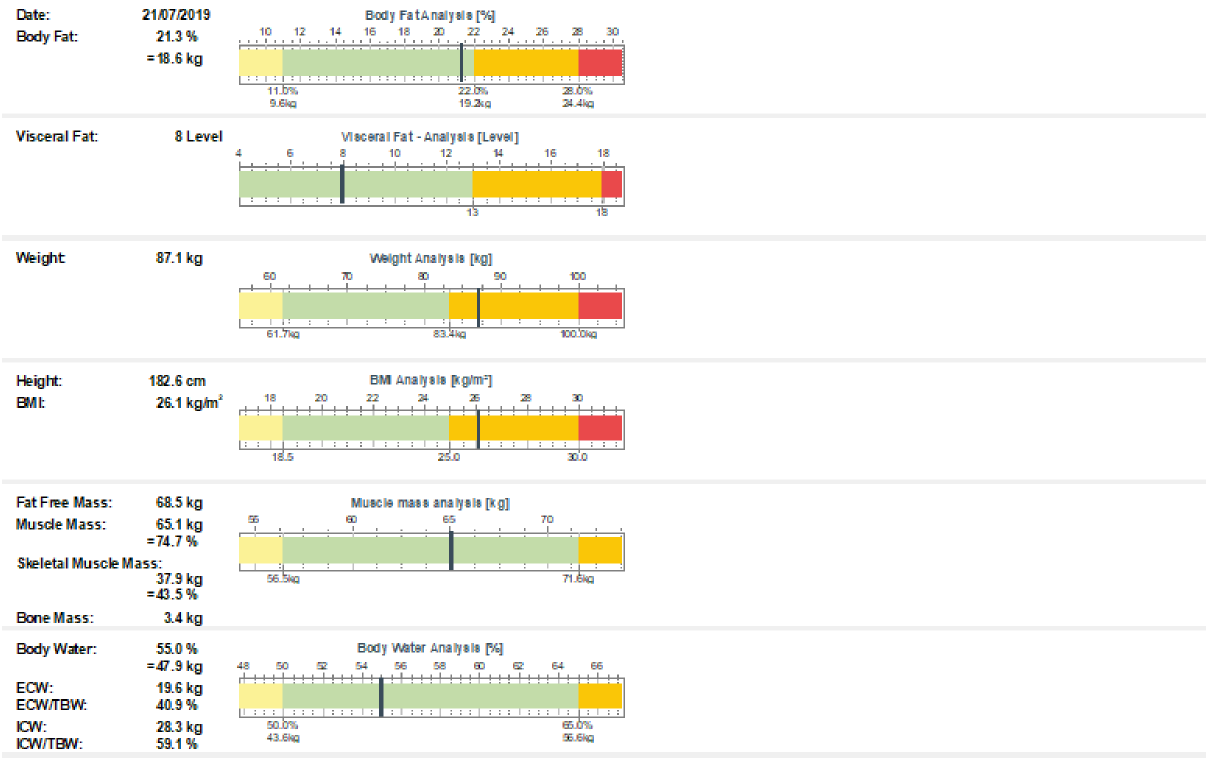
Veg: Leaves: 1 cereal bowl, broccoli: 2 spears, Peas: 3 tablespoons, Green beans: 4 tablespoons, Baked beans: 3 tablespoons, sweetcorn: 3 tablespoons, Lentils: 3 tablespoons, brussels sprouts: 8, Cooked kale: 4 tablespoons, Beetroot: 7 slices, onion: 1, Beansprouts: 2 handfuls, Cooked turnip: 3 tablespoons, avocado: half, Chopped mushrooms: 3 tablespoons, Cucumber: 2 inch slice, celery: 3 sticks, Leek: 1, Pepper: half, cauliflower: 8 florets

LFB
LONDON FIRE BRIGADE

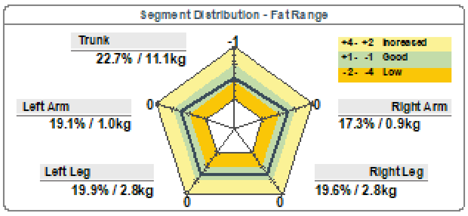
Appendix 7.5. Mess modification suggestions

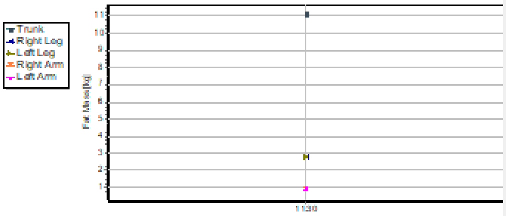
- Introduce a fruit bowl: Bananas and easy peelers are crowd pleasers!
- Leave leftovers in the kitchen
- Consider using smaller plates
- Use wholegrains where possible

Appendix 7.6. Example of a baseline body composition analysis report

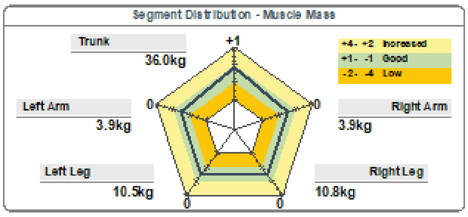


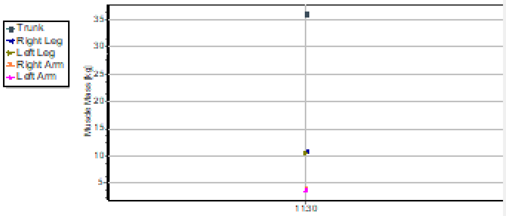
Segment Distribution
Fat Range
21/07/2019



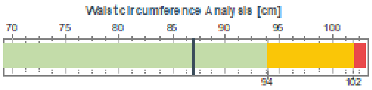


Segment Distribution
Muscle Mass
21/07/2019





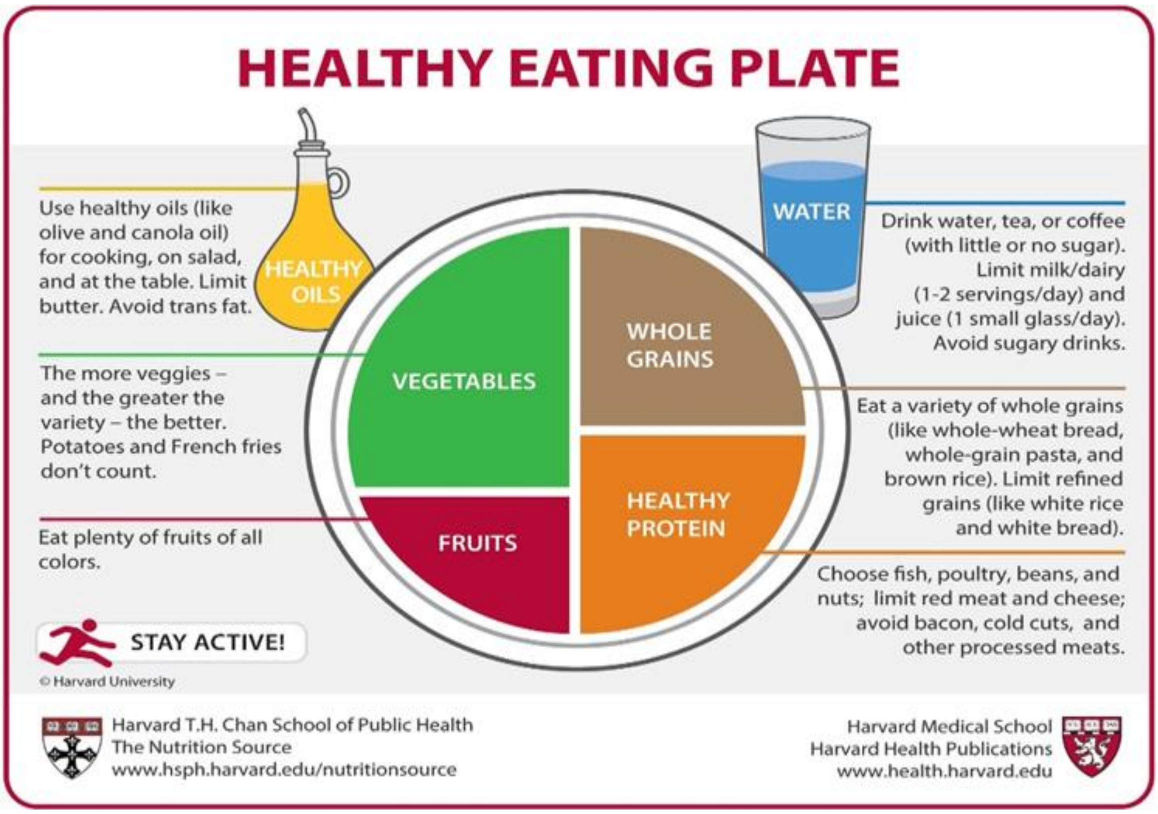
Waist 87 cm



Legend: Low Decreased Good Increased High Improved Unchanged Degraded

Appendix 7.7. GIS Nutrition Advice

- Eat a ***minimum*** of 5-a-day of various fruit and **veg**. Risk of all-cause mortality (death by any cause) reduces by 14%: 1-3 portions, 29%: 3-5 portions, 36%: 5-7 portions and 42%: 7 or more portions.
- Include lots of fibre on your plate. Vegetables, fruits and beans will fill you up instantly.
- Protein rich foods will help you to feel fuller for longer, helping reduce the total amount of calories you consume.
- Take a vitamin D supplement. 10 micrograms per day is recommended.



Copyright © 2011, Harvard University. For more information about The Healthy Eating Plate, please see The Nutrition Source, Department of Nutrition, Harvard School of Public Health, www.thenutritionsource.org, and Harvard Health Publications, www.health.harvard.edu.

- Reduce/exclude free sugars. Studies are showing free sugars to be a main culprit for the metabolic syndrome, increasing risk factors for coronary heart disease and type 2 diabetes.
- Reduce salt intake. Salt elevates blood pressure which increases risk of cardiovascular disease i.e. heart attack and stroke.
- Minimise/exclude junk/ultra-processed food. Read labels! Salt and sugar are hiding everywhere.
- Avoid over-eating. Studies show that appetite and calorie intake are ***not*** related. Eat from a smaller plate, or a smaller container if away from the home. Use the above picture template.
- Limit alcohol intake to a maximum of 14 units per week (males and females) spread evenly over three days or more.

Health and Lifestyle Advice

If your measurements are in the amber or red ranges, following the advice below and on the previous page will help you move toward healthy ranges (green). Once within healthy ranges, you will significantly reduce your risk of suffering from health conditions including coronary heart disease, type 2 diabetes and several cancers.

Exercise advice

Aerobic: Exercise for a minimum of 150 mins (moderate aerobic activity) per week, or 75 mins (vigorous aerobic activity), or a combination of both. This should be spread throughout the week.

Strength: Do strength training for all major muscle groups at least twice per week. Start with a single set per exercise, setting the resistance/weight heavy enough to fatigue your muscles after approx. 12-15 repetitions.

Examples of moderate aerobic exercise: Gardening, brisk walking and swimming.

Examples of vigorous aerobic exercise: Running, circuit training and rowing.

Strength training can involve machines, free weights, your body weight or resistance bands.

Aim for a minimum of 30 mins of physical activity per day.

Greater health benefits and fat loss can be gained by increasing to 300 mins per week.

Reduce sitting time! The more hours of sitting each day, the greater your risk of metabolic diseases, even if you meet the recommended daily amount of exercise. Even short durations of activity produce benefits. Example: If a 30 minute walk cannot be fitted in, try for three walks of 10 minutes instead. *It is vital to make regular physical activity a part of your lifestyle.*

Improving sleep

- Not eating or drinking anything except water after 7pm/8pm, until breakfast may improve sleep duration and quality. This is also likely to reduce weight.
- Reduce/eliminate consumption of caffeinated beverages (especially later in the day).
- Reduce alcohol intake. Whilst alcohol may encourage the onset of sleep, it diminishes sleep quality by disrupting deep sleep and waking you up earlier.
- Exercise regularly. Alongside all of the other weight loss/health benefits, exercise strengthens sleep.

Personal advice / goals:

Appendix 7.8. Healthy snack ideas

- Fruit
- Low fat, low sugar (around 5% is ok) Greek/natural yoghurt with berries
- Half a handful of raw nuts with dried fruit (No more than this amount per day due to high calorie content)
- Low sugar, low salt and low calorie popcorn (Most supermarkets now sell this)
- Vegetable sticks and Hummus (Peppers, carrots, celery sticks, cucumber etc.)
- 2 squares of dark chocolate (the higher the cocoa content the healthier. Try not to exceed this amount per day).
- Rice cake and peanut butter

Appendix 7.9. Food group compositions

FOOD ITEM	FOOD GROUP
FRIED_FISH	Fish & fish products
WHITE_FISH	Fish & fish products
OILY_FISH	Fish & fish products
SHELLFISH	Fish & fish products
ICE_CREAM	Sugars; preserves and snacks
CHOCOLATES	Sugars; preserves and snacks
CHOCOLATE_BARS	Sugars; preserves and snacks
SWEETS	Sugars; preserves and snacks
SUGAR	Sugars; preserves and snacks
CRISPS	Sugars; preserves and snacks
APPLES	Fruit
ORANGES	Fruit
PEARS	Fruit
BANANAS	Fruit
GRAPES	Fruit
MELONS	Fruit
PEACHES	Fruit
STRAWBERRIES	Fruit
DRIED_FRUIT	Fruit
CARROTS	Vegetables
SPINACH	Vegetables

BROCCOLI	Vegetables
SPROUTS	Vegetables
CABBAGE	Vegetables
PEAS	Vegetables
GREEN_BEANS	Vegetables
MARROW, COURGETTES	Vegetables
CAULIFLOWER	Vegetables
PARSNIPS	Vegetables
LEEKS	Vegetables
ONIONS	Vegetables
GARLIC	Vegetables
MUSHROOMS	Vegetables
PEPPERS	Vegetables
BEANSPROUTS	Vegetables
GREEN_SALAD	Vegetables
TOMATOES	Vegetables
SWEETCORN	Vegetables
BEETROOT	Vegetables
COLESLAW	Vegetables
AVOCADO	Fruit
BEANS	Vegetables
LENTILS	Vegetables

Appendix 7.10. Expressions of gratitude from intervention study participants

From: [redacted]
Sent: 10 March 2020 09:27
To: [redacted]
Subject: Greg's Nutrional input

Dear [redacted],

Forgive the informal approach to this email but I hope it its received in the positive manner that it was intended.

We ([redacted]) have just finished our 9 month cycle with Greg Lesson's nutritional input. Everybody on the watch has commented how great this was. It was really well received. Greg is obviously very knowledgeable in this field and has a great and non offensive way of informing , advising and collecting peoples statistics in what could be quite a delicate subject.
I cant emphasis enough what positive impact this sort of schemes has on staff at station level.
For staff receiving the input, Obvious benefits are health, advice, moral, increased fitness levels, motivation to name but a few.

But also for me as an Officer, When staff are moaning (yes it does happen occasionally) Schemes like these give me positive example to offer staff.
Gregg lessons Nutrional input
A brilliant and well received concept organised and executed to the highest standard.

Please forward my thanks to Greg , Yourself and [redacted] for making this happen
.
I am generally positive regarding the future of the LFB as I can see a change direction and a positive investment in staff with schemes like this, the Training for trainers input from [redacted] going on at present (which was another well received day) and the upcoming fire safety training (I've been asking for this for years)

Many thanks [redacted]

[redacted]

Sub Officer

Homerton Fire Station
London Fire Brigade
169 Union Street London SE1 0LL
T [redacted]
From: [redacted]
Sent: 10 December 2019 23:46
To: [redacted]
Cc: LESSONS, GREG; [redacted]
Subject: Brigade Nutritionist

Sir
<u>I am writing with reference to Nutritionist Advice Service</u>

I attended a neutralist advice meeting with Greg Lesson, I just want to express my gratitude and delight that we are finally addressing issues that have been long over due that need education.

This is such a positive approach to wellbeing in the work force, that I am sure will pay dividends in the future, both financially to the LFB with regards to reduction in short/long term sickness and could be a UK fire service leader.
It is a very refreshing approach that we don't normally adopt, we are on so many occasions reactive, rather than proactive to this kind of subject.

I personally and I know members of my watch have gained valuable knowledge on how to address issues that have arisen, before they become problematic to individual and the organisation.
Its not often we find ourselves writing emails of approval, it's often too easy to look at the negatives within the LFB.

Once again I want to express my gratitude what a GREAT IDEA !!

Regards
Stn/O [redacted]
[redacted] Dagenham

London Fire Brigade
02085551200 [redacted]
Mobile: [redacted]

From: [redacted]
Sent: 10 March 2020 09:50
To: [redacted]
Subject: RE: Greg's Nutrional input
Importance: High

Hi [redacted]

No worries re the direct approach. When I first met Greg and he told me about this concept like you I thought fantastic hence both my and the Commissioner's support. If only we had something like this sooner I would have avoided years of mince and nutty! ☺ As you will be aware Greg is going from strength to strength in terms of external recognition and awards which is brilliant for him personally and the LFB. Thanks for all the feedback below its nice to receive positive experiences from colleagues as we are generally striving to improve all areas of the service.

I will share your email with the Commissioner and AC Fire Stations.

Regards,

[redacted]

[redacted]
Deputy Assistant Commissioner
London Fire Brigade
North East Area Operations
Area HQ
2 Ferns Road
London E15 4LX
T: [redacted]
M: [redacted]
P: F2
E: [redacted]