Cross-education and neuromuscular factors relating to the prevention and rehabilitation of anterior cruciate ligament (ACL) knee injuries

MPhil Thesis

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Abstract

Background: The purpose of this study was to use unilateral neuromuscular training following a period of bilateral training compared to a control detraining group. Functional output measures were used to assess cross-education adaptations with a view to their potential use in the rehabilitation of anterior cruciate ligament (ACL) injuries. No cross-education research to date has incorporated functional interventions or output measures and only one ACL rehabilitation study has investigated the potential effects of cross-education.

Methods: Eighteen recreationally active females (21.2 ± 3 years of age, with a stature of 166.4 ± 6.6 cm, and body mass of 61.9 ± 3.6 kg) were recruited (*n* = 18). The participants all completed a six week bilateral plyometrics programme to raise their functional performances above their baselines. The participants were then divided into two groups, a cross-education group (CEG) (*n* = 9) and a detraining group (DTG) (*n* = 9). The CEG completed a nine week unilateral neuromuscular training programme while the DTG ceased their training. Output measures were recorded before and after the bilateral training programme (weeks 0 and 7) and again post-intervention (week 16) for drop jumps (DJs) and single leg vertical jumps (SLVJs). The data for all tests were recorded using Bioware software and a Kistler 9286A Force Platform (Kistler, UK). Additionally an eight channel surface electromyography (sEMG) unit (ME6000, Megawin sEMG, Finland) and two dimensional video analysis were used for the pre and post-intervention tests at week 7 and 16. The variables tested were peak force (N), force adjusted for bodyweight (N·Kg), contact time (s), average rate of force development

(N·m·s^{-1}), propulsion (m·s^{-1}), deceleration (m·s^{-1}), velocity (m·s^{-1}), power (W), flight time (s), jump height (cm), knee abduction moment probability (KAM) and knee valgus (cm).

Findings: This study found there to be significant effect for DJ velocity on first landing on time ($P = 0.02$), velocity on take off for SLVJ on interaction ($P = 0.02$) and peak power on take off on interaction ($P = 0.04$). For all other variables there was no significant ($P > 0.05$) unilateral retardation of the detraining effect for any of the kinetic variables for DJs or SLVJs following a nine week neuromuscular cross-education training programme. There were also no significant adaptations to the kinematic variables of KAM for either DJs or SLVJs.

Interpretation: There are clear kinetic differences between DJs and SLVJs primarily related to the utilisation of the stretch shortening cycle for DJs given the counter movement nature of the first landing and take off. Other differences include the key muscle groups and joint movements for force generation, which are specific to each jump type.

Clinical relevance: Cross-education adaptations for a contralateral limb are well established and there is an increasing interest in its potential use for rehabilitation purposes including the management of ACL injury risks.

Key words: Cross-education, ACL, rehabilitation, neuromuscular training, kinetic, kinematic.

Chapter 1

1.1 Introduction

Epidemiological studies from sporting events such as the Olympics and the Pan American Games have shown that injury rates for athletes range from 10% (Alonso *et al.,* 2010) to 66% (Dias Lopes *et al.,* 2009) and up to 80% affecting the lower limb (Alonso *et al.,* 2010). Anterior cruciate ligament (ACL) injuries affecting the lower limb are both serious and common, with approximately 250,000 cases per year in the USA it means such injuries can have a serious financial, psychological and long-term degenerative impact on an individual (Silvers and Mandlebaum, 2007; Silvers and Mandlebaum, 2011). The cost of ACL reconstruction each year in the United States is over 2 million dollars and approximately 100,000 surgical procedures take place (Lyman *et al.,* 2009, Wilk *et al.,* 2012 in Otzel, Chow and Tillman, 2015, p.23). These figures highlight the need to focus on preventative measures which could help both the NHS and athletes (Dias Lopes *et al.,* 2009; Alonso *et al.,* 2010; Junge *et al.,* 2009).

Injured athletes with ACL ruptures will typically be out of their sport for between six and nine months (Silvers and Mandlebaum, 2011). During a period such as this the average athlete may suffer a number of adverse effects caused by periods of inactivity and immobilisation (Couppé *et al.,* 2012). For example, a reduction in strength caused by muscle atrophy occurs evidenced by a reduced cross-sectional area of the quadriceps (Thom *et al.,* 2001). Decreases in muscle mass have been shown to occur at a rate of approximately 3% per week (Berg, Larsson and Tesch, 1997). The greater loss in strength relative to decreased cross-sectional area (CSA) suggests specific tension of muscle and/or neural input to muscle is reduced (Mujika and Padilla, 2000).

Females have been shown to be at increased risk of ACL injuries compared with their male counterparts (Silvers and Mandlebaum, 2011). In football, Arendt and Dick (1995) reported females to be over twice as likely to sustain an ACL rupture and probabilities are higher in other sports such as basketball. It is proposed that this is because females display a larger Q angle, greater tibial torsion, femoral anteversion and sub-talar pronation (Silvers and Mandlebaum, 2011). Gender-specific hormone differences in oestrogen and relaxin may also play a role (Silvers and Mandlebaum*,* 2007). However, it is the biomechanical factors that are of most interest as these may be positively affected by neuromuscular training programmes (Silvers and Mandlebaum*,* 2011). These include side to side asymmetries in peak electrical activity during jumps (Bates *et al.,* 2013) and a greater quadriceps to hamstrings ratio (Ford *et al.,* 2011, Hewett *et al.,* 2008, Padua *et al.,* 2005 in Bates *et al.,* 2013 p. 465).

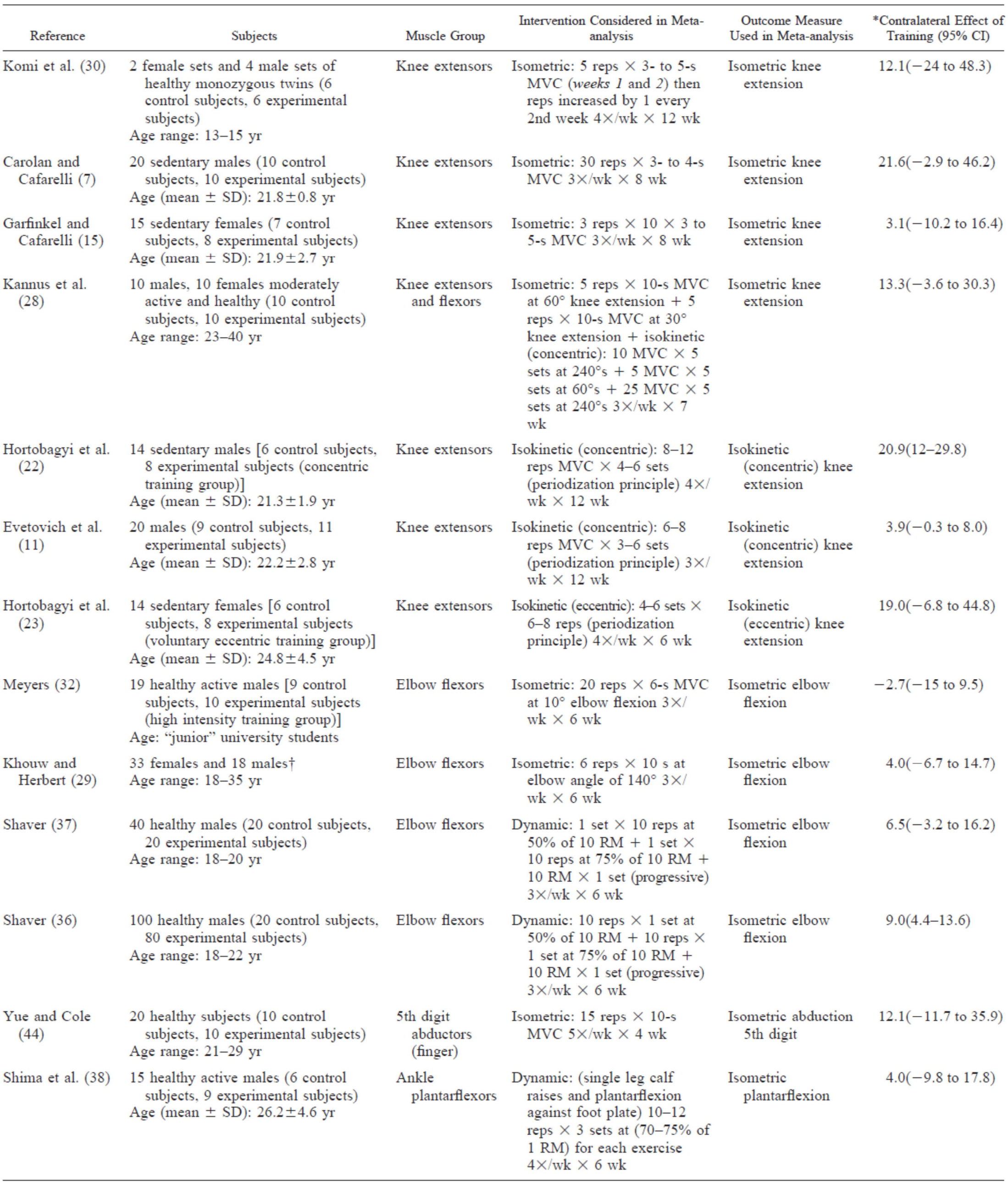
Unilateral strength training has long been known to create positive contralateral adaptations via a mechanism known as cross-education (Farthing and Zehr, 2014). Until recently, cross-education had not been considered as a rehabilitative tool and to date no study has incorporated functional training or output measures (Farthing Krentz and Magnus, 2009; Magnus *et al.,* 2010; Farthing *et al.,* 2011; Papandreou *et al.,* 2013). The current study’s main aim was to investigate the benefits of cross-education during a period of detraining with a view to positively influence the factors known to increase the risk of non contact ACL injuries (Silvers and Mandlebaum, 2007).

1.2.1 Cross-education: definition and results from training studies

Cross-education is a phenomenon first discovered over a century ago (Fechner, 1858 in Farthing and Zehr, 2014 p. 3; Scripture, Smith and Brown, 1894 in Shaver, 1975 p.9). It describes the increased strength of a contralateral homologous muscle group following the unilateral training of a limb (Munn *et al.*, 2004 p. 1861). Individual studies have shown contralateral strength gains that range from 0% to 77% (Hortobagyi, Lambert and Hill, 1997; Tesch and Karlsson, 1984 in Kannus *et al.,* 1992; Young *et al.,* 1983 in Kannus *et al.* 1992).

Munn *et al.* (2004) performed a meta-analysis within which 17 studies met their inclusion criteria of randomly allocated studies using at least 50% maximal voluntary contraction. Thirteen of these had enough data which allowed them to be pooled for analysis. See table 1.1 for a breakdown of each of the studies.

Table 1.1 Details of trials included in the meta-analysis of contralateral effects of unilateral resistance training.



Reference	Subjects	Muscle Group	Intervention Considered in Meta-analysis	Outcome Measure Used in Meta-analysis	*Contralateral Effect of Training (95% CI)
Komi et al. (30)	2 female sets and 4 male sets of healthy monozygous twins (6 control subjects, 6 experimental subjects) Age range: 13–15 yr	Knee extensors	Isometric: 5 reps × 3- to 5-s MVC (*weeks 1* and *2*) then reps increased by 1 every 2nd week 4×/wk × 12 wk	Isometric knee extension	12.1(−24 to 48.3)
Carolan and Cafarelli (7)	20 sedentary males (10 control subjects, 10 experimental subjects) Age (mean ± SD): 21.8±0.8 yr	Knee extensors	Isometric: 30 reps × 3- to 4-s MVC 3×/wk × 8 wk	Isometric knee extension	21.6(−2.9 to 46.2)
Garfinkel and Cafarelli (15)	15 sedentary females (7 control subjects, 8 experimental subjects) Age (mean ± SD): 21.9±2.7 yr	Knee extensors	Isometric: 3 reps × 10 × 3 to 5-s MVC 3×/wk × 8 wk	Isometric knee extension	3.1(−10.2 to 16.4)
Kannus et al. (28)	10 males, 10 females moderately active and healthy (10 control subjects, 10 experimental subjects) Age range: 23–40 yr	Knee extensors and flexors	Isometric: 5 reps × 10-s MVC at 60° knee extension + 5 reps × 10-s MVC at 30° knee extension + isokinetic (concentric): 10 MVC × 5 sets at 240°s + 5 MVC × 5 sets at 60°s + 25 MVC × 5 sets at 240°s 3×/wk × 7 wk	Isometric knee extension	13.3(−3.6 to 30.3)
Hortobagyi et al. (22)	14 sedentary males [6 control subjects, 8 experimental subjects (concentric training group)] Age (mean ± SD): 21.3±1.9 yr	Knee extensors	Isokinetic (concentric): 8–12 reps MVC × 4–6 sets (periodization principle) 4×/wk × 12 wk	Isokinetic (concentric) knee extension	20.9(12–29.8)
Evetovich et al. (11)	20 males (9 control subjects, 11 experimental subjects) Age (mean ± SD): 22.2±2.8 yr	Knee extensors	Isokinetic (concentric): 6–8 reps MVC × 3–6 sets (periodization principle) 3×/wk × 12 wk	Isokinetic (concentric) knee extension	3.9(−0.3 to 8.0)
Hortobagyi et al. (23)	14 sedentary females [6 control subjects, 8 experimental subjects (voluntary eccentric training group)] Age (mean ± SD): 24.8±4.5 yr	Knee extensors	Isokinetic (eccentric): 4–6 sets × 6–8 reps (periodization principle) 4×/wk × 6 wk	Isokinetic (eccentric) knee extension	19.0(−6.8 to 44.8)
Meyers (32)	19 healthy active males [9 control subjects, 10 experimental subjects (high intensity training group)] Age: "junior" university students	Elbow flexors	Isometric: 20 reps × 6-s MVC at 10° elbow flexion 3×/wk × 6 wk	Isometric elbow flexion	−2.7(−15 to 9.5)
Khouw and Herbert (29)	33 females and 18 males† Age range: 18–35 yr	Elbow flexors	Isometric: 6 reps × 10 s at elbow angle of 140° 3×/wk × 6 wk	Isometric elbow flexion	4.0(−6.7 to 14.7)
Shaver (37)	40 healthy males (20 control subjects, 20 experimental subjects) Age range: 18–20 yr	Elbow flexors	Dynamic: 1 set × 10 reps at 50% of 10 RM + 1 set × 10 reps at 75% of 10 RM + 10 RM × 1 set (progressive) 3×/wk × 6 wk	Isometric elbow flexion	6.5(−3.2 to 16.2)
Shaver (36)	100 healthy males (20 control subjects, 80 experimental subjects) Age range: 18–22 yr	Elbow flexors	Dynamic: 10 reps × 1 set at 50% of 10 RM + 10 reps × 1 set at 75% of 10 RM + 10 RM × 1 set (progressive) 3×/wk × 6 wk	Isometric elbow flexion	9.0(4.4–13.6)
Yue and Cole (44)	20 healthy subjects (10 control subjects, 10 experimental subjects) Age range: 21–29 yr	5th digit abductors (finger)	Isometric: 15 reps × 10-s MVC 5×/wk × 4 wk	Isometric abduction 5th digit	12.1(−11.7 to 35.9)
Shima et al. (38)	15 healthy active males (6 control subjects, 9 experimental subjects) Age (mean ± SD): 26.2±4.6 yr	Ankle plantarflexors	Dynamic: (single leg calf raises and plantarflexion against foot plate) 10–12 reps × 3 sets at (70–75% of 1 RM) for each exercise 4×/wk × 6 wk	Isometric plantarflexion	4.0(−9.8 to 17.8)

(Munn *et al.,* 2004 p. 1864)

Using the data from the 13 pooled studies a 7.8% increase for contralateral strength was recorded with a range of -3% to 22%. This was compared with the initial strength of the contralateral limb representing 35% of the strength gains observed for the ipsilateral limb (Munn *et al.,* 2004). As Table 1.1

shows, both upper and lower limb interventions were included along with isometric and dynamic testing protocols. The main muscle groups tested were the knee extensors and elbow flexors. The meta-analysis provided no evidence to suggest the cross-education effects were dependent on these factors (Munn *et al.,* 2004).

The increases in contralateral strength are not normally associated with any increase in muscle girth (Munn *et al.,* 2005; Rasch and Morehouse, 1957; Houston, Froese and Valeriote, 1983 in Munn, Herberty and Gandevia, 2004). In support of this, Munn *et al.* (2005) found no changes in the circumference of contralateral untrained upper arm elbow flexors following 18 sessions of unilateral strength training over a period of six to seven weeks. The muscle circumference measures used by Munn *et al.* (2005) may have been a limitation in comparison to more sensitive measures such as ultrasound, computer tomography, magnetic resonance imaging or muscle biopsy (Farthing and Chilibeck, 2003; Garfinkel and Cafarelli, 1992; Housch *et al.,* 1996; Narici *et al.,* 1989; Houston *et al.,* 1983 in Munn *et al.* 2005 p. 1883). The lack of reported morphological changes mean proposed strength adaptations may be neurological in origin (Gabriel, Kamen and Frist*,* 2006).

Munn *et al.* (2005) also found that contralateral strength gains were related to the magnitude of strength gained in the trained limb. This was a highly significant relationship along with a contralateral strength increase of 7%. Contralateral increases in motor excitability have been shown to be larger when it is the dominant limb that is trained unilaterally (Cernacek, 1961 in

Hendy, Spittle and Kidgell, 2011 p.3). This theory is well supported and is proposed to be a result of adaptations to the cortical mechanisms (Imamizu and Shimojo, 1995, Parlow and Kinsbourne, 1989, Stoddard and Vaid, 1996 in Farthing, 2009 p. 178; Farthing, 2009). The magnitude of cross-education adaptations have been shown to be the greatest when the dominant limb is the most proficient and the task is complex thus requiring a high level of motor control. However, if a simple strength or training task is novel it may still elicit similar effects. A dominant limb that is more proficient for a task and subsequently becomes more proficient still has a chance of enhancing processes at the motor planning level, command level, peripheral muscle level and can improve force generation which can increase the possibility of cross-education adaptations. It should be noted that most research in this area is derived from upper limb data so whilst the general principles can be applied to the lower limb further research is required (Farthing, 2009). Whilst conceptual models can propose particular motor tasks will lead to a greater transfer of skill or strength they do not identify the exact processes of neural control (Farthing, 2009).

Training speed is thought to influence the magnitude of the strength adaptations for a trained limb (Farthing and Chilibeck 2003, Paddon-Jones *et al.,* 2001 in Munn *et al.,* p. 1880). Speed of contraction has been shown to be a potential factor in relation to cross-education with higher speed training leading to a non-significant ~5% trend overall in strength increases for the contralateral limb. An 11% increase was observed for arm muscles compared with those training at lower speeds (Munn *et al.,* 2005). This trend for favourable results during higher speed training may be related to the increased magnitude of strength gained when training at higher speeds (Munn *et al.,* 2005 in Munn *et al.,* 2005 p. 1883). Magnitude of strength in the trained limb has been shown to relate significantly to the strength gains in the contralateral limb (Zhou, 2000 in Munn *et al.,* 2005 p. 1882).

1.2.2 Mechanisms

There is some contention regarding underlying mechanisms of cross-education. One suggestion is that effects for the contralateral limb occur at a cortical level and activate the ipsilateral and contralateral sensorimotor cortex which may be influenced by changes at spinal and supraspinal levels (Munn *et al.,* 2005).

Benjamin *et al.* (2000) used 20 subjects and an eight week cross-education intervention performed three times a week for the ankle and found a cross transfer effect of 19% for the eccentric inversion of the ankle. Three mechanistic theories were suggested for these effects: 1) enhancement of neuromuscular facilitation; 2) reduction of central inhibitory impulses to the untrained limb; and 3) undetectable isometric contractions of the untrained limb during strength training (Benjamin *et al.,* 2000 p. 572). Komi *et al.* 1978 in Benjamin *et al.* (2000 p. 572) found that motor recruitment was improved in both the trained and untrained limb following 12 weeks isometric training. Ikai and Steinhaus 1961 in Benjamin *et al.* (2000 p. 572) identified a reduction in central inhibition as a possible mechanism for cross-education in their study investigating forearm flexor strength. Hellebrandt *et al.* 1947 in

Benjamin *et al.* (2000 p. 572) identified that non-exercising symmetric muscles of a trained limb produced a powerful isometric tension. In support of this, neuromuscular facilitation has been proposed by Kannus *et al.* (1992) as the primary mechanism suggesting that the untrained limb adapts much the same as the trained limb during the first eight weeks of training. Other factors that could influence contralateral strength gains may be hypnotic gains and increases in isometric tension whilst the ipsilateral limb is trained. Such increases in tension have been shown to be as high as 20% (Komi *et al.,* 1978 in Kannus *et al.,* 1992). It may be possible that this could lead to a greater level of activation at the muscle site as a result of reduced inhibitory input to the active alpha motor neurons and increased receptor activation at a superficial level (Komi *et al.,* 1978 in Kannus *et al.,* 1992; Gabriel *et al.,* 2006).

There are two main categories that explain cross-limb transfer. The first suggests that motor engrams related to practice reside at a central nervous site that can also be accessed by the opposing limb. This is known at the ‘Bilateral Access Hypothesis’ within which the ‘Callosal Access Hypothesis’ falls proposing that the opposite hemisphere is allowed access to motor engrams developed in the dominant hemisphere via the corpus callosum which enhances task performance in the untrained limb (see figure 1.1) (Taylor & Heilman, 1980 in Lee *et al.,* 2010 p. 202). The site of adaptation is represented by the ‘X’. The cortical or sub-cortical motor areas are represented by the shaded circle and MCx means motor cortex.

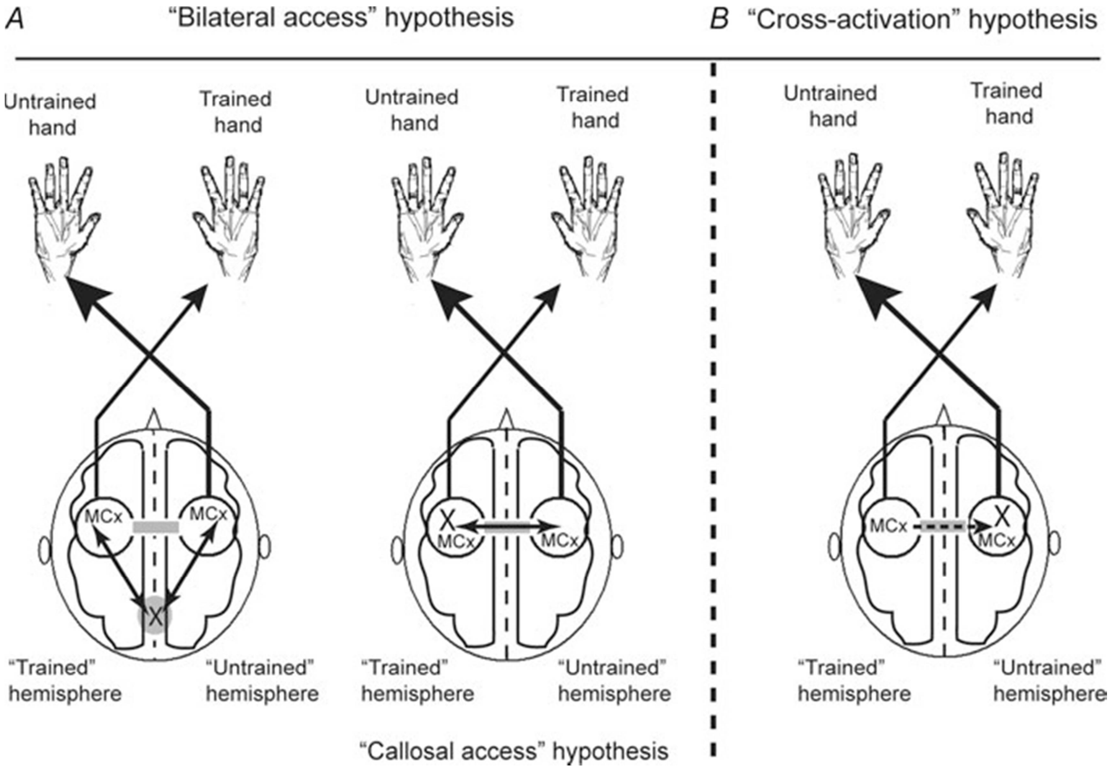


Figure 1.1 A schematic representation of the two main classes of mechanism that could underpin cross-limb transfer of motor skill.
(Lee *et al.,* 2010 p. 202)

The second category is known as the 'Cross-activation Hypothesis' which describes the effect of unilateral training which causes motor circuit adaptations for the opposing homologous muscles (see figure 1.1) (Davis, 1898; Hellebrandt, 1951; Parlow and Kinsbourne, 1989 in Lee *et al.,* 2010 p. 202).

Lee *et al.* (2010) used electromyographic (EMG) measures to investigate electrical activity at the first dorsal interosseus and abductor digiti minimi. They also used trans-cranial magnetic stimulation to provide a measure of motor evoked potentials (MEP). Figure 1.2 shows the raw data following finger acceleration.

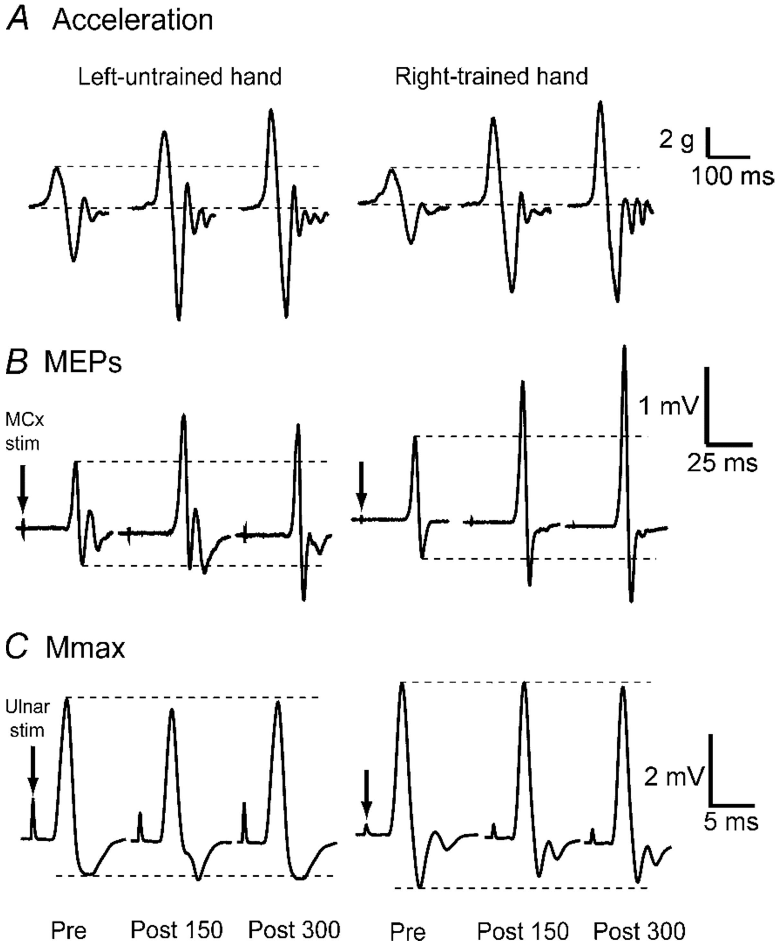


Figure 1.2 Examples of raw records of index finger acceleration.

(Lee *et al.,* 2010 p. 206)

These results showed that practice of a ballistic finger abduction task for the right hand gave rise to significant improvement in the untrained and via enhanced MEP ($P < 0.01$) and acceleration ($P < 0.001$). A bilateral increase in corticospinal excitability was also observed. These findings are consistent with the 'Cross-activation Hypothesis' but do not address whether there is a contribution from the untrained motor cortex in relation to the retention of long-term ballistic gains. However, this study does show that high-force tasks can lead to bilateral cortical adaptations (Lee *et al.,* 2010; Hess *et al.* 1986; Stedman *et al.* 1998; Tinazzi & Zanette, 1998; Muellbacher *et al.* 2000a; Stinear *et al.* 2001; Hortobagyi *et al.* 2003; Perez & Cohen, 2008 in Lee *et al.,* 2010 p. 202). The force of contraction has been shown to affect the magnitude of cross cortical effects which helps support the ‘Cross Activation Hypothesis’ and suggests that a strong descending drive is preferable for a simple task (Kawashima *et al.,* 1994, Dettmers *et al.,* 1995, Cramer *et al.,* 1999, Lee *et al.,* 2003, Koeneke *et al.,* 2006, Hess *et al.,* 1986, Stedman *et al.,* 1998, Tinazzi & Zanette, 1998, Muellbacher *et al.,* 2000a, Stinear *et al.,* 2001, Hortobagyi *et al.,* 2003; Perez and Cohen, 2008 in Lee *et al.,* 2010 p. 202).

In section 1.2.1 leg dominance was identified as a factor relating to the amplitude of cross-education effect. Motor irradiation may be the mechanism responsible for this finding (Carson, 2005, Hortobagyi *et al.,* 2010, Strens *et al.,* 2003, Perez and Cohen, 2008 in Hendy, Spittle and Kidgell, 2011 p.3). Motor irradiation (see figure 1.3) can be measured using transcranial magnetic stimulation which measures adaptations within the pathways for the cortico-spine. The solid black line shows the pathway for the intended motor output and the dotted line shows the unintended. Interhemispheric communication between the right and left motor cortex via the corpus callosum occurs at ‘a’ and fibres of the ipsilateral corticospine that do not cross at the medulla are represented by ‘b’ (Hendy, Spittle and Kidgell, 2011 p.3). The peak to peak amplitude of the motor evoked potential shows how many descending synapses reach the muscle in question. This represents corticospinal excitability (Hallett, 2000 in Hendy, Spittle and Kidgell, 2011 p.3). Whilst this form of measurement demonstrates direct evidence for motor irradiation, it does not help determine precise sites within the nervous system (Hendy, Spittle and Kidgell, 2011).

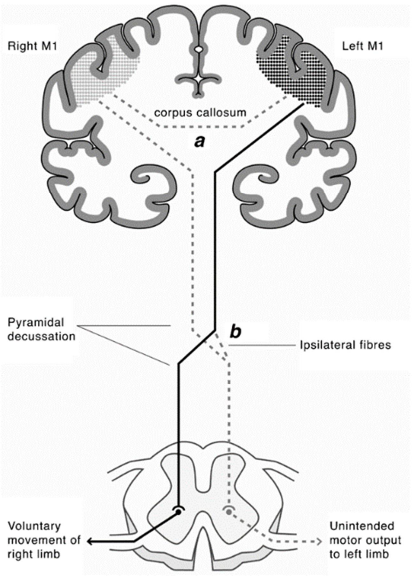


Figure 1.3 Visual representation of motor irradiation.

(Hendy, Spittle and Kidgell, 2011 p.3)

Similarities can be drawn with the cross-education gains observed for skill and strength (Farthing, Chilibeck and Binstead, 2005; Farthing, 2009 in Hendy, Spittle and Kidgell, 2011 p.3). These gains as a result of cross-education have been shown to occur at multiple sites across the central nervous system (CNS) (Carroll *et al.,* 2006; Hortogbagyi 2005; Farthing, Chilibeck and Binstead, 2005; Farthing, 2009; Munn, Herbert and Gandevia, 2004 in Hendy, Spittle and Kidgell, 2011 p.2). Figure 1.4 shows activation at regions of the primary motor cortex (M1), supplementary motor area and premotor cortex are similar between motor learning and strength training studies (Karni *et al.,* 1995; Muellbacher *et al.,* 2002; Pascual-Leone, Grafman and Hallet, 1994; Perez *et al.,* 2007 in Farthing 2009 p. 182; Hortobagyi *et al.,* 2009 in Farthing 2009 p. 183).

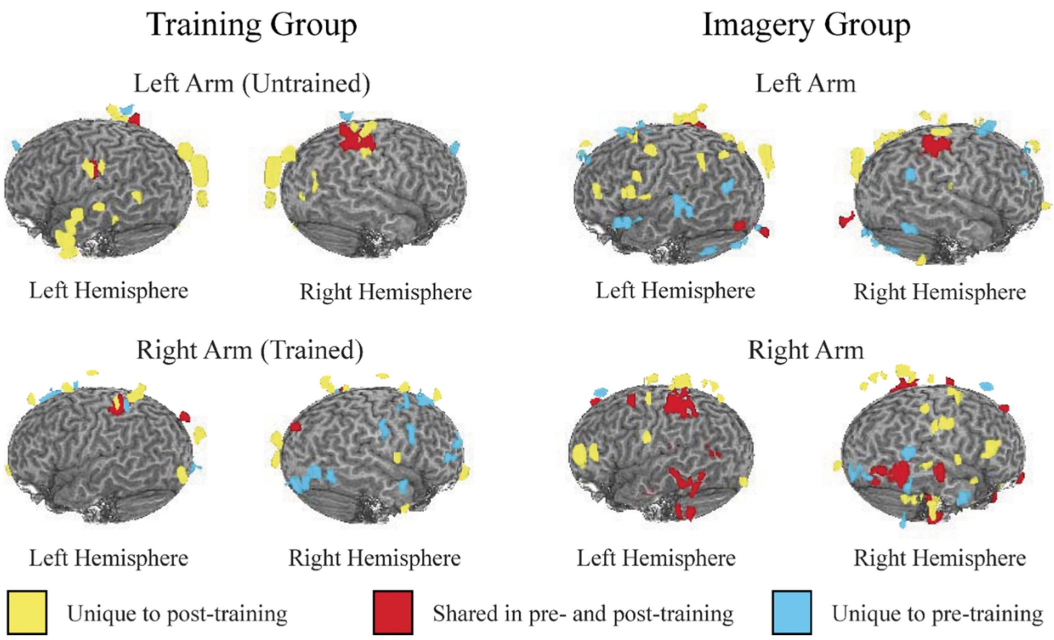


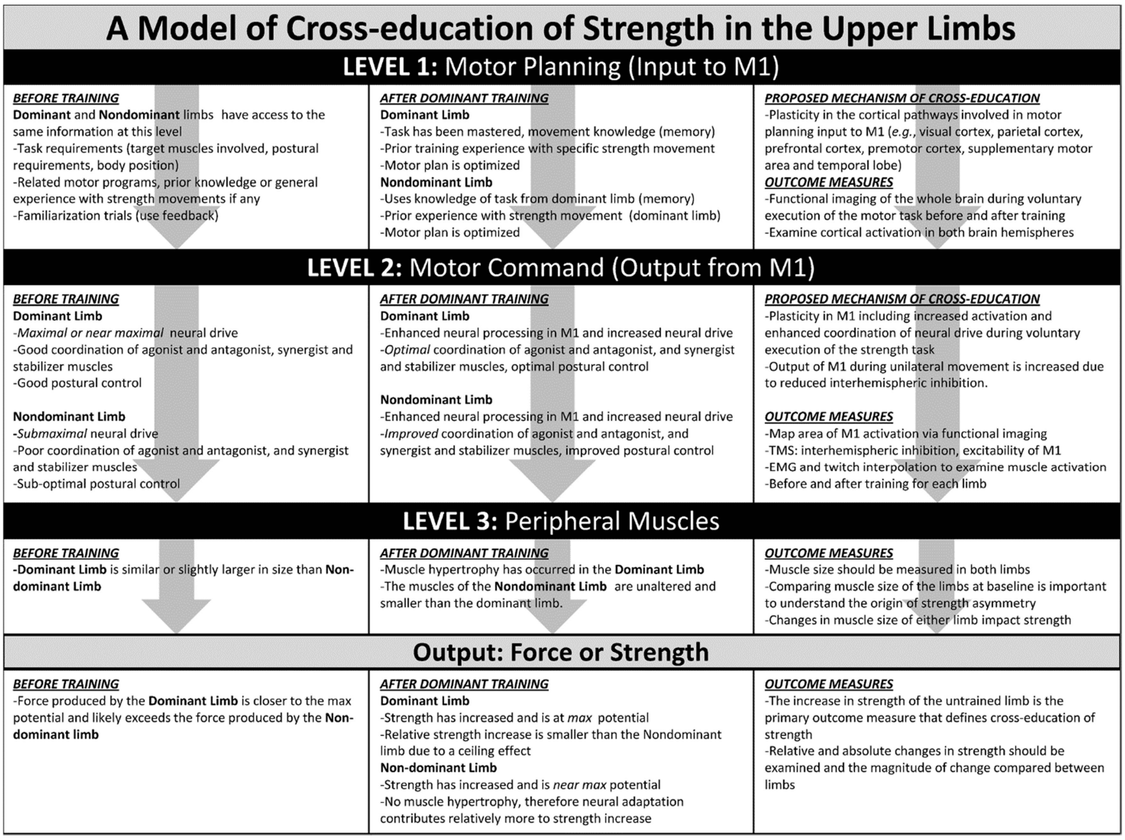
Figure 1.4 Changes in brain activation as demonstrated by functional magnetic resonance imaging during unilateral contraction before and after strength training of the right arm.

(Farthing, 2009 p. 182)

In support of the morphological changes that have recently been proposed in relation to cross-education, Farthing *et al.* (2011) used functional magnetic resonance imaging for an immobilisation cross-education study, which showed enhanced motor cortex activity in addition to maintenance of strength, measured using an isometric handgrip dynamometer. This study also reported some positive morphological differences for the unilateral training / immobilised group. Farthing *et al.* (2011) measured changes to muscle thickness using B-Mode ultrasound which is a small portable linear/convex sector ultrasound scanner providing a two dimensional tomographic image of a scanning plane. Farthing *et al.* (2011) observed that muscle thickness was retained compared with the non-training group that were also immobilised using a cast and contralateral isometric hand grip contractions five days a week over a three week period. The suggestion that unilateral training and low level activation may be able to reduce atrophy in an immobilised limb is an area that requires further research.

Pearce *et al.* (2012) demonstrated maintenance of corticospinal excitability, strength and muscle thickness using an immobilisation model that placed untrained healthy participants in arm slings and used a unilateral training intervention for the cross-education group. The output measures included one repetition maximum (1-RM) strength, isometric force, muscle thickness, transcranial magnetic stimulation and M-wave recording. This study did not identify precise corticospinal mechanisms but does provide further support to the previous immobilisation and rehabilitation related cross-education research.

Figure 1.5 uses previous models of skill acquisition and applies to cross-education in the context of strength gains by utilising evidence from transcranial magnetic stimulation studies (Farthing, 2009). The cortical mechanisms of Levels 1 (plasticity in the coritical pathways) and 2 (plasticity in neural processing of the motor cortex) are proposed to be the primary adaptation for cross-education strength gains with the greatest magnitude of changes occurring as a result of the dominant arm training. Level 3 relates to hypertrophic gains for the trained limb. No change in muscle size is predicted for the untrained contralateral limb supporting that cortical adaptations lead to cross-education strength gains.



A Model of Cross-education of Strength in the Upper Limbs

LEVEL 1: Motor Planning (Input to M1)

BEFORE TRAINING	***AFTER DOMINANT TRAINING***	***PROPOSED MECHANISM OF CROSS-EDUCATION***
Dominant and **Nondominant** limbs have access to the same information at this level -Task requirements (target muscles involved, postural requirements, body position) -Related motor programs, prior knowledge or general experience with strength movements if any -Familiarization trials (use feedback)	**Dominant Limb** -Task has been mastered, movement knowledge (memory) -Prior training experience with specific strength movement -Motor plan is optimized **Nondominant Limb** -Uses knowledge of task from dominant limb (memory) -Prior experience with strength movement (dominant limb) -Motor plan is optimized	-Plasticity in the cortical pathways involved in motor planning input to M1 (*e.g.*, visual cortex, parietal cortex, prefrontal cortex, premotor cortex, supplementary motor area and temporal lobe) ***OUTCOME MEASURES*** -Functional imaging of the whole brain during voluntary execution of the motor task before and after training -Examine cortical activation in both brain hemispheres

LEVEL 2: Motor Command (Output from M1)

BEFORE TRAINING	***AFTER DOMINANT TRAINING***	***PROPOSED MECHANISM OF CROSS-EDUCATION***
Dominant Limb -*Maximal or near maximal* neural drive -Good coordination of agonist and antagonist, synergist and stabilizer muscles -Good postural control **Nondominant Limb** -*Submaximal* neural drive -Poor coordination of agonist and antagonist, and synergist and stabilizer muscles -Sub-optimal postural control	**Dominant Limb** -Enhanced neural processing in M1 and increased neural drive -*Optimal* coordination of agonist and antagonist, and synergist and stabilizer muscles, optimal postural control **Nondominant Limb** -Enhanced neural processing in M1 and increased neural drive -*Improved* coordination of agonist and antagonist, and synergist and stabilizer muscles, improved postural control	-Plasticity in M1 including increased activation and enhanced coordination of neural drive during voluntary execution of the strength task -Output of M1 during unilateral movement is increased due to reduced interhemispheric inhibition. ***OUTCOME MEASURES*** -Map area of M1 activation via functional imaging -TMS: interhemispheric inhibition, excitability of M1 -EMG and twitch interpolation to examine muscle activation -Before and after training for each limb

LEVEL 3: Peripheral Muscles

BEFORE TRAINING	***AFTER DOMINANT TRAINING***	***OUTCOME MEASURES***
-Dominant Limb is similar or slightly larger in size than **Non-dominant Limb**	-Muscle hypertrophy has occurred in the **Dominant Limb** -The muscles of the **Nondominant Limb** are unaltered and smaller than the dominant limb.	-Muscle size should be measured in both limbs -Comparing muscle size of the limbs at baseline is important to understand the origin of strength asymmetry -Changes in muscle size of either limb impact strength

Output: Force or Strength

BEFORE TRAINING	***AFTER DOMINANT TRAINING***	***OUTCOME MEASURES***
-Force produced by the **Dominant Limb** is closer to the max potential and likely exceeds the force produced by the **Non-dominant limb**	**Dominant Limb** -Strength has increased and is at *max* potential -Relative strength increase is smaller than the Nondominant limb due to a ceiling effect **Non-dominant Limb** -Strength has increased and is *near max* potential -No muscle hypertrophy, therefore neural adaptation contributes relatively more to strength increase	-The increase in strength of the untrained limb is the primary outcome measure that defines cross-education of strength -Relative and absolute changes in strength should be examined and the magnitude of change compared between limbs

Figure 1.5 A theoretical model of cross-education of strength in the upper limbs after training the dominant limb.

(Farthing, 2009 p. 184)

Despite the theory of cross-education being well recognised within disciplines such as kinesiology, motor control and neurobiology, it is often seen merely as a trivial side effect to unilateral training in the field of rehabilitation

(Farthing and Zehr, 2014). Similarities have been proposed between the motor learning patterns related with skill transfer and cross-education (Lee and Carroll, 2007; Farthing, 2009) but the potential for functional gains offered by the effects of cross-education are still unknown (Munn *et al.,* 2005). The paucity of studies investigating cross-education in relation to rehabilitation may well be responsible for this but some of the most recent cross-education research has begun to explore this area using immobilisation interventions and discussing the relationship with injury (Magnus *et al.,* 2013; Farthing, 2009; Farthing, Chilibeck and Binsted, 2005; Hendy, Spittle and Kidgell, 2011). These studies have helped draw attention to the consequences of detraining effects associated with periods of injury and immobilisation.

1.2.3 Detraining

ACL rehabilitation programmes can be divided into conservative and accelerated approaches aiming to return the patient back to their sport within 9 to 12 months or within six months respectively (Shutte *et al.,* 1988 in Silva, Riberio and Oliveira, 2012 p. 140). Even with an accelerated programme fully weight bearing exercises utilising full active range of movement do not commence until approximately week 16 which are followed by sports specific power related exercises (Wilk *et al.,* 1999). Therefore, there are long periods of time where the affected lower limb has to remain under stimulated in order to respect the healing tissue including the revascularisation period for the reconstructed ligament, which has been shown to leave the graft at its weakest around week 8 (Alm and Stromberg, 1974, Clancy *et al.,* 1984 in

Wilk and Andrews, 1992 p. 287). Minimising the negative effects of immobilisation is a specific objective of these programmes (Wilk and Andrews, 1992).

Engstrom *et al.,* 1993; Patel *et al.,* 2003; Williams *et al.,* 2003 in Taggesson *et al.* (2008 p. 298) reported that muscle weakness continues to be a problem for patients following rehabilitation after ACL injury and it is generally agreed that patients will suffer a loss of strength in the quadriceps muscles (Eastlak, Axe and Snyder-Mackler, 1999, Keays *et al.,* 2003, Morrisey *et al.,* 2004, Noyse, Barber and Mangine, 1991, Snyder-Mackler *et al.,* 1995, Williams *et al.,* 2005 in Taggesson *et al.* 2008 p. 299). Therefore, measures should be taken where possible to address this dysfunction.

Losses in maximal voluntary forces can be 3% to 4% per day within one week of immobilisation (Appell, 1999 in Bruton p. 401). Unloading or immobilisation for periods of four weeks or less has been shown to cause significant decreases in strength. These changes may or may not be associated with loss in muscle mass suggesting that neural adaptations are a key factor in the early stages of detraining just as they may feature in early stages of strength training (Deschenes *et al.,* 2002; Hortobagyi *et al.,* 2000; Houston *et al.,* 1983 in Farthing, Krentz and Magnus, 2009 p. 830; Gabriel, Kamen and Frost, 2006). Housch *et al.* (1996) found that subjects retained 81% of training induced 1-RM for eccentric strength across an eight week period of detraining. In support of the neural component to this type of detraining, Berg, Larsson and Tesch (1997) found that rectified EMG decreased by 19% ±

23%. Whilst the majority of these losses can be attributed to atrophy (approximately 3% per week) which is in line with previous studies, the changes in EMG activity suggest a reduced tension and neural drive (Berg, Larsson and Tesch, 1997, Adams, Hather, and Dudley, 1994, Berg, Dudley, Haggmark, Ohlsen, and Tesch, 1991, Berry, Berry, and Manelfe, 1993 in Berg, Larsson and Tesch, 1997 p.185). Enoka 1988 in Bruton (2002 p. 403) suggested that whilst strength can be gained without morphological adaptations, it does not occur without neural changes.

Immobilising a limb has been shown to cause significant reductions in the size and strength of muscle. In a period of five to six weeks strength loss has been shown to be as high as 60% (Booth, 1987; Appell, 1990; Fuglsang-Frederiksen & Scheel, 1978; Wigerstad-Lossing *et al.,* 1988 in Thom *et al.,* 2001 p. 141). In addition to reduced neural drive, morphological changes can be expected. Glover *et al.* (2010) found a 6% decrease in cross sectional area for the mid-thigh following a 14 day immobilisation model. At two days they also reported an up regulation of ubiquinated proteins (Berg *et al.,* 1997 in Bruton, 2002 p.401).

Studies investigating the effects of 4 to 12 weeks detraining following heavy periods of resistance training have shown reductions in strength performance of 7% to 12% for 1-RM squats (Hakkinen, Alen and Komi, 1985, Hakkinen and Komi, 1983, Hakkinen, Komi and Alen, 1985, Hakkinen, Komi and Tesch, 1981, in Izquierdo *et al.,* 2007 p. 773). Aspects of power for strength-trained athletes appear to be lost at a greater rate than strength during periods of inactivity (Izquierdo *et al.,* 2007). This may be related to specific type II muscle fibre atrophy (Hortobagy *et al.,* 1993, Staron *et al.,* 1991 in Izquierdo *et al.,* 2007 p. 773) and reductions in neural drive (Andersen *et al.,* 2005, Hakkinnen, Alen and Komi, 1985, Hakkinen and Komi, 1983, Hakkinen, Komi and Tesch, 1981 in Izquierdo *et al.,* 2007 p. 773).

Immobilisation has been shown to reduce motor performance (Clark *et al.,* 2008) and can be responsible for up to 50% of the loss of strength following the unweighting of limbs (Clark *et al.,* 2006 in Clark *et al.,* 2008 p. 868). Studies have reported reduced firing rates and coupling between motor cortext and spinal motorneurone activity in relation to one week of immobilisation (Seki *et al.,* 2007, Lundbye-Jensen and Nielsen, 2008 in Clark *et al.,* 2008 p.868). However, the neural mechanisms responsible are poorly understood (Deschenes *et al.,* 2002 in Clark *et al.,* 2008 p. 868). Conversely, some studies have reported an increase in corticospinal excitability following periods of joint immobilisation (Clark *et al.,* 2008; Roberts *et al.,* 2007, Zanettee *et al.,* 2004 in Leukel *et al.,* 2014 p. 137). There are numerous potential mechanisms for an increased excitability post-immobilisation including a change in the motor map area or an increase in projection area excitability.

Otzel, Chow and Tillman (2015) found ACL reconstructed legs demonstrated isokinetic knee-extensor deficits of 6% to 9% compared to their uninvolved limbs. Previous studies have found greater differences of between 10% and 27% (Rosenberg *et al.,* 1992, Kobayashi *et al.,* 2004, Wilk *et al.,* 1994 in

Otzel, Chow and Tillman, 2015, p.25). Otzel, Chow and Tillman (2015) and also showed a significant decrease in central activation ratio for the involved limb. This can be an indication of neural drive inhibition (Hunter *et al.,* 1998 in Otzel, Chow and Tillman, 2015 p. 26). Rehabilitation has been shown to restore alpha and gamma-motoneuron excitability and this can also aid the enhancement of proprioceptive function (Hurley, 1997, Risberg *et al.,* 2007 in Otzel, Chow and Tillman, 2015 p.26).

1.2.4 Cross-education and rehabilitation

Previous cross-education studies have been limited by the failure to simulate functional training and testing modes making it difficult to relate their findings to rehabilitation (Kannus *et al.,* 1992). Munn *et al.* (2005) investigated training at higher speeds but found a non-significant increase in strength gains for the contralateral limb. Studies have begun to place a focus on the rehabilitation implications of cross-education effects and have demonstrated some interesting findings. Farthing, Krentz and Magnus (2009) showed a reduction in atrophy during a period of immobilisation, which was the first evidence to support any kind of potential morphological relationship with cross education (see figure 1.6). Farthing Krentz and Magnus (2009) hypothesise that these negative effects could be addressed during a period of detraining by creating adaptations in the untrained contralateral limb as a result of unilateral training using cross-education.

Farthing, Krentz and Magnus (2009) used a three week immobilisation model to investigate the effects of cross-education on isometric ulnar deviation peak torque, electrical activity and muscle thickness measured by isokinetic dynamometry, EMG and ultrasound respectively. Fibreglass casts were applied to the experimental group. Each group completed a progressive isometric training programme with their dominant limb 5 days per week. Strength was improved by 24% for the trained arm of the Cast-Train group and no significant difference was found for strength changes to the opposite casted arm (2%). In comparison, a significant -15% decrease in strength was observed for the Casted group whom did not receive the unilateral training (see figure 1.6).

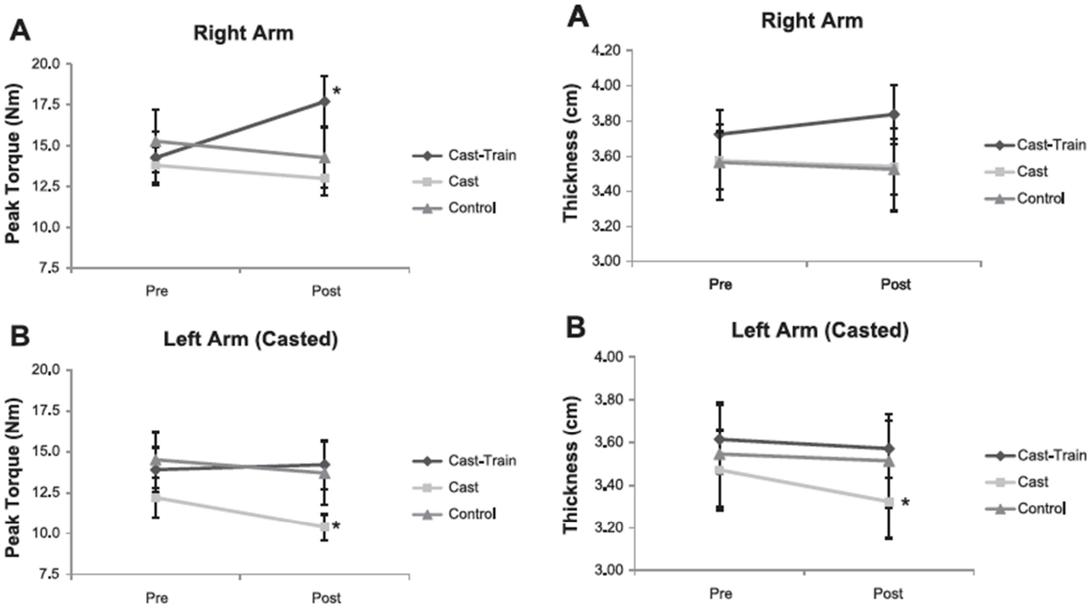


Figure 1.6 Right and left arms for Cast-Train, Cast and control groups for the variables of peak torque and muscle thickness.

(Farthing, Krentz and Magnus, 2009 p. 832-833)

This therefore suggests that strength loss may be successfully attenuated during a period of immobilisation if unilateral training of the unaffected limb is conducted. This study, along with the work of Magnus *et al.* (2010) and Farthing *et al.* (2011), are the only investigations to demonstrate such a direct link to an immobilisation model via the use of healthy subjects. No significant difference was found for muscle thickness for the Cast-Train group (-1%) in comparison to a significant decrease of -4% for the Casted group arm of whom did not conduct any training (see figure 1.6). This was the first support that suggests atrophy may be minimised through the use of unilateral training. There were no significant interaction effects seen between the groups for muscle activation during maximal isometric contraction following a conversion of raw EMG signals into the mean absolute value. It was suggested that this might be due to the brief intervention period. These findings have clinical implications but further research is needed before specific recommendations in relation rehabilitation can be made. It should also be noted that the cellular environment of this immobilisation design would differ considerably to that of injured tissue due to the associated metabolic disturbances that occur throughout the acute inflammatory, proliferative and remodelling phases (Kannus, 2000). These include but are not limited to ischemia, infiltrations of inflammatory cells, fibrin exudation, fibroblastic proliferation and decreased proteoglycan-water content (Kannus, 2000).

Magnus *et al.* (2010) used a similar immobilisation design to Farthing, Krentz and Magnus (2009). Magnus *et al.* (2010) used a shoulder sling and swathe to immobilise the non-dominant limb, which was accompanied by a four week training programme for the right limb. The dependent variables were isometric strength, muscle thickness and maximal voluntary contraction measured as indicated by interpolated twitch via EMG. A beneficial effect on muscle thickness was demonstrated for the immobilised limb of the Training group, 2% for biceps brachii and 3% for triceps brachii. The Immobilised group, however, showed respective decreases in muscle thickness of -3% and -5%. This supports the findings of Farthing, Krentz and Magnus (2009) by suggesting that loss of muscle thickness may be attenuated by the effects of cross-education. There were minimal levels of muscle activation for the immobilised limb during training of the contralateral limb, which suggests that isometric tension was not a significant limiting factor. It should be noted that these findings were non-significant in comparison to the control group which means caution should be applied when considering the practical implications (Magnus *et al.,* 2010). There were no significant effects observed for the maximal voluntary activation or strength gains for the immobilised limb during this study.

Farthing *et al.* (2011) used an immobilisation model incorporating, circular cast and hand grip strength training with dependent measures of muscle thickness, isometric strength, EMG and functional magnetic resonance imaging activity. Handgrip strength of the immobilised limb of the training group demonstrated a maintenance of strength (1% gain) and increased volume of activation. Conversely, an 11% decrease in strength was seen for the non-training immobilised group, which was associated with no contralateral motor cortex activation changes. These changes were not a result of changes to muscle size, which showed an average 3% decrease for the immobilised limb.

More recently the latest studies have been incorporating genuine injury and immobilisation designs (Papandreou *et al.,* 2013; Magnus *et al.*, 2013). No established ACL programmes recommend utilising the proposed benefits of cross-education as part of rehabilitation (Papandreou *et al.,* 2013). Papandreou *et al.* (2013) was the first of its kind to investigate the effects of cross-education in relation to ACL reconstruction. Using 42 ACL reconstructed participants from the Greek army, the study compared two cross-education groups comprising of sub-maximal (80% of 1-RM) eccentric exercises using a 1-RM knee extension to flexion movement applied via an isokinetic dynamometer at two different frequencies (3 and 5 days per week) with a standard rehabilitation programme which used a 5 days per week frequency. The study measured quadriceps strength and quadriceps strength deficit over an eight week period that coincided with the revascularisation period for ACL graft. A decrease in quadriceps strength across the groups for the injured knee of 16 ± 25% for Group A (3 days per week) and 6 ± 26% for Group B (5 days per week) was observed for the cross-education groups and 38 ± 17% for Group C (control group). Quadriceps deficit between the uninjured and injured knees was shown to be smaller for the two experimental groups compared with the control, Group A: 28 ± 24% and Group B: 30 ± 21% compared to the control group 53 ± 24%. There were numerous limitations with this study including strength measures that were specific to 60° of knee flexion, use of a non-progressive exercise programme and no control for leg dominance. Furthermore, wider clinical application of the Papandreou *et al.* (2013) findings may be limited by the potential need for an isokinetic dynamometer and represent a need for further research investigating cross-education in relation to lower limb rehabilitation.

A study by Magnus *et al.* (2013) is believed to be the first randomly controlled trial investigating cross-education in a clinical setting using real immobilisation modalities. The study used injured subjects who were recovering from fractures to their distal radius. A progressive 12 week strength training intervention for the uninjured limb led to improved strength and range of motion (at week 12, see figure 1.7) for the immobilised and, initially, fractured limb. The training group demonstrated a 34% increase in strength compared with 4% for the control group between weeks 9 and 12. The average transfer of strength in cross-education studies has been shown to be 52% (Carroll *et al.,* 2006 in Magnus *et al.,* 2013 p. 1252). The range of movement for the same period was a 2% decrease for the control group and a 29% increase for the training group. These findings help to highlight a new direction for cross-education research that may be of greater relevance to a rehabilitative setting (see figure 1.7 and 1.8).

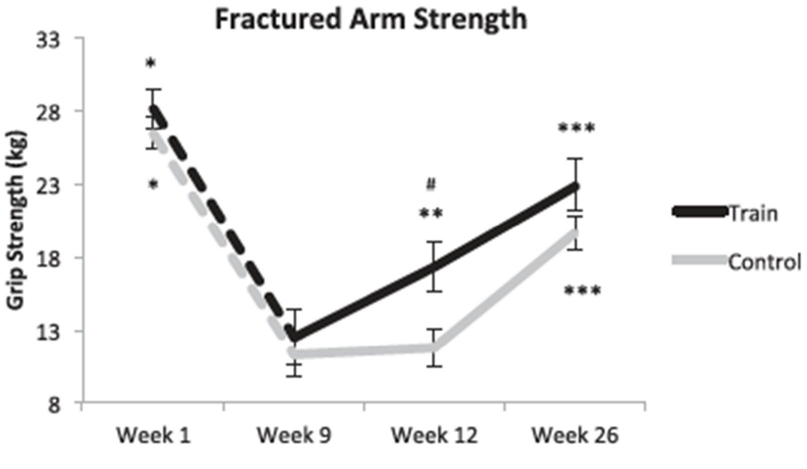


Figure 1.7 Fractured limb handgrip strength (mean ± SD).

(Magnus *et al.* 2013 p. 1252-1253)

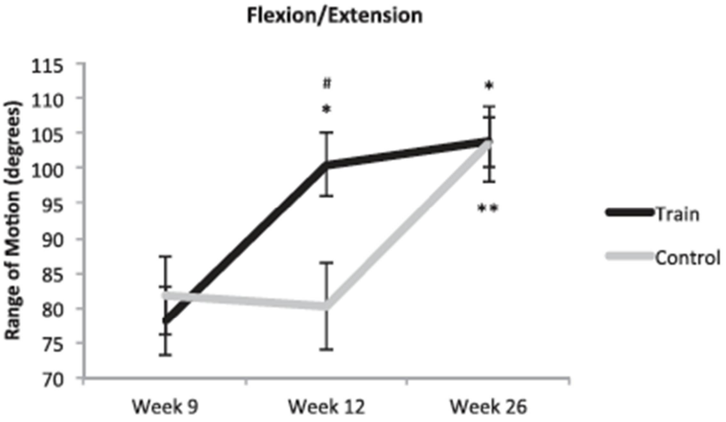


Figure 1.8 Flexion/extension ROM for fractured hand only (mean ± SD).

(Magnus *et al.* 2013 p. 1252-1253)

This study used a female population > 50 years old which means that findings may not be widely transferable to different age groups, an athletic population or males. Further limitations include that the intervention was unsupervised and surgical processes were not considered.

Positive relationships between cross-education and rehabilitation are clearly being established but there is a lack of research investigating functional methods of training and performance specific output measures. Furthermore, the majority of rehabilitation related cross-education research focuses on the upper limb.

Populations that could benefit from the potential clinical implications of cross-education related benefits such as maintenance of strength and function during periods of immobilisation include athletes, stroke patients, the elderly and employees especially those whose work commands a high physical demand (Stevenson *et al.,* 2003, Sattin *et al.,* 1990 and Leigh *et al.*, 1999 in

Hendy, Spittle and Kidgell, 2011 p. 5; Farthing, 2009). Characteristics of strength and conditioning and rehabilitation may be of potential use to help deliver cross-education benefits. For example, neuromuscular strength training (Silvers and Mandlebaum, 2011), which includes rehabilitation aspects such as proprioception (Weber *et al.,* 2012), and core strength (Borghuis, 2008) offer the chance to significantly influence the biomechanics of the athlete (Silvers and Mandlebaum, 2011). The Performance Enhancement Programme (PEP) and F-Marc's FIFA 11+ are recent examples of such approaches (Silvers and Mandlebaum, 2007; FIFA, 2014).

Until recently, cross-education studies had focused primarily on training adaptations but studies are now beginning to include specific aspects of rehabilitation (Farthing, Krentz and Magnus, 2009; Magnus *et al.,* 2010; Farthing *et al.,* 2011; Papandreou *et al.,* 2013; Magnus *et al.*, 2013).

1.3 Characteristics of rehabilitation

1.3.1 Risk factors during ACL rehabilitation

An expert consensus group met in Santa Monica in 1999 and identified the four main risk factors for non-contact ACL ruptures as anatomy, hormones, environment and biomechanical/neuromuscular (Silvers and Mandlebaum, 2007). Neuromuscular prevention strategies have remained a relevant topic in an effort to address the key biomechanical dysfunctions that have been shown to increase the risk of ACL injuries (Silvers and Mandelbaum, 2011). These include dynamic joint stability and associated feedback and feedforward mechanisms, muscular strength and recruitment patterns, quadriceps to hamstring ratios, hip and knee flexion on landing, hamstring activation during squats, increased tibial rotation and associated knee valgus and loading of the joint (Silvers and Mandlebaum, 2007).

1.3.2 Strength and power training

Hypertrophic adaptations in response to resistance strength training are well established (Jones *et al.,* 2013; Murton and Greenhaff, 2013; Scott *et al.,* 2002, Pette and Staron, 1997 in Bruton, 2002 p. 398; Seynnes, de Boer and Narici, 2006; Fisher and Steele, 2013; Toigo and Boutellier, 2006 in Schoenfeld, 2010 p. 2858; Zou *et al.,* 1985 in Schoenfeld, 2013 p. 2; Kraemer and Ratamess, 2000 in Kraemer and Ratamess, 2005 p. 340). Muscle mass has been shown to increase significantly following strength training resulting in a greater proportion of type IIa fibres and a concomitant decline in type IIx fibres (Adams *et al.,* 1993, Anderson and Aagaard, 2000, Jones *et al.,* 1989 in Zaras *et al.,* 2013 p. 130). However, initial changes have been shown to be predominantly neural with clear changes to muscle mass not taking place until weeks 3-5 of training despite significant gains in strength (Akima *et al.,* 1999; Mortiani and deVries, 1979). These early changes in strength lead to the hypothesis that neural adaptations may be a key factor. Neural drive, which could be central or peripheral, has been shown via investigations using surface electromyography (sEMG) to be enhanced by strength training (Gabriel, Kamen and Frost, 2006). This includes enhanced motor unit activation, firing rate, synchronisation and doublet firing (Gabriel, Kamen and Frost, 2006). Stimulation of multiple motor units has been termed ‘motor synchronisation’ and may lead to enhanced force production. However, the validity of the sEMG techniques of the study has been questioned (Yue *et al.,* 1995 in Gabriel *et al.,* p. 137). Semmler and Nordstrom (1998) reported increased motor synchronisation for untrained participants, musicians and athletes respectively. If rate of force development (RFD) or speed of contraction is high then it may lead to ‘doublet firing’ which can be described as an alteration to the pattern of motor firing by way of a ‘short interspike interval in a motor unit train’ (Gabriel *et al.,* 2006 p. 136).

Studies have also shown that age influences the changes in 1-RM strength during both strength training and detraining but gender does not (Lemmer *et al.,* 2000). Interventions with durations of approximately eight weeks have been shown to be long enough to elicit training adaptations (Housch *et al.,* 1996; Benjamin *et al.,* 2000; Kannus *et al.,* 1992) and it is recommended that studies should incorporate resistance training that uses at least 50% of maximal voluntary strength to elicit strength adaptations (American College of Sports Medicine, 2002 in Munn *et al.,* 2004 p.1861). Participant supervision, exercise progression monitoring and periodisation are key factors and standardised verbal encouragement and feedback are also important (Munn *et al.,* 2003; Baechle and Earle, 2000). Munn *et al.* (2003) support this by highlighting the value of repeated testing and elimination of subject-perceived submaximal efforts.

Power is the result of force and velocity (Judge, 2007, Kawamori *et al.,* 2004 in Zaras *et al.,* 2013 p. 130) which is determined by the composition of the fibre type, the muscle mass and the number of motor units activated during a specific movement (Moritani, 2002 in Zaras *et al.,* 2013 p. 130). Ballistic training has been shown to produce significant increases in force and power (Newton *et al.,* 1996, Cormie *et al.,* 2011 in Zaras *et al.,* 2013 p. 130).

There is well established evidence, to support the benefits of functional and sport specific training such as plyometrics and power-based training modalities (Markovic *et al.,* 2007) which can also be used prophylactically to help prevent ACL injuries (Mandlebaum *et al.,* 2005). It is widely agreed that these methods enhance 'explosive' athletic performance (Markovic *et al.,* 2007). However, the aggressive nature of such exercises means that their implementation as part of a functional unilateral cross-education programme must be considered carefully so as not to risk damaging the recovering contralateral limb. It may mean that these exercises would not be able to commence until at least the intermediate phase of rehabilitation when the injured leg is able to weight bear in case the limb is needed to maintain balance (Prentice, 2011).

Plyometric exercises have long been recognised as a beneficial way to create power related adaptations and include exercises such as vertical jumps (Reilly, 1977) and are defined as a rapid eccentric stretch followed by a maximal concentric contraction by utilising the stretch shortening cycle (Crowther *et al.,* 2007; Wadden *et al.,* 2012). It has been proposed that this type of exercise works using 3 main mechanisms;

1) Mechanical – this refers to the storage of elastic energy within the series elastic component, a non-contractile component of the muscle that allows this energy storage whilst muscle filaments from the contractile component of the muscle lengthen. The time, velocity and magnitude of the movement are all relevant. The pre-stretch must be short and the size of the stretch large and executed quickly. Fast twitch muscle fibres have been shown to respond best to this type of activation (Bosco and Komi, 1979 in Prentice, 2011 p. 227; Bosco *et al.,* 1987 in Prentice, 2011 p. 227). Gender differences have been observed for the function of the stretch shortening cycle (SSC) ability with females displaying 64% compared with males (Villarreal, Requena and Newton, 2010). This may be related to female dominance in Type I muscle fibres (Staron *et al.,* 2000 Villarreal, Requena and Newton, 2010 p. 519), differences in the level of nervous system inhibition for females and gender specific differences in morphology including pennation angles and muscle fascicle length (Dudley *et al.,* 1990 in Villarreal, Requena and Newton, 2010 p. 519).

2) Neurophysiological – Muscle spindles which are orientated in a parallel fashion are incapable of detecting forces but are activated by the stretch of a muscle (Macefield, 2005), receive a lower level of stimulus when a concentric contraction occurs compared with an eccentric contraction and can allow golgi tendon organs (GTO's) to dominate. However, over time GTO's have been shown to desensitise. The net result is less muscular inhibition and greater force production, which may also be enhanced by an increased muscle stiffness caused by chronic stretch reflex actions (Gabriel *et al.,* 2006, Rowinski 1988 in Prentice, 2011 p. 228).

3) Neuromuscular – enhanced neuromuscular efficiency in the form of greater motor recruitment which leads to non-morphological changes that contribute to a greater level of power output (Akima *et al.,* 1999; Gandevia, 2001). This includes enhancement of motor unit synchronisation, firing frequency, excitability and efferent motor drive. An improved co-activation of the synergist muscles resulting from the reduced activation of the antagonist muscle (Hakikinen, 1994 in Villarreal, Requena and Newton, 2010 p. 518).

1.3.3 Neuromuscular training

1.3.3.1 Definition and general findings for both genders

Neuromuscular training is a form of exercise that can be used for prevention of injuries, enhancement of performance and rehabilitation purposes (Di Stasi and Snyder-Mackler, 2011). This type of training includes components such as plyometric training in combination with technique training via biomechanical feedback (Hewett, Ford and Myer, 2006, Thacker *et al.,* 2003 in Filipa *et al.,* 2010 p. 551). This visual demonstration and verbal feedback are important aspects of neuromuscular training to ensure that a strong focus is placed on proper technique and the quality of the movements (Filipa *et al.,* 2010).

Proprioception forms an important aspect of neuromuscular training (Silvers and Mandlebaum, 2007). Hubscher *et al.* (2009) conducted a meta-analysis of 32 proprioceptive neuromuscular training studies of which seven qualified as high quality randomly controlled trials. All but one of the trials demonstrated that balance related training could reduce the incidence of injury in pivoting sports such as football, basketball and handball among adolescent and young adult athletes. The pooled data showed a 54% reduction in acute knee injuries (Hubscher *et al.,* 2009). The skin, synovial structures, muscles and tendons all house somatic sensory receptors that provide afferent proprioceptive signals to the central nervous system. Muscles spindles and GTOs are two examples and provide information related to velocity of contraction and its tension respectively (Matthews, 1981; Fukami and Wilkinson, 1977 in Weber, Freison and Miller, 2012 p. 405). There are numerous cutaneous receptors that respond to tactile stimulation including pressure and vibration. For example, texture and shapes can be detected by Ruffini endings and Merkel discs which are slow adapting receptors. Fast adapting receptors such as Messiners corpuscles detect touch thanks to their superficial location in the skin (Blake, Hsiao and Johnson, 1997; Phillips and Johnson, 1981 in Weber *et al.,* 2012 p. 405). The location of these neurons and axons of nociceptors are the spinal cord dorsal horn, laminae I, V and VI (Bassbaum and Jessel, 200 in Weber *et al.,* 2012 p. 406). Information from the somatic sensory system is processed at the central nervous system via afferent signals travelling along neurons and into the spinal cord grey matter followed by the brain stem. Synaptic processing at the brain stem nuclei originating in the cuneate and terminating in ventral posterior nucleus of the thalamus leads to proprioceptive feedback to the peripheral limbs (Bosco and Poppele, 2000 in Weber *et al.,* 2012 p. 406).

A study by Vathrakokilis *et al.* (2008) demonstrated that after a mean of 22 months following ACL reconstruction there was still a significant deficiency in the proprioceptive function of the ACL between the injured and non-injured limb. Neurophysiological studies help support that postural control is enhanced and subsequently a feeling of improved knee stability due to the ACL's effect on the gamma motor neurons and the influence of the vestibular and visual systems Ageberg *et al.* (2005 in Vathrakokilis *et al.,* 2008 p. 237). There is well established evidence for the importance of neuromuscular training is for late stage rehabilitation of ACL reconstructions (Risberg *et al.,* 2007) but over the past 10 years, it has also become a key part of prehabilitation programmes designed to help prevent injuries specifically non-contact injuries such as ACL ruptures (Meyer *et al.,* 2006).

The PEP was a neuromuscular training programme developed by the expert panel convened by the Santa Monica Orthopaedic and Sports Medicine Foundation in 1999 with a view to enhance knee stabilisation and optimise biomechanical function (Gilchrist *et al.,* 2008). The PEP was developed to help prevent non contact lower limb injuries in female soccer players and served as precursor to the more highly publicised FIFA 11+ initiative (FIFA 11+, 2011) which was developed by FMARC, the medical research centre of The Federation Internationale de Football Association (FIFA) (Kilding, Tunstall and Kuzmic, 2008).

The PEP and similar protocols generally use a combination of core, balance, flexibility, strength, agility and sports specific exercises as an intervention for longitudinal ACL prevention studies, some of which have produced dramatic findings including reductions in rates of ACL injury as high as 89% (Silvers and Mandlebaum, 2007). Grindstaff *et al.* (2006) identified that optimal duration and frequency of ACL prevention programmes were 10 to 20 minutes 1 to 3 times per week with the lower end of the range being utilised for pre-season. The summary of mechanisms for injury were in line with Silvers and Mandelbaum (2007) and included increased peak ground reaction force (GRF), decreased neuromuscular control of the hip and knee, increased knee abduction angle and moment, decreased knee flexion on landing and exposure to high risk positions during sport.

Neuromuscular training can be aggressive and high intensity (Risberg *et al.,* 2007) but it can also involve low intensity core, proprioceptive and controlled strengthening exercises (Silvers and Mandlebaum, 2007). This means that it is practical to suggest that functional unilateral neuromuscular exercise programmes could be implemented during the early phases of ACL injury or post reconstruction without putting the contralateral limb at risk.

1.3.3.2 Gender differences

There are many studies that have observed a higher rate of injury incidence for females compared with males. Females have been shown to be at far higher risk (1 to 10 times more likely) of sustaining a serious knee injury compared with their male counterparts (Landry *et al.,* 2007; Hewitt *et al.,* 1996; Hewitt *et al.,* 1999; Arendt and Dick, 1996 in Grindstaff *et al.,* 2006 p. 450; Arendt, Agel and Dick, 1999, Chandy and Grana, 1985, Faude and

Jackson, 1997, Gray *et al.,* 1985, Gwinn *et al.,* 2000, Junge and Dvorak, 2004, Lindenfield *et al.,* 1992, Mandelbaum *et al.,* 2005, Strans *et al.,* 1990 in Gilchrist *et al.,* 2008 p. 1477).

Anatomical factors that place the female athlete at high risk include a greater Q angle, increased tibial torsion, increased femoral anteversion and greater sub-talar pronation in comparison to male athletes (Silvers and Mandlebaum, 2011). It has also been found that the female inter-condular notch is significantly smaller along with the diameter of the ACL itself. However, despite suggestions the latter two factors may contribute to ACL rupture risk in females, there are not yet any studies to support this (Silvers and Mandlebaum, 2007).

Hormonal factors relate to the increases in oestrogen that precede the ovulatory phase of menstruation and a rise in relaxin during the second half of the luteal phase. Receptors for these hormones have been shown to reside in the ACL (Silvers and Mandlebaum*,* 2007) and collagen synthesis to reduce by as much as 40% during these spikes in hormone levels (Yu *et al.,* in Silvers and Mandlebaum, 2007 p. 54).

Environmental factors are external and largely attributed to circumstance, and athlete choice such as playing surface, weather and footwear has less female specific relevance. However, biomechanical and neuromuscular factors, which are rapidly being considered the most important, can be well linked to female ACL injury risk. For example, reduced hip and knee flexion on landing coupled with increased knee valgus moments, greater torsional force and reduced synergistic hamstring activity for females compared to males potentially heighten their ACL injury risk (More *et al.,*1993; Malinzak *et al.,* 2001; McLean *et al.,* 1999 in Silvers and Mandlebaum, 2007 p. 55). One high risk position is pivoting and females have been shown to demonstrate an increased load and lower extremity valgus alignment in comparison to males (Ford, Myer and Hewett, 2003, Chappell *et al.,* 2002, Ford *et al.,* 2006, Malinzak *et al.,* 2001, Hewett, Myer and Ford, 2004, McLean *et al.,* 2004, Kernozek *et al.,* 2005, Zeller *et al.,* 2003, Pappas *et al.,* 2007, Hewett *et al.,* 2006 in Myer *et al.,* 2008 p.426).

EMG studies have shown that females demonstrate neuromuscular imbalances which can be related to ACL injury risk (Sell *et al.,* 2004, White, 2003 in Myer, Ford and Hewett, 2005 p. 182). Anterior tibial loads may be increased by a greater co-activation of the quadriceps by females which may increase the strain on the ACL (Myer, Ford and Hewett, 2005). Disproportionate vastus lateralis activation may also increase the anterior shear force experienced at the knee (Sell *et al.,* 2004, Markolf *et al.,* 1995 in Myer, Ford and Hewett, 2005 p. 182-183). It has also been proposed that neuromuscular imbalances of the hamstring to quadriceps ratio are observed for females (Myer, Ford and Hewett, 2005). Myer, Ford and Hewett (2005) used RMS and rectified maximum amplitude EMG measurements to investigate the effect of gender on quadriceps activation and found that neuromuscular firing rates were unbalanced for the females. Myer, Ford and Hewett (2005) found significant differences (P = 0.026) between the medial and lateral quadriceps activation as a ratio between females (0.78) and males (1.25) (see figure 1.9). Loads at the lateral joint may be increased by an imbalanced or low medial-lateral quadriceps firing rate, in turn this can increase the anterior shear load at the knee joint (Markolf *et al.,* 1995, Rozzi *et al.,* 1999, Sell *et al.,* 2004 in Myer, Ford and Hewett, 2005 p. 186). A neuromuscular recruitment pattern such as this can lead to increased dynamic knee valgus (Ford, Myer and Hewett, 2003, Hewett, Myer and Ford, 2004, Hewett *et al.,* 1996 in Myer, Ford and Hewett, 2005 p. 186).

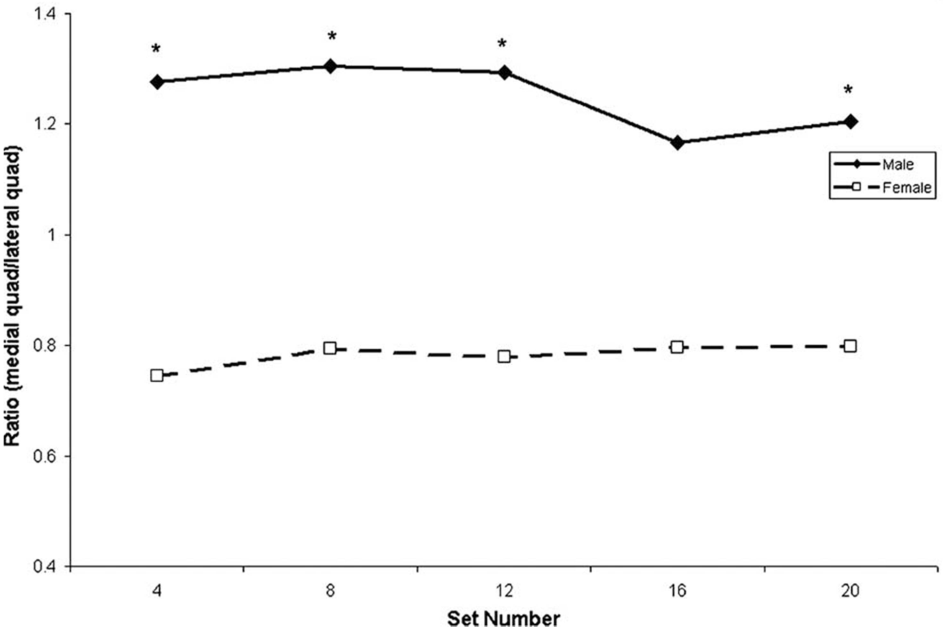


Figure 1.9 RMS ratio of medial-to-lateral quadriceps activation during performance of exercise sets. Females demonstrated significantly decreased Med/ Lat quad activation.

(Myer, Ford and Hewett, 2005 p.184)

Significant levels of side to side asymmetry (see figure 1.10) were reported during the second landing for “rotation angles, hip sagittal plane and adduction moments, knee flexion angle and knee sagittal plane and adduction moments.” The first landing showed significant increased peak side to side differences for hip internal rotation, knee extension and knee external rotation moment (Bates *et al.,* 2013 p. 461). An increase in flexion moments at peak vGRF where observed for the second landing (*P* < 0.001) (Bates *et al.,* 2013).

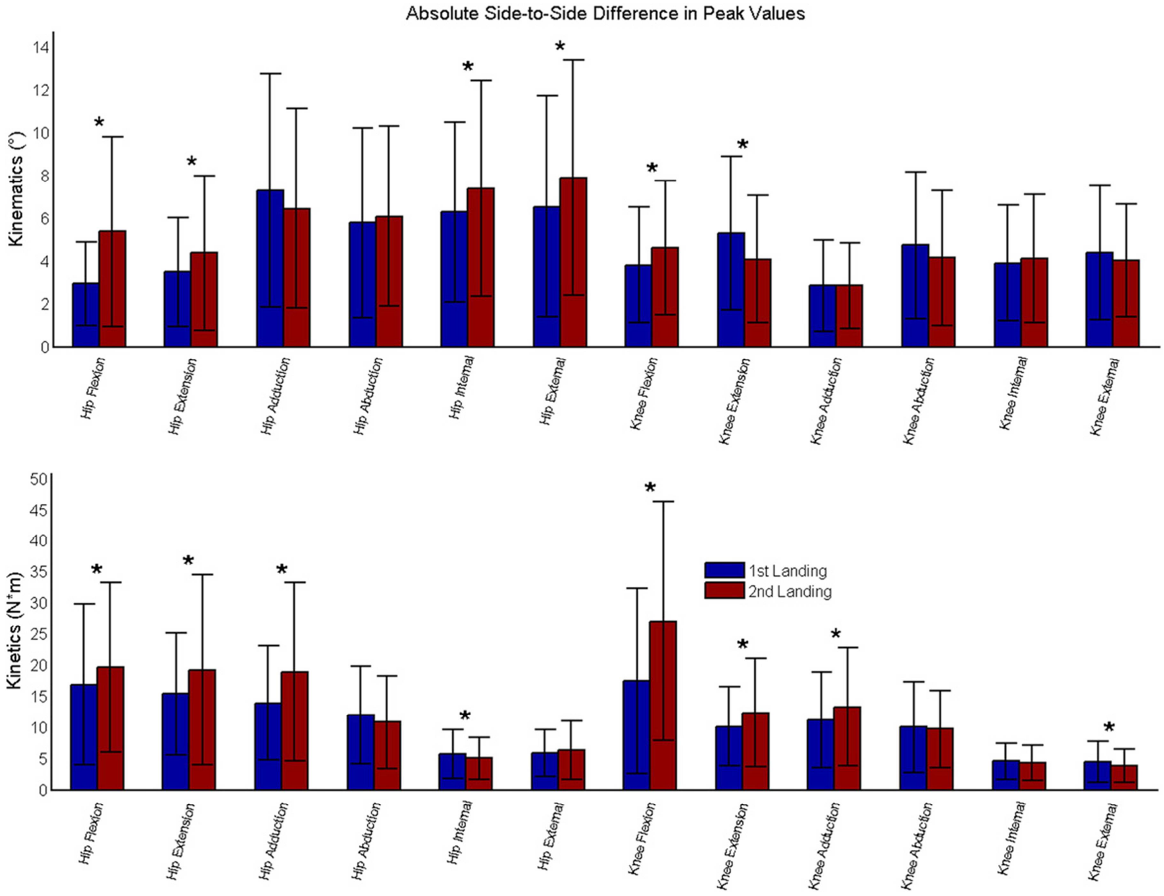


Figure 1.10 Displays the mean absolute magnitude of side-to-side differences plus standard deviation in peak values for kinematic and kinetic variables at the hip and knee. *Indicates significant differences between landings.

(Bates *et al.,* 2013 p. 463)

A lack of hip and knee flexion on landings has been shown to be related to ACL injury risk (Myers *et al.,* 2011, Paterno *et al.,* 2010, Pollard *et al.,* 2010 in Bates *et al.,* 2013 p. 464) and is related to greater frontal plane moments and motion and a stiffer joint condition compared with greater flexion which can reduce valgus torque (Kipp *et al.,* 2011, Pollard *et al.,* 2010 in Bates *et al.,* 2013 p. 464). Vertical GRFs have been shown to be greater for athletes landing with stiffer condition for their joints which can in turn transmit energy through passive structures including the ACL (DeVita and Skelly, 1992, Myers *et al.,* 2011 in Bates *et al.,* 2013 p. 464).

Despite the clear gender specific risk factors that have been identified it would appear that athletes such as professional dancers who have received neuromuscular training to enhance landing mechanics do not display this disparity in lower limb biomechanics in comparison to their male counterparts (Orishimo *et al.,* 2009 in Bates *et al.,* 2013 p. 465).

1.3.3.3 The effect of training interventions on females

Kiefer *et al.* (2013) found that sensorimotor deficits in females exist following ACL injury and coordination based neuromuscular training may be of benefit. Silvers and Mandlebaum (2005) achieved promising results with a non-randomised study in female soccer comparing 1,012 girls participating in a PEP group compared with 1,905 girls in a control group showing two ACL injuries compared to 23 respectively, an 83% decrease in ACL injury risk. A study by Gilchrist *et al.* (2008) followed on from this work using 1,435 athletes split into an intervention group using the PEP (852) and a control group (583). They found a non-significant 41% reduction in ACL injuries over one NCAA soccer season in 2002. There were significant reductions for ACL injury risk in the second half of the season which provides support for the suggestion that repeated execution of the programme is required to allow time for the accumulative and relevant musculoskeletal adaptations to occur. There were numerous limitations for this study including a lack of control measures for completion of the drills, no validation for the reports provided by the athletic training coaches and there was a lack of statistical power to allow comparisons to be made among sub groups such as age and experience. One measure that may help combat some elements of control is the use of oral and visual feedback. This may serve to enhance the quality of the techniques performed by better educating the participants and subsequently lead to improved results. Etnoyer *et al.* (2013) found that knee flexion was significantly increased following a combination of verbal and video based feedback following box drop jumps (DJ). In contrast, there was no significant difference in injury risk between two groups of 13 to 18 year old males over four months from 31 teams, one of which received on field supervision and instruction and the other used a web based delivery of the content (Steffan *et al.,* 2013). A further study by Steffan *et al.,* (2014) also found that on field support provided only minimal benefits.

The FIFA 11+ programme was implemented on a countrywide campaign in Switzerland and there was a 56% compliance rate and a 12% reduction in injury risk during 2008 across a sample of 5,549 coaches (Junge *et al.,* 2010). A well designed study using blinded injury recorders to monitor an intervention modelled on the PEP and FIFA 11+ programme across 1,892 female soccer players in Norway failed to demonstrate an overall reduction in lower limb injuries but did demonstrate a significant reduction in the risk of severe injuries. It should be noted that this research was funded by FMARC (Soligard *et al.,* 2008).

Neuromuscular training has been shown to have a positive influence on the RFD during voluntary muscular contractions (Gruber and Gollhofer, 2004 in Salaj, Milanovic and Jukic, 2007 p. 132). An enhanced neural activation can also lead to a positive effect on the stretch shortening cycle (Palma, 2005 in Salaj, Milanovic and Jukic, 2007 p. 132). Hewett, Myer and Ford, 2005 in Klugman *et al.* (2011 p. 826) suggest a neuromuscular programme should contain biofeedback, strength, plyometrics and balance exercises.

Isometric tests of maximal voluntary contractions are often used as a standard measure of strength following ACL reconstructions (Hartigan *et al.,* 2012 in Knezevic *et al.,* 2014 p. 1039). However, 'explosive' measures are considered an important factor in recovery and RFD (force-time curve) is a recognised measure of this variable (Aagaard *et al.,* 2002 in Knezevic *et al.,* 2014 p. 1039). This is relevant to neuromuscular training as these indices of 'explosive strength' relate to neural excitation (Knezevic *et al.,* 2014). A reduced level of feedback from the knee via gamma motor neurones can lead to a lower level of recruitment at high threshold motor units (Konishi, 2007, Konishi 2002 in Knezevic *et al.,* 2014 p. 1039). It has been suggested that recruiting muscles at an optimal rate is of greater importance than strength for optimising functional performance (Aagaard *et al.,* 2002 in Knezevic *et al.,* 2014 p. 1039-40). Knezevic *et al* (2014) found significant asymmetries between maximum and explosive strength (See figure 1.11). The asymmetries were larger still when the uninvolved leg was used as a control. This highlights the need to include RFD measures in ACL related prevention and rehabilitation programmes. In further support of this, Larsen *et al.* (2014) found RFD for knee extension 9 to 12 months post-surgery for ACL reconstruction patients was significantly lower than healthy control subjects.

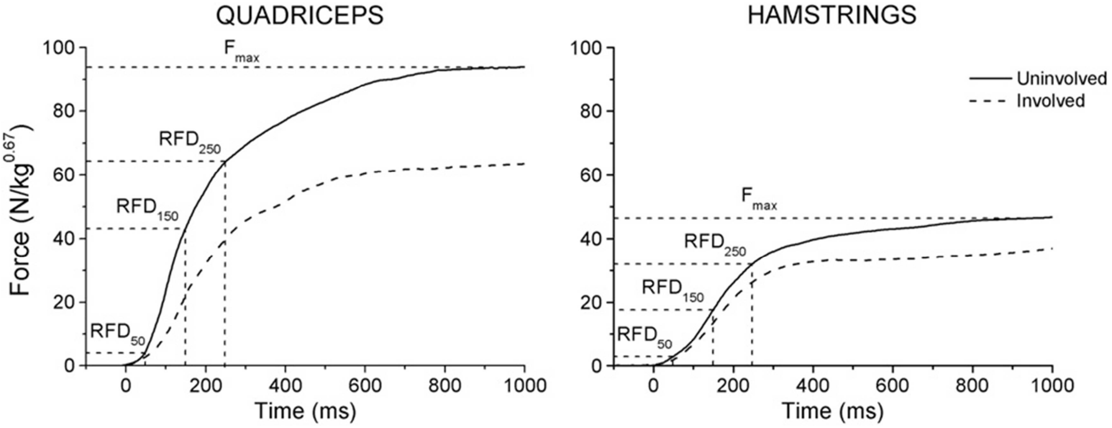
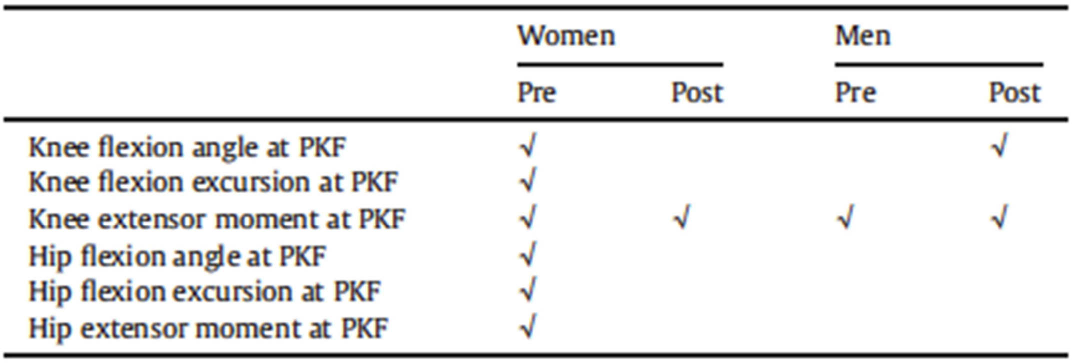


Figure 1.11 The force–time profiles of quadriceps and hamstrings recorded from the involved leg (dashed line) and uninvolved (solid line) leg of a representative subject.

(Knezevic *et al.,* 2014 p. 1042)

Perturbation training, a form of proprioceptive neuromuscular training, has been shown to address the asymmetry of female athletes with ACL deficiency (see table 1.2). A three dimensional (3D) motion capture system was used to record the excursion values (Di Stasi and Snyder-Mackler, 2011).

Table 1.2 Limb asymmetry of male and females before pre and post perturbation training. Minimal clinically important differences between limbs are denoted with a check.



	Women		Men	
	Pre	Post	Pre	Post
Knee flexion angle at PKF	√			√
Knee flexion excursion at PKF	√			
Knee extensor moment at PKF	√	√	√	√
Hip flexion angle at PKF	√			
Hip flexion excursion at PKF	√			
Hip extensor moment at PKF	√			

(Di Stasi and Snyder-Mackler, 2011 p. 363)

A systematic review by Zech *et al.* (2009) of randomised controlled trials and controlled trials without randomisation found proprioceptive and neuromuscular training improved the functionality and prevention of further injury following ankle instability and ACL rupture. These measures included ankle range of movement (ROM) measured in degrees and knee functionality measured by the ‘Lysholm Score’. However, it should be noted that no significant enhancement of strength or EMG was observed. This may have been due to the methodological limitations of the papers included.

In support of functional improvements Risberg *et al.* (2007) found knee functionality measured by the Cincinnati Knee Score following ACL rupture to be greater following neuromuscular training in comparison to traditional strength training (see figure 1.12).

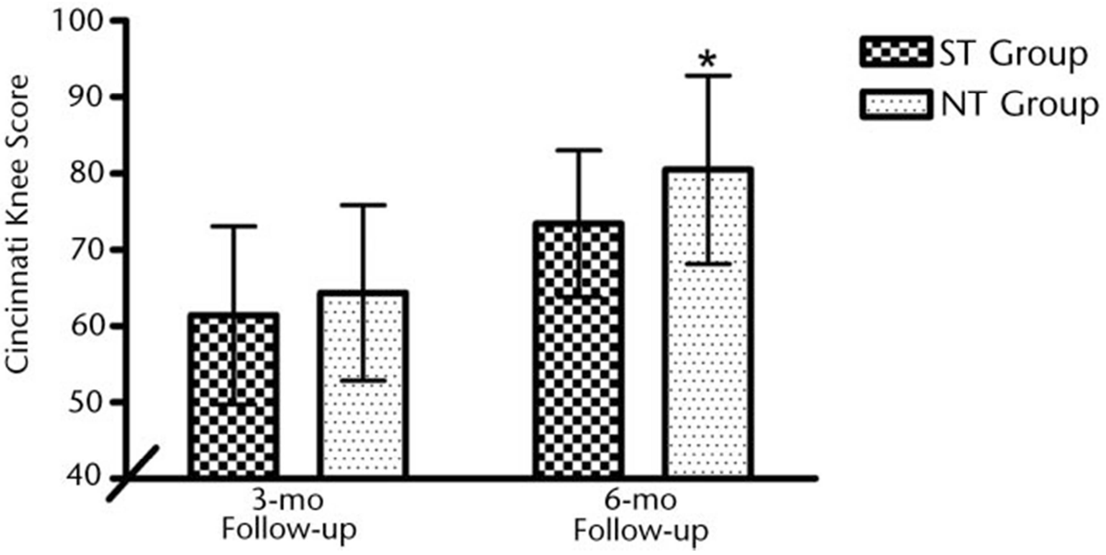


Figure 1.12 Cincinnati Knee Score at 3 and 6 month follow-ups for the strength training (ST) group and the neuromuscular training (NT) group. Asterisk indicates significant differences between groups at 6 months (*P* < 0.01).

(Risberg *et al.,* 2007 p.743)

No significant differences were found for the secondary measures such as proprioception, hop test, balance or strength.

1.3.3.4 The role of core in ACL injury risk

Core stability refers to the control of the trunk by the body in response to external and internal forces (Zazulak *et al.,* 2007). Hibbs *et al.* (2008) has theorised that a distinction should be drawn between ‘core stability’ and ‘core strength’ with the latter referring to functional performance relevant to an athletic population.

Distal segments of the body including the knee are related to the neuromuscular control that leads to their displacement throughout movements (Hewett *et al.,* 2005). There is ambiguity within the literature concerning the definition of 'core stability' and whether it can reduce injury risk. Furthermore, many studies addressing core stability use lower back pain models as opposed to athletic populations (Hibbs *et al.,* 2008).

It is understood that in addition to the passive stiffness and stability of the spine, its associated structures such as bone, ligament, intervertebral discs and tendons require active support from the muscles (Kibbler *et al.,* 2006; Ebenbichler *et al.,* 2001 in Borghuis *et al.,* 2008 p. 897). Dysfunction occurring between mobilising muscles such as the quadriceps and stabilising muscles such as transverse abdominus and multifidus leads to a change in the timing of recruitment and the length between the stabilising and mobilising muscles which are generally biarticular and mono-articular respectively (Commerford and Mottram 2001; Commerford and Mottram 2001b in Borghuis, 2008 p. 903). The forces generated by extremities can be damaging. The spine's multisegmental structure renders it prone to such perturbations, which means that muscular control is essential for stability (Zazulak *et al.,* 2007 in Borghuis *et al.,* 2008 p. 900). It has been stated that motor control made up of spinal reflex, brain stem balance and cognitive programming is responsible for the activation of the relevant muscles (Radebold *et al.,* 2001 in Borghuis, 2008 p. 900). Proprioceptive feedback plays an important role for the spinal reflex aspect of motor control via input from the GTO's and muscle spindles. The brain stem pathway utilises proprioceptive input from joint receptors and coordinates the visual and vestibular systems. This supports the centrally stored programmes that allow for ‘anticipatory’ contractions to enhance stability prior to voluntary contractions for the distal limbs (Kibler *et al.,* 2006; Radebold *et al.,* 2001 in Borghuis, 2008 p. 900). Eibenbichler *et al.,* 2001 in Borghuis *et al.,* 2008 p. 900) showed that task reaction time is inversely proportional to postural stability. This highlights the importance of muscle recruitment and its timing to spinal stability.

Zazulak *et al.* 2007 in Borghuis *et al.* (2008 p. 901) found that decreased proprioceptive function, and in turn, core stability can lead to increased knee valgus angle and strain on the ligaments of the knee. Ireland (2002 in Borghuis *et al.,* 2008 p. 902) supports this and highlights the potential connection to ACL injury due to the increased hip adduction and internal rotation at the knee (see figure 1.13). Neuromuscular training targeting improvements in trunk control for females prior to pubertal development may help reduce the risk of these biomechanical factors in relation to ACL injuries (Myer *et al.,* 2008).

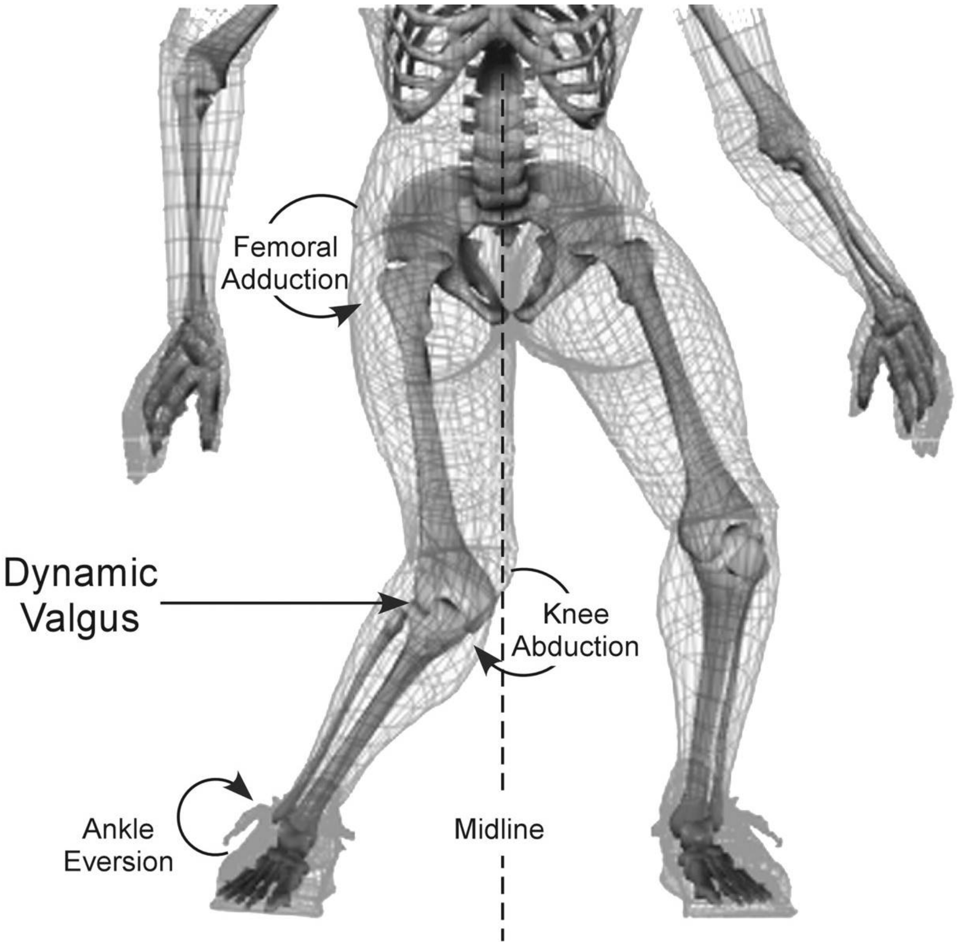


Figure 1.13 Faulty biomechanics that may result from dysfunctional neuromuscular control.

(Hewett *et al.*, 2005 p. 495)

The glutei are not technically seen as part of the core due to their key role stabilising a planted leg during functional activity but of course, they are connected to the trunk via the pelvis and also thoracolumbar fascial attachments (Kibler *et* al., 2006 in Borghuis, 2008 p. 898-899). Hip abductors and external rotators help prevent the lower limb from moving into hip adduction and internal rotation especially during single leg movements (Ireland, 2002 in Borghuis *et al.,* 2008 p. 902). Delayed firing of the hip extensor (glueteus maximus) and hip abductor (gluteus medius) has been shown to be linked to lower back pain and instability of the lower extremities (Nadler *et al.,* 2002 in Borghuis *et al.,* 2008 p. 902).

Changes to motor control in relation to core has been shown to influence injury risk at the knee (Zazulak *et al.,* 2007). An increased knee abduction torque can be the result of the knee deviating from its trajectory due to either an internal or external force (Hewett *et al.,* 2005 in Zazulak *et al.,* 2007 p. 1128). This decreased neuromuscular control coupled with high GRF can lead to decreased knee stability especially in female populations (Zazulak *et al.,* 2007).

As there is clear evidence to suggest females are at high risk for non contact ACL injuries, caution must be applied when designing a rehabilitation programme especially a functional cross-education protocol that utilises unilateral exercises (Landry *et al.,* 2007; Hewitt *et al.,* 1996; Hewitt *et al.,* 1999; Arendt and Dick, 1996 in Grindstaff *et al.,* 2006 p. 450; Arendt, Agel and Dick, 1999, Chandy and Grana, 1985, Faude and Jackson, 1997, Gray *et al.,* 1985, Gwinn *et al.,* 2000, Junge and Dvorak, 2004, Lindenfield *et al.,* 1992, Mandelbaum *et al.,* 2005, Strans *et al.,* 1990 in Gilchrist *et al.,* 2008 p. 1477). Females risk during landings has been shown to be significantly higher than that of their male counterparts (Pappas and Carpes, 2012). Therefore carefully planned progressions, supervision and a focus on technique (Steffan *et al.,* 2013) should be incorporated with a view to mitigate the risks.

1.4 Potential methods for functional cross-education training

The prevention programmes discussed in section 1.3 have been designed to focus primarily on biomechanical function via neuromuscular training (Silvers and Mandelbaum, 2007). It is generally agreed that that laboratory based motion analysis systems are the gold standard for assessing biomechanical function. However, there is a need for lower cost field-based measures. The Landing Error Scoring System (LESS) is an example of such a tool. It measures data to highlight landing 'errors' including the trunk, lower extremity and foot positioning as well as global measures considered from a sagittal plane. The LESS uses 'off the shelf' video cameras and has been successfully validated against a laboratory based 3D motion analysis system. The inter-rater and intra-rater for the LESS was found to be good-excellent (Padua *et al.,* 2009). A study by Smith *et al.* (2011) that used 5,047 high school and college participants who were screened pre-season for drop vertical jumps but did not find the LESS was successful at predicting ACL injuries.

As the training interventions and their objectives are functional, finding field based measures has become a focus of recent studies. These aim to be more accessible to practitioners thus enhancing the practical implications of the studies. However, it is important that such measures maintain appropriate levels of accuracy to allow evidence-based decisions to be made in the field. A more recent field based tool is an nomogram developed by Myer *et al.* (2012), which has been validated against 3D motion analysis. The development of the algorithm used 744 female basketball and soccer players and considered maturation, laxity, flexibility, anthropometrics, strength and landing biomechanics. Knee abduction moment was modelled using linear regression and logistic regression for high vs low knee abduction moment, which served as surrogate for ACL injury risk. Myer *et al.* (2012) found a moderate to high agreement between the laboratory and field based techniques. An 80% and 75% prediction accuracy was demonstrated for knee abduction moment between 3D motion analysis and the field based measures following regression analysis.

The field-based measures developed by Myer *et al.* (2012) were designed to consider tibia length, knee flexion range of motion, knee valgus motion and quadriceps to hamstrings ratio. Myer *et al.* (2012) used two dimensional (2D) cameras, one in the frontal plane and one in the sagittal plane.

Another clinic based algorithm was developed by Goetschius *et al.* (2012) and tested using 1,855 college students over a three year period. The study found that the algorithm measuring knee abduction moment was not able to predict non-contact ACL injury risk with significant accuracy. The study suggests that further research is needed into clinic-based ACL injury prediction tools. It also calls into question the capabilities of 2D video analysis despite previous validation (Myer *et al.,* 2012) suggesting that 3D motion capture may be necessary to capture the intricacies of the knee movement on landing.

Ford *et al.* (2006) used 3D motion analysis to compare female and males during landing tasks. It was found that females had an increased knee and hip excursion (see figure 1.14 and 1.15) and lateral landings created the largest excursion differences (see figure 1.16).

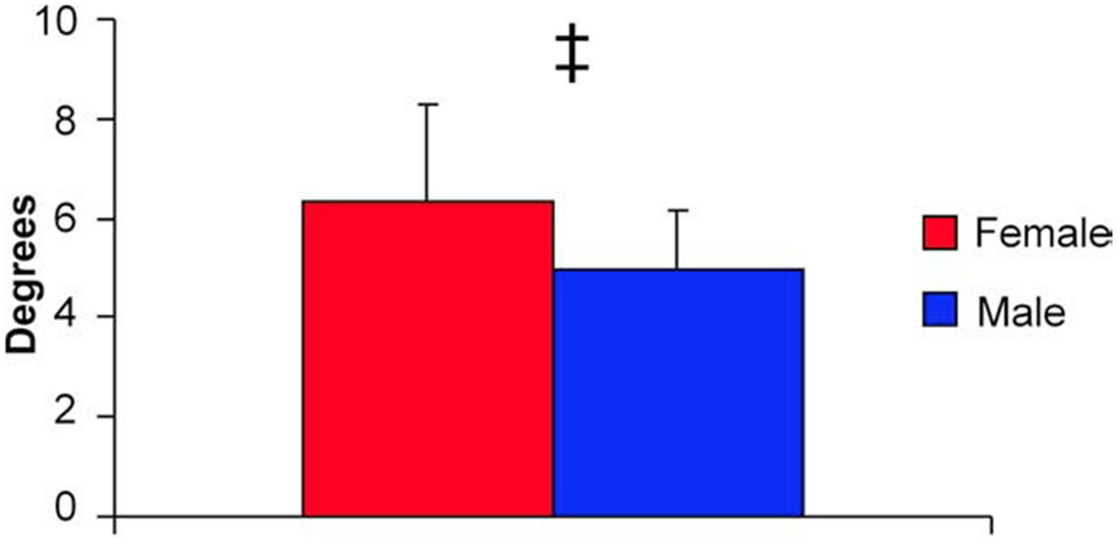


Figure 1.14 Knee abduction–adduction excursion collapsed across landing conditions, Significant gender main effect $P < 0.05$.
(Ford *et al.,* 2006 p. 37)

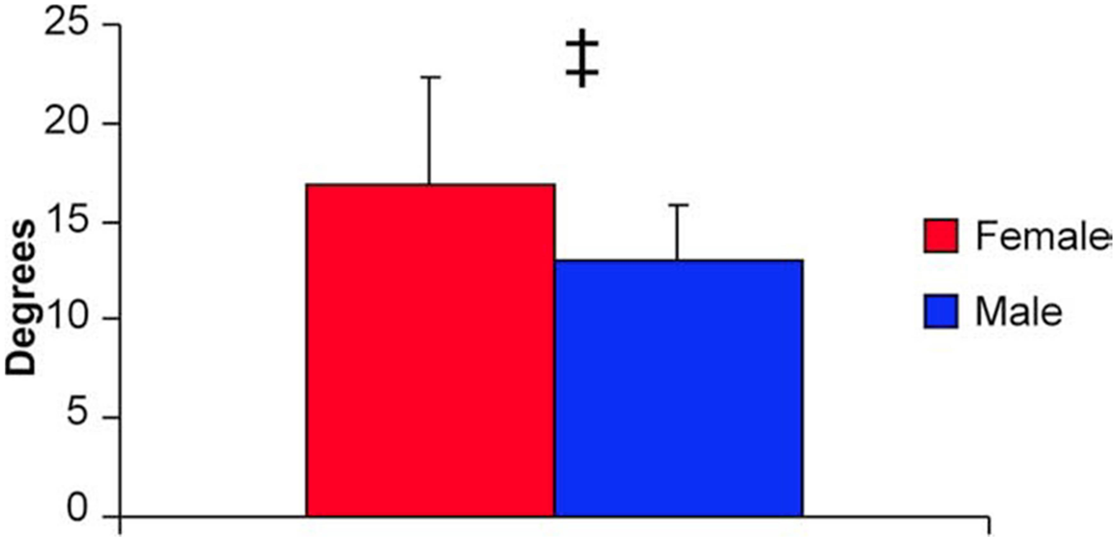


Figure 1.15 Hip abduction–adduction excursion collapsed across landing conditions. Significant gender main effect $P < 0.05$.
(Ford *et al.,* 2006 p. 38)

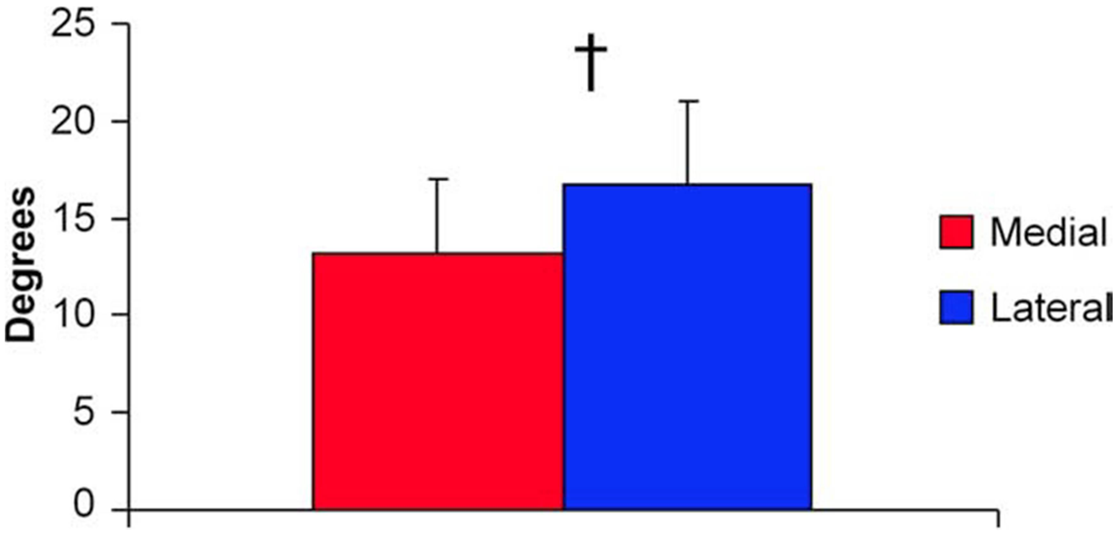


Figure 1.16 Hip abduction–adduction excursion collapsed across male and females. Significant task main effect $P < 0.05$.

(Ford *et al.,* 2006 p. 38)

DiStefano *et al.* (2009) conducted a study to investigate the influence of age, sex and technique following an ACL prevention programme using the LESS. DiStefano *et al.* (2009) identified the need for greater biomechanical focus in future studies to provide stronger links to associated injury risks.

sEMG is frequently used in parallel with the video analysis for DJs as a non invasive way of collecting electrical activity produced by muscle contractions (Mello, Oliveria and Nadal, 2007). Studies commonly use a root mean squared (RMS) value averaged over a period of time such as 50 ms before normalising in relation to MVIC measures (Fujii, Sato and Takahira, 2012). In support of this, the data of Padulo *et al.* (2013) were rectified and smoothed using RMS for their study comparing jumping and landing. See figure 1.17 and 1.18 for examples of a counter movement jump and squat jump respectively. These exercises relate to the neuromuscular programmes discussed in section 1.3.3. Doorenbosch and Harlaar (2003) used sEMG to test biceps femors, vastus lataralis, vastus medialis and semi tendinosis during single leg vertical jumps. They used a band-pass filter (20-1500 Hz) which was then rectified with a second order filter at 2 Hz before sampling at 100 Hz. Filters are utilised to help reduce unwanted noise that may interfere with the signals and does so via attenuation. The antigravitational muscles may cause this noise whilst they are in a standing position and the application of the Butterworth Filter has been shown to be effective in reducing such noise (Mello, Oliveria and Nadal, 2007; Mello, Oliveria and Nadal, 2006 in Mello, Oliveria and Nadal, 2007 p. 28).

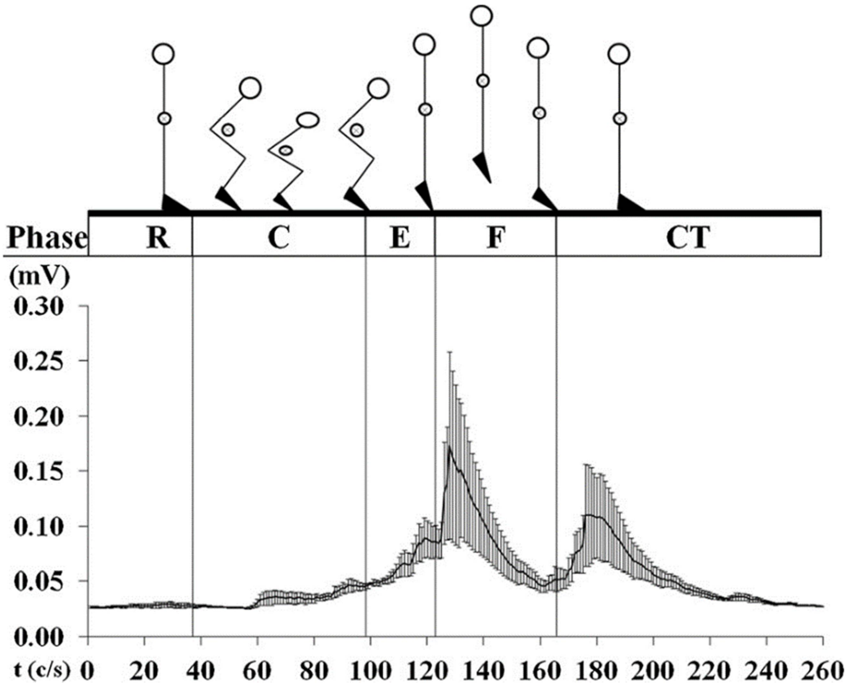


Figure 1.17 Rectified and smoothed EMG curves indicate electrical activity of the biceps femoris during Counter Movement Jump, all synchronised with different phase: ready (R), concentric (C), eccentric (E), flight (F) and contact time (CT).

(Padulo, 2013 p. 4)

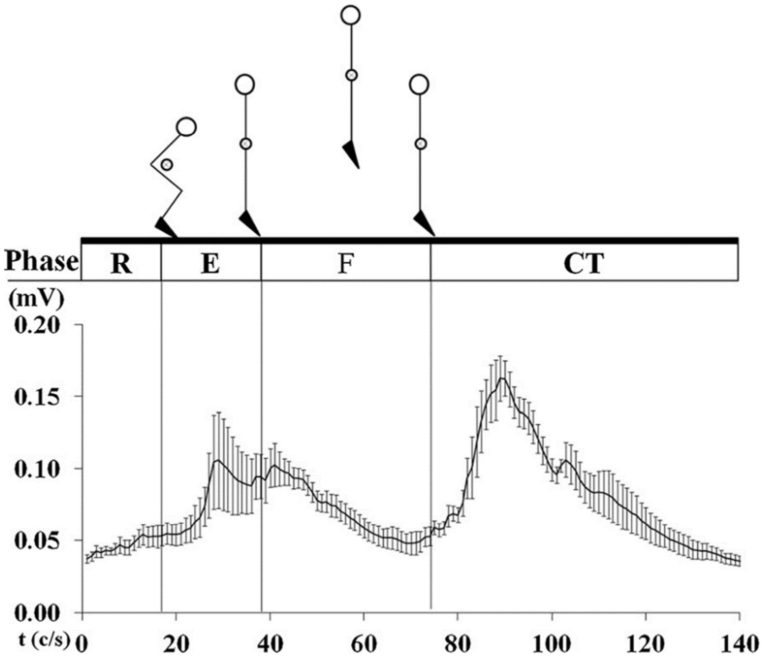


Figure 1.18 Rectified and smoothed EMG curves indicate electrical activity of the biceps femoris during Squat Jump, all synchronised with different phase: ready (R), eccentric (E), flight (F) and contact time (CT).

(Padulo, 2013 p. 4)

Bates *et al.* (2013 p. 460) used adolescent females and drop vertical jumps to investigate the kinetic and kinematic differences between the first and second landings measured using Visual3D (version 4.0, C-Motion, Inc., Germantown, MD) with custom MATLAB (version 2010b, The Mathworks, Inc, Narick, MA) code and vertical GRF (vGRF) using force platforms.

The greater quadriceps to hamstrings ratios and associated strain on the ACL that have been demonstrated in female populations may be responsible for the reduced flexion angles seen on the second landing (Ford *et al.,* 2011, Hewett *et al.,* 2008, Padua *et al.,* 2005 in Bates *et al.,* 2013 p. 465). This may occur by increasing anterior tibial shear force when landings illicit flexion angles that are less than 45 degrees (Markolf *et al.,* 1995; Myer *et al.,* 2005 in Bates *et al.,* 2013 p. 465).

Dysfunctional movement patterns in the frontal plane have been to shown to be more closely related to ACL injury risks including predictors such as peak landing forces and knee valgus (Hewett *et al.,* 1996, 2005, Markolf *et al.,* 1995 in Bates *et al.,* 2013 p. 465). Females have been shown to display greater kinematic asymmetries during side to side movements compared to males during bilateral movements (Ford *et al.,* 2003, Pappas and Carpes, 2012 in in Bates *et al.,* 2013 p. 465). The findings of Bates *et al.* (2013) demonstrated differences between the first and second jump including asymmetries in the sagittal and frontal plane for the hip but did not show increased knee valgus on the second landing. The second landing showed decreased angles of all lower limb joints. These findings suggest that the second landing may be best matched for evaluation of neuromuscular control in the sagittal plane whereas the increased knee valgus present on the first landing may be best matched with assessment of movement dysfunction in the frontal plane (Bates *et al.,* 2013). It should be noted that overall the second landing was deemed to be more demanding biomechanically than the first (Bates *et al.,* 2013).

A study by Pappas and Carpes (2012), using an AMTI biomechanical platform and eight Eagle cameras (Motion Analysis Corp. Santa Rosa, CA), offers support to the findings of Bates *et al.* (2013) by showing female specific asymmetries. However, Pappas and Carpes (2012) also demonstrated that forward landings for both genders may be a cause of greater kinematic asymmetry than drop landings. Knee valgus and hip adduction asymmetries were significantly greater on forward landings compared with DJs. Females landed with greater knee valgus asymmetry on forward landings than the males. Therefore, it may be worthwhile considering forward landings as part of screening protocols (Pappas and Carpes, 2012).

3D motion analysis using a 6 camera Vicon MX-system has also been used to highlight the biomechanical dysfunction present following ACL reconstruction whereby numerous significant asymmetries were shown to exist between post-surgery (2 years) subjects and controls (Holsgaard-Larsen *et al.,* 2013). These asymmetries included hamstring maximum voluntary contraction (MVC) ($N\cdot m\cdot kg^{-1}$) (77% vs 101%), distance jumps measured in cm (93% vs 99%), degrees of ROM for counter movement jump (96% vs 103%) and single leg counter movement jump (87% vs 100%) (Holsgaard-Larsen *et al.,* 2013). These measures of reduced function, specifically at the hamstrings due to their role in controlling anterior shear of the tibia, are indicators of secondary ACL rupture or chronic disruption such as osteoarthritis (Holsgaard-Larsen *et al.,* 2013).

A field based technique has been developed to measure and analyse jumping biomechanics and identify associated ACL risk factors (Myer *et al.,* 2012a). Those risk factors include tibia length, knee valgus, knee flexion, mass and quadriceps to hamstrings ratio which are analysed using a nomogram that produces a figure for knee abduction moment (KAM) probability. Neuromuscular training has been shown to reduce high KAM risk (Hewett *et al.,* 1996, Hewett *et al.,* 2004, Hewett *et al.,* 2006a, Myer *et al.,* 2004, Myer *et al.,* 2005, Myer *et al.,* 2006a, Myer *et al.,* 2006b, Myer *et al.,* 2007 in Myer *et* *al.,* 2010 p. 696). The field based technique developed by Myer *et al.,* (2010) has been shown to have excellent inter-rater reliability using both 3D and field based methods (Myer *et al.,* 2011 in Myer *et al.,* 2012a p. 2267). Additionally, moderate to high agreement between 3D analysis and field based measures have been reported (Myer *et al.,* 2012a) and findings to suggest that clinic based measures may facilitate the prescription of appropriate interventions for ACL injury risk (Myer *et al.,* 2010).

The findings of these studies offer support for the design and objectives of the PEP and FIFA 11+ programmes as discussed in section 1.3 (Silvers and Mandlebaum, 2007; FIFA, 2014). As long as the safety of the injured contralateral limb is considered it should be feasible to design and implement a functional unilateral cross-education programme that can be used from the early stage of rehabilitation. The benefits of functional and sports specific training are well established (Markovic *et al.,* 2007) and the use of such exercises should be considered prophylactically to help prevent ACL injuries (Mandlebaum *et al.,* 2005). No cross-education research to date has incorporated functional interventions or output measures and only one ACL rehabilitation study has investigated the potential effects of cross-education (Papandreou *et al.,* 2013). This study aims to be the first to use neuromuscular unilateral training and functional outcome measures to assess cross-education adaptations (Kannus *et al.,* 1992; Munn *et al.,* 2005) with a view for their potential use in the rehabilitation of ACL injuries.

1.5 Hypotheses

H_1

Unilateral training would lessen the loss of flight time, jump height, GRF, velocity, RFD, power, force, propulsion and deceleration of DJs and SLVJs for the CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_{01}

Unilateral training would not lessen the loss of flight time, jump height, GRF, velocity, RFD, power, force, propulsion and deceleration of DJs and SLVJs for the CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_2

Unilateral training would lessen the increases to contact time of DJs and SLVJs for the CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_{02}

Unilateral training would not lessen the increases to contact time of DJs and SLVJs for the CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_3

Unilateral training would decrease knee valgus for SLVJs or CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_{03}

Unilateral training would not decrease knee valgus for SLVJs or CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_4

Unilateral training would decrease KAM probability for DJs for CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_{04}

Unilateral training would not decrease KAM probability for DJs for CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_5

Unilateral training would lessen the loss in sEMG RMS for DJs and SLVJs for CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_{05}

Unilateral training would not lessen the loss in sEMG RMS for DJs and SLVJs for CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_6

Unilateral training would lessen the delay in EMG muscle activation times for DJs and SLVJs for CEG compared with the DTG through the cross-education effect ($P < 0.05$).

H_{06}

Unilateral training would not lessen the delay in EMG muscle activation times for DJs and SLVJs for CEG compared with the DTG through the cross-education effect ($P < 0.05$).

Chapter 2. Methodology

2.1 Participants

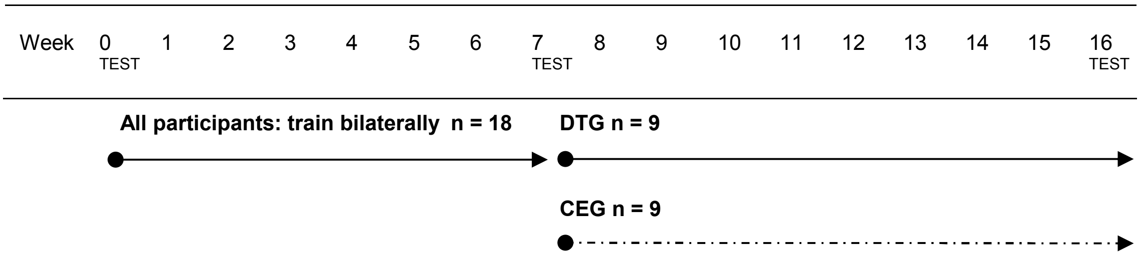
Eighteen randomly selected, recreationally active, adult, female participants (21.2 ± 3 years of age, with a stature of 166.4 ± 6.6 cm, and body mass of 61.9 ± 3.6 kg) were recruited (*n* = 18). Volunteers were sought from London Metropolitan University. Participants qualified as 'recreationally active' if their activities did not include any lower body strength training for six months prior to the commencement date of the study (Munn *et al.,* 2005). Exclusion criteria relating to previous injuries were determined by any participant unable to take part in their regular recreational or daily activities. Participants were asked to adhere, to a restricted level of activity outside of the experiment whereby they were not permitted to take part in, or have taken part in, any progressive strength training for the lower limb including weight training or plyometrics for the 12 weeks prior to the study.

The study was approved by the London Metropolitan University ethics committee (see Appendix A). Participants received all necessary information in written and oral form including a written informed consent form (see Appendix B).

2.2 Procedure

A 15 week intervention separated testing at week 0 and week 16 (see figure 2.1). All participants trained bilaterally for six weeks at which point they were randomly selected to stop training and formed one of two groups; the Detraining Group (DTG; *n* = 9), or Cross-education Group (CEG; *n* = 9). The

CEG participants continued to train for a further nine weeks but only their dominant leg (which was determined by the leg they would prefer to kick with) (Gabbard, 1996 in Holsgaard-Larsen, 2013 p. 67) and underwent analysis on both limbs (trained and untrained). The DTG acted as a control group by detraining both limbs allowing comparison of the contralateral detraining effect with the CEG (detraining).



Legend
DTG = De-training group (detraining for both limbs)
CEG = Cross-education group (detraining for the non-dominant limb and unilateral training for the dominant limb)

Figure 2.1 The experiment design showing the weeks that performance tests took place and the overall training plan for each group. A between groups comparison was conducted to investigate the cross-education effects resulting from a unilateral training programme in comparison to a detraining programme following a period of bilateral training for all participants.

2.2.1 Bilateral training (pre and post-tests)

Testing took place at week 0 prior to the start of training to measure baseline variables. A second set of tests took place during week 7 after completion of the bilateral training programme. These measured the same performance parameters with the addition of maximal voluntary isometric contractions (MVIC), sEMG and video measurements.

2.2.2 Unilateral training (post-tests)

Tests were completed during week 16 for comparison between the CEG (trained) limb, untrained, non-dominant, contralateral limb of the CEG (detraining) and the corresponding non-dominant limb for the DTG (control) participants with the intention of demonstrating a cross-education effect resulting from the unilateral training. If, for any reason, participants were unavailable for training or testing, the potential effects on the validity of the data were considered and, if compromised, participants were withdrawn from the experiment. Participants were permitted to continue if they missed no more than 2 sessions throughout the intervention and were not delayed by more than days for the testing. The protocol used two to three sessions per week of varying intensities (see Table 2.1).

Table. 2.1 A weekly breakdown of training frequency and intensity for the training aspects of the intervention period to investigate the cross-education effects resulting from a unilateral training programme in comparison to a detraining programme following a period of bilateral training for all participants.

Week No.	0*	1	2	3	4	5	6	7*	8	9	10	11	12	13	14	15	16*
Training Frequency	0	2	2	3	2	3	3	2	3	3	3	3	3	3	3	3	0
Plyometric Intensity	n/a	L	L	M	H	H	H	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Legend
* Tests
L = Low
M = Moderate
H = High
n/a = Not applicable

The training programme was designed primarily to improve lower limb power development using plyometric exercises. This was a progressive (Vissing *et al.*, 2008) programme employing aspects of periodisation (Bartolomei *et al.,* 2014; Bompa 1999 in Kell, 2011 p. 734) using the principles of training frequency, intensity and volume (Rønnestad *et al.,* 2007; Paulsen, Myklestad and Raastad, 2003; Schlumberger, Stec and Schmidtbleicher 2001; Wernbom, 2007 in Naclerio *et al.,* 2013 p. 1832), progressive overload (Taylor, Doss and Damiano, 2005) and recovery periods (Kell, 2011; Fleck and Kramer, 1987 in Herrick and Stone, 1996 p. 72). The exercises incorporated were based on studies that have achieved positive effects on power output and were as follows; two foot ankle hops, squat jumps, jump and reaches, lateral jumps, cycled split squat jumps, double-leg tuck jumps, zig zag forward squat jumps, single-leg vertical jumps and forward single leg jumps (Ozbar, Ates and Agopyan, 2014; Tsang and DiPasquale, 2011; Barber-Westin, Hermeto and Noyes, 2010; Fatourous *et al.,* 2000; Baechle and Earle, 2000). These exercises were carefully taught to each participant in a one to one session following the first set of tests. Guidelines were included in their hand-out literature (see Appendix C). The bilateral training programme (see Appendix C) incorporated a standardised warm-up, which included test and programme-specific exercises such as practice squat jumps. The same warm-up was incorporated prior to testing. The participants were also provided with a series of weekly videos (see Appendix D) to support their written instructions. These were available via a Dropbox™ link which was sent to them by email. In addition to the weekly emails each participant was sent a text message during the training periods to enhance adherence to the intervention and levels of motivation (Munn *et al.,* 2004).

The DTG were advised by email (see Appendix E) on what activities were to be avoided for the nine week period before the final testing period. This advice was based on the exclusion criteria meaning the participants had to avoid any progressive lower limb strengthening activities. The remaining participants who had been randomly selected to be in the CEG were given one to one sessions to teach them how to accurately and safely perform the unilateral exercises from the unilateral maintenance programme (see Appendix F) for the remaining nine weeks on their dominant limb. The unilateral programme was designed by including and adapting the key elements from the PEP and F-Marc FIFA 11+ ACL prevention programmes (Silvers and Mandlebaum, 2011; FIFA, 2014). The CEG (training) were also provided with a video guide to these exercises and the associated progressions via a Dropbox™ link sent by email (see Appendix D). Weekly emails (see Appendix D) and text messages (see Appendix G) were sent just as they had been for the first six weeks.

Due to ethical restraints it was not possible to physically immobilise one limb of each of the participants for the entire study such as Magnus *et al.* (2010), Farthing (2011), Farthing *et al.* (2009) and Magnus *et al.* (2013). However, the design of the training protocol was developed with careful consideration so as to minimise the use of the non-training limb and in turn undetectable isometric contractions that may occur (Benjamin *et al.,* 2000). An additional aim of the unilateral programme was to provide exercises that could be safely completed during early to intermediate stages of rehabilitation for lower limb injuries to provide data of a transferable nature to the field of sports therapy. Therefore, these exercises could theoretically be completed if the contralateral limb were in a non-weight bearing phase of rehabilitation. For example, in a soft or hard cast or a brace allowing the protection required for the healing tissue (Kannus, 2000) whilst potentially offering the proven benefits of cross-education to periods of detraining (Magnus *et al.,* 2010; Farthing, 2011; Farthing *et al.,* 2009; Magnus *et al.,* 2013).

2.2.3 Drop jump test

The DJ tests were performed after the standardised warm-up (see Appendix C). The protocol for the DJ utilised a 310 mm wooden box that the participant stood on with the front of their trainers aligned with the front edge of the box similar to Etnoyer *et al.* (2013) and Pappas *et al.* (2012) who used 300 mm and 400 mm respectively. Participants were instructed to drop directly forwards landing on both feet (landing) (Pappas *et al.,* 2012) before jumping as high as possible to achieve maximum jump height (Etnoyer *et al.,* 2013) with their arms and hands free to avoid a coaching effect (Pappas *et al.,* 2012) and landing (second landing) again on the force platform. See figure 2.2 for identification of the first and second landings.

Figure 2.2 Force trace showing first and second landing.

Three sub-maximal practice jumps were performed to allow familiarisation prior to three maximal jumps on each leg for the single-leg vertical jumps. The best jump was chosen from their data to reduce the possibility of an anomolous technique affecting results. The hardware was operated adhering to the strict protocol and consistent strong verbal encouragement was given to the participants to maximise their motivation.

2.2.4 Single leg vertical jump test

The single-leg vertical jump (SLVJ) tests were performed after the standardised warm-up (see Appendix C). Each participant stood on two feet until the audible beep signalled the beginning of the 8 s window for data capture at which point they performed knee flexion to lift one foot and bent the contralateral knee to 110°. They proceeded to perform a vertical jump with their arms and hands free to aid their balance. In addition to standardising the knee bend, arm and head movements were further considerations and were observed during practice by the supervisor who suggested modifications to jump technique to avoid any unwanted influence on biomechanics.

2.3.1 Instrumentation

The location for testing was the Science Centre of London Metropolitan University. The force platform tests were carried out in room SC1-03 on a pre-checked surface that allowed the platform to operate without any movement. The other hardware such as the amp, computer and associated wiring were all beside the platform set-up on a temporary desk to enable operation of the equipment whilst providing a vantage point to observe participant performance and supervise participant adherence to the strict protocol (Gandevia, 2001). The room temperature was a set and maintained at 20° centigrade for all testing using the room's thermostatic control dial.

The variables measured through the use of the force platform and video analysis were as follows:

- Peak Force (N)
- Force Adjusted for Bodyweight (N·Kg)
- Contact Time (s)
- Average RFD ($N \cdot m \cdot s^{-1}$)
- Propulsion (s)
- Deceleration ($m \cdot s^{-1}$)
- Velocity ($m \cdot s^{-1}$)

- Power (W)
- Flight Time (s)
- Jump Height (cm)
- KAM Probability
- Knee Valgus (cm)

Bioware software and a Kistler 9286A Force Platform (Kistler, UK) with its associated amp were used to measure the variables for DJs and SLVJs. Vertical jump height (cm) was be calculated by using the following formula $gt^2/8$ (g = acceleration due to gravity ($9.81ms^{-2}$) t = flight time of the jump (s) (Young, 1995 in Maulder and Cronin, 2005 p. 77). Take off *(T1)* and landing *(T2)* were identified by the disappearance and reappearance of the *Fz* trace; these figures were used to calculate Flight Time *(FT)* by subtracting *T1* from *T*2.

The force platform was chosen for its capacity to produce functional and biomechanical measurements. To standardise jumps a goniometer was employed to gauge the angle of knee bend for the single-leg vertical jumps using the lateral epicondyle of the tibia. The angle of knee bend was set at 110° providing a relatively shallow and repeatable angle compared to the 120° used by Maulder and Cronin (2005) for double leg vertical jumps. This was then employed through the use of a metal stand (see figure 2.3) which held a metre ruler in place horizontally which was positioned so a participant’s gluteal muscles would come into contact when knee bend was at 110°.

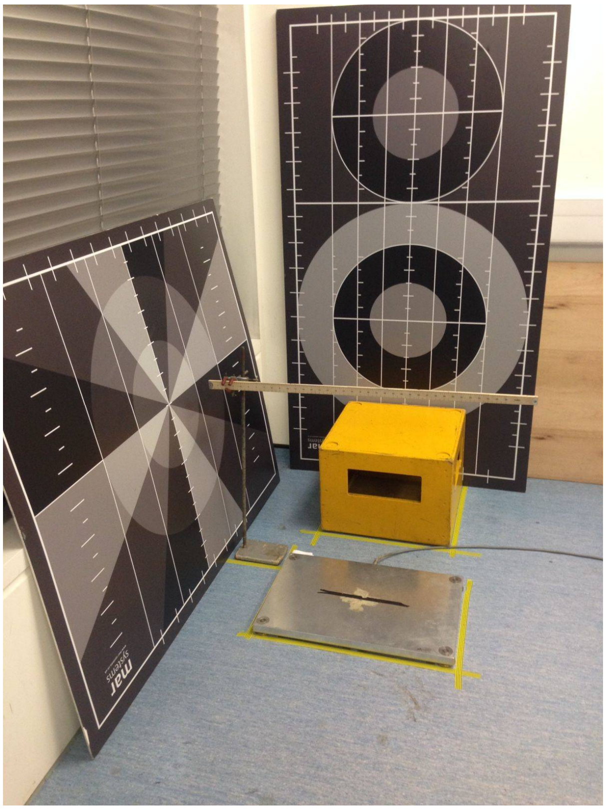
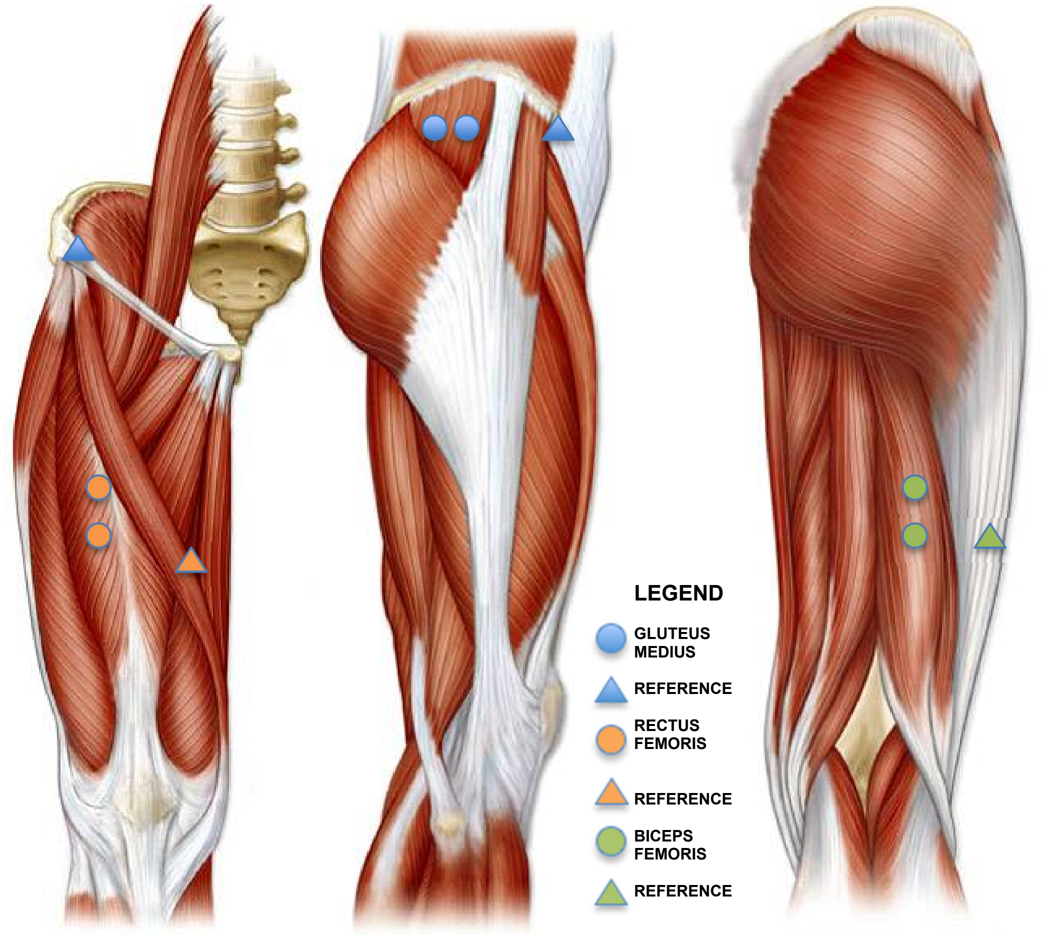


Figure 2.3 Drop jump box, force platform and metal stand to standardise knee flexion angle during unilateral jumps.

An eight channel surface electromyography (sEMG) unit (ME6000, Megawin sEMG, Finland) was used to assess the muscle activation of gluteus medius, rectus femoris and biceps femoris during jumps. In preparation for electrode placement, participants' skin was shaved with disposable plastic razors, lightly scoured using a small square of scouring material and cleaned with alcohol wipes. This was to reduce the inter-electrode impedance below 5 KΩ and ensure that the electrode connection was optimal (Padulo *et al.*, 2013; Hayes and Morse, 2010 p. 703). Electrode placement for gluteus medius included placing two, pre-gelled, 4 x 3.3 cm, Ag/AgCl, 3M 2228, Canada foam adhesive monitoring electrodes on the hip, 20 to 30 mm below the iliac crest and 20 mm apart. The reference electrode was placed on the anterior iliac spine (in accordance to the Megawin 3.0 Software User Manual, 2010) (see figure 2.4).



(a) Right thigh, anterior view (b) Right thigh, lateral view (a) Right thigh, posterior view

Figure 2.4 Megawin sEMG electrode placement for gluteus medius, rectus femoris and biceps femoris muscles.

(Francis Marion University, 2013)

Rectus femoris electrodes were placed at 50% on the line from the anterior spina iliaca superior to the superior part of the patella (see figure 2.4) and 20 mm apart (Hermens *et al.,* 2000 in Padulo, 2013 p. 2; SENIAM, 2014). The reference electrode was placed nearby on the adductors close to the tendon (in accordance to the Megawin 3.0 Software User Manual, 2010).

Bicep femoris electrodes were placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia (see figure 2.4) and 20 mm apart (SENIAM, 2014). The reference electrode was placed on the iliotibial band (in accordance to the Megawin 3.0 Software User Manual, 2010). Palpations and visual identification determined the placement of the electrodes (Hayes and Morse, 2010).

sEMG data were initially recorded in .TFF files unique to Megawin software. These data were band-pass filtered (10 to 350 Hz) using a Butterworth Filter (4th order) to smooth and convert to positive figures. The RMS figure provided a trace that indicated the intensity of the sEMG reading sampled at 1000Hz similar to Malliaras *et al.* (2013) who used 1500Hz. Maximum figures for a given EMG channel were calculated and 10% of that figure was used to determine the start and end of electrical activity during a muscular contraction. A mean and integrated figure over 1 s (Hayes and Morse, 2010) for the RMS data were calculated for the MVIC reading for each muscle group (f(x)dx).

The same calculations were made for the jump data between the start and end of the electrical activity and the MVIC results were used to determine a percentage MVIC contraction for the different phases of the jumps. This process provided a reading of the RMS but also afforded the opportunity to overlay the graphs using the time point 0 compared with the ‘start’ of each trace to allow a comparison between the timings of activation for each muscle group during each test.

MVICs in conjunction with sEMG readings for gluteus medius, rectus femoris and bicep femoris were measured using an isokinetic dynamometer (Computer Sports Medicine, Inc. (CSMI) HUMAC®/NORM™ Testing and Rehabilitation System, USA). Cross-validation between Biodex and Cybex HUMAC®/NORM™ systems has been conducted showing a good level of agreement (Alvares *et al.,* 2015). sEMG measures for jump performance were calculated as a percentage of the MVIC. A side lying position was used to test the MVIC of the gluteus medius muscle and incorporated the following parts; Knee / Hip Adaptor, Knee / Hip Pad and Toso Belt (CSMI, 2006). The scale settings for this position can be seen in Table 2.2 and participant position in figure 2.5. Participants' ROM was recorded and settings were calibrated to recognise the limb's positioning at 0°. Three trials of 5 s each were used to record the MVIC for both right and left hip abduction with 30 s rest period between trials. Verbal encouragement was given throughout each of these tests to optimise participant engagement and motivation.

Table 2.2 Scale positions for the HUMAC®/NORM™ for right and left abduction (CSMI, 2006)

Scale or Position	Setting
Chair-Back Translation	0°
Chair Rotation Scale	0°
Chair-Back Angle	0°
Chair-Seat position	Flat
Dyna Tilt Scale	0°
Dyna Height Scale	23
Dyna Rotation Scale	0°
Monorail Scale	0°

Figure 2.5 HUMAC®/NORM™ positioning for the hip abduction MVIC test for the left gluteus medius.

A seated position was used to test the MVIC for the rectus femoris and biceps femoris and involved the following parts; Knee/Hip Adaptor, Contralateral Limb Stabilizer, Knee/Hip Pad and Lumbar Cushion (CSMI, 2006). The knee / hip pad was placed just above the talo-crural joint on the involved limb. This pad was placed anteriorly for the rectus femoris tests and posteriorly for the biceps femoris tests. For all tests the axis of rotation of the joint was in line with that of the dynamometer. See table 2.3 for the scale settings and figure 2.6 for participant position. Participants' range of movement was recorded and the settings were calibrated to recognise the limb's positioning at 45°. Three trials of 5 s each were used to record the MVIC for both right and left hip abduction. Verbal encouragement was given throughout each of these tests to optimise participant engagement and motivation (Munn *et al.,* 2003; Baechle and Earle, 2000).

Table 2.3 Scale positions for the HUMAC®/NORM™ for right and left knee extension and flexion (CSMI, 2006)

Scale or Position	Setting
Chair Rotation Scale	40°
Chair-Back Angle	85°
Chair-Seat position	Up
Dyna Tilt Scale	0°
Dyna Height Scale	8°
Dyna Rotation Scale	40°
Monorail Scale	38


[redacted]

Figure 2.6 HUMAC®/NORM™ positioning for the knee for the MVIC test for the left biceps femoris.

2.3.2 Video analysis

A field based algorithm with excellent inter-rater reliability developed by Myer *et al.* (2012a) was used to measure and analyse jumping biomechanics and identify associated ACL risk factors (Myer *et al.,* 2011 in Myer *et al.,* 2012a p. 2267).

Video cameras (SONY Handycam HDR-XR520VE Exmor R HDD 240GB) were placed 620 mm using a tripod and as far away as possible from the jump area, in this case 2066 mm (frontal plane) and 1750 mm (sagittal plane) (Myer *et al.,* 2012a). Myer *et al.* (2012a p. 2268) recommends that four video frames should be used; '(I1) frontal plane view with frame before initial contact, (I2) frontal plane view of frame with knee in maximum medial (valgus) position, (I3) sagittal plane view with frame before initial contact and (I4) sagittal plane view of frame with knee in maximum flexion position.' Kinovea video analysis software was utilised to analyse the jumps (Kinovea, 2015). The Kinovea (version 0.8.15 software) scale tool was calibrated using the measurement for the front and side edges of the force platform to allow lines to be drawn to scale on the jump videos.

Tibia Length was measured in the sagittal view with the participant's knees in extension. Electronic markers were placed at the lateral joint line of the left leg and the distal tip of the left lateral malleolus. The distance between the two markers was then measured with the Kinovea measurement tool (Myer *et al.,* 2012a).

Knee valgus motion was measured in the frontal view and used electronic markers placed in the centre of each patella. The distance between I1 and I2 was measured using the Kinovea measurement tool (Myer *et al.,* 2012a; (Myer *et al.,* 2012b).

Knee Flexion ROM was measured in the sagittal view using an electronic marker placed on the left lateral joint line with lines drawn through the left lateral malleolus and left greater trochanter for the Kinovea angle tool to produce angles at I3 and I4 to produce the total degrees of knee flexion on landing (Myer *et al.,* 2012a).

Body mass was recorded to the nearest kilogram and a surrogate measure was obtained for the quadriceps to hamstrings ratio by multiplying 0.01 by the participants mass and adding the result to 1.10 (Myer *et al.,* 2012a). These data were then plotted on a nomogram (see figure 2.7) to provide the probability of high knee load (Myer *et al.,* 2012a).

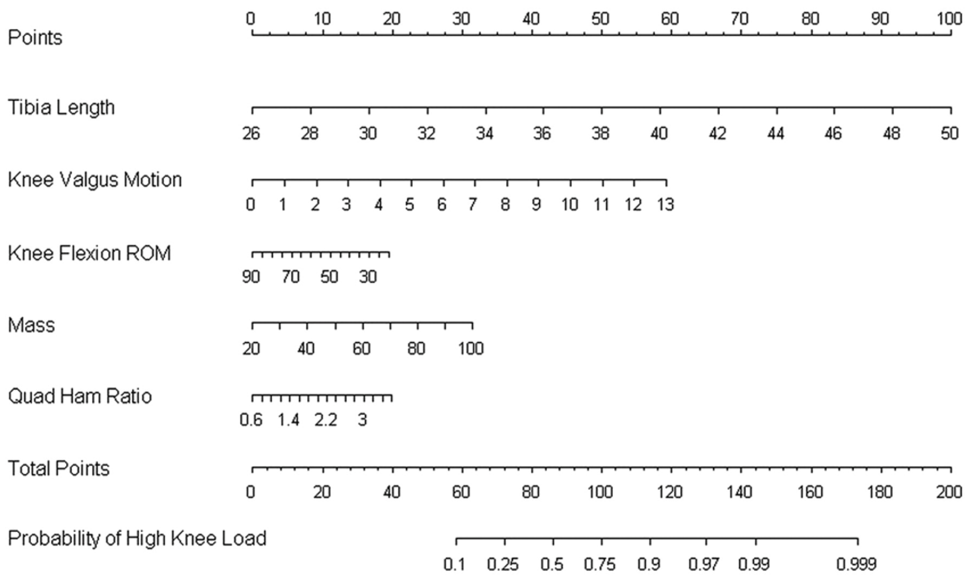


Figure 2.7 Nomogram used to predict the probability of high knee load.

(Myer *et al.,* 2012a p. 2266)

2.5 Data analysis

All data were analysed using SPSS version 22.0.0.0 software. Normality of distribution were analysed using Shapiro-Wilk tests. Data are reported as the mean ± standard deviation (SD). The training intervention (weeks 1 to 6) were analysed using a student t-test. An Alpha was set *a* priori at $P < 0.05$ was considered statistically significant.

A 2-way ANOVA with repeated measures was used to test the effects of group (CEG vs DTG) and time (pre vs post-intervention) on all outcome variables. Where significant differences were identified a Tukey post-hoc test was used to determine where they lay. An Alpha was set *a* priori at $P < 0.05$ was considered statistically significant. Effect sizes were calculated using Cohen's $d = M_1 - M_2 / s_{pooled}$ where $s_{pooled} = \sqrt{[(s_1^2 + s_2^2) / 2]}$ (Becker, 1999) and eta squared $\eta^2 = SS_{between} / SS_{total}$.

Chapter 3. Results

The data were found to be parametric.

3.1 Pre-plyometrics vs post-plyometrics (bilateral training time 1 vs 2)

Drop Jumps

There was no significant difference between pre and post-tests for peak force for the first landing (*P* = 0.06, *d* = 0.24). There was no significant difference between pre and post-tests for force adjusted for bodyweight for the first landing (*P* = 0.85, *d* = -0.03). There was no significant difference between pre and post-tests for force adjusted for bodyweight for the second landing (*P* = 0.05, *d* = 0.43). There was a significant reduction between pre and post-tests for RFD (*P* = 0.04, *d* = -0.14).

There was a significant greater contact time post-test for the first landing (*P* = 0.02, *d* = -0.52). There was no significant difference between pre and post-tests for flight time or jump height (*P* = 1.00, *d* = 0.01).

There was a significantly reduced deceleration post-test for the first landing (*P* = 0.01, *d* = 0.27). There was no significant difference between pre and post-tests for velocity for the first landing (*P* = 0.17, *d* = -0.24). There was no significant difference between pre and post-tests for deceleration for the second landing (*P* = 3.36, *d* = 0.18).

There was no significant difference between pre and post-tests for power for the first landing (*P* = 0.27, *d* = -0.15). There was no significant difference between pre and post-tests for power for the second landing (*P* = 0.44, *d* = 0.25).

3.1.2 Pre-plyometrics vs Post-plyometrics (bilateral training time 1 vs 2)

Single Leg Vertical Jumps (left)

There was a significantly reduced propulsion time post-test (*P* = 0.02, *d* = 1.30). There was a significantly reduced flight time and jump height post-test (*P* = 0.01, *d* = 0.40).

There was no significant difference between pre and post-tests for peak force for take off (*P* = 0.12, *d* = -0.21). There was no significant difference between pre and post-tests for RFD (*P* = 0.07, *d* = 0.53). There was no significant difference between pre and post-tests for landing force (*P* = 0.18, *d* = 0.29).

There was a significantly reduced velocity post-test for take off (*P* = 0.02, *d* = 0.98). There was no significant difference between pre and post-tests for deceleration on landing (*P* = 0.13, *d* = 0.33).

There was a significantly reduced peak power post-test for take off (*P* = 0.02, *d* = 0.82).There was no significant difference between pre and post-tests for peak power adjusted for bodyweight for take off (*P* = 0.63, *d* = 0.16). There was a significantly reduced peak power post-test for landing (*P* = 0.01, *d* = 0.92). There was no significant difference between pre and post-tests for peak power adjusted for bodyweight on landing (*P* = 0.05, *d* = 0.41).

3.1.3 Pre-plyometrics vs Post-plyometrics (bilateral training time 1 vs Single Leg Vertical Jumps (right)

There was a significantly reduced for propulsion time post-test (*P* = 0.00, *d* = 1.77). There was a significantly reduced flight time and jump height post-test (*P* = 0.03, *d* = 0.47).

There was no significant difference between pre and post-tests for peak force for take off (*P* = 0.42, *d* = 0.26). There was no significant difference between pre and post-tests for RFD (*P* = 0.21, *d* = 1.02). There was no significant difference between pre and post-tests for peak landing force (*P* = 0.30, *d* = 0.33).

There was a significantly reduced velocity post-test for take off (*P* = 0.02, *d* = 0.88). There was no significant difference between pre and post-tests for deceleration on landing (*P* = 0.17, *d* = 0.32).

There was a significantly reduced peak power post-test for take off (*P* = 0.02, *d* = 0.69). There was no significant difference between pre and post-tests for peak power adjusted for bodyweight for take off (*P* = 0.78, *d* = 2.83). There was significantly reduced peak power post-test on landing (*P* = 0.01, *d* = 0.87). There was no significant difference between pre and post-tests for peak power adjusted for bodyweight on landing (*P* = 0.13, *d* = 0.41).

3.2.1 Pre-intervention vs post-intervention (unilateral training time 2 vs 3) Drop Jumps (CEG and DTG)

There was no significant effect on force for time (P = 0.45, η^2 = 0.01), interaction (P = 0.69, η^2 = 0.01) or group (P = 0.97, η^2 = 0.01) for the first landing. There was no significant effect on force adjusted for bodyweight for the first landing for time (P = 0.63, η^2 = 0.01), interaction (P = 0.99, η^2 = 0.01) or group (P = 0.21, η^2 = 0.01). There was no significant effect on RFD for time (P = 0.34, η^2 = 0.02), interaction (P = 0.74, η^2 = 0.02) or group (P = 0.77, η^2 = 0.02). There was no significant effect on force adjusted for bodyweight for the second landing for time (P = 0.45, η^2 = 0.01), interaction (P = 0.65, η^2 = 0.01) or group (P = 0.22, η^2 = 0.01).

There was no significant effect on contact time for the first landing for time (P = 0.22, η^2 = 0.02), interaction (P = 0.79, η^2 = 0.02) or group (P = 0.55, η^2 = 0.02). There was no significant effect on flight time or jump height time (P = 0.07, η^2 = 0.01), interaction (P = 0.59, η^2 = 0.01) or group (P = 0.55, η^2 = 0.01).

There was no significant effect on time for deceleration for the first landing for time (P = 0.44, η^2 = 0.01), interaction (P = 0.31, η^2 = 0.01) or group (P = 0.70, η^2 = 0.01). There was a significant effect on velocity for the first landing for time (P = 0.02, η^2 = 0.10) and no significant effect on interaction (P = 0.50, η^2 = 0.10) or group (P = 0.21, η^2 = 0.10). There was no significant effect on deceleration for the second landing for time ($P = 0.07$, $\eta^2 = 0.01$), interaction ($P = 0.74$, $\eta^2 = 0.01$) or group ($P = 0.91$, $\eta^2 = 0.01$).

There was no significant effect on power for the first landing time ($P = 0.75$, $\eta^2 = 0.01$), interaction ($P = 0.69$, $\eta^2 = 0.01$) or group ($P = 0.58$, $\eta^2 = 0.01$) There was no significant difference between pre and post-tests for power for the second landing ($P = 0.69$, $\eta^2 = 0.01$).

There was no significant effect on KAM probability on DJ landing and take off for time ($P = 0.32$, $\eta^2 = 0.18$), interaction ($P = 0.96$, $\eta^2 = 0.18$) or group ($P = 0.52$, $\eta^2 = 0.18$).

3.2.2 Pre-intervention vs Post-intervention (Time 2 vs 3)

Single Leg Vertical Jumps (CEG (training limb and detraining limb) DTG)

There was no significant effect on propulsion time for time ($P = 0.21$, $\eta^2 = 0.01$), interaction ($P = 0.36$, $\eta^2 = 0.01$) or group ($P = 0.60$, $\eta^2 = 0.01$). There was no significant effect on flight time or jump height for time ($P = 0.51$, $\eta^2 = 0.01$), interaction ($P = 0.83$, $\eta^2 = 0.01$) or group ($P = 0.97$, $\eta^2 = 0.01$).

There was no significant effect on peak force for take off for time ($P = 0.13$, $\eta^2 = 0.05$), interaction ($P = 0.65$, $\eta^2 = 0.05$) or group ($P = 0.53$, $\eta^2 = 0.05$). There was no significant effect on RFD for take off for time ($P = 0.17$, $\eta^2 = 0.03$), interaction ($P = 0.51$, $\eta^2 = 0.03$) or group ($P = 0.57$, $\eta^2 = 0.03$). There was no significant effect on peak landing force time (P = 0.32, η^2 = 0.04), interaction (P = 0.78, η^2 = 0.04) or group (P = 0.58, η^2 = 0.04).

There was no significant effect on velocity for take off for time (P = 0.69, η^2 = 0.02), a significant effect on interaction (P = 0.02, η^2 = 0.02) and no significant effect on group (P = 0.74, η^2 = 0.02). There was no significant effect on landing for time (P = 0.25, η^2 = 0.01), interaction (P = 0.75, η^2 = 0.01) or group (P = 0.87, η^2 = 0.01).

There was no significant effects on peak power for take off for time (P = 0.87, η^2 = 0.01), a significant effect on interaction (P = 0.04, η^2 = 0.01) and no significant effect on group (P = 0.39, η^2 = 0.01). There was no significant effect on peak power adjusted for bodyweight for take off time (P = 0.24, η^2 = 0.06), interaction (P = 0.99, η^2 = 0.06) or group (P = 0.51, η^2 = 0.06). There was no significant effect on peak power on landing for time (P = 0.24, η^2 = 0.01), interaction (P = 0.09, η^2 = 0.01) or group (P = 0.39, η^2 = 0.01). There was no significant effect on peak power adjusted for bodyweight on landing for time (P = 0.15, η^2 = 0.01), interaction (P = 0.84, η^2 = 0.01) or group (P = 0.54, η^2 = 0.01).

There was no significant effect on knee valgus for landing for time (P = 0.29, η^2 = 0.01), interaction (P = 1.00, η^2 = 0.01) or group (P = 0.88, η^2 = 0.01).

Table 3.1 Pre-plyometric DJ tests compared with post-plyometric DJ tests (test period 1 vs 2) for all participants

Variable	Mean Pre-Plyos (SD)	Mean Post-Plyos (SD)	P Value	Cohen's *d*
DJ Peak Force on First Landing (N)	2189 (596.34)	2060 (493.71)	0.06	0.24
DJ Contact Time on First Landing (s)	0.37 (0.08)	0.42 (0.11)	0.02*	-0.52
DJ average RFD (**N·m·s^{-1}**)	6727.03	4904.76	0.04*	-0.14
DJ Deceleration (m·s^{-1}) **(Force Acel First Landing)**	35.79 (10.24)	33.34 (8.30)	0.01*	0.27
DJ Velocity on First Landing (m·s^{-1})	7.94 (0.95)	8.21 (1.30)	0.17	-0.24
DJ Power on First Landing (W)	9940 (1698)	10199 (1791)	0.27	-0.15
DJ Force Adjusted For Bodyweight on First Landing (N/Kg)	143356 (65137)	145340 (54652)	0.85	-0.03
DJ Flight Time (s)	0.44 (0.06)	0.44 (0.06)	1.00	0.01
DJ Jump Height (cm)	23.74 (0.06)	23.74 (0.06)	1.00	0.01
DJ Deceleration on Second Landing (m·s^{-1})	42.47 (9.36)	40.94 (7.22)	3.36	0.18
DJ Power on Second Landing (W)	26614 (14061)	24026 (4560)	0.44	0.25
DJ Force Adjusted for Bodyweight on Second Landing (N·Kg)	228655 (126650)	185110 (66703)	0.05	0.43

Table 3.2 Pre-plyometric SLVJ tests compared with post-plyometric SLVJ tests (test period 1 vs 2) for all participants

Variable	Mean Pre-Plyos (SD)	Mean Post-Plyos (SD)	P Value	Cohen's *d*
SLVJ L Propulsion Time (s)	0.81 (0.21)	0.6 (0.09)	0.02*	1.30
SLVJ L Peak Force on Take Off (N)	1107 (173.26)	1148 (166.23)	>0.05	-0.24
SLVJ L Average RFD (N·m·s^{-1})	1366.67	1913.33	>0.05	0.53
SLVJ L Acceleration on Take Off (m·s^{-1}) (acceltakeoff)	17.78 (2.64)	18.22 (1.45)	>0.05	-0.21
SLVJ L Velocity of Take Off (m·s^{-1})	39.38 (8.96)	31.70 (6.61)	0.02*	0.98
SLVJ L Peak Power on Take Off (W)	41288 (8810)	34251 (8280)	0.02*	0.82
SLVJ L Peak Power on Take Off Adjusted for Bodyweight (W·Kg)	8075 (6170)	7367 (1403)	>0.05	0.16
SLVJ L Flight Time (s)	0.32 (0.05)	0.30 (0.05)	0.01*	0.40
SLVJ L Height (cm)	12.56 (0.05)	11.30 (0.05)	0.01*	0.40
SLVJ L Peak Landing Force (N)	1974 (391.10)	1866 (363.76)	>0.05	0.29
SLVJ L Deceleration on Landing (m·s^{-1}) (accel landing)	32.01 (7.61)	29.72 (6.15)	>0.05	0.33
SLVJ L Peak Power on Landing (W)	80849 (28509)	60171 (13879)	0.01*	0.92
SLVJ L Peak Power on Landing Adjusted for Bodyweight (W·Kg)	130634 (71545)	104091 (56043)	>0.05	0.41
SLVJ R Propulsion Time (s)	0.83 (0.20)	0.58 (0.01)	0.00*	1.77
SLVJ R Peak Force on Take Off (N)	1310 (833.00)	1155 (177.67)	>0.05	0.26
SLVJ R Average RFD (m·s^{-1})	1578.31	1991.37	>0.05	1.02
SLVJ R Acceleration on Take off (m·s^{-1})	18.16 (2.34)	18.56 (2.05)	>0.05	-0.18
SLVJ R Velocity of Take Off (m·s^{-1})	44.10 (15.76)	33.32 (7.15)	0.02*	0.88
SLVJ R Peak Power on Take Off (W)	46025 (17067)	36517 (9303)	0.02*	0.69
SLVJ R Peak Power on Take Off Adjusted for Bodyweight (W·Kg)	8167 (4087)	7845 (1304)	>0.05	2.83
SLVJ R Flight Time (s)	0.32 (0.06)	0.30 (0.06)	0.03*	0.47
SLVJ R Height (cm)	12.56 (0.06)	11.30 (0.06)	0.03*	0.47
SLVJ R Peak Landing Force (N)	2356 (2064)	1859 (380.64)	>0.05	0.33
SLVJ R Deceleration on Landing (m·s^{-1}) (accel landing)	31.50 (6.45)	29.50 (5.90)	>0.05	0.32
SLVJ R Peak Power on Landing (W)	87778 (35859)	63632 (16044)	0.01*	0.87
SLVJ R Peak Power on Landing Adjusted for Bodyweight (W·Kg)	129277 (86113)	99934 (53373)	>0.05	0.41

Table 3.3 Post-plyometric DJ tests compared with post-intervention DJ tests (test period 2 vs 3) for CEG and DTG

Variable	Mean Post-Plyos CEG (SD)	Mean Post-Intervention CEG (SD)	Mean Post-Plyos DTG (SD)	Mean Post-Intervention DTG (SD)	P Value	Effect Size (Group) Eta squared
DJ Peak Force on First Landing (N)	2068 (368.20)	2092 (467.14)	2052 (618.26)	2129 (783.64)	>0.05	0.01
DJ Contact Time on First Landing (s)	0.43 (0.09)	0.45 (0.08)	0.40 (0.13)	0.41 (0.14)	>0.05	0.02
DJ Average RFD (m·s^{-1})	4809.30	4648.89	5130.00	5192.68	>0.05	0.02
DJ Deceleration (m·s^{-1})	33.08 (6.41)	32.83 (6.65)	33.60 (10.65)	35.51 (10.94)	>0.05	0.01
DJ Velocity on First Landing (m·s^{-1})	8.35 (0.80)	8.76 (1.15)	7.53 (0.96)	8.22 (1.65)	0.02*	0.10
DJ Power on First Landing (W)	10445 (1921)	10393 (2103)	9952 (1729)	10140 (2177)	>0.05	0.01
DJ Force Adjusted For Bodyweight on First Landing (N)	162884 (42058)	168198 (61357)	127797 (62335)	133527 (75360)	>0.05	0.01
DJ Flight Time (s)	0.45 (0.08)	0.44 (0.08)	0.44 (0.04)	0.42 (0.04)	>0.05	0.03
DJ Jump Height (cm)	24.83 (0.08)	23.74 (0.08)	23.74 (0.08)	21.63 (0.04)	>0.05	0.03
DJ Deceleration on Second Landing (m·s^{-1}) (DJ_Force Accel Second Landing)	41.05 (7.93)	37.18 (8.64)	40.83 (6.92)	38.14 (8.09)	>0.05	0.01
DJ Power on Second Landing (W)	25266 (4464)	23840 (5041)	22786 (4560)	24782 (11606)	>0.05	0.01
DJ Force Adjusted for Bodyweight on Second Landing (N·Kg)	208895 (72735)	246058 (208822)	161324 (53771)	170516 (79846)	>0.05	0.01
DJ KAM Probability	62.78 (25.58)	61.00 (23.58)	55.38 (20.13)	52.22 (23.77)	>0.05	0.18

Table 3.4 Post-plyometric SLVJ tests compared with post-intervention SLVJ tests (test period 2 vs 3) for CEG (unilateral training limb and detraining limb) and DTG

Variable	Mean Post-Plyos CEG (training) (SD)	Mean Post-Intervention CEG (training) (SD)	Mean Post-Plyos CEG (detraining) (SD)	Mean Post-Intervention CEG (detraining) (SD)	Mean Post-Plyos DTG (SD)	Mean Post-Intervention DTG (SD)	P Value	Effect Size (Group) Eta squared
SLVJ Propulsion Time (s)	0.54 (0.05)	0.63 (0.12)	0.59 (0.10)	0.61 (0.11)	0.62 (0.08)	0.61 (0.14)	>0.05	0.01
SLVJ Peak Force on Take Off (N)	1197 (155.78)	1182 (127.18)	1183 (163.93)	1127 (193.18)	1113 (183.83)	1092 (195.64)	>0.05	0.05
SLVJ Average RFD ($m \cdot s^{-1}$)	2216.67	1876.19	2005.98	1847.54	1795.16	1790.16	>0.05	0.03
SLVJ Acceleration on Take Off ($m \cdot s^{-1}$)	18.84 (1.53)	18.56 (1.25)	18.64 (1.66)	18.09 (1.51)	18.12 (1.96)	18.26 (2.33)	>0.05	0.02
SLVJ Velocity of Take Off ($m \cdot s^{-1}$)	30.65 (6.75)	36.39 (8.40)	31.75 (6.38)	32.69 (9.41)	33.62 (7.20)	28.64 (6.03)	>0.02*	0.02
SLVJ Peak Power on Take Off (W)	35109 (10677)	41069 (11646)	35511 (7017)	34532 (11913)	35149 (9670)	29247 (8665)	>0.04*	0.01
SLVJ Peak Power on Take Off Adjusted for Bodyweight (W·Kg)	7925 (730.74)	8260 (1395)	7320 (1860)	7739 (837.89)	7526 (1082)	7829 (1488)	>0.05	0.06
SLVJ Flight Time (s)	0.30 (0.07)	0.30 (0.07)	0.30 (0.06)	0.29 (0.05)	0.30 (0.05)	0.29 (0.04)	>0.05	0.01
SLVJ Height (cm)	11.30 (0.07)	11.30 (0.07)	11.30 (0.06)	10.31 (0.05)	11.30 (0.05)	10.31 (0.04)	>0.05	0.01
SLVJ Peak Landing Force (N)	1937 (339.82)	2059 (486.40)	1912 (376.22)	1936 (533.45)	1782 (389.76)	1822 (406.67)	>0.05	0.04
SLVJ Deceleration on Landing ($m \cdot s^{-1}$) (accel landing)	30.62 (5.19)	32.35 (7.31)	30.34 (6.34)	30.43 (7.82)	29.13 (6.30)	30.82 (7.37)	>0.05	0.01
SLVJ Peak Power on Landing (W)	62554 (21841)	78281 (32064)	61756 (12807)	67713 (32721)	60506 (11103)	53437 (15972)	>0.05	0.01

SLVJ Peak Power on Landing Adjusted for Bodyweight (W·Kg)	115020 (50198)	149375 (102857)	113289 (64962)	125025 (90964)	88778 (43369)	112236 (60502)	>0.05	0.01
SLVJ Video Knee Valgus (cm)	2.32 (1.69)	2.62 (2.50)	1.90 (1.81)	2.19 (2.55)	1.99 (1.33)	2.33 (1.77)	>0.05	0.01

3.3.1 sEMG muscle activation and percentage MVIC integrated during pre and post-intervention DJs

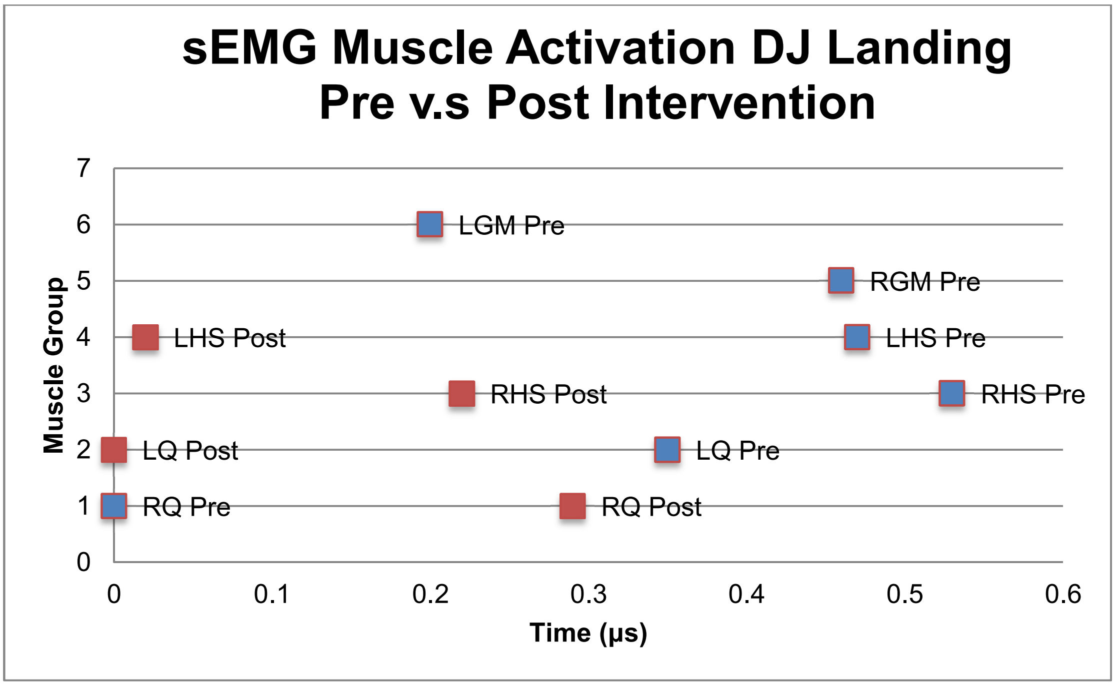


Figure 3.1 sEMG muscle activation for DJ landing pre vs post intervention.

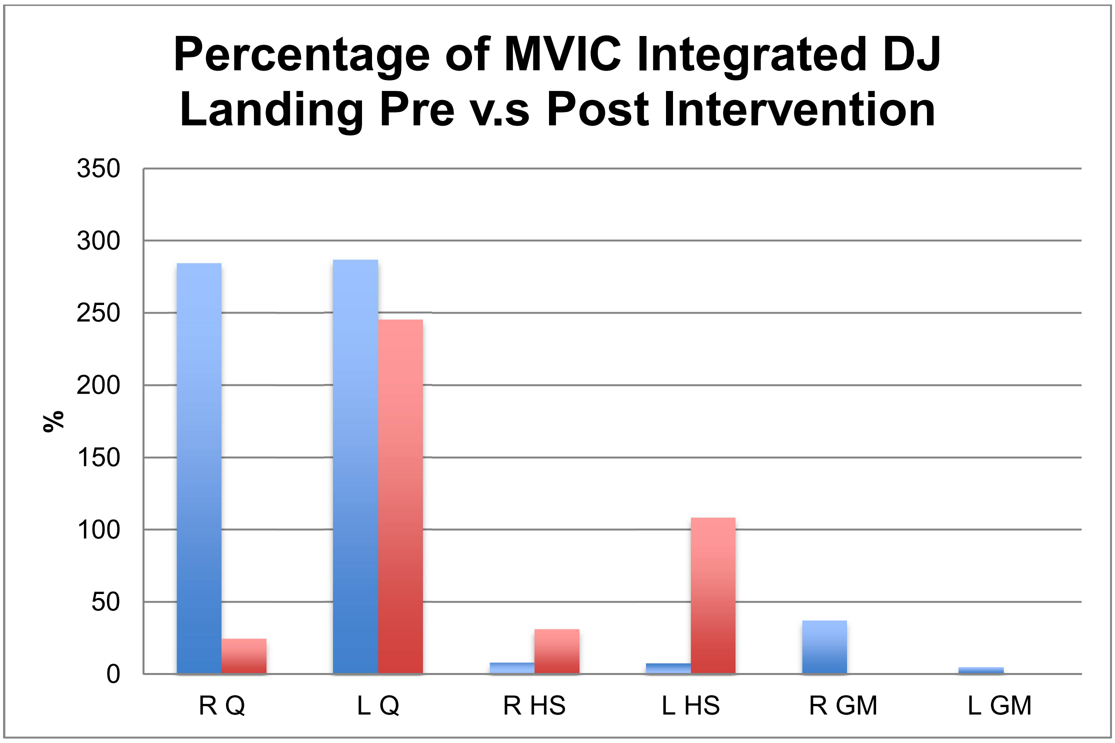


Figure 3.2 Percentage of MVIC integrated for landing of DJs pre vs post intervention.

R Q = right quadriceps, L Q = left quadriceps, R HS = right hamsrings, L HS = left hamstrings, R GM = right gluteus medius, L GM = left gluteus medius.

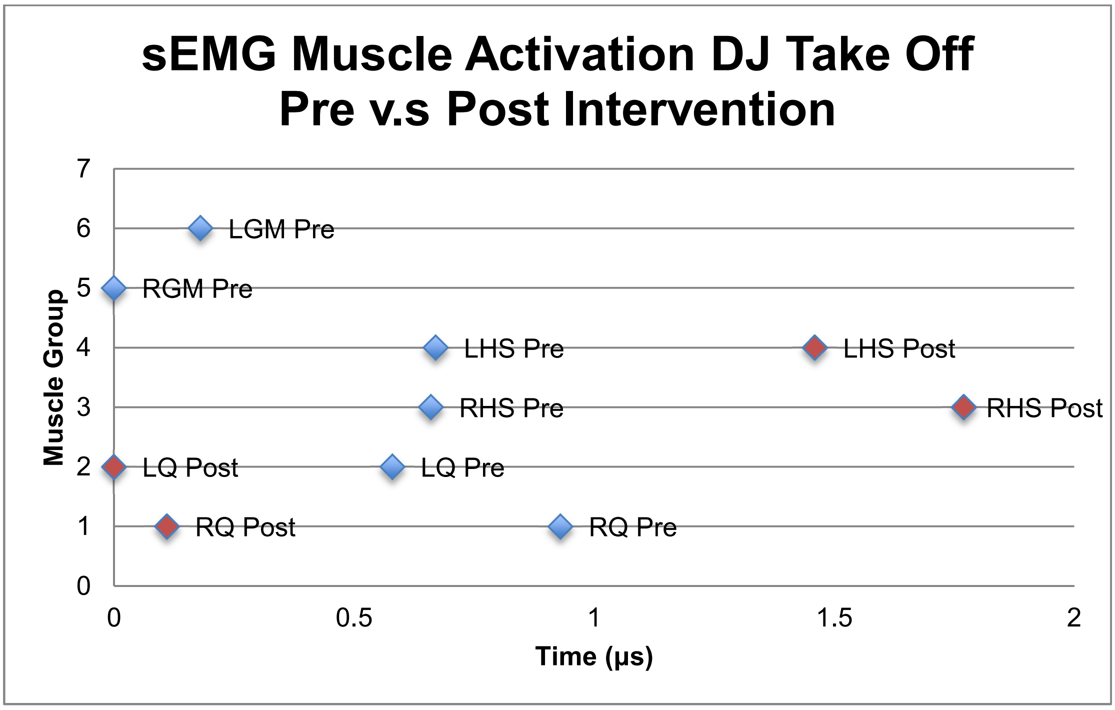


Figure 3.3 sEMG muscle activation for DJ take off pre vs post intervention.

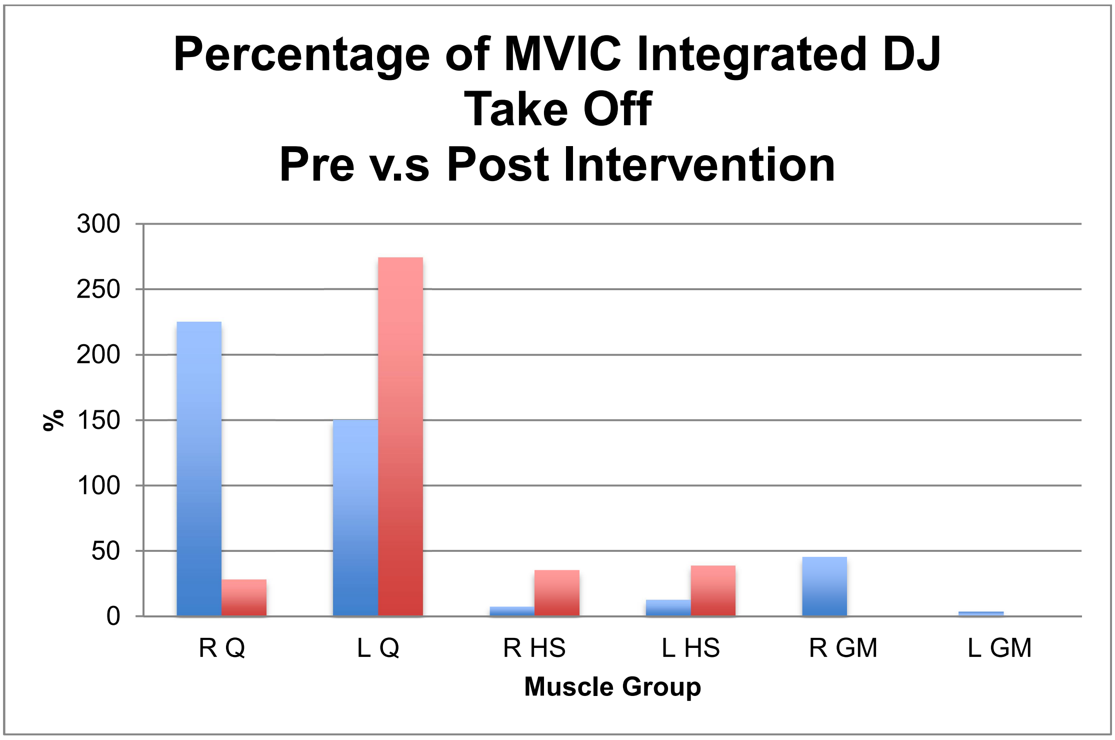


Figure 3.4 Percentage of MVIC integrated for take off of DJs pre vs post intervention.

R Q = right quadriceps, L Q = left quadriceps, R HS = right hamsrings, L HS = left hamstrings, R GM = right gluteus medius, L GM = left gluteus medius.

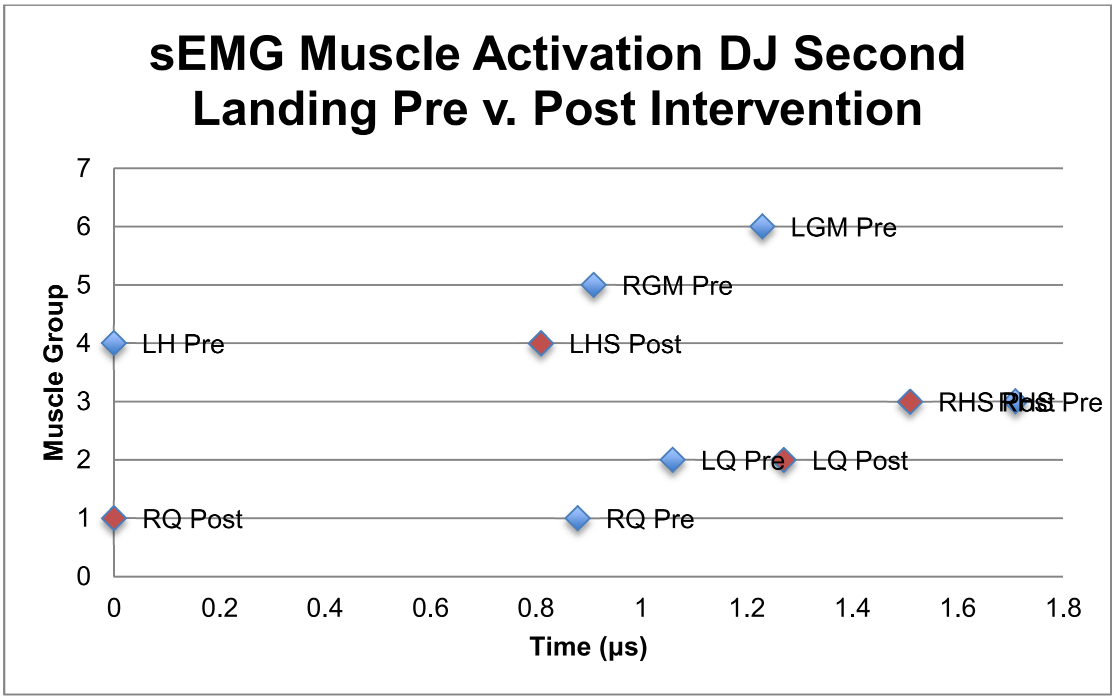


Figure 3.5 sEMG muscle activation for DJ second landing pre vs post intervention.

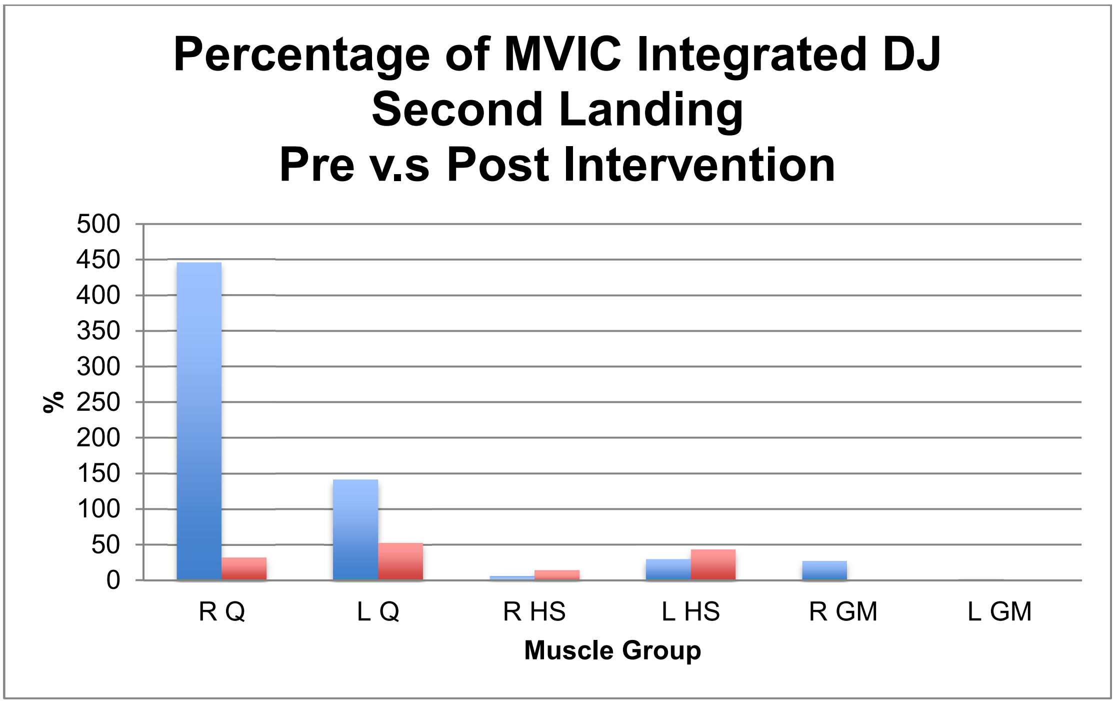


Figure 3.6 Percentage of MVIC integrated for second landing of DJs pre vs post intervention.

R Q = right quadriceps, L Q = left quadriceps, R HS = right hamsrings, L HS = left hamstrings, R GM = right gluteus medius, L GM = left gluteus medius.

Data were not available for R GM and L GM for the post-intervention results for all DJs. Figure 3.1 shows the post-intervention timing of activation for landings to be shorter in relation to the first muscle activated (R Q for pre and L Q for post in this case). R Q however was the last muscle to be activated post-intervention despite being the first for the initial measures. Figure 3.2 shows that MVIC was greater for the pre measures for the quadriceps but for hamstrings it was greater post-intervention.

Figure 3.3 shows R Q and L Q were both activated earlier for the DJ take off phase relative to the other muscles and both RHS and LHS were activated later during the post-intervention measures. Figure 3.4 shows that L Q, R HS and L HS all demonstrated a larger MVIC post-intervention.

Figure 3.5 shows less variation in the timing of muscle activation for the DJ second landing compared with the previous measures. L HS was the first muscle to contract for the pre tests and R Q was the first for the post-tests. Figure 3.6 shows that MVIC for R Q and LQ was greater during the pre-tests. R HS and L HS showed a small magnitude increase of MVIC for the post-tests.

3.3.2 sEMG muscle activation and percentage MVIC integrated during pre and post-intervention SLVJs

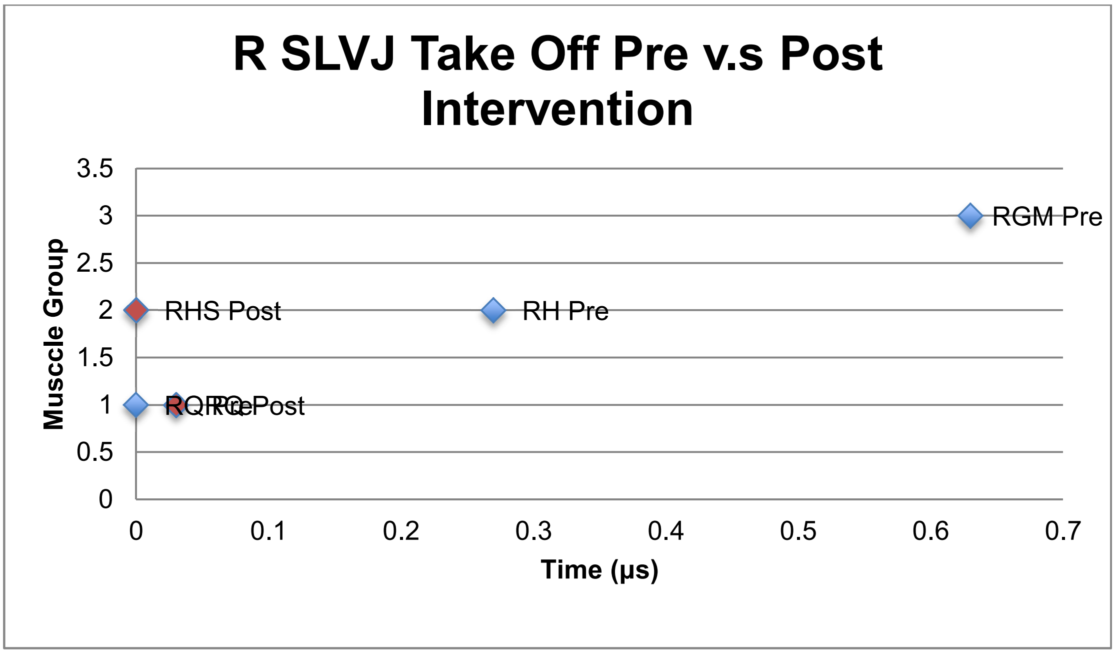


Figure 3.7 sEMG muscle activation for right SLVJ take off pre vs post intervention.

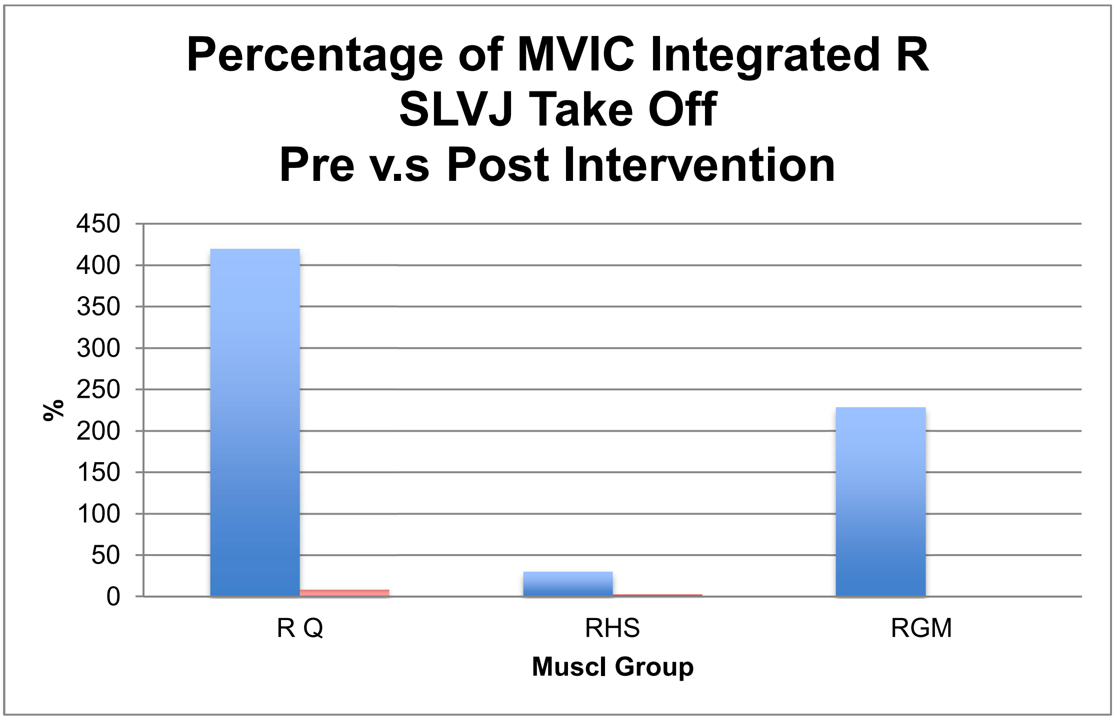


Figure 3.8 Percentage of MVIC integrated for take off of right SLVJs pre vs post intervention.

R Q = right quadriceps, L Q = left quadriceps, R HS = right hamsrings, L HS = left hamstrings, R GM = right gluteus medius, L GM = left gluteus medius.

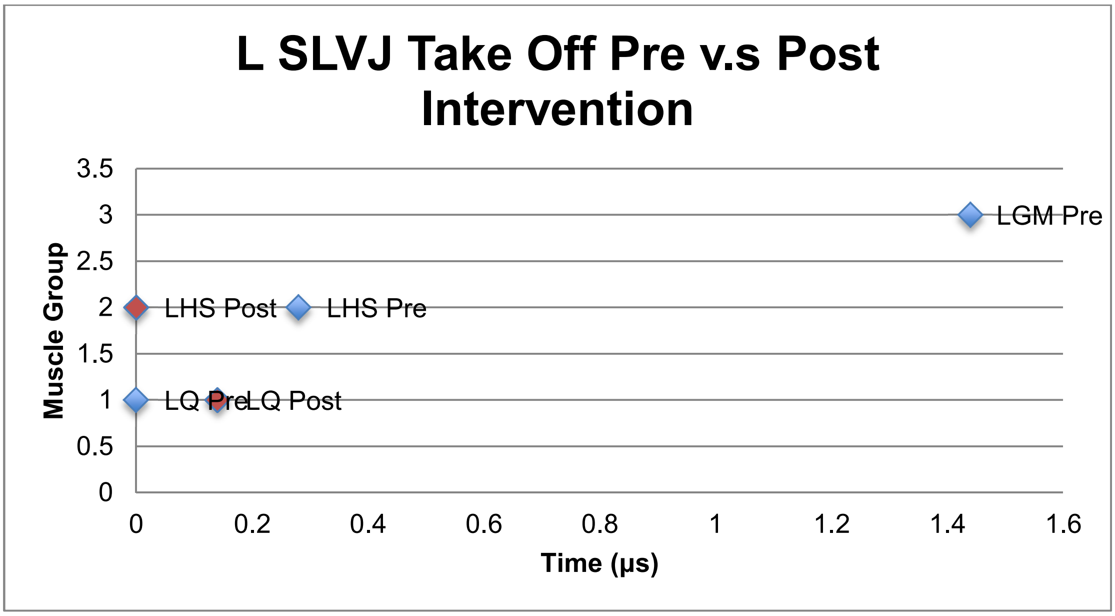


Figure 3.9 sEMG muscle activation for left SLVJ take off pre vs post intervention.

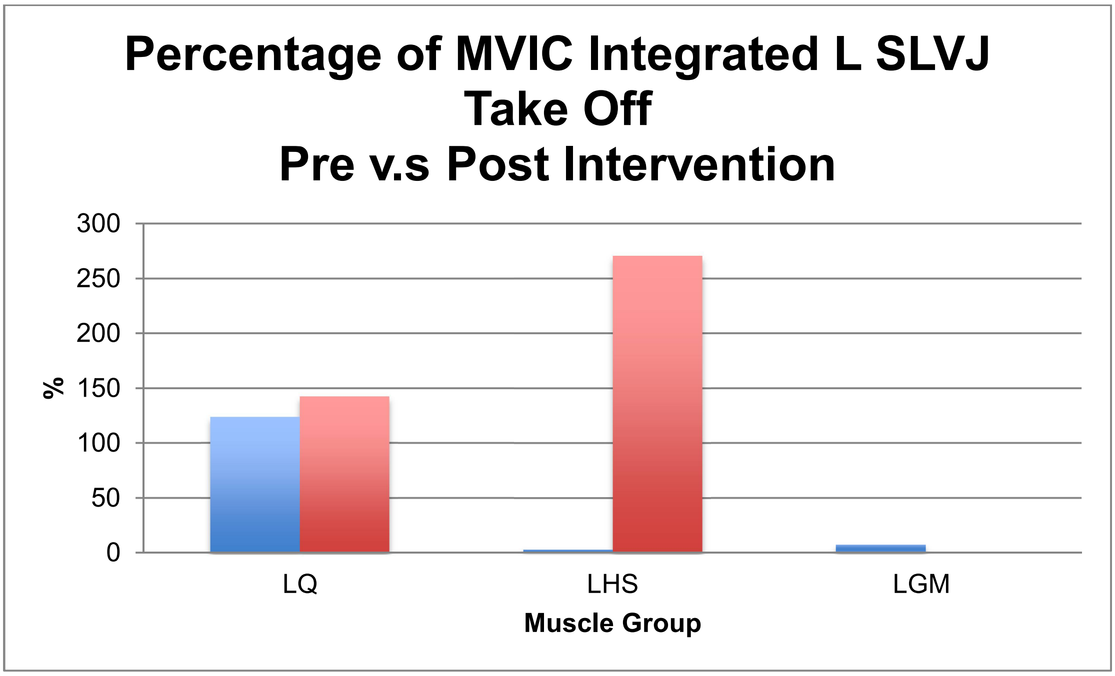


Figure 3.10 Percentage of MVIC integrated for take off of left SLVJs pre vs post intervention.

R Q = right quadriceps, L Q = left quadriceps, R HS = right hamsrings, L HS = left hamstrings, R GM = right gluteus medius, L GM = left gluteus medius.

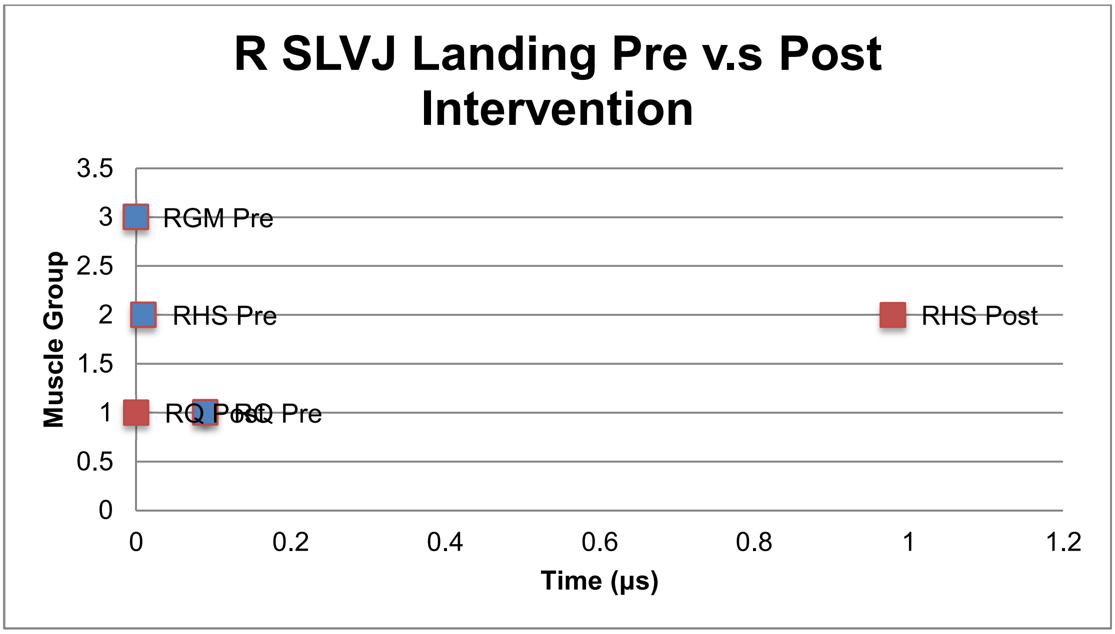


Figure 3.11 sEMG muscle activation for landing of right SLVJ pre vs post intervention.

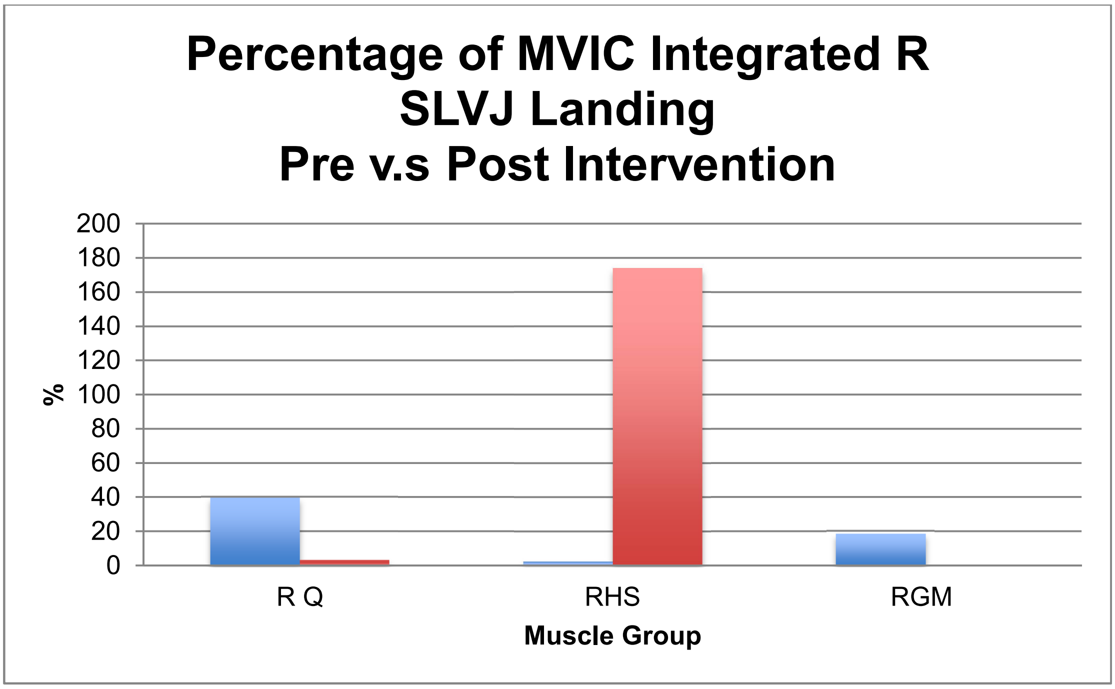


Figure 3.12 Percentage of MVIC integrated for landing of right SLVJs pre vs post intervention.

R Q = right quadriceps, L Q = left quadriceps, R HS = right hamsrings, L HS = left hamstrings, R GM = right gluteus medius, L GM = left gluteus medius.

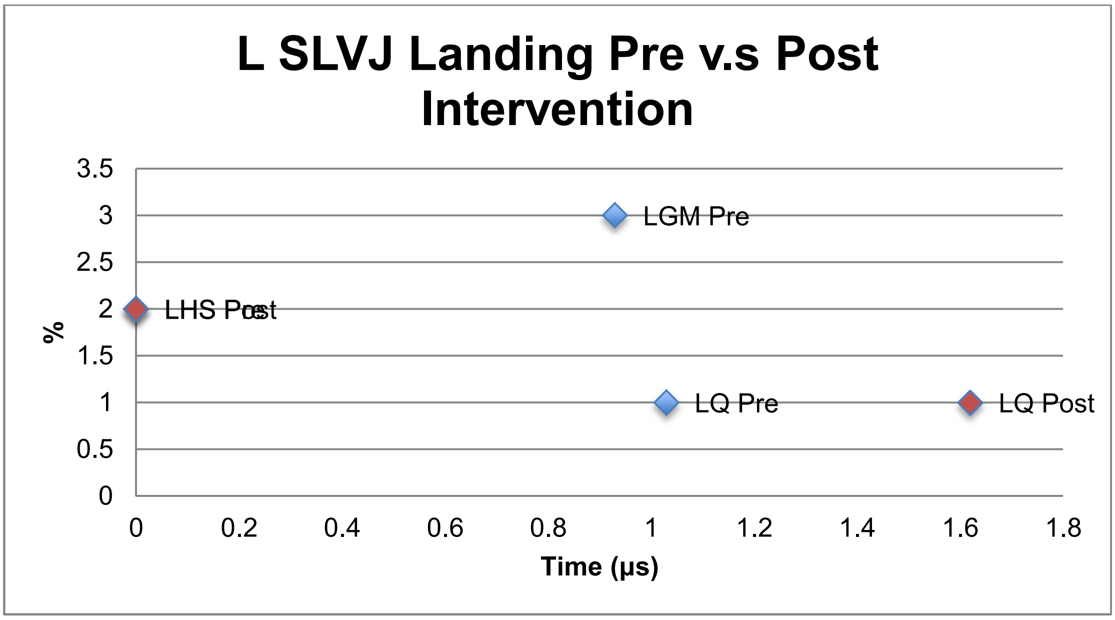


Figure 3.13 sEMG muscle activation for landing of left SLVJ pre vs post intervention.

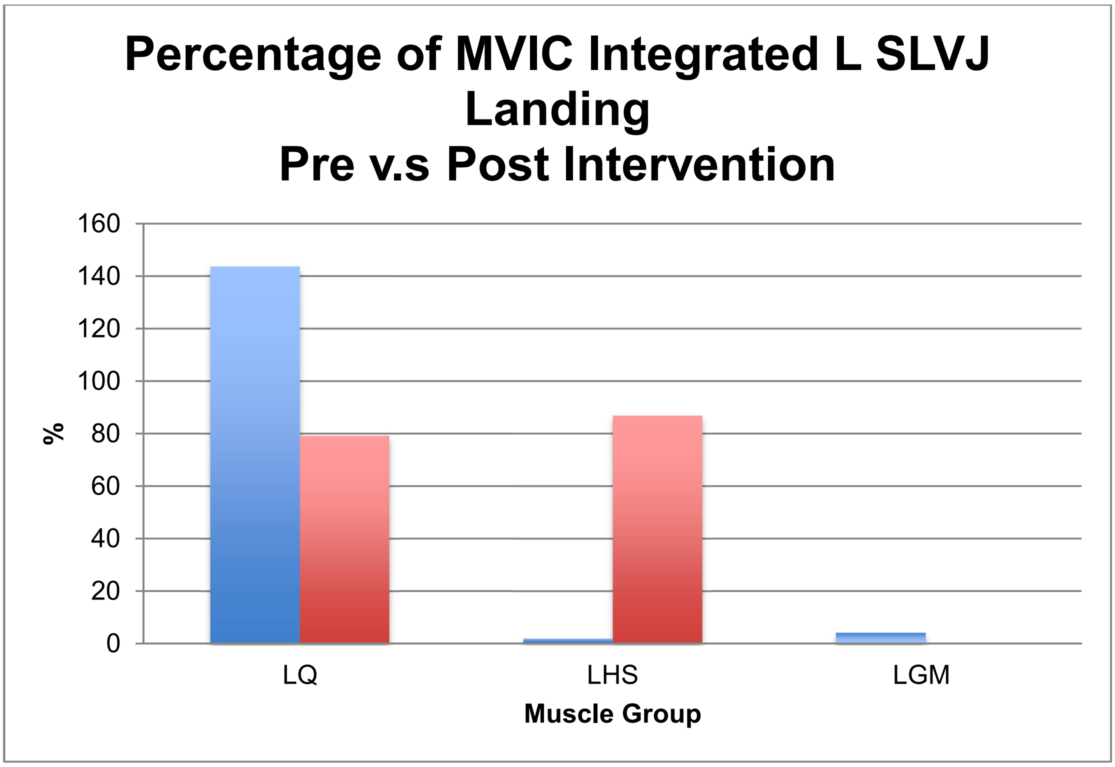


Figure 3.14 Percentage of MVIC integrated for landing of left SLVJs pre vs post intervention.

R Q = right quadriceps, L Q = left quadriceps, R HS = right hamsrings, L HS = left hamstrings, R GM = right gluteus medius, L GM = left gluteus medius.

Data were not available for RGM and LGM for the post-intervention results for all SLVJs. Figure 3.7 shows that RHS moved from the second muscle activated during the pre-intervention tests for R SLVJ take off to the first for the post intervention measures. Figure 3.8 shows that the MVIC for the R Q was > 400% for the pre intervention measures. RHS also demonstrated a higher pre-intervention MVIC but of a lesser magnitude. The L SLVJ for take off showed a similar shift for the L HS in comparison to the right which became the first to be activated following the post-intervention tests (see figure 3.9). However, in contrast to the R SLVJ the post-intervention measures demonstrated a higher MVIC for L Q and L HS (see Figure 10). LHS showed a far greater increase in MVIC > 250% compared to the L Q < 20%.

Figure 3.11 shows that R HS contracted before R Q during the landing phase of the R SLVJ pre intervention tests. The post-intervention tests demonstrated that R Q became the first to contract and the activation of R HS occurred almost 1µs later. Figure 3.12 shows MVIC was greater pre intervention for R Q < 5% but post intervention for R HS was > 150%. Figure 3.13 shows L HS were the first to contract for L SLVJ pre and post intervention tests for the landing phase. L Q was delayed in relation to L HS for the post intervention tests by 0.59µs. Figure 3.14 shows that the MVIC for the L Q was greater during the pre intervention tests and the L HS MVIC was greater during the post intervention measures.

Chapter 4. Discussion

This was the first study of its kind to investigate cross-education using a functional lower limb intervention and jump performance output measures with a view to apply the findings to a rehabilitation setting. A study by Papandreou *et al.* (2013) investigated cross-education in relation to ACL rehabilitation. However, no cross-education studies have incorporated functional exercises as part of the intervention or output measures. Significant improvements were seen for jump performance parameters following the initial six week plyometric programme. Following the nine week unilateral training intervention significant changes were recorded for DJ velocity on first landing for time ($P = 0.02$), SLVJ velocity on take off for interaction ($P = 0.02$) and SLVJ peak power on take off for interaction ($P = 0.04$). No other significant differences for kinetic or kinematic parameters were observed for the CEG vs DTG following the intervention.

4.1 Bilateral training

Prior to the cross-education intervention the initial six week bilateral plyometric training programme resulted in the significant improvement of the following jump performance parameters; DJ contact time, DJ deceleration, L SLVJ propulsion, velocity on take off, power on take off, power on landing, R SLVJ propulsion, power on take off and power on landing meaning the participant's neuromuscular performances were elevated above their baselines. There were also non-significant trends identified for the following parameters which displayed a large effect size of > 0.5 *d* (Cohen, 1988); L SLVJ peak power on landing adjusted for bodyweight ($d = 2.83$), R SLVJ peak power on landing (*d* = 0.87). The following parameters displayed a moderate effect size of 0.3 to 0.5 *d* (Cohen, 1988); DJ force on second landing adjusted for bodyweight (*d* = 0.43), L SLVJ deceleration on landing (*d* = 0.33), L SLVJ peak power on landing adjusted for bodyweight (*d* = 0.41), R SLVJ peak force on landing (*d* = 0.33), R SLVJ deceleration on landing (*d* = 0.32), R SLVJ peak power on landing adjusted for bodyweight (*d* = 0.41).

4.2.1 CEG vs DTG (contralateral effects of unilateral training)

The aim of the final nine weeks of the study was to assess whether a single leg cross-education training programme could reduce the level of performance loss in the contralateral limb following detraining. The CEG comprised of two groups from the same participants. CEG (training) refers to the participants' unilaterally trained dominant limb and CEG (detraining) refers to their non-training contralateral limbs which were not trained and were potentially subject to the cross-education adaptations. Four weeks has been shown to be long enough to elicit significant decreases in strength and neural adaptations are likely to play a key role during a detraining period (Deschenes *et al.,* 2002; Hortobagyi *et al.,* 2000; Houston *et al.,* 1983 in Farthing, Krentz and Magnus, 2009 p. 830; Gabriel, Kamen and Frost, 2006). Excluding the changes to DJ velocity on first landing, SLVJ velocity and peak power on take off there were no significant findings for any of the variables across DJs or SLVJs and all effect sizes were < 0.3 Cohen's *d* / Eta squared. Consequently all null hypotheses were accepted.

4.2.2 DJs & SLVJs

Flight time / jump height

DJ flight time decreased non-significantly by 5% ($P > 0.05$) and SLVJ flight time decreased non-significantly by 3% ($P > 0.05$). Piazza (2013) used two six week training programmes with a population of pre-adolescent gymnasts, one using unspecific resistance exercises and one using specific explosive exercises. Their findings for squat jumps were also non-significant showing 3% increases. The counter movement jump flight time improved significantly for both unspecific and specific training by 7% and 6% respectively. This mode of jumping is comparable to the ‘explosive’ characteristics and mechanisms of the DJ in the present study. However, the current study showed non-significant decreases. Piazza (2013) also used a female population but their ages were lower than those of the current study. Increases to strength do not always lead to performance enhancement (Clutch *et al.,* 1983 in McErlain-Naylor *et al.,* 2014 p. 1806). Technique and coordination have been shown to contribute to 8% increases in the utilisation of mechanical energy (Luhtanen and Komi, 1978 in McErlain-Naylor *et al.,* 2014 p. 1806). McErlain-Naylor *et al.,* (2014) found three kinematic parameters to be key for explaining counter movement jump performance variation, these were peak knee and ankle power and take off shoulder angle. Johnston *et al.* (2015) offers support to jump specific parameters indicating jump height performance. Peak knee flexion and extension velocity and hip extension moment were identified for SLVJs. These measures could be considered for future studies. Vertical jump height (cm) can be calculated by using the following formula $gt^2/8$ (g = acceleration due to gravity ($9.81 m \cdot s^{-2}$) t

= flight time of the jump (s) (Young, 1995 in Maulder and Cronin, 2005 p. 77). There are few studies investigating jump height predictors for SLVJs which make comparisons with current study difficult (Vint and Hinrichs, 1996, Young, MacDonald and Flowers, 2001 in Johnston *et al.,* 2015 p. 405). It would appear that there is no general set of variables for predicting jump height performances. The relevant variables are instead specific to the jump type (Johnston *et al.,* 2015). The current study demonstrated a non-significant reduction of 9% for DTG DJ jump height and a 4% ($P > 0.05$) increase for the CEG. SLVJ height showed no change for the CEG (training limb), a non-significant 9% decrease for the CEG (detraining limb) and DTG ($P > 0.05$). Peak power has been shown to be the best predictor of jump height for countermovement jumps but which joint's power contributes the most is not clear (Aragon-Vargas and Gross, 1997, Ashley and Weiss, 1994, Dowling and Vamos, 1993, Gonzalez-Badillo and Marques, 2010, Meylan *et al.,* 2010, Rousanoglou, Barzouka and Boudolos, 2013 in Johnston *et al.,* 2015 p. 396). Changes to the peak power for the DJs in the current study were also non-significant.

4.2.3 Force

The present study found no significant changes to peak forces on first landing for DJ's. Peak force on first landing for DJs increased by 1% for the CEG and 4% for the DTG ($P > 0.05$). Similar results were recorded for force adjusted for body weight parameters for first landing for DJ showing a 3% increase for the training group, 5% for the detraining group ($P > 0.05$). There were no significant changes to the average RFD, the CEG increased by 4% and the DTG decreased by 1% for DJ's (*P* > 0.05).

It may be that the training programme for the current study lacked the sufficient 'explosive' characteristics to induce significant changes to the RFD. Plyometrics have been identified as an Important factor in neuromuscular training that can positively influence RFD (Hewett, Myer and Ford, 2005 in Klugman *et al.,* 2011 p. 826). The current study was designed to accommodate a partially immobilised limb in the early stages of healing therefore unilateral plyometric exercises for the opposing limb were not deemed safe. However, the inclusion of RFD for ACL rehabilitation programmes should not be overlooked as it has been shown to be important to functional performance (Aagaard *et al.,* 2002 in Knezevic *et al.,* 2014 p. 1039-40) and ACL patients have been shown to exhibit decreased levels of RFD 9 to 12 months post-reconstruction (Larsen *et al.,* 2014).

Changes in peak force on take off for SLVJ were also non-significant, 1% for the CEG (training), -5% for the CEG (detraining) and -2% for the DTG (*P* > 0.05). Changes to the average RFD were non-significant. An 18% decrease for average RFD was recorded for the CEG (training), 9% for the CEG (detraining and no change for the DTG (*P* > 0.05). Adjustment to the performance of the jumps as a result of a neuromuscular training programme can be explained by the neuromuscular aspects of the SSC (Palma, 2005 in Salaj, Milanovic and Jukic, 2007 p. 132). Due to the lack of cross-education studies using functional output measures force is not a commonly measured variable. However, correlations between muscle strength and jump performance have been found (Vuk, Gregov and Markovic, 2015). Theoretically, the improvement of muscle strength may have an important influence on the key factors that determine the reduction of ACL injury risk, including the reduction in ground reaction force. This suggests that a greater absorption of shock during landings may be possible as a result of enhancing strength (Mizner, Kawaghuchi and Chmielewski, 2008). However the strength alone of major muscle groups of the trunk, hip, knee and ankle have been shown to be poor predictors of optimal landing patterns (Mizner, Kawaghuchi and Chmielewski, 2008). Other factors such as the coordination, which can influence the muscle firing patterns and instructional cues to reduce the magnitude of knee valgus on landing, were shown to be of greater importance. In support of this, knee valgus moment has been shown to be reduced by 21% following short term verbal instructions (Mizner, Kawaghuchi and Chmielewski, 2008).

Papandreou *et al.* (2013) used an eight week ACL programme which commenced one week after ACL reconstruction. The programme was based on established rehabilitation principles (Majima *et al.,* in Papandreou *et al.,* 2013 p. 52) and a cross-eccentric exercise programme (Housch *et al.,* 1996; Herbert and Gandeiva, 1996; Howard and Enoka, 1991 in Papandreou *et al.,* 2013 p. 53). Their study demonstrated a 6% to 16% decrease in quadriceps strength for cross-education groups following an eight week detraining period and a 37% decrease for the control group. This represented significant differences between the two cross-education groups training at a frequency of

3 or 5 days per week compared with the control group (*P* = 0.01 and *P* = 0.04 respectively). A similar scale of difference was observed in a detraining study by Farthing, Krentz and Magnus (2009) which incorporated an immobilisation design using a casted forearm and a three week isometric strength training programme using a Humac NORM dynamometer. The strength of the cross-education group for isometric ulnar deviation decreased by 2% in comparison to 15% for the control group. The current study demonstrated a trend for increased sEMG muscle activation (RMS) for the hamstrings for DJs and SLVJs as a result of unilateral training. This enhanced neuromuscular activation may mean that force would be decreased and subsequent levels of shock absorption would be improved (Mizner, Kawaghuchi and Chmielewski, 2008).

4.2.4 Peak power

Peak power on the first landing for DJs showed a non significant 2% (*P* > 0.05) increase for the DTG compared with a 1% decrease for the CEG and power on the second landing showed a non-significant 8% increase for the DTG compared with a 6% decrease (*P* > 0.05) for the CEG. SLVJs demonstrated a significant 20% decrease in peak power on take off for the DTG in comparison to a 15% increase for the CEG (training) and a 3% decrease for the CEG (detraining) for interaction (*P* = 0.04). There was a non-significant 13% decrease in peak power on landing for the DTG compared with a 20% increase for the CEG (training) and a 9% CEG (detraining) (*P* > 0.05). In comparison, Ingle, Sleap and Tolfrey (2015) found a small but significant 5% (*P* < 0.05) decrease in anaerobic power following a 12 week detraining period which itself followed a 12 week training period. The total duration of this study is comparable with the current study although the division of training to detraining differs as the current study used nine weeks. Ingle, Sleap and Tolfrey (2015) used a male population (12.3 ± 0.3 years) therefore direct comparisons should be made with caution.

A DJ requires eccentric contractions of the hip and knee extensors which increases the lengths of these muscles prior to a rapid concentric contraction of the same muscles. On landing eccentric contractions help control the energy related to the downward movement of the body due to gravity (Padulo *et al.,* 2013). The contractile and elastic components play key roles leading to force production and energy storage respectively. The elastic component has been represented mechanically as a ‘spring’ due to its passive nature (Bosco *et al.,* 1982 in Padulo *et al.,* 2013 p. 4; Padulo *et al.,* 2013). An increase in positive output and power has been recorded when pre-stretches of the muscle occur prior to contraction (Cavagna and Citterio 1974, Fenn 1924, Padulo *et al.,* 2012 in Padulo *et al.,* 2013 p. 4). Force potentiation, reflexes, storage and release of elastic energy and time to develop force have all been proposed as potential mechanisms associated with the SSC (Enoka, 2008 in Padulo *et al.,* 2013 p, 4). The nature of the landing and take off of a DJ should help harness this storage and release of energy in comparison to SLVJ’s meaning a greater power output. However the results of the current study did not suggest that this distinction translated to a greater likelihood of demonstrating significant differences for the DJs following a period of unilateral training. It may have been that the unilateral nature of the training did not suit the bilateral characteristics of the DJs.

DJ’s have been shown to enhance neuromuscular function via improved alpha motor neuron activation which leads to the stretched muscle being activated following reception of the stretch by muscle spindles (Bosco *et al.,* 1981, Enoka, 2008 in Padulo *et al.,* 2013 p. 4). Concentric muscle activation has been shown to be enhanced by the storage and utilisation of elastic energy via the series elastic component of the muscle (Asmussen and Bonde-Petersen, 1974, Komi and Bosco, 1978 in Maulder and Cronin, 2005 p. 82), long latency periods (Melvill-Jones and Watt, 1971 in Maulder and Cronin, 2005 p. 82) and spinal reflexes (Dietz and Schmidtbleicher, 1981 in Maulder and Cronin, 2005 p. 82). Maulder and Cronin (2005 p. 82) calculated this neuromuscular enhancement by subtracting results for squat jumps (SJ) from counter movement jumps (CMJ) or as a percentage [(CMJ – SJ / CMJ) x 100] and found a 2.3 cm and 12% difference respectively which is in line with previous findings (Young, 1995, Asmussen and Bonde-Petersen, 1974 in Maulder and Cronin, 2005 p. 82). The current study used both unilateral jumps and bilateral plyometric jumps but did not investigate the difference between DJ and SLVJ. The findings of Maulder and Cronin (2005) serve to illustrate the mechanistic differences between the two types of jump. A greater relative power output would be expected for the plyometric DJ’s given the activation of the SSC (Enoka, 2008 in Padulo *et al.,* 2013). The lack of ‘explosive’ plyometric exercises in the intervention previously mentioned may have also been a factor for the lack of significance for RFD. The possibility of changes in this area may have been less likely for the SLVJs than the DJs due to the aforementioned mechanistic features that distinguish the two types of jump (Maulder and Cronin, 2005; Enoka, 2008 in Padulo *et al.,* 2013).

There are also biomechanical differences between DJs and SLVJs. It has been suggested that the free swinging leg (Young, MacDonald and Flowers, 2001, in Johnston *et al.,* 2015 p. 405) or centre of mass are the key variables in SLVJ performance (Vint and Hinrichs, 1996, in Johnston *et al.,* 2015 p. 405). However, Johnston *et al.* (2015) found that a combination of peak knee flexion and knee extension velocity followed by peak hip extension moment and peak knee power accounted for a 58% variance in jump height. Johnston *et al.* (2015) found peak hip velocity in addition to peak vertical ground reaction force accounted for 37% of the variance in jump height for DJs. This is in contrast to the study by Ferreira *et al.* 2010 in Johnston *et al.* (2015 p. 406) which found peak leg power and RFD to be the best predictor of DJ height. However, Ferreira did not allow the participants free movement of their arms, as was the case in Johnston's and the present study. A larger range of motion at the ankle and knee for DJ may be an additional factor to support the increases in jump height but it does appear that the majority of power production during a DJ occurs via the hip during contact with the ground (Johnston *et al.,* 2015).

Reciprocal inhibition also plays a role by inhibiting the antagonistic muscle. This reduction in activation in relation to the agonist muscle means that performance and power output can be improved (Hultborn, 2006, Sherrington, 1897 in Padulo *et al.,* 2013 p. 4). The current sEMG case study did show a general trend for the hamstrings as the antagonist muscle group to the quadriceps to demonstrate a lower MVIC percentage for the landing, take off and second landing of the DJs. The nature of the DJ means that lower extremity musculature such as the gastrocnemius and biceps femoris (due to their bilateral nature) are subject to stretching and stretch reflex responses, unlike a SLVJ or squat jump, which is performed from a static starting position (Kawakami *et al.,* 2002 in Padulo *et al.,* 2013 p. 5). Motor recruitment optimisation is supported by the evidence that counter movement jumps have been shown to activate less muscle fibres in comparison to squat jumps despite non-significant findings between their comparative jump heights (Kawakami *et al.,* 2002 in Padulo *et al.,* 2013 p. 5).

Farthing, Krentz and Magnus (2009) used an immobilisation model as part of their detraining programme, which has been shown to reduce motor activity (Seki *et al.,* 2007, Lundbye-Jensen and Nielsen, 2008 in Clark *et al.,* 2008 p.868) and may mean the current study which restricted only progressive strengthening exercises was less likely to produce the same magnitude of strength deficit. Papandreou *et al.* (2013) used subjects who had suffered a complete ACL rupture within the past 40 days to 6 months and were deemed to be in the sub-acute phase of an ACL injury (Wasilewski *et al.,* 1993, Shelbourne and Foulk, 1995 in Papandreou *et al.,* 2013 p. 52). During the sub-acute phase of healing soft tissue in the damaged area will see a proliferation of capillaries, synovial cells and fibroblasts and fibrin clotting (Kannus, 2000). Extracellular matrix components are elevated by the process of phagocytosis and the presence of fibroblasts. As the injury moves towards the maturation and remodelling phase proteoglycan-water content increases within the healing tissue and type 1 collagen fibres develop a more orderly orientation (Kannus, 2000). The ACL has been shown to provide 85% of the passive resistance to anterior translation of the tibia (Bessett and Hunter 1990 in Beard *et al.,* 1993 p. 313). A complete rupture of the ACL is likely to result in severe deficits in afferent proprioception (Barrack, Skinner and Buckley 1989, Barrett, Cobb and Bentley, 1991, Corrigan, Cashman and Brady, 1992 in Beard *et al.,* 1993 p. 311). It should be noted that evidence for efferent signals leading to improved muscle stiffness and joint stability is not well established (Beard *et al.,* 1993). If conservative treatment of an ACL rupture does not work reconstructive surgery is indicated (Beard *et al.,* 1993). These cellular changes, in tandem with the loss of neurophysiologic proprioceptive function of the ACL, can disrupt the sensory input to the CNS (Tippett and Voight in Vathrakokilis *et al.,* 2008 p. 233). Therefore the pathophysiological environment of the local tissue for the subjects in the Papandreou *et al.* (2013) study and low activity levels of the Farthing, Krentz and Magnus (2009) study were very different to that of the present study which used healthy subjects with no recent injuries. It may be fair to suggest these differences in activity level and cellular environment would provoke a much lower level of detraining in comparison the studies that have used an injury/immobilisation design. This may be a key factor underpinning the lack of significant findings in the current study.

4.2.5 Contact time

There were very small increases to DJ contact time on first landing for the training and detraining group (5% and 3% respectively) both of which were non significant (*P* > 0.05). No cross-education studies to date have investigated contact time. As previously discussed a foot contact time greater than 200ms may cause energy to be transformed into heat energy (Komi, 2000, Komi and Nicol, 2000 in Coh *et al.,* 2015 p. 163). Therefore an increase in contact time could be considered an effect of detraining. Shorter contact times have been associated with increased leg stiffness and maintaining sprinting speeds (Chelly and Denis, 2001 in Walsh *et al.,* 2004 p. 561). Relatively long contact times (179 to 222 ms) have been shown to utilise a greater percentage (~45%) of power from the knee in comparison to jumps using shorter contact times (160 to 167 ms). Walsh *et al.* (2004) found take off velocity to be ~2.40 $m \cdot s^{-1}$ for 20 cm, 40 cm and 60 cm DJs. In the current study the velocity on first landing was 8.76 $m \cdot s^{-1}$ and 8.22 $m \cdot s^{-1}$ for the training and detraining groups respectively from 31 cm. The contact times of the current study were considered beyond the definition of 'long' (Chelly and Denis, 2001 in Walsh *et al.,* 2004 p. 561) which were 450 ms and 410 ms for the training and detraining groups respectively. These long contact times and the relatively slow velocity on take off could suggest that energy loss via heat transfer may have occurred (Komi, 2000, Komi and Nicol, 2000 in Coh *et al.,* 2015 p. 163). It could be possible that the low training level of the current study's participants may have meant that their jumping and landing techniques may have been a factor (Luhtanen and Komi, 1978 in McErlain-Naylor *et al.,* 2014).

The current study did not measure contact time for the SLVJ as it was only one jump but Makaruk *et al.* (2011) found ground contact time to be greater for unilateral jumps in comparison to bilateral and suggested that that this can lead to leg extensor muscles shortening at a greater velocity suggesting a lower force production as a result of the force-velocity relationship (Bobbert *et al.,* 2006 in Makaruk *et al.,* 2011 p. 3317). A greater activation of stabilising musculature has been observed for unilateral jumps in comparison to bilateral which may be as a result of the base of support not being aligned with the body's centre of gravity. Gastrocnemius and vastus medialis activation have been shown to be 10% to 20% lower for bilateral jumps (Makaruk *et al.,* 2011). The current sEMG case study offers some support for this as the right quadriceps muscle group demonstrated a 225% MVIC for DJs compared with 420% MVIC for SLVJs for the take off phase of the pre-intervention. As the figures demonstrate a > 100% MVIC they should be interpreted with caution. Furthermore the left quadriceps actually showed a lower activation for the SLVJs, 124% compared to 150% for DJs for the same take off phase.

Contact time should be considered an important variable when designing training / prehabilitation programmes that include jumps. Whilst increasing the height of DJs clearly appears to increase force there are more subtle options available via the manipulation of contact time (Walsh *et al.,* 2004). For example, focus may be put on short contact times if the practical goal is to improve acceleration whereas longer contact times may be used if the main objective is to increase height and force (Walsh *et al.,* 2004). Therefore, the design of the current study or at least the practical execution of the jumps would be best suited to maximal force gains due to the long contact times and slow velocity. These parameters may also point to poor jump technique for the participants which does not appear to have been altered by either the training intervention or the cross-education/detraining protocols. Participants were advised to minimise their contact with the floor which should in theory lead to shorter contact times than were reported. It may have been the case that participants subconsciously elected for longer periods between eccentric and concentric contractions in an effort to reach maximal performance. The participants in the current study were relatively untrained and not partaking in any progressive strength training programmes. Therefore, the data were not available to identify individual sports or training practices that may have influenced each participant's execution of contact time. Their activities outside of the study especially during the detraining period may have influenced the results in relation to contact time and also been a contributory factor to the non significant findings (Walsh *et al.,* 2004).

Negative power-related adaptations can be linked to the potential loss of type II muscle fibres (Hortobagy *et al.,* 1993, Staron *et al.,* 1991 in Izquierdo *et al.,* 2007 p. 773) and a reduction in neuromuscular function during periods of detraining (Andersen *et al.,* 2005, Hakkinnen, Alen and Komi, 1985, Hakkinen and Komi, 1983, Hakkinen, Komi and Tesch, 1981 in Izquierdo *et al.,* 2007 p. 773). The current study did not investigate morphological adaptations or include immobilisation but did show there were no significant differences for power related parameters such as velocity of contractions, acceleration or power on take off and landings for DJ or SLVJ tests. Izquierdo *et al.* (2007)

reported significant power decreases for the leg muscles in their detraining group (-14% $P < 0.01$) in comparison with a tapering period group (3%) over a duration of four weeks. Even larger decreases in power were seen for the upper limb during bench press exercises (-17% $P < 0.001$). These results were similar to the changes seen in peak power on take off for the SLVJ which were -20% for the DTG, -3% for the CEG (detraining) and 15% for the CEG (training) for interaction ($P = 0.39$).

The experimental design for the detraining in the Izquierdo *et al.* (2007) study was more closely matched with the current study as it did not incorporate any element of immobilisation. Therefore the mechanisms resulting from the reduction in training stimuli may be similar. However, the study did use a 16 week period of heavy resistance training prior to the detraining and tapering period, 10 weeks longer and a different mode of training than the intervention used in the current study. Izquierdo *et al.* (2007) also had a far larger sample size of 46 active male participants. Therefore caution should be applied when drawing comparisons due to these differences including gender. Resistance training when combined with plyometric exercises may have an impact on contact times as a result of its effect on eccentric muscle function. A six week resistance training programme specifically designed to help explosive power via the inclusion of jump training led to a 22% reduction in ground contact time for hopping tests. Conversely, the traditional moderate load / high repetition resistance programme did not lead to any changes in ground contact time (Piazza *et al.,* 2013). This suggests that plyometric training is likely to lead to greater neuromuscular related adaptations such as reductions in contact time. However, changes caused resulting from resistance training should not be overlooked, Tomljanović *et al.* (2011) found a 21% decrease in ground contact time following a traditional resistance training programme over a period of five weeks. Counter movement jumps have been shown to require a lower magnitude of muscle fibre activation in comparison to squat jumps despite non-significant findings between their comparative jump heights (Kawakami *et al.,* 2002 in Padulo *et al.,* 2013 p. 5). This suggests an enhanced level of motor optimisation. Padulo *et al.* (2013) suggest that due to the reduced muscle fibre activation and the potential for energy dissipation the plyometric nature of a DJ may be less likely to cause hamstring injuries than a concentric only activity such as a squat jump. This may be of relevance to the prehabilitation considerations of the current study due to the importance of hamstring function to the prevention of ACL injuries (Silvers and Mandlebaum, 2011).

The closed kinetic chain nature of a DJ and the relationship between the hip and knee mean that kinematic function of surrounding hip muscles may influence force moments at the tibiofemoral joint (Carcia and Martin, 2007). There is evidence to suggest that females are subject to increased dynamic forces leading to a dynamic valgus position for the knee which places the ACL at risk (Ford *et al.,* 2003 in Carcia and Martin, 2007 p.170; Russell *et al.,* 2006). The hip musculature including gluteus medius have been proposed to work eccentrically during closed kinetic activity to provide deceleration forces and control internal rotation of the lower limb. Therefore, should there be weakness or dysfunction, tibiofemoral torques may be increased and, in turn, ACL injury risk (Carcia and Martin, 2007). Clairborne *et al.* 2006, Zazulak *et al.* 2005, Zeller *et al.* 2003 in Carcia and Martin (2007 p. 170); Russell *et al.* 2006) found no gluteus medius gender differences for unilateral activities. Carcia and Martin (2007) found this was also the case for bilateral activity during a DJ. Their study looked at gluteus medius activity at 200 ms before and 250 ms after ground contact and found the peak amplitude for male versus female to be 45% (P = 0.20) and 44% (p = 0.19) for right gluteus medius and 21% (P = 0.41) and 22% (P = 0.45) for the left gluteus medius (see figure 4.1). The current sEMG case study was not superimposed on the force trace to allow a direct comparison with the study by Carcia and Martin (2007) but it was shown that the right and left gluteus medius demonstrated a 37% and 5% MVIC for the landing of the pre-intervention tests for DJs. The timing of their activation was later than the left hamstrings and both right and left quadriceps. This is of potential concern given the evidence to support the role of the hip musculature for controlling force moments at the knee (Carcia and Martin, 2007).

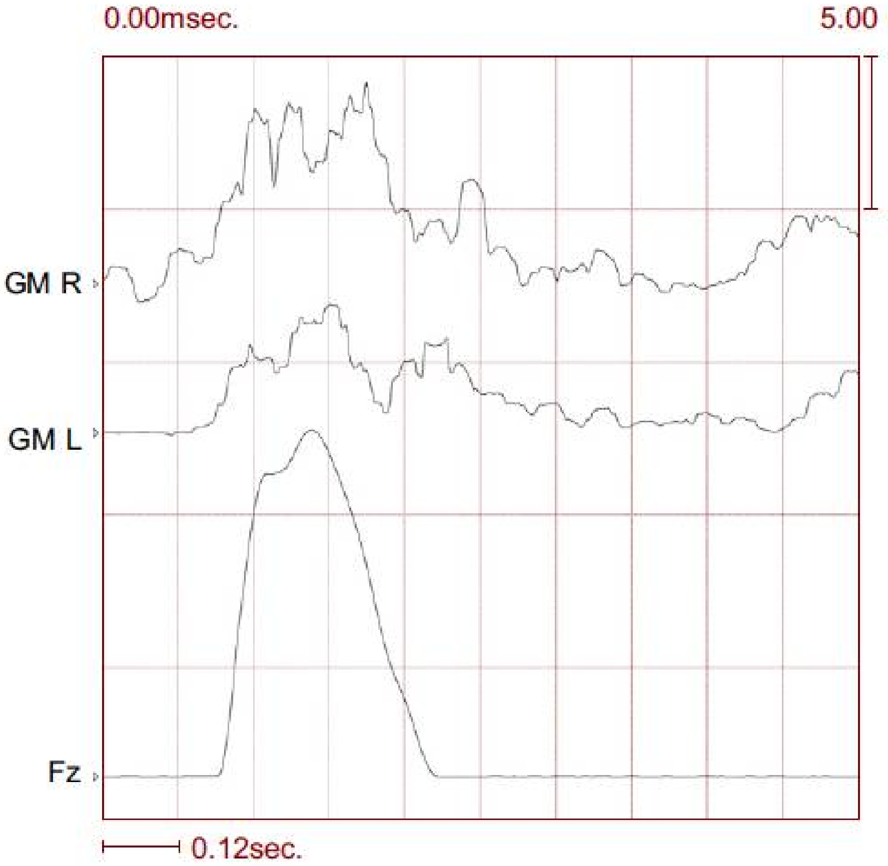


Figure 4.1 Signal averaged bilateral gluteus medius sEMG from a subject DJ. GM r = gluteus medius right; GM L gluteus medius left' Fz = vertical ground reaction force.

(Carcia and Martin, 2007 p. 171)

4.2.6 Deceleration

The current study did not observe any significant changes to deceleration for either the first or second landing for DJ's or the SLVJ landing (*P* > 0.05). The deceleration phase of jumping is inherently related to the eccentric function of the muscles (Hairsine, 2011). Efficient and effective deceleration phases require optimisation of eccentric movement patterns globally as well as locally (Hairsine, 2011). Fast eccentrics (defined at ≤ 180°·s^{-1}) which are key to DJs have been proposed to provoke a number of performance related changes including the change to Type IIx from Type IIa muscle fibres (Paddon-Jones *et al.,* 2001 in Hairsine, 2011 p. 14). Sudden descents such as those that feature in DJ's may not be well controlled by muscle fibres with slow relaxation times. Therefore, the selective recruitment of these faster twitch Type IIx fibres may better equip the fibres to manage the 'catch phase' of a DJ (Hairsine, 2011). Task specificity, velocity, force and demands of the movement can stimulate modifications to the motor recruitment (Stone, Stone and Sands, 2006, Nardone Romano, Shieppati 1989 in Hairsine, 2011 p.15). This is related to the functional nature of the intervention and output measures of the current study. For example, single leg squats, proprioceptive exercises and counter movement jumps.

Skill acquisition is key to DJ's and, given the current study did not offer ongoing coaching or supervision, participants may not have developed the optimal whole body movement patterns to help stimulate significant adaptations to performance (Hairsine, 2011). A cross-education study by Weir *et al.* (1995) found no significant decrease in eccentric performance following an eight week detraining period which is in line with numerous studies that found no significant adaptations following short detraining periods such as the one used in the current study (Colliander and Tesch, 1990, Hortobagyi *et al.,* 1993, Shaver, 1975, Staron *et al.,* 1991 in Weir *et al.* 1995 p. 214).

Functional training adaptations, like those of cross-education occur largely due to neurophysiological adaptations (Taube, Gruber and Gollhofer, 2008; Farthing, 2009; Lee and Carroll, 2007; Munn *et al.,* 2005; Benjamin *et al.,* 2000; Kannus *et al.,* 1992). Therefore it is logical to theorise that a combination of the two modes of training in the current study could result in positive adaptations for the contralateral limb. However, Munn *et al.* (2005) highlights that the functional benefits as a result of cross-education are as yet unknown. Furthermore, the methodological rigor of previous cross education studies has been questioned, In support of this the cross education meta-analysis conducted by Munn *et al.* (2004) identified that the training type (isometric or dynamic) could not confidently be identified nor do many methodologies meet established criteria for optimal measurement of maximal voluntary strength (Gandevia, 2001 in Munn *et al.,* 2004 p. 1865).

4.3 Speed of intervention exercises

Munn *et al.* (2005) found a non-significant trend for training at higher speeds to lead to a ~5% increase in contralateral strength. This may relate to the theories that support alterations to motor firing as a result of higher speed contractions which can lead to 'doublet firing' (Gabriel *et al.,* 2006 p. 136). The present study used relatively slow contractions to ensure the intervention programme remained aligned with the underpinning philosophy of rehabilitating a non-weight bearing ACL injury. As such safety considerations meant 'explosive' and high speed contractions were not practical. Consequently this may have been a contributory factor for the lack of significant findings.

4.4 Dominant leg use

The participants in the present study used their dominant leg for the unilateral training as determined by the leg they would prefer to kick with (Gabbard 1996 in Holsgaard-Larsen 2013 p. 67). Cernacek, 1961 in Hendy, Spittle and Kidgell (2011 p.3) found motor excitability in the contralateral limb to be greater when it is the dominant limb that is trained. This theory is well supported by other cross-education studies (Imamizu and Shimojo, 1995, Parlow and Kinsbourne, 1989, Stoddard and Vaid, 1996 in Farthing, 2009 p. 178). Farthing (2009) support this theory and suggest that the corticol mechanisms of strength and skill cross-education are similar. This is supported by functional imaging and transcranial magnetic stimulation studies, which suggest this model results in greater changes when the more proficient and dominant limb is trained. However, it should be noted that this only represents what occurs at one site and there is evidence to suggest cross-education mechanisms may occur at multiple sites (Carroll *et al.,* 2006 in Farthing, 2009 p. 186). The complexity of potential mechanisms means that it is difficult to predict the level of influence the use of a dominant limb may have and other mechanistic factors may have reduced the possibility of the present study finding significant differences.

4.5 Contraction type

Many cross-education studies use maximal voluntary isometric contractions as their intervention and testing protocols (Munn *et al.,* 2004). Furthermore this is also a recognised measure of strength following ACL reconstructions (Hartigan *et al.,* 2012 in Knezevic *et al.,* 2014 p. 1039). However, neuromuscular indices that represent ‘explosive’ strength can lead to more optimal muscle recruitment which has been shown to be of greater importance than strength with regards to functional performance (Aagaard *et al.,* 2002 in Knezevic *et al.,* 2014 p. 1039-40). The lack of functional training or output measures in existing cross-education studies means it is difficult to draw direct comparisons with the present study (Kannus *et al.,* 1992). However, Papandreou *et al.* (2013) used an isokinetic dynamometer to deliver eccentric exercises to ACL reconstructed patients and found quadriceps deficit to be smaller for the experimental groups 28% (additional cross education eccentric exercises 3 days per week) and 30% (additional cross education eccentric exercises 5 days per week) compared to the 53% for the control group (progressive eight week rehabilitation programme) (Wilk *et al.,* 2003, Majima *et al.,* 2002 in Papandreou *et al.,* 2013 p. 52). There was no consideration for leg dominance but the level of supervision, equipment and the cellular differences due the actual rehabilitation (Kannus, 2000) taking place were all factors that could increase the chance of significant findings and represent similar issues with the current study. The significant findings of Papandreou *et al.* (2013) offer support that eccentric contractions, which are key to the functional exercises and output measures (Padulo *et al.,* 2013) used in the current study, can elicit favourable strength related cross-education adaptations.

4.6 Technique

A neuromuscular programme such as the intervention used for the present study is designed to create improved movement patterns and functional performance (Silvers and Mandlebaum, 2007; FIFA, 2014). One way it does this is by trying to correct dysfunctional patterns such as the dominant activation patterns for the quadriceps observed in females (Griffin *et al.,* 2006 in Shultz *et al.,* 2009 p. 857). This means that the quadriceps are contracted earlier than the hamstrings (Hutson and Wojtys, 1996, Shultz *et al.,* 2001 in Shultz *et al.,* 2009 p. 857) which can be the case for landing and cutting tasks both pre and post-contact with the ground (Chappe *et al.,* 2007, Nagano *et al.,* 2007, Malinzak *et al.,* 2001, Sigward and Powers, 2006 in Shultz *et al.,* 2009 p. 857). In support of this the current sEMG case study recorded at least one incidence of the quadriceps firing first either right or left or pre/post intervention for all DJ and SLVJs tests. In the case of the DJ landing, right quadriceps fired first pre-intervention and left quadriceps post-intervention. Shultz *et al.* (2009) found that the muscle strength of the thigh only accounted for some variability and did not support the theory of greater quadriceps activation in females. The study highlights the importance of the kinetic chain as a whole and suggest that the trunk position may play a key role. A more upright landing position has been shown to reduce hip angular impulses by 11% and hip energy absorption by 18%. This suggests that the energy dissipation demands at the knee may be higher the more vertical the position of the trunk (Kulas *et al.,* in Shultz *et al.,* 2009 p. 865). This is supported by Schmitz *et al.,* (2007 in Shultz *et al.,* 2009 p. 865) who found the knee extensors to absorb less energy during upright landings which may put the ACL under greater strain. The lack of supervision and specific guidance on body position within the current study may have reduced the chance of significant findings.

4.7 KAM probability and knee valgus

There were no significant differences recorded for changes to the probability of knee abduction moment or knee valgus for SLVJs (*P* > 0.05). Knee valgus was subject to a 13% increase for the CEG (detraining) compared with a 15% increase for the detraining limb. The CEG (training) also showed an increase in knee valgus of 12%. Knee abduction moment probability for DJs showed a non-significant 3% decrease for the CEG and a non-significant 6% decrease for the DTG.

Knee valgus and knee abduction moment can be used as predictors of knee injury risk specifically at the ACL (Hewett *et al.,* 1996, 2005, Markolf *et al.,* 1995 in Bates *et al.,* 2013 p. 465; Myers *et al.,* 2011, Paterno *et al.,* 2010, Pollard *et al.,* 2010 in Bates *et al.,* 2013 p. 464). This was the first study to attempt to investigate kinematic function as part of a cross-education intervention with a view to relating the findings to ACL injury risk. Cross transfer of strength changes are well established (Munn *et al.,* 2004; Munn *et al.,* 2005) and more recently, reductions in detraining effects have also been demonstrated (Magnus *et al.,* 2013; Farthing, 2009; Farthing, Chilibeck and Binsted, 2005; Hendy, Spittle and Kidgell, 2011). However, no study has investigated whether contralateral biomechanical function can be significantly influenced by a single leg training programme. Numerous bilateral studies have demonstrated that targeted neuromuscular training programmes such as the validated field-based algorithm, the PEP and FIFA 11+ can elicit positive biomechanical changes that are able to reduce the risk on non-contact ACL injuries (Myer *et al.*, 2012; Silvers and Mandlebaum, 2007; FIFA, 2014). Some of these studies have resulted in up to 89% reductions in ACL injuries (Silvers and Mandlebaum, 2007). The magnitude of these effects suggest that further investigation regarding the potential of cross-education of kinematic factors is warranted.

Russell *et al.* (2006 p. 169) found women to land in valgus (-0.651 ± 3.32°) and men in varus (3.85 ± 4.03°) at initial contact from a DJ. These faulty kinematics are occurring prior to the forces being transmitted through the limbs which means there may be a prevalence for females to land with a pre-programmed strategy that may increase their risk of injury (Russell *et al.,* 2006). To put this is into context, a knee valgus position of 5° from neutral has been shown to increase the load through the ACL by up to six times (Bendijaballah, Shirazi-Adl and Zukor, 1997 in Russell *et al.,* p.169). It should be noted Russell *et al.* (2006) used single leg DJs rather than SLVJs as was the case in the current study. Limitations of the Russell *et al.* (2006) study were comparable to the current study including potential inaccuracies of body makers in relation to precise movements of the bones and the skill requirements for the activity.

Pappas *et al.* (2007) used a repeated measures design to compare bilateral and unilateral landings between male and female participants. The study found there to be significant differences between genders and the landing types. Females demonstrated increased knee valgus of 4.5° compared with men. Knee valgus was also shown to be greater for unilateral landings compared with bilateral, 1° compared with -1.4° respectively.

These studies offer some support for the findings of the present study, which found the female participants to be landing in knee valgus and also recognises some similar limitations such as the way in which markers are used for motion analysis and the influence of other areas of the body such as the movement of the trunk.

The methods used to obtain the results in the current study were modelled on the field tool developed by (Myer *et al.,* 2012a). In support of this a study by Stensrud *et al.* (2010) suggests that screening tests for single leg squats using only observation could be a useful clinical measure for poor knee control. Whilst these methods have been validated as reliable clinical measures they are likely to be considerably less accurate than the 'gold standard' of 3D motion analysis (Holsgaard-Larsen *et al.,* 2013).

4.8 Study design

The current study split the participants into a training group and non-training group and compared the differences in performance related parameters between the two groups. This is something that not all cross-education studies have previously done (Munn *et al.,* 2004). Furthermore, the majority of studies that have employed this design have failed to show a significant difference between groups (Garfinkel and Caferelli, 1992, Meyers, 1966 in Munn *et al.,* 2004 p. 1861). Many cross-education studies have claimed significant contralateral strength changes by comparing pre and post-test results for that limb. However, had these findings been compared with the equivalent untrained limb of the control group the differences would have been non-significant (Carolan and Carafelli, 1992, Evetovich *et al.,* 2001, Hortobagyi *et al.,* 1999, Kannus *et al.,* 1992, Komi, 1978, Shaver, 1970, Shima *et al.,* 2002, Yue and Cole, 1992 in Munn *et al.,* 2004 p. 1865). Whilst these were training and not detraining related studies the lack of significant difference recorded in relation to cross-education are similar to those of the current study. In further support of this, Meyers (1966) showed a negative (-3%) difference for the contralateral effects of cross education on isometric elbow flexion. Numerous cross-education studies can be deemed to be low quality and do not meet selection criteria for meta-analyses (Bowers, 1965, Hortobagyi *et al.,* 1996, Smith, 1970, Uh *et al.,* 2000 in Munn *et al.,* 2004 p. 1862). Munn *et al.* (2004) analysed 13 studies comparing untrained limb strength changes with the equivalent limb in the control group (something that has been rarely reported); only one provided evidence of a statistical difference (Munn *et al.,* 2004; Hortabagyi, Lambert and Hill, 1997 in Munn *et al.,* 2004 p. 1865). The number of participants in the current study (n = 17) is comparable to previous cross education studies which have been shown to be on average to contain n = 10 participants in each group (Munn *et al.,* 2004). However, the effect sizes for the CEG and DTG were all < 0.3 and defined as low (Cohen, 1988).

Cross-education has previously been related to injuries and immobilisation (Munn *et al.,* 2004; Munn *et al.,* 2005; Magnus *et al.,* 2013; Farthing, 2009; Farthing, Chilibeck and Binsted, 2005; Hendy, Spittle and Kidgell, 2011). It may be that the freedom of the detraining protocol may have led to a lower level of detraining compared with existing detraining studies. For example, decreases in motor performance have been linked to 50% reductions in strength during immobilisation (Clark *et al.,* 2006 in Clark *et al.,* 2008 p. 868). In the majority of cases periods of immobilisation do lead to a decreased central activation potentially as a result of neural drive inhibition (Hunter *et al.,* 1998 in Otzel, Chow and Tillman, 2015 p. 26). However, it has been shown that a period of immobilisation can be followed by a period of increased neural excitability (Clark *et al.,* 2008; Roberts *et al.,* 2007, Zanettee *et al.,* 2004 in Leukel *et al.,* 2014 p. 137) which may be related to increases in projection excitability or changes to the motor map area (Ziemann, 2002 in Clark *et al.,* 2008 p. 868). This suggests that periods of immobilisation do not always lead to a predictable pattern of behaviour for soft tissue.

4.9 Limitations

The length of training programme was designed in line with previous research (Housch *et al.,* 1996; Benjamin *et al.,* 2000; Kannus *et al.,* 1992) but may have been too short to elicit positive adaptations across all variables. The cross-education intervention length of nine weeks was also in line with existing studies (Deschenes *et al.,* 2002; Hortobagyi *et al.,* 2000; Houston *et al.,* 1983 in Farthing, Krentz and Magnus, 2009 p. 830; Gabriel, Kamen and Frost, 2006; Housch *et al.,* 1996) but a longer period more closely matched with the work of Hakkinen, Alen and Komi, 1985, Hakkinen and Komi, 1983, Hakkinen, Komi and Alen, 1985, Hakkinen, Komi and Tesch, 1981, in Izquierdo *et al.* (2007 p. 773) may have helped yield significant findings. A meta analysis identified intervention periods of up to 12 weeks (Munn *et al.,* 2004). Munn *et al.* (2004) reported that only 3 of 13 studies reviewed used female only participants. This highlights a lack of existing gender specific evidence for discursive comparison.

Neither the training programme nor the cross-education intervention were supervised. Measures were taken to mitigate this risk such as careful initial demonstration and observation of the participants conducting the exercises. A video tutorial was also produced and released on a weekly basis to help guide the participants along with weekly email and text message instruction and encouragement. However, supervision for each session is likely to be a more superior method of monitoring technique and effort levels (Munn *et al.,* 2003; Baechle and Earle, 2000). Weekly adherence to the programmes was not reported to be a problem. However, it should be noted that there were no measures beyond the email and text message reminders to ensure participant adherence. Therefore, non-adherence is a potentially viable reason for the lack of significant findings.

The participants were not in any way immobilised and were permitted to go about their activities of daily living. They were also allowed to take part in moderate exercise as long as they did not conduct any progressive lower limb strength training. These restrictions did help rule out the possibility a similar or related training regime interfering with the accuracy of the findings. However, it is likely the activities of daily living would be considerably greater than that of ACL reconstructed patient suffering the effects of detraining during certain periods of the rehabilitation period. This may have reduced the possibility of significant findings following the nine week intervention. A study by Farthing, Krentz and Magnus (2009) used an immobilisation design for an upper limb cross education study that used casts to restrict the amount of movement. As previously discussed the detraining effect during immobilisation is well established (Clark *et al.,* 2006 in Clark *et al.,* 2008 p. 868).

The number of participants may have been a limiting factor in terms of statistical power. Munn *et al.* (2004) states that participant numbers would need to be in excess of 280 to provide adequate statistical power when trying to demonstrate significant differences of 8% (the average in their meta analysis) for data with large standard deviations. Therefore a much larger sample size may have allowed for an improved level of reliability for the data. However, this also provides further support to the argument that much of the existing cross-education research is methodologically flawed and thus of questionable reliability.

The field-based methods have been utilised for biomechanical analysis, were validated against laboratory based 3D motion analysis systems (Padua *et al.,* 2009; Myer *et al.* (2012) and were deemed to be ‘good-excellent’. However, Goetschius *et al.* (2012) suggest 3D motion analysis is still required to capture the intricacies of knee biomechanics during landings from jumps.

4.10 Future research

The design of this study meant that KAM probability was being measured in relation to a detraining period. What may be useful to know is whether a single leg cross education programme is capable of creating a significant improvement in contralateral kinematic function from an initial base line. This information was not available in the current study as kinematic measures were only taken at the beginning and end of the cross-education intervention period. Therefore the nine week cross-education intervention could only investigate any subsequent changes following the six week plyometric training period. If future studies were to demonstrate cross-education could improve contralateral lower limb biomechanics then there were would be the exciting prospect of using cross-education to help address these deficits. This would allow an aspect of neuromuscular ACL rehabilitation to occur at an earlier time point than otherwise possible with a view to improve kinematic function. Given the research (Hewett *et al.,* 1996, 2005, Markolf *et al.,* 1995 in Bates *et al.,* 2013 p. 465; Myers *et al.,* 2011, Paterno *et al.,* 2010, Pollard *et al.,* 2010 in Bates *et al.,* 2013 p. 464) regarding biomechanical dysfunction it is reasonable to suggest ACL deficient or reconstructed patients will have dysfunctional movement patterns and therefore benefit from potential early cross-education related improvements to kinematic function.

Future functional neuromuscular cross-education studies should evolve by incorporating sEMG to afford the opportunity to overlay the force platform readings with muscle recruitment timings and contraction magnitude (Mello, Oliveria and Nadal, 2007; Fujii, Sato and Takahira, 2012). This could provide muscle specific information, which could then be interpreted in relation to cross-education effect and injury risk. This would also be the first sEMG study of its kind measuring functional output following a neuromuscular cross-education intervention. The use of 3D motion analysis to assess the biomechanical function of participants would also increase the validity of the findings (Goetschius *et al.,* 2012).

The use of a more specific population may be beneficial. For example, ACL deficient or reconstructed patients with associated biomechanical dysfunction (Di Stasi and Snyder-Mackler, 2011; Holsgaard-Larsen *et al.,* 2013). It would also be beneficial for future studies to be as closely related to a rehabilitation model as possible. For example, a comparison between a traditional post-operative ACL rehabilitation programme and one that incorporates single leg cross-education exercises similar to the study by Papandreou *et al.* (2013). This would mean that the ACL reconstruction associated soft tissue of the participants would be subject to the natural histological healing processes of inflammation, proliferation and remodelling (Kannus, 2000). This may provide a more realistic depiction of the detraining and cross education effects and allow for a greater translation to practical implications in a rehabilitative setting.

4.11 Conclusion

This study found there to be significant effects for DJ velocity on first landing on time (P = 0.02), SLVJ velocity on take off on interaction (P = 0.02) and peak power on interaction (P = 0.04). There were no other significant unilateral retardation of the detraining effect for any of the kinetic or kinematic variables for DJs or SLVJs following a nine week neuromuscular cross-education training programme. There are clear kinetic differences between DJs and SLVJ primarily related to the utilisation of the SSC for DJs given the counter movement nature of the first landing and take off. Other differences include the key muscle groups and joint movements for force generation, which are specific to each jump type. Technique, trunk positions and free limb movement have also been shown to be key factors. The speed of contraction during exercises may be a factor but further research is required. The body of literature for cross-education, detraining and injury prevention suggests some common findings. Cross-education adaptations for a contralateral limb are well established and there is an increasing interest in its potential use for rehabilitation purposes through the use of immobilisation and detraining. However, there is a paucity of research using functional interventions and output measures or investigations regarding the effects on kinematic function. There is strong evidence to suggest a high prevalence of dynamic knee valgus for female populations specifically during single leg landings. In turn this has been shown to increase the risk of non-contact ACL injuries. There appears to be numerous methodological flaws within existing cross-education studies and a general lack of statistical power, which highlights the need for further studies in this area. Future research should incorporate larger sample sizes, sEMG, 3D motion analysis and consider the use of ACL injury/reconstruction specific populations.

References

Akima, H., Hideyuki, T., Shin-Ya, K., Kazumi, M., Tadashi, M., Hitoshi, S., Izumi, A., Yuji, I. and Shigeru, K. (1999) ‘Early phase adaptations of muscle use and strength to isokinetic training’, *Medicine and Science of Sports and Exercise*, 31(4), pp. 588-594.

Alonso, J.M., Tscholl, P.M. and Engebrestsen, L. (2010) ‘Occurrence of injuries and illnesses during the 2009 IAAF World Athletics Championships’, *British Journal of Sports Medicine,* 44 (15), pp. 1100-1105.

Appell, H.J. (1990) ‘Muscular atrophy following immobilisation: a review’ *Sports Medicine*, 10(1), pp. 42-48.

Arendt, E. and Dick, R. (1995) ‘Knee injury patterns among men and women in collegiate basketball and soccer’, *The American Journal of Sports Medicine*, 23(6), pp. 694-701.

Baechle, T.R. and Earle, R.W. (2000) Essentials of Strength Training and Conditioning, 3rd edn. U.S., IL: Human Kinetics.

Barber-Westin, S.D., Hermeto, A.A. and Noyes, F.R. (2010) ‘A six-week neuromuscular training program for competitive junior tennis players’, *Journal of Strength and Conditioning Research*, 24(9), pp. 2372-2382.

Bartolomei, S., Hoffman, J.R., Merni, F. and Stout, J.R. (2014) ‘A comparison of traditional and block periodized strength training programs in trained athletes’, *Journal of Strength and Conditioning Research*, 28(4), pp. 990-997.

Bates, N.A., Ford, K.R., Myer, G.D. and Hewett, T.E. (2013) ‘Kinetic and kinematic differences between first and second landings of a drop vertical jump task: Implications for injury risk assessment’, *Clinical Biomechanics*, 28(4), pp. 459-466.

Beard, D.J., Kyberd, P.J., Fergusson, C.M. and Dodd, C.A.F. (1993) ‘Proprioception after rupture of the anterior cruciate ligament’, *Journal of bone & Joint Surgery*, 75(B), pp. 311-315.

Benjamin, S.U.H., Beynnon, B.D., Helie, B.V., Alosa, D.M. and Renstrom, P.A. (2000) ‘The benefit of a single-leg strength training program for the muscles around the untrained ankle’ *The American Journal of Sports Medicine*, 28(4), pp. 568-573.

Berg, H.E., Larsson, L. and Tesch, P.A. (1997) ‘Lower limb skeletal muscle function after 6wk of bed rest’, *Journal of Applied Physiology*, 82(1), pp. 182-188.

Blake, D.T., Hsiao, S.S. and Johnson, K.O. (1997) 'Neural coding mechanism in tactile pattern recognition: the relative contributions of slowly and rapidly adapting mechanoreceptors to perceived roughness' *Journal of Neuroscience*, 17(19), pp. 7480-7489.

Booth, F.W. (1987) 'Physiologic and biochemical effects of immobilization on muscle', *Clinical Orthopaedics and Related Research*, 219, pp. 15-20.

Borghuis, J., Hof, A.L. and Lemmink, K.A.P.M. (2008) 'The importance of sensory-motor control in providing core stability', *Sports Medicine*, 38(11), pp. 893-916.

Bruton, A. (2002) 'Muscle plasticity response to training and detraining', *Physiotherapy*, 88(7), pp. 398-408.

Carcia, C.R. and Martin, R.L. (2007) 'The influence of gender on gluteus medius activity during a drop jump'*, Physical Therapy in Sport* 8(4), pp. 169-176.

Carroll, T.J., Herbert, R.D., Munn, J., Lee, M. and Gandevia, S.C. (2006) 'Contralateral effects of unilateral strength training: evidence and possible mechanism', *Journal of Applied Physiology*, 48(19), pp. 1400-1406.

Clark, B.C., Issac, L.C., Lane, L.J., Damron, L.A. and Hoffman, R.L. (2008) 'Neuromuscular plasticity during and following 3wk of human forearm cast immobilization', *Journal of Applied Physiology,* 105(5), pp. 868-878.

Coh, M., Matjacic, Z., Peharec, S., Bacic, P., Rausavljevic, N. and Mackala, K. (2015) 'Kinematic, dynamic and EMG analysis of drop jumps in female elite triple jump athletes', *Collegium Antropologicum*, 39(1), pp. 159-166.

Cohen, J. (1988) *Statistical power analysis for the behavioral sciences*. 2nd edn. Hillsdale, NJ: Lawrence Erlbaum Associates.

Couppe, C., Suetta, C., Kongsgaard, M., Justesen, L., Hvid, L.G., Aagaard, P., Kjaer, M. and Magnusson, S.P. (2012) 'The effects of immobilisation on the mechanical properties of the patellar tendon in younger and older man', *Clinical Biomechanics*, 27(9), pp. 949-954.

Comerford, M.J. and Mottran (2001) 'Functional stability re-training: principles and strategies for managing mechanical dysfunction', *Manual Therapy*, 6(1), pp. 3-14.

Crowther, R.G., Spinks, W.L., Leicht, A.S. and Spinks, C.D. (2007) 'Kinematic responses to plyometric exercises conducted on compliant and noncompliant surfaces', *Journal of Strength and Conditioning Research,* 21(2), pp. 460-465.

Davis, W. (1898) 'Research in cross-education', *Yale Psychology Laboratory*, 6, pp. 6-50.

De Villarreal, E.S.S., Requena, B. and Newton, R.U. (2010) ‘Does plyometric training improve strength performance? A meta-analysis’, *Journal of Science and Medicine in Sport*, 13(5), pp. 513-522.

Deschenes, M.R., Giles, J.A., McCoy, R.W., Volek, J.S., Gomez, A.L. and Kraemer, W.J. (2002) ‘Neural factors account for strength decrements observed after short term muscle unloading’, *American Journal of Physiology and Regulatory Integrative and Comparative Physiology*, 282(2), pp.578-583.

Dias Lopes, A., Barreto, H.J., Aguiar, R.C., Gondo, F.B. and Neto, J.G. (2009) ‘Brazilian physiotherapy services in the 2007 Pan-American Games: injuries, their anatomical location and physiotherapeutic procedures’, *Physical Therapy in Sport*, 10(2), pp. 67-70.

Di Stasi, S.L. and Snyder-Mackler, L. (2012) ‘The effects of neuromuscular training on the gait patterns of ACL-deficient men and women’, *Clinical Biomechanics*, 27(4), pp. 360-365.

Distefano, L.J., Blackburn, J.T., Marshall, S.W. and Padua, D.A. (2009) ‘Gluteal muscle activation during common therapeutic exercises’, *Journal of Orthopaedic Sports and Physical Therapy*, 39(7), pp. 532-540.

Doorenbosch, C.A.M. and Harlaar, J. (2003) ‘A clinically applicable EMG-force model to quantify active stabilization of the knee after a lesion of the anterior cruciate ligament’, *Clinical Biomechanics*, 18(2), pp. 142-149.

Etnoyer, J., Cortes, N., Ringbled, S.I., Van Lunen, B.L., Onate, J.A. (2013) ‘Instruction and jump-landing kinematics in college-aged female athletes over time’, *Journal of Athletic Training*, 48(2), pp. 161-171.

Farthing, J.P. and Zehr, P.E. (2014) ‘Restoring symmetry: clinical applications of cross-education’ *Exercise Sports Science Review*, 42(2), pp. 70-75.

Farthing, J.P., Chilibeck, P.D. and Binsted, G. (2005) ‘Cross-education of arm muscular strength is unidirectional in right-handed individuals’, *Medicine Science of Sports Exercise*, 37(9), pp.1594-1600.

Farthing, J.P., Krentz, J.R. and Magnus, C.R.A. (2010) ‘Strength training the free limb attenuates strength loss during unilateral immobilisation’, *Journal of Applied Physiology*, 109(6), pp. 1887-1894.

Farthing, J.P., and Zehr, E.P. (2014) ‘Restoring symmetry: clinical applications of cross-education’, *Exercise Sports Science Review*, 42(2), pp. 70-75.

Farthing, J.P., Krentz, J.R., Magnus, C.R.A., Barss, T.S., Lanovaz, J.L., Cummine, J., Esopenko, C., Sarty, G.E. and Borowsky, R. (2011) ‘Changes in functional magnetic resonance imaging cortical activation with ross education to an immobilized limb’, *Medicine and Science in Sport and Exercise*, 43(8), pp. 1394-1405.

Farthing, J.P. (2009) ‘Cross-education of strength depends on limb dominance: implications for theory and application’, *Exercise Sport Science Review*, 37(4), pp. 179-187.

Farthing, J.P., Krentz, J.R. and Magnus, R.A. (2009) ‘Strength training the free limb attenuates strength loss during unilateral immobilisation’, *Journal of Applied Physiology*, 106(3), pp. 830-836.

Fatouros, I.G., Jamurtas, A.Z., Leontsini, D., Tazildaris, K., Aggelousis, N., Kostopoulos, N. and Buckenmeyer, P. (2000) ‘Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength’, *Journal of Strength and Conditioning Research*, 14(4), pp. 470-476.

Filipa, A., Byrnes, R., Paterno, M.V., Myer, G.D. and Hewett, T.E. (2010) ’Neuromuscular training improves performance on the star excursion balance test in young female athletes’, *Journal of Orthopaedic & Sports Physical Therapy*, 40(9), pp. 551-558.

Fisher, J., Steele, J. and Smith, D. (2013) ’Evidence-based resistance training recommendations for muscular hypertrophy’ *Medicina Sportiva*, 17(4), pp. 217-235.

Ford, K.R., Myer, G.D., Schmitt, L.C., U.H.L., T.L., Hewett, T.E. (2011) ‘Preferential quadriceps activation in female athletes with incremental increase in landing intensity’, *Journal of Applied Biomechanics*, 27(3), pp. 215-222.

Ford, K.R., Myer, G.D., Smith, R.L., Vianello, R.M., Seiwert, S.L. and Hewett, T.E. (2006) ’A comparison of dynamic coronal plane excursion between matched male and female athletes when performing single leg landings’, *Clinical Biomechanics*, 21(1), pp. 33-40.

Fuglsang-Frederiksen, A. and Scheel, U. (1978) ‚Transient decrease in number of motor units after immobilisation in man’, *Journal of Neurology Neurosurgery Psychiatry*, 41(10), pp. 924-929.

Fuji, M., Sato, H. and Takahira, N. (2012) ‚Muscle activity response to external moment during single leg drop landing in young basketball players: The importance of biceps femoris in reducing internal rotation of knee during landing’, *Journal of Sports Science and Medicine*, 11(2), pp. 255-259.

Gabriel, D.A., Kamen, G. and Frost, G. (2006) ‘Neural adaptations to resistive exercise‘, *Sports Medicine,* 36(2), pp. 133-142.

Gandevia, S.C. (2010) ‘Spinal and supraspinal factors in human muscle fatigue’, *Physiological Reviews*, 81(4), pp. 1725-1788.

Garfinkel, S. and Caffarelli, E. (1992) ‘Relative changes in maximal force, EMG, and muscle cross-sectional area after isometric training’, *Medical Science of Sports and Exercise*, 24(11), pp. 1220-1227.

Gilchrist, J., Mandelbaum, B.R., Melancon, H., Ryan, G.W., Silvers, H.J., Griffin, L.Y., Watanabe, D.S., Dick, R.W. and Dvorak, J. (2008) ‘A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players’, *The American Journal of Sports Medicine*, 36(8), pp. 1476-1483.

Grindstaff, T.L., Hammil, R.R. and Tuzson, A.E. (2006) ‘Neuromuscular control training programs and noncontact anterior cruciate ligament injury rates in female athletes: A numbers-needed-to-treat analysis’, *Journal of Athletic Training*, 41(4), pp. 450-456.

Glover, E.I., Yasuda, N., Tarnopolsky, M.A., Abadi, A. and Stuart, M.P. (2010) ‘Little change in markers of protein breakdown and oxidative stress in humans in immobilization-induced skeletal muscle atrophy’, *Applied Physiology*, 35(2), pp. 125-133.

Goetschius, J., Smith, H.C., Vacek, P.M., Holterman, L.A., Shultz, S.J., Tourville, T.W., Slauterbecl, J., Johnson, R.J. and Beynnon, B. (2012) ‘Application of a clinic-based algorithm as a tool to identify female athletes at risk for anterior cruciate ligament injury’, *The American Journal of Sports Medicine*, 40(9), pp. 1978-1984.

Hairsine, J. (2011) ‘Drop jumps’, *UK Strength and Conditioning Association*, 14(24), pp. 14-17.

Hayes, L.D. and Morse, C.I. (2010) ‘The effects of progressive dehydration on strength and power: is there a dose response’, *European Journal of Applied Physiology*, 108 (4), pp. 701-707.

Hebert, R.D. and Gandevia, S.C. (1996) ‘Muscle activation in unilateral and bilateral efforts assessed by motor nerve and cortical stimulation’, *Journal of Applied Physiology*, 80(4), pp. 1351-1356.

Hellebrandt, F.A. (1951) ‘Cross education; ipsilateral and contralateral effects of unimanual training’, *Journal of Applied Physiology*, 4(2), pp. 136-144.

Hendy, A.M., Spittle, M. and Kidgell, D. (2011) ‘Cross education and immobilisation: Mechanisms and implications for injury rehabilitation’, *Journal Of Science and Medicine in Sport,* 15(2), pp. 94-101.

Herrick, A.B. and Stone (1996) ‘The effects of periodization versus progressive resistance exercise on upper and lower body strength in women’, *Journal of Strength and Conditioning Research*, 10(2), pp. 72-76.

Hewett, T.E., Stroupe, A.L., Nance, T.A. and Noyes, F.R. (1996) ‘Plyometric training in female athletes’, *The American Journal of Sports Medicine*, 24(6), pp. 765-773.

Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V. and Noyes, F.R. (1999) ‘The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study’, *American Journal of Sports Medicine*, 27(6), pp. 699-706.

Hewett, T.E., Myer, G.D. and Zazulak, B.T. (2008) ‘Hamstrings to quadriceps peak torque ratios diverge between sexes with increasing isokinetic angular velocity’, *Journal of Science and Medicine in sport*, 11(5), pp. 452-459.

Hewett, T.E., Myer, G.D., Ford, K.R., Heidi, R.S., Colosimo, A.J., McLean, S.G., van den Bogert, A.J., Paterno, M.V. and Succop, P. (2005) ‘Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study’, *American Journal of Sports Medicine*, 33(4), pp. 492-501.

Hibbs, A.E., Thompson, K.G., French, D., Wrigley, A. and Spears, I. (2008) ‘Optimizing performance by improving core stability and core strength’, *Sports Medicine*, 38(12), pp. 995-1008.

Holsgaard-Larsen, A., Jensen, C., Mortesen, N.H.M. and Aagaard, P. (2014) ‘Concurrent assessment of lower limb loading patterns, mechanical muscle strength and functional performance in ACL-patients- a cross-sectional study’, *The Knee*, 21(1), pp. 66-73.

Hortobagyi, T., Lambert, N.J. and Hill, J.P. (1997) ‘Greater cross education following training with muscle lengthening than shortening’, *Medical Science of Sports and Exercise*, 29(1), pp. 107-112.

Hortobagyi, T. (2005) ‘Cross education and the human central nervous system’, *Engineering in Medicine and Biology Magazine*, 24(1), pp. 22-28.

Housch, D.J., Weir, J. and Weir, L.L. (1996) ‘Effects of eccentric-only resistance training and detraining’, *International Journal of Sports Medicine*, 17(2), pp. 145-148.

Hubscher, M., Zech, A., Pfeifer, K., Hansel, F., Vogt, L. and Banzer, W. (2009) ‘Neuromuscular training for sports injury prevention: A systematic review’, *Medical Science in Sports and Exercise*, 42(3), pp. 413-421.

Ingle, L., Sleap, m. and Tolfrey, K. (2006) ‘The effect of a complex training and detraining programme on selected strength and power variables in early pubertal boys’, *Journal of Sports Sciences*, 24(9), pp. 987-997.

Izquierdo, M., Ibanez, J., Gonzalez-Bandillo, J.J., Ratamess, N.A., Kraemer, W.J., Hakkinen, K., Bonnabau, H., Granados, C., French, D.N. and Gorostiaga, E.M. (2007) ‘Detraining and tapering effects on hormonal responses and strength performance', *Journal of Strength and Conditioning Research*, 21(3), pp. 768-775.

Jones, T.W., Howaston, G., Russell, M. and Duncan, N.F. (2013) 'Performance and neuromuscular adaptations following differing ratios of concurrent strength and endurance training', *Journal of Strength and Conditioning Research*, 27(12), pp. 3342-3351.

Johnston, L.A., Butler, R.J., Sparling, T.L. and Queen, R.M. (2015) 'A single set of biomechanical variables cannot predict jump performance across various jumping tasks', *Journal of Strength and Conditioning Research*, 29(20), pp. 396-407.

Junge, A., Engebretsen, L., Mountjoy, M.L., Alonso, J.M., Aubry, M.J. and Dvorak, J. (2009) 'Sports injuries during the summer Olympic games 2008', *The American Journal of Sports Medicine*, 37(11), pp. 2165-72.

Junge, A., Lamprecht, M., Stamm, H., Hasler, H., Bizzini, M., Tschopp, M., Reuter, H., Wyss, H., Chilvers, C. and Dvorak, J. (2010) 'Countrywide campaign to prevent soccer Injuries in Swiss amateur players', *The American Journal of Sports Medicine*, 39(1), pp. 57-63.

Kannus, P. (2000) 'Immobilization of early mobilization after an acute soft-tissue injury', *The Physician and Sports Medicine*, 28(3), pp. 1-8.

Kannus, P. (1992) 'Effect of one-legged exercise on the strength, power and endurance of the contralateral leg. A randomized, controlled study using isometric and concentric isokinetic training', *European Journal of Applied Physiology and Occupational Physiology*, 64(2), pp. 117-126.

Karni, A., Meyer, G., Jezzard, P., Adams, M.M., Turner, R. and Ungerlaider, L.G. (1995) 'Functional MRI evidence for adult motor cortex plasticity during motor skills learning', *Nature*, 377(6545), pp. 155-158.

Keays, S.L., Bullock-Saxton, J.E., Newcombe, P. and Keays, A.C. (2003) 'The relationship between knee strength and functional stability before and after anterior cruciate ligament reconstruction' *Journal of Orthopaedic Research*, 21(2), pp. 231-237.

Kell, R.T. (2011) 'The influence of periodized resistance training on strength changes in men and women', *Journal of strength and Conditioning Research*, 25(3), pp. 735-744.

Kiefer, A.W., Ford, K.R., Paterno, M.V., Schmitt, L.C., Myer, G.D., Riley, M.A., Shockley, K. and Hewett, T.E. (2013) 'Inter-segmental postural coordination measures differentiate athletes with ACL reconstruction from uninjured athletes', *Gait and Posture*, 37(2), pp. 149-153.

Kibler, W.B., Press, J. and Aaron Sciascia (2006) 'The role of core stability in athletic function' *Sports Medicine*, 36(3), pp. 189-198.

Kilding, A.E., Tunstall, H. and Kuzmic, D. (2008) ‘Suitability of FIFA’s “The 11” training programme for young football players-impact on physical performance’, *Journal of Sports Science and Medicine*, 7(3), pp.320-326.

Klugman, M.F., Brent, J.L., Myer, G.D., Ford, R.K. and Hewett, T.E. (2011) ‘Does an in-Season only neuromuscular training protocol reduce deficits quantified by the tuck jump assessment?’, *Clinical Sports Medicine*, 30(4), pp. 825-840.

Knezevic, O.M., Mirkov, D.M., Kadija, M., Nedeljkovic, A. and Jaric, S. (2014) ‘Asymmetries in explosive strength following anterior cruciate ligament reconstruction’, *The Knee*, 21(6), pp. 1039-1045.

Kraemer, W.J. and Ratamess, N.A. (2005) ‘Hormonal responses and adaptations to resistance exercise and training’, *Sports Medicine*, 35(4), pp. 339-361.

Landry, C.R., Lemos, B., Rifkin, S.A., Dickinson, W.J. and Hartl, D.L. (2007) ‘Genetics properties influencing the evolvability of gene expression’ *Science*, 317(5834), pp. 118-121.

Larsen, J.B., Farup, J., Lind, M. and Daglas, U. (2015) ‘Muscle strength and functional performance is markedly impaired at the recommended time point for sport return after anterior cruciate ligament reconstruction in recreational athletes’, *Human Movement Science*, 39, pp. 73-87.

Leukel, C., Taube, W., Rittweger, J., Gollhofer, A., Ducos, M., Weber, T. and Lundbye-Jensen, J. (2014) ‘Changes in corticospinal transmission following 8 weeks of ankle joint immobilization’, *Clinical Neurophysiology,* 126(1), pp. 131-139.

Lemmer, J.T. (2000) ‘Age and gender responses to strength training and detraining’, *Medicine of Science of Sports and Exercise*, 32(8), pp.1505-1512.

Lee, M., Hinder, M.R., Gandevia, S.C. and Carroll, T.J. (2010) ‘The ipsilateral motor cortex contributes to cross-limb transfer of performance gains after ballistic motor practice’, *Journal of Physiology*, 588(1), pp. 201-212.

Lee, M. and Carroll, T.J. (2007) ‘Cross education: possible mechanisms for the contralateral effects of unilateral resistance training’, *Sports Medicine,* 37(1), pp. 1-14.

Macefield, V.G. (2005) ‘Physiological characteristics of low-threshold mechanoreceptors in joints, muscle and skin in human subjects’, *Clinical and Experimental Pharmacology and Physiology*, 32(1-2), pp. 135-144.

Magnus, C.R.A., Barss, T.S., Lanovaz, J.L. and Farthing, J.P. (2010) ‘Effects of cross-education on the muscle after a period of unilateral limb immobilisation using a shoulder sling and swathe', *Journal of Applied Physiology*, 109(6), pp. 1887-1894.

Magnus, C.R.A., Arnold, C.M., Johnston, G., Dal-Bello Haas, V., Basran, J., Krentz, J.R. and Farthing, J.P. (2013) 'Cross-education for improving strength and mobility after distal radius fractures: A randomized controlled trial' *Physical Medicine and Rehabilitation*, 94(7), pp. 1247-1255.

Mandelbaum, B.R., Silvers, H.J., Watanabe, D.S., Knarr, J.F., Thomas, S.D., Griffin, L.Y. and Garrett, W. (2005) 'Effectiveness of neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up', *American Journal of Sports Medicine*, 33(7), pp. 1003-1010.

Malinzak, R.A., Colby, S.M., Kirkendall, D.T., Yu, B. and Garrett, W. (2001) 'A comparison of knee joint motion patterns between men and women in selected athletic tasks', *Clinical Biomechanics*, 16(5), pp. 438-445.

Malliaras, P., Kamal, B., Nowell, A., Farley, T., Dhamu, H., Simpson, V., Morrissey, D., Langberg, H., Maffulli, N. and Reeves, N.D. (2013) 'Patellar tendon adaptation in relation to load-intensity and contraction type', *Journal of Biomechanics*, 46(11), pp. 1893-1899.

Makaruk, H., Winchester, J.B., Sadowski, J., Czaplicki, A. And Sacewicz, T. (2011) 'Effects of unilateral and bilateral plyometric training on power and jumping ability in women', *Journal of Strength and Conditioning Research*, 25(120), pp. 3311-3318.

Markovic, G., Juric, I., Milanovic, D. and Metikos, D. (2007) 'Effects of sprint and plyometric training on muscle function and athletic performance', *Journal of Strength and Conditioning Research*, 21(2), pp. 543-549.

Markolf, K.L., Burchfield, D.M., Shapiro, M.M., Shepard, M.F., Finerman, G.A. and Slauterbeck, J.L. (1995) 'Combined knee loading states that generate high anterior cruciate ligament forces', *Journal of Orthopaedic Research*, 13(6), pp. 930-935.

Matthews, P.B. (1981) 'Evolving views on the internal operation and functional role of the muscle spindle', *Journal of Physiology*, 320, pp. 1-30.

Maulder, P. and Cronin, J. (2005) 'Horizontal and vertical jump assessment: Reliability, symmetry, discriminative and predictive ability', *Physical Therapy in Sport*, 6(2), pp.74-82.

McErlain-Naylor, S., King, M. and Pain, M.T.G. (2014) 'Determinants of countermovement jump performance: a kinetic and kinematic analysis', *Journal of Sports Sciences*, 32(19), pp. 1805-1812.

Megawin 3.0 Software User Manual (2010) Manualzz. Available at: http://manualzz.com/doc/4221445/megawin-3.0-software-user-manual (Accessed 4th of April 2016).

Mello, R.G.T., Oliviera, L.F. and Nadal, J. (2007) 'Digital Butterworth filter for subtracting noise from low magnitude surface electromyogram', *Computer Methods and Programs in Biomedicine*, 87(1), pp. 28-35.

Meyer, K., Kaplan, J.T., Essex, R., Webber, C., Damasio, H. and Damasio, A. (2010) 'Predicting visual stimuli on the basis of activity in auditory cortices', *National Neuroscience*, 13(6), pp. 667-668.

Meyer, K., Kaplan, J.T., Essex, R., Damasio, H. and Damasio, A. (2011) 'Seeing touch is correlated with content-specific activity in primary somatosensory cortex', *Cerebral Cortex*, 21(9), pp. 2113-2121.

Mizner, R.L., Kawaguchi, J.K. and Chmielewski, T.L. (2008) 'Muscle strength in the lower extremity does not predict post instruction improvements in the landing patterns of female athletes', *Journal of Orthopaedic Sports and physical Therapy*, 38(6), pp. 353-361.

More, R.C.K.B.T., Neiman, R., *et al* (1993) 'Hamstrings: an anterior cruciate ligament protagonist: an in vitro study.' *American Journal of Sports Medicine*, 21, pp. 231-237.

Mortiani, T. and de Vries, H. (1979) 'Neural factors versus hypertrophy in the time course of muscle 'strength Gain', *American Journal of Physical Medicine*, 58(3), pp. 115-130.

Muellbacher, W., Ziemann, U., Wissel, J., Dang, N., Kofler, M., Facchini, S., Boroojerdi, B., Poewe, W. and Hallett, M. (2002) 'Early consolidation in human primary motor cortex', *Nature*, 415(6872), pp. 640-644.

Mujika, I. and Padilla, S. (2000) 'Detraining: loss of training-induced physiological and performance adaptations. Part 1: short term insufficient training stimulus' *Sports Medicine*, 30(2), pp. 79-87.

Munn, J., Herbert, R.D. and Gandevia, S.C. (2004) 'Contralateral effects of unilateral resistance training: a meta-analysis', *Journal of Applied Physiology*, 96(5), pp. 1861-1866.

Munn, J., Herbert, R.D., Hancock, M.J. and Gandevia, S.C. (2005) 'Training with unilateral resistance exercise increases contralateral strength', *Journal of Applied Physiology*, 99(5), pp. 1880-1884.

Murton, A.J. and Greenhaff, P.L. (2013) 'Resistance exercise and the mechanism of muscle mass regulation in humans: acute effects on muscle protein turnover and the gaps in our understanding of chronic resistance exercise training adaptation', *Journal Biochemistry and Cell Biology*, 45(10), pp. 2209-14.

Myer, G.D., Ford, K.R., Brent, J.L. and Hewett, T.E. (2006) ‘The effects of plyometric vs. dynamic stabilisation and balance training on power, balance, and landing force in female athletes’, *Journal of Strength and Conditioning Research*, 20(2), pp. 345-353.

Myer, G.D., Hewett, T.E. and Ford, K.R. (2005) ‘Reducing knee and anterior cruciate ligament injuries among female athletes: a systematic review of neuromuscular training interventions’, *Journal of Knee Surgery*, 18(1), pp. 82-88.

Myer, G.D., Ford, K.R. and Hewett, T.E. (2008) ‘Tuck jump assessment for reducing anterior cruciate ligament injury risk’ *Athletic Theory Today*, 13(5), pp. 39-44.

Myer, G.M., Ford, K.R., Brent, J.L. and Hewett, T.E. (2012a) ‘An integrated approach to change the outcome part I: neuromuscular screening methods to identify high ACL injury risk athlete’, *Journal of Strength and Conditioning Research*, 26(8), pp. 2265-2271.

Myer, G.D., Ford, K.R., Brent, J.L. and Hewett, T.E. (2012b) ‘An integrated approach to change the outcome part II: targeted neuromuscular training techniques to reduce identified ACL injury risk factors’, *Journal of Strength and Conditioning Research*, 26(8), pp. 2272-2292.

Naclerio, F., Faigenbaum, A.D., Larumbe-Zabala, E., Perez-Bibao, T., Kang, J., Ratamess, N.A. and Triplett, N.T. (2013) ‘Effects of different resistance training volumes on strength and power in team sports athletes’, *Journal of Strength and Conditioning Research*, 27(7), pp. 1832-1840.

Narici, M.V., Roi, G.S., Landoni, L., Minetti, A.E. and Cerretelli, P. (1989) ‘Changes in force, cross-sectional area and neural activation during strength training and detraining of the human quadriceps’, *European Journal of Applied Physiology and Occupational Physiology*, 59(4), pp. 310-390.

Otzel, D.M., Chow, J.W. and Tillman (2015) ‘Long-term deficits in quadriceps strength and activation following anterior cruciate ligament reconstruction’, *Physical Therapy in Sport*, 16(1), pp. 22-28.

Ozbar, N., Ates, S. and Agopyan, A. (2014) ‘The effect of 8-week plyometric training on leg power, jump and sprint performance in female soccer players’, *Journal of Strength and Conditioning Research*, 28(10), pp. 2888-2894.

Padua, D.A., Carcia, C.R., Arnold, B.L. and Granata, K.P. (2005) ‘Gender differences in leg stiffness and stiffness recruitment strategy during two-legged hopping’, *Journal of Motor Behaviour*, 37(2), pp. 111-125.

Padua, D.A. (2009) ‘The landing error scoring system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: the jump-ACL study’, *American Journal of Sports Medicine*, 37(10), pp. 1996-2002.

Padulo, J., Tiloca, A., Powell, D., Grantelli, G., Bianco, A. and Paoli, A. (2013) ‘EMG amplitude of the biceps femoris during jumping compared to landing movements’, *Springer Plus*, 2(1), pp.1-7.

Papandreou, M., Bills, E., Papathanasiou, G., Spyropoulos, P. and Papaioannou, N. (2013) ‘Cross-exercise on quadriceps deficit after ACL reconstruction’, *Journal of Knee Surgery*, 26(1), pp. 51-58.

Pappas, E. and Carpes, F.P. (2012) ‘ Low extremity kinematic asymmetry in male and female athletes performing jump-landing tasks’, *Journal of Science and Medicine in Sport*, 15(1), 87-92.

Pappas, E., Hagins, M., Sheikhzadeh, A., Nordin, M. and Rose, D. (2007) ‘Biomechanical differences between unilateral and bilateral landings from a jump; gender differences’, *Clinical Journal of Sports Medicine*, 17(4), pp. 263-268.

Pascual-Leone, A., Grafman, J. and Hallet, M. (1994) ‘Modulation of cortical motor output maps during development of implicit and explicit knowledge’, *Science*, 263(5151), pp. 1287-1290.

Paulsen, G., Myklestad, D. and Raastad, T. (2003) ‘The influence of volume of exercise on early adaptations to strength training’, *Journal of Strength and Conditioning Research*, 17(1), pp. 115-120.

Pearce, A.J., Hendy, A., Bowen, W.A. and Kidgell, D.J. (2012) ‘Corticospinal adaptations and strength in the immobilized arm following 3 weeks unilateral strength training’ *Scandinavian Journal of Medicine and Science in Sports*, 23(6), pp.740-748.

Prentice, W.E. (2011) *Rehabilitation techniques for sports medicine and athletic training*. 5th edn. McGraw Hill Professional.

Piazza, M., Battaglia, C., Fiorilli, G., Innocenti, G., Iuliano, E., Aquino, G., Calgano, G., Giombini, A. And Di Cagno, A. (2014) ‘Effects of resistance training on jumping performance in pre-adolescent rhythmic gymnasts: a randomized controlled study’, *Italian Journal of Anatomy and Embryology*, 119(1), pp. 10-19.

Rasch, P.J. and Morehouse, L.E. (1957) ‘Effects of static and dynamic exercises on muscular strength and hypertrophy’, *Journal of Applied Physiology*, 11(1), pp. 29-34.

Reilly, T. (1977) ‘Some risk factors in selected track and field events’, *British Journal of Sports Medicine*, 11(1), pp. 53-56.

Risberg, M.A., Holm, I., Myklebust, G. and Engebretsen, L. (2007) ‘Neuromuscular training versus strength training during first 6 months after anterior cruciate ligament reconstruction: a randomized clinical trial', *Journal of the American Physical Therapy Association*, 87(6), pp. 737-750.

Ronnestad, B.R., Wilhelm, E., Kvamme, N.H., Refsnes, P.E., Kadi, F. and raastad, T. (2007) 'Dissimilar effects of one-and three set strength training on strength and muscle mass gains in upper and lower body in untrained subjects', *Journal of Strength and Conditioning Research*, 21(1), pp. 157-163.

Russell, K.A., Palmieri, R.M., Steven, M.Z. and Ingersoll, C.D. (2006) 'Sex differences in valgus knee angle during a single-leg drop jump', *Journal of Athletic Training*, 41(2), pp. 166-171.

Salaj, S., Milanovic, S. and Jukic, D. (2007) 'The effects of proprioceptive training on jumping and agility performance', *Kinesiology*, 39(2), pp. 131-141.

Schlumberger, A., Stec, J. and Schmidtbleicher, D. (2001) 'Single-vs. multiple-set strength training in women', *Journal of Strength and Conditioning Research*, 15(3), pp. 284-289.

Schoenfeld, B.J. (2010) 'The mechanism of muscle hypertrophy and their application to resistance training', *Journal of Strength and Conditioning Research*, 24(10), pp. 2857-2872.

Schoenfeld, B.J. (2013) 'The muscle pump: potential mechanism and applications for enhancing hypertrophic adaptations', *Journal of Strength and Conditioning,* pp. 1-5.

Semmler, J.G. and Nordstrom, M.A. (1998) 'Motor unit discharge and force tremor in skill-and strength-trained individuals', *Experimental Brain Res*earch 119(1), pp. 27-38.

Seynnes, O.R., de Boer, M. and Narici M.V. (2006) 'Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training', *Journal of Applied Physiology*, 102(1), pp. 368-373.

Shaver, L.G. (1975) 'Cross transfer effect of conditioning and deconditioning on muscular strength', *Ergonomics*, 18(1), pp. 9-16.

Shima, N., Ishida, K., Katayama, K., Morotome, Y and Miyamura, M. (2002) 'Cross education of muscular strength during unilateral resistance training and detraining', *European Journal of Applied Physiology*, 68(4), pp. 287-294.

Shultz, S.J., Nguyen, A.D., Leonard, M.D. and Schmitz, R.J. (2009) 'Thigh strength and activation as predictors of knee biomechanics during a drop jump task', *Medicine and Science in Sports and Exercise*, 41(4), pp. 857-866.

Silvers, H.J. and Mandelbaum, B.R. (2007) 'Prevention of anterior cruciate ligament injury in the female athlete', *British Journal of Sports Medicine*, 41(1), pp. 52-59.

Silvers, H.J., Mandelbaum, B.R., Watanabe, D.S., Knarr, J.F., Thomas, S.D., Griffin, L.Y., Kirkendall, D.T. and Garrett, W. (2005) 'Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow up', *American Journal of Sports Medicine*, 33(7), pp. 1003-1010.

Silvers, H.J. and Mandelbaum, B.R. (2011) 'ACL injury prevention in the athlete', *Sport Orthopadie Traumatologie*, 27(1), pp. 18-26.

Smith, H.C., Johnson, R.J., Shultz, S.J., Tourville, T., Holterman, L.A., Slauterbeck, J., Vacek, P.M. and Beynnon, B.D. (2011) 'A prospective evaluation of the landing error scoring system (LESS) as a screening tool for anterior cruciate ligament injury risk', *The American Journal of Sports Medicine*, 40(3), pp. 521-526.

Soligard, T., Myklebust, G., Steffen, K., Holme, I., Silvers, H., Bizzini, M., Junge, A., Bahr, R. and Andersen, T.E. (2008) 'Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomized controlled trial', *British Medical Journal*, 337, pp. 1-9.

Steffen, K., Meeuwisse, W.H., Romiti, M., Kang, J., McKay, C., Bizzini, M., Dvorak, J., Finch, C., Myklebust, G. and Emery, C.A. (2013) 'Evaluation of how different implementation strategies of an injury prevention programme (FIFA 11+) impact team adherence and injury risk in Canadian female youth football players: a cluster-randomised trial', *British Journal of Sports Medicine*, 47(8), pp. 480-487.

Steffen, K., Emery, C.A., Romiti, M., Kang, J., Bizzini, M., Dvorak, J., Finch, F.C. and Meeuwisse, W.H. (2014) 'High adherence to a neuromuscular injury prevention programme (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players: a cluster randomised trial', *British Journal of Sport Medicine*, 47(12), pp. 794-802.

Stensrud, S., Myklebust, G. and Kristianslund, E. (2010) 'Correlation between two-dimensional video analysis and subjective assessment in evaluating knee control among elite female team handball players', *British Journal of Sports Medicine*, 45(7), pp. 589-595.

Taggesson, S., Oberg, B., Good, L. and Kvist, J. (2008) 'A comprehensive rehabilitation program with quadriceps strengthening in closed versus open Kknetic chain exercises in patients with anterior cruciate ligament deficiency', *The American Journal of Sports Medicine,* 36(2), pp.298-307.

Taylor, N.F., Dodd, K.J. and Damiano, D.L. (2005) 'Progressive resistance exercise in physical therapy; a summary of systematic reviews', *Physical Therapy*, 85(11), pp. 1208-1223.

Taube, W., Gruber, M. and Gollhofer (2008) ‘Spinal and supraspinal adaptations and their functional relevance’, *Acta Physiology*, 193(2), pp. 101-116.

Thom, J.M., Thompson, M.W., Ruell, P.A., Bryant, G.J., Fonda, J.S., Harmer, A.R., Janse De Jonge, X.A.K. and Hunter, S.K. (2001) ‘Effect of 10-day cast immobilisation on sarcoplasmic reticulum calcium regulation in humans’, *Acta Physiology Scandinavian,* 172(2), pp. 141-147.

Tomljanovic, M., Spasic, M., Gabrilo, G., Uljevic, O. and Foretic, N. (2011) ‘Effects of five weeks of functional vs. traditional resistance training on anthropometric and motor performance variables’, *Kiniesology*, 42(20), pp. 145-154.

Tsang, K.K.W. and DiPasquale, A.A. (2011) ‘Improving the Q:H strength ratio in women using plyometric exercises’, *Journal of Strength and Conditioning Research*, 25(10), pp. 2740-2745.

Vathrakokilis, K., Malliou, P., Gioftsidou, A., Beneka, A. and Godolias, G. (2008) ‘Effects of a balance training protocol on knee joint proprioception after anterior cruciate ligament reconstruction’, *Journal of Back and Musculoskeletal Rehabilitation,* 21(4), pp. 233-237.

Villarreal, E.S., Requena, B. and Newton, R.U. (2010) ‘Does plyometric training improve strength performance? A meta-analysis’, *Journal of Science and Medicine in Sport*, 13(5), pp. 513-522.

Vissing, K., Brink, M., Lonbro, S., Sorensen, H., Overgaard, K., Danborg, K., Mortensen, J., Elstrom, O., Rosenhoj, N., Ringgaard, S., Andersen, J.L. and Aagaard, P. (2008) ‘Muscle adaptations to plyometric vs. resistance training in untrained young men’, *Journal of Strength and Conditioning*, 22(6), pp. 1799-1810.

Vuk, S., Gregov, C. and Markovic, G. (2015) ‘Relationship between knee extensor muscle strength and movement performance: the effect of load and body size’, *Kinesiology*, 47(1), pp. 27-32.

Wadden, K.P., Button, D.C. Kibele, A. and Behm, D.G. (2012) ‘Neuromuscular fatigue recovery following rapid and slow stretch-shortening cycle movements’, *Applied Physiology of Nutrition Metabolism*, 37(3), pp. 437-447.

Walsh, M., Arampatzis, A., Schade, F. and Bruggemann, G.P. (2004) ‘The effect of drop jump starting height and contact time in power, work performed, and moment of force’, *Journal of Strength and Conditioning Research*, 18(30), pp. 561-566.

Weber, D.J., Friesen, R. and Miller, L.E. (2012) ‘ Interfacing the somatosensory system to restore touch and proprioception: essential considerations’, *Journal of Motor Behaviour*, 44(6), pp. 403-18.

Weir, J.P., Housh, D.J., Housh, T.J. and Weir, L.L. (1995) ‘The effect of unilateral eccentric weight training and detraining on joint angle specificity, cross-training, and the bilateral deficit’, *Journal of Orthopaedic & Sports Physical Therapy*, 22(5), pp. 207-215.

Wilk, K.E., Arrigo, C., Andrews, J.R. and Clancy, W.G. (1999) ‘Rehabilitation after anterior cruciate ligament reconstruction in the female athlete’, *Journal of Athletic Training*, 34(2), pp. 177-193.

Wilk, K.E. and Andrews, J.R. (1992) ‘Current concepts in the treatment of anterior cruciate ligament disruption’, *Journal of Orthopaedic & Sports Physical Therapy*, 15(6), pp. 176-181.

Zaras, N., Spengos, K., Methentis, S., Papadopoulos, C., Karampatsos, G., Georgiadis, G., Stasinaki, A., Manta, P. and Terzis, G. (2013) ‘ Effects of strength v.s ballistic-power training on throwing performance’, *Journal of Sports Science and Medicine*, 12(1), pp. 130-137.

Zazulack, B.T., Hewett, T.E., Reeves, N.P., Goldberg, B. and Cholewicki (2007) ‘Deficit in neuromuscular control of the trunk predict knee injury risk’, *The American Journal of Sports Medicine*, 35(7), pp. 1035-1130.

Zech, A., Hubscher, M., Vogt, L., Banzer, W., Hansel, F. and Pfeifer, K. (2009) ‘Neuromuscular training for rehabilitation of sports injuries: a systematic review’, *Medical Science of Sports and Exercise*, 41(10), pp. 1831-1841.

APPENDICES

APPENDIX A

University research ethics review form

UNIVERSITY RESEARCH ETHICS REVIEW FORM

In the case of **postgraduate research student** projects (i.e. MRes, MA by Project/Dissertation, MPhil, PhD and DProf), this form should be completed by the student concerned in full consultation with their supervisor.

In the case of **staff** research projects, this form should be completed by the member of staff responsible for the research project (i.e. as Principal Investigator and/or grant-holder) in full consultation with any co-investigators, research students and research staff.

Further guidance on the University's Research Ethics Policy and Procedures, along with links to relevant research ethics materials and advice, can be found on the Research & Postgraduate Office Research Ethics webpage:

http://www.londonmet.ac.uk/research/the-research-and-postgraduate-office/current-students/research-ethics.cfm

This form requires the completion of the following three sections –

SECTION A: APPLICANT DETAILS
SECTION B: THE PROJECT - ETHICAL ISSUES
SECTION C: THE PROJECT - RISKS AND BENEFITS

SECTION A: APPLICANT DETAILS

A1	**Background information**
	Research project title: THE EFFECTS OF CROSS-EDUCATION ON NEURO-MUSCULAR CONTROL, BIOMECHANICS AND FUNCTIONAL PERFORMANCE DURING DETRAINING
	Date of submission for ethics approval: 30th August 2013
	Proposed start date for project: 14th October 2013
	Proposed end date for project: 7th February 2014
	Ethics ID no: * (to be completed by RERP)

A2	**Applicant details, if for a research student project**
	Name: Nick Gardiner
	London Met Email address: n.gardiner@londonmet.ac.uk

A3	**Principal Researcher/Lead Supervisor** Member of staff at London Metropolitan University who is responsible for the proposed research project either as Principal Investigator/grant-holder

	or, in the case of postgraduate research student projects, as Lead Supervisor
	Name: Dr David McCarthy
	Job title: Professor
	London Met Email address: d.mccarthy@londonmet.ac.uk

SECTION B: THE PROJECT - ETHICAL ISSUES

B1 **The Research Proposal**

Please attach a brief summary of the research project including:

- Background/rationale
- Aims/objectives
- Research methodology
- Review of the key literature in this field & conceptual framework for study
- References

See separate document

B2

Research Ethics

Please outline any ethical issues that might arise from this study and how they are to be addressed.

***NB** all research projects have ethical considerations. Please complete this section as fully as possible using the following pointers for guidance.*

- Does the project involve potentially deceiving participants? No
- Will you be requiring the disclosure of confidential or private information? No
- Is the project likely to lead to the disclosure of illegal activity or incriminating information about participants? No
- Does the project require a Criminal Records Bureau check for the researcher? No
- Is the project likely to expose participants to distress of any nature? Yes
- Will participants be rewarded for their involvement? No
- Are there any potential conflicts of interest in this project? No
- Any other potential concerns? No

If you answered yes to any of the points above, please explain.

B3

The training programme is likely to cause delayed onset muscle soreness (DOMS) as the participants will be untrained and as such they will be unaccustomed to the exercises. The risk of DOMS will be mitigated by the inclusion of a warm up and cool down before and after the training sessions and testing.

There is a low risk of muscle strains or ligament sprains but these are no more likely than they would be with normal training activities. The bilateral plyometric training will progress gradually and subjects will be tested by the use of a standing long jump for their appropriateness to participate. The unilateral exercises have been carefully designed so as to be hypothetically safe during the early and intermediate stage of rehabilitation so should not pose any substantial injury risk. Furthermore, the participants will be carefully instructed and will each receive video instructions that they will be able to access via a smart phone or tablet, which should help, minimise the risk of any incorrect techniques being performed.

B4

B5

Prior to the application of the EMG electrodes, participant's skin will require abrading and cleansing. Some moderate pressure during the application will also be required. These procedures may cause individuals some mild discomfort or embarrassment. However, the procedures will be clearly explained within the consent form and the participants will be given warnings before the procedures are carried out and will be permitted to request a chaperone if desired.

Does the proposed research project involve:

- The analysis of existing data, artefacts or performances that are **not** already in the public domain (i.e. that are published, freely available or available by subscription)? No
- The production and/or analysis of physical data (including computer code, physical entities and/or chemical materials) that **might involve** potential risks to humans, the researcher(s) or the University? No
- The direct or indirect collection of **new data** from humans or animals? Yes

If you answered yes to any of the points above, please explain.

sEMG, force platform, video analysis, MVC, light gate data will be collected from the subjects all of which will be by non-invasive methods.

Will the proposed research be conducted in any country outside the UK? If so, are there independent research ethics regulations and procedures that either:

- **Do not** recognise research ethics review approval from UK-based research ethics services? No
- Require **more** detailed applications for research ethics review than would ordinarily be conducted by the University's Research Ethics Review Panels and/or other UK-based research ethics services? No

If you answered yes to any of the points above, please explain.

Does the proposed research involve:

- The collection and/or analysis of body tissues or fluids from humans or animals? No
- The administration of any drug, food substance, placebo or invasive procedure to humans or animals? No
- Any participants lacking capacity (as defined by the UK Mental Capacity Act 2005)? No

	• Relationships with any external statutory-, voluntary-, or commercial-sector organisation(s) that require(s) research ethics approval to be obtained from an external research ethics committee or the UK National Research Ethics Service (this includes research involving staff, clients, premises, facilities and data from the UK National Health Service, Social Care organisations and some other statutory public bodies within the UK)? No **If you answered yes to any of the points above, please contact your faculty's RERP chair for further guidance.**

SECTION C: THE PROJECT - RISKS AND BENEFITS

C1 **Risk Assessment**

Please outline

- the risks posed by this project to both researcher and research participants
- the ways in which you intend to mitigate these risks
- the benefits of this project to the applicant, participants and any others

The risks associated with this project are DOMS, muscle strains and ligament sprains due to the demands of the training intervention and explosive nature of the testing procedures.

These risks will be mitigated by a warm-up and cool-down protocol before and after the training and testing. All testing will take place in the Science Centre which is equipped with accessible and complete first aid kits, defibrillators and a fully functional sports injury clinic. All members of data collection team will be insured, graduate sports therapists who have also been trained in first aid. Therefore, immediate and qualified care will be on hand at all times during the testing should anyone suffer an injury or distress. Participants will be required to complete the training intervention in their own time. Advice will be given at the start of the study for how to deal with any minor aches and pains but should any serious injury be sustained the participants will be advised to seek medical advice either via A&E or a graduate sports therapist. Each participant will have my contact details so will be able to ask me directly for advice if required. Please note risks of significant injury or distress are minimal and numerous measures are in place to ensure that remains the case.

The risks to the participants' modesty during preparation for the testing will be mitigated by clear written and verbal explanations and the right to request a chaperone.

The benefits of this project to the applicant are that it will allow them to submit the work for publication, which if successful, would be the first study to investigate cross-education by looking at functional performance following a period of detraining. It will also form the main study of the applicant's MPhil.

The participants for this project will be undergraduate students form sports courses at LMU and will benefit from the exposure to numerous output measures and the general experience of the data collection. They will also obtain knowledge regarding their own strength, jump height and sprint times which may help shape their own training in the future. The participants will be recruited via a verbal pitch to undergraduate BSc students on LMU sports courses at the start of their lectures. They will be given a sheet to fill in their name and email address if they are interested. I will then contact each student via email explaining exactly what the study entails, the eligibility criteria and the PIS and consent form.

In addition to investigating the cross-education effects following a period of detraining the study also aims to investigate its effect on knee biomechanics and the associated risk for ACL injury. As such the study is designed to use female participants due to their dramatically higher propensity to suffer non-contact ACL injuries compared to their male counterparts (Ortiz *et al.,* 2010; Myer *et al.,* 2008). This study intends to use untrained females who have been shown to be at the highest risk of the knee injury (Hewitt *et al.,* 1999).

The data will be collected by myself, Anne Delextrat (supervisor), Ollie Williams (graduate study assistant) and Raffaella Pontonutti (graduate study assistant) using the following equipment and its associated software; force platform, light gates, isokinetic dynamometer, sEMG's and video analysis. Data will be transferred to a prepared Excel spreadsheet and stored using password protection. All paper copies of personal information and study related data will be confidential and stored in accordance with the ICO Data Protection requirements. No one but the aforementioned persons will have access to the data other than the participants who will be permitted to their own information on request.

The data will be stored safely for 7 years. Some of the data may be utilised for further studies as part of the candidate's transfer to their PhD.

The project supervisor and any other individuals who assist with the project will benefit by being named contributors when the work is submitted for publication. Those that are involved in the training or treatment of athletes may also benefit by applying any potentially significant findings to their own practices.

The PIS and consent form state the risks to the participants and identifies that they can withdraw at any time.

Checklist to be completed by applicant prior to submission of the form

Section	***Completed***
Section A	Y
Section B	Y
Section C	Y
Research Proposal attached	Y

Please submit this *Form* as an email attachment to the Chair of your faculty's Research Ethics Review Panel (RERP) and copy in all of the staff and students who will be involved in the proposed research.

See: http://www.londonmet.ac.uk/research/the-research-and-postgraduate-office/current-students/research-ethics.cfm

Please note that research ethics approval can be granted for a maximum of 4 years or for the duration of the proposed research on the condition that:

- The researcher must inform their faculty's Research Ethics Review Panel (RERP) of any changes to the proposed research that may alter the answers given to the questions in this form or any related research ethics applications

- The researcher must apply for an extension to their ethics approval if the research project continues beyond 4 years.

APPENDIX B

Participant information sheet

PARTICIPANT INFORMATION SHEET

Dear Participant,

You are being invited to take part in a research project. Before you decide to participate 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 and discuss it with others if you wish. Ask if anything is unclear or if you would like more information.

The study aims to look at performance measures in relation to a plyometric training programme, followed by a period of detraining and, for half the participants, a period of unilateral strength training. Activation of the gluteal, hamstring and quadriceps muscles will be measured to investigate their response to cross-education. The biomechanics are to be measured using video analysis during a single leg vertical jump with $110°$ of knee flexion and a drop jump from a 31cm box. A drop jump is maximum effort vertical jump, carried out immediately after dropping down off of an object. Electrical activity of the aforementioned muscles will be simultaneously measured during the drop jump.

If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form.

- If you have had any lower limb injuries, conditions or surgery in the last 6 months unfortunately you will not be eligible for this trial on safety grounds.
- If you currently take part in any regular and progressive strength training for the lower limb such as weight training or plyometrics or have done in the previous 12 weeks you will not be eligible for the trial as you will not meet the participant criteria.
- The required time for participation is a 15 week period comprising of 2-3 15 minute training sessions. There will be 5 testing periods which will require you to be present for half a day each period;
  1) 15/10/13, 16/10/13
  2) 03/12/13, 04/12/13

3) 17/12/13, 18/12/13

4) 14/01/14, 15/01/14

5) 04/02/14 and 05/02/14.

Exactly what half day you will be needed for will be arranged with you via email.

- There are some risks that you will suffer delayed onset muscle soreness (aching muscles) due to the unaccustomed activity. Risk of injury is minimal as the training programme will be demonstrated to you, is designed to be gradually progressive and will incorporate warm-ups and cool-downs. You will also be provided with tutorial videos for your smart phone, tablet, lap top or pc to ensure you understand how to do each exercise.
- The appropriate attire is loose-fitting shorts and your usual sports footwear such as running shoes or cross-training shoes.
- Preparation before the tests include placing two, adhesive electrodes on the hip, just 2-3 cm below the hip bone (iliac crest), rectus femoris, at 50% on the line from the anterior spina iliaca superior to the superior part of the patella, bicep femoris at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia. Additional electrodes must be placed on the collar-bone (clavicle) around the ankle. The electrodes contain a small amount of conductive gel; therefore a small patch of skin will be test beforehand to make sure there are no adverse reactions. Before placing the electrodes on the skin, the side must be lightly scoured and cleaned with alcohol wipes in order to ensure optimal conductivity.
- The test requires you to stand on top of a 31 cm high box. You must then drop down off of the box and subsequently jump as *high* as possible. The single leg vertical jump will require you bend your knee to 110° (a bar will be in place to guide you) and jump *as high* as possible. You can use your arms for both jumps. You will be allowed 3 sub-maximal practice trials for each jump beforehand to get used to the manoeuvre. You will then carryout 3 drop jumps and 3 single leg vertical jumps. These will be filmed.
- You will be required to complete a maximal voluntary isometric contraction on an isokinetic dynamometer using three different positions for both your left and right limb to test the gluteals, quadriceps and hamstrings. You will be permitted 3 attempts.
- Once this is completed, the electrodes will be removed and you are free to go.

If you decide to participate in this study, your participation and any information collected from you will be strictly confidential, and only available to the research team.

We would like to thank you, in advance, for your participation.

Nick Gardiner
n.gardiner@londonmet.ac.uk

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 minimal risks involved in the participation of this study and these have been explained to me.
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): ________________________________

Tick this box if you would like to receive a summary of the results by e-mail ☐

I agree to receive text reminders during the training programme ☐

E-mail: ____________________________

Mobile: ____________________________

Date: __________

APPENDIX C

Plyometric training programme

PLYOMETRIC TRAINING PROGRAMME

Warm-up

1 min Jogging

30 secs Sidesteps

30 secs Backwards jogging

30 secs Skipping

3 x Mini hops (left & right)

3 x Mini squat jumps

20 (10 left, 10 right) x Forward lunges

Avoid static stretching before these exercises

Cool Down

2 min Jogging

Stretching if desired

Guidelines

- Warm-up to be carried out before each session
- Cool-down to be carried out after each session
- Always complete the specified number of sessions/week
- Allow a minimum of 48 hrs rest in between sessions
- Jumps should be of maximal effort at all times
- Use a minimum of 1:4 Work:Rest ratio so if it takes 10s to perform, the rest period should be at least 40s
- Use the videos as a reference for the correct technique

*** Participants take part in this programme completely at their own risk ***

GREEN = Low intensity
ORANGE = Medium intensity
RED = High intensity

* Please note all exercises should be completed at 100% effort

Week 1
(21/10/13)
2 SESSIONS

3 x 10 Two footed ankle hops (on the spot)

3 x 10 Squat jumps (on the spot)

3 x 10 Jump & reach (on the spot)

Week 2
(28/10/13)
2 SESSIONS

3 x 10 Squat jumps (on the spot)

3 x 10 Jump & reach (on the spot)

3 x 10 Lateral Jumps (left and right)

Week 3
(04/11/13)
3 SESSIONS

3 x 10 Forward squat jumps

3 x 10 Split squat jump (on the spot)

3 x Double-leg tuck jump (on the spot)

Week 4
(11/11/13)
2 SESSIONS

3 x 10 Zig zag forward squat jumps

3 x 10 Cycled split squat jump (on the spot)

3 x 20 (10 left, 10 right) Single leg vertical jump (on the spot)

Week 5
(18/11/13)
3 SESSIONS

3 x 20 (10 left, 10 right) Forward single leg jumps

3 x 10 Cycled split squat jump (on the spot)

3 x 20 (10 left, 10 right) Single leg vertical jump (on the spot)

Week 6
(25/11/13)
3 SESSIONS

3 x 20 (10 left, 10 right) Forward single leg jumps

3 x 10 Cycled split squat jump (on the spot)

3 x 20 (10 left, 10 right) Single leg vertical jump (on the spot)

3 x 20 (10 left, 10 right) Zig zag single leg forward jumps

APPENDIX D

Weekly emails to participants for bilateral training and unilateral CEG (training) including Dropbox^{TM} training videos

WEEKLY EMAILS TO PARTICIPANTS FOR BILATERAL TRAINING AND UNILATERAL CEG (TRAINING)

WEEK 1

Dear Participant,

Thank you again for volunteering for this study and for taking part in last weeks testing.

Please see attached for the revised training programme and please now discard the original one. This modified version has clarified names to the exercises, a slightly adjusted programme and highlights using green, orange and red the intensity level of each exercise (all require 100% effort). The other important addition is the rest period which is to be a minimum of 1:4 work:rest. So if it takes 10s to complete a set then give yourself a minimum of 40s rest (more is fine but please do not do less).

See below for the instructional videos for the warm up, cool down and this weeks exercises. You need to complete 2 sessions this week (from Mon 21st Oct 2013) and remember to leave 2 days in between. Therefore, it is best to avoid leaving the second session to Sunday as it makes it harder fit in the following week's exercises.

Warm up: https://www.dropbox.com/s/qzo9qspzl5tix86/Warm%20Up.mov
Week 1: https://www.dropbox.com/s/ji4021df9vuu1ov/Week%201.mov
Cool down: https://www.dropbox.com/s/mlnjrlneu0ujpxj/Cool%20Down.mov

If you have any questions at all please do not hesitate to ask.

GOOD LUCK!

WEEK 2

Dear Participant,

I hope the first week has gone well.

Here are the videos for next week.

Warm up https://www.dropbox.com/s/qzo9qspzl5tix86/Warm%20Up.mov
Week 2 https://www.dropbox.com/s/e26yodf03tlf3ek/Week%202.mov
Cool down https://www.dropbox.com/s/mlnjrlneu0ujpxj/Cool%20Down.mov

2 sessions next week please and it would be good to aim to complete them earlier rather than later to allow plenty of time for the following week which is 3 sessions.

Good luck.

WEEK 3

Dear All,

You are headed towards the halfway mark for the plyos - well done!

3 new exercises this week, there was an error on the programme which said 3 x double leg tuck jumps, it is meant to read 3 x 10 (see attached for a revised version).

Warm up: https://www.dropbox.com/s/qzo9qspzl5tix86/Warm%20Up.mov
Week 3: https://www.dropbox.com/s/s42nbhi2kkzq2li/Week%203.mov
Cool down: https://www.dropbox.com/s/mlnjrlneu0ujpxj/Cool%20Down.mov

Best of luck and make sure you spread out this week's sessions as much as you can.

WEEK 4

Dear Participant,

I hope all is well and you have been enjoying the programme. Personally, I have enjoyed the forward squat jumps the most so far :)

Another 3 new exercises this coming week. The cycled split squat is similar to last week's split squat exercise but you land with your feet switched this time (see vid) and please alternate which foot forward you start with for each set.

Back to 2 sessions again so it should be a bit easier to fit in.

Warm up: https://www.dropbox.com/s/qzo9qspzl5tix86/Warm%20Up.mov
Week 4: https://www.dropbox.com/s/7620hekq7jge09s/Week%204.mov
Cool down: https://www.dropbox.com/s/mlnjrlneu0ujpxj/Cool%20Down.mov

WEEK 5

Dear Participant,

It is the penultimate week of the plyos!

3 sessions this week please. Don't forget to keep a focus on your techniques as well as making the exercises maximal.

I will be getting in touch with you soon to make arrangements for your follow up tests which will be on the 4th, 5th or 6th of December.

Good luck for this week, here are the vids:

Warm up: https://www.dropbox.com/s/qzo9qspzl5tix86/Warm%20Up.mov
Week 5: https://www.dropbox.com/s/5dwf4aeks92sazf/Week%205.mov
Cool down: https://www.dropbox.com/s/mlnjrlneu0ujpxj/Cool%20Down.mov

WEEK 6

Dear Participant,

The final plyo week is here!

Good luck and I look forward to seeing you for the testing the week after.

Warm up: https://www.dropbox.com/s/qzo9qspzl5tix86/Warm%20Up.mov
Week 6: https://www.dropbox.com/s/otm4xz51t9nj23o/Week%206.mov
Cool down: https://www.dropbox.com/s/mlnjrlneu0ujpxj/Cool%20Down.mov

WEEK 7

Dear Single Leg Trainer's,

Firstly thank you so much for the first 6 weeks and for testing this week.

Please see attached for your programme for the next 9 weeks and below for the video instructions.

Warm
Up: https://www.dropbox.com/s/o1a211fgzjrvva0/Warm%20Up%201.mov

Week 7: https://www.dropbox.com/s/2xt3g7ebwlqhfkr/Week%207.mov
Cool Down:
https://www.dropbox.com/s/o4mpibkq15pdi04/Cool%20Down%201.mov

Remember you are performing ALL exercises on your dominant leg ONLY and you need to avoid any strength or resistance training on your other leg.

This is WEEK 7 so you need to do 2 sessions this week but they can be done on consecutive days.

Further videos showing progressions will follow.

Good luck!

Best wishes,
Nick

WEEK 8

Dear Participant,

I hope Week 8 is going well and you are getting used to the new programme. Remember it is 3 sessions this week and each week from now on. The exercises can be on consecutive days if required.

Here are the videos for the progressions for when you need them:

Single Leg Squats Progressions:
https://www.dropbox.com/s/2cvnirva44mrd6g/Progressions_Single%20Leg%20Squats.mov

Single Leg Hamstring Curls Progressions:
https://www.dropbox.com/s/v3twkoa8bpbay7y/Progressions_Hamstring%20Curls.mov

Single Leg Plank Progressions:
https://www.dropbox.com/s/4ueyiwk5mw91s29/Progressions_Single%20leg%20plank.mov

Single Leg Side Plank Progressions:
https://www.dropbox.com/s/c1knriwjow5teeo/Progressions_Single%20leg%20side%20plank.mov

Stork Progressions:
https://www.dropbox.com/s/oxivvt6o90hrxgl/Progressions_Stork.mov

WEEK 9

Dear Participant,

You are a good way through Week 9 now.

I hope you have begun to incorporate progressions where necessary. Please make sure you maintain quality and control of the exercises as they get harder.

Remember it is 3 sessions every week now.

Have a great weekend.

WEEK 10

Dear Participant,

Week 10 and Christmas are here!

You are now two thirds of the way through the study so the final stretch is ahead of you.

Good luck with this week's exercises and progressions if required, they should be a good break from the TV and food :)

Merry Christmas.

WEEK 11

Dear Participant,

You are well into the last 4 weeks now.

Remember to keep progressing the exercises if you need to and use the videos to guide you.

Have a good weekend.

WEEK 12

Dear Participant,

You are well into the last 4 weeks now.

Remember to keep progressing the exercises if you need to and use the videos to guide you.

Have a good weekend.

WEEK 13

Dear Participant,

Not long to go now!

I'll be in touch next week to start making plans for the final data collection appointments.

Keep up the good work.

WEEK 14

Dear Participant,

I hope your penultimate week is going well.

I would like to start to coordinate the final data collection days. Please see attached for the options. Please complete and return to me by the end of this week.

Many thanks.

WEEK 15

Dear Participant,

If you are in the training gorup, there's just a few days left! Well done for getting this far and please keep up the good work for these last sessions.

Thank you for all completing the time slots form and returning it. Please see attached for the confirmed time slots for next week. We will be in the same room as before and all being well it each slot will be 1hr long.

Please remember to bring shorts and trainers with you.

I look forward to seeing you.

APPENDIX E

Emails to DTG participants

EMAILS TO DTG PARTICIPANTS

WEEK 7

Dear Non Training Participant,

Firstly thank you so much for your hard work and commitment throughout the first 6 weeks and for testing this week.

All I need you to do for the next 9 weeks is avoid any lower limb strength or resistance training and return for the last tests in February.

Thanks again, I will be in touch again in the future to remind you of the testing dates and arrange times. Have a great DOM-free Christmas!

Best wishes,
Nick

APPENDIX F

Maintenance training programme

MAINTENANCE TRAINING PROGRAMME

Warm-up

30 secs ‘Cycling’ single leg forwards lying on your back

30 secs ‘Cycling’ single leg backwards lying on your back

1 min Mini single leg squats

Cool Down

30 secs ‘Cycling’ single leg forwards lying on your back

30 secs ‘Cycling’ single leg backwards lying on your back

Stretching if desired

Guidelines

- Warm-up to be carried out before each session
- Cool-down to be carried out after each session
- Always complete the specified number of sessions/week
- ONLY perform on your dominant leg (the leg you would kick with)
- Avoid ALL strength and resistance training on your non-dominant side
- Do not complete the whole programme more than once/day
- Strength exercises (single leg squats and hamstring curls) should be performed and progressed so as to maintain a high level of effort
- Balance and core exercises (planks and stork) should be performed and progressed so as to maintain a high level of difficulty
- Use the videos as a reference for the correct technique and for progresions

*** Participants take part in this programme completely at their own risk ***

Week 7
(2/12/13)
2 SESSIONS

2 x 10 Single leg squats

3 x 10 Hamstring curls

3 x 20s Single leg plank

3 x 20s Single leg side plank

2 x 30s Stork

Weeks 8-15
(9/12/13 to 27/01/14)
3 SESSIONS

2 x 10 Single leg squats (Progressions: deeper and slower)

3 x 10 Hamstring curls (Progressions: further away, slower, knee up)

3 x 20s Single leg plank (Progressions: increase time, arms further away)

3 x 20s Single leg side plank (Progressions: increase time, arms further away)

2 x 30s Stork (Progressions: increase time, eyes shut, pass the bottle, mini single leg squats)

APPENDIX G

Weekly text messages to participants during the bilateral training and for the CEG (training)

WEEKLY TEXT MESSAGES TO PARTICIPANTS DURING THE BILATERAL TRAINING AND FOR THE CEG (TRAINING)

Week 1 is here! 2 sessions this week please. Remember each set needs to be 100% effort. Keep those knees straight & aim for soft landings. Good luck. I hope

Week 2 is going ok. I have DOMS if it makes you feel any better! 2 sessions this week please. Don't forget it's 3 next week so try to leave some recovery time. Nick

Week 3. Remember to leave time to fit 3 sessions in this week. All new exercises so be careful with technique. Good luck

Week 4 is well under way. It's back to 3 sessions next week so try to get the last sesh this week sorted as early as possible so you have time to rest. Keep up the good work, it's much appreciated 👍

Week 5 Keep up the good work, you've nearly made it to the last week of the Plyos.

Week 6 I hope the final week is going well - nearly there! If you have not already emailed your availability pls do so by tomorrow morning so I can coordinate next week's testing.

Week 7: direction given during testing visits.

I hope Week 8 has gone well. There's still time to complete the third session if you need to. Keep up the good work.

Week 9 is just about done. I hope you've squeezed the sessions in around Christmas shopping.

I hope u all had a great Christmas & uv still been able to keep up with Week

10. Still a couple of days left if u need to fit ur last sessions in.

Happy New Year. Week 11 is nearly finished. I hope it's been going well.

I hope Week 12 has been good. There's still time if u need it to do ur last session this week. Keep up the good work :)

2 more days of Week 13 left. I hope it's going well. Hv a great wkend.

Only 1 more week left! If you haven't already, please email me back ur availability for testing. Thanks.

It's the final day! 15 weeks - well done & a huge thank you. See u in the week for the final tests.

APPENDIX H

Participant force platform data and copies of SPSS output

DJ_Force Max First Landing 1_2

1941.37	1741.37
2253.47	2033.60
1758.47	1804.42
2325.70	2349.93
1740.17	1799.40
2259.00	1923.85
2407.00	2375.87
4161.77	3598.73
1540.23	1486.13
2570.13	1879.38
1744.03	1824.47
1981.23	1972.58
1444.70	1468.22
1840.53	1991.20
2315.87	2266.57
2238.40	2140.42
2372.23	1726.93
2498.10	2690.93

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Maxfirstlanding1	.206	18	.043	.794	18	.001
DJ_Maxfirstlanding2	.188	18	.093	.835	18	.005

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Maxfirstlanding1 - DJ_Maxfirstlanding2	128.80000	265.87665	62.66773	-3.41735	261.01735	2.055	17	.056

PARAMETRIC NON SIG

DJ_Force Time First Landing 1_2

.39	.46
.28	.31
.40	.48
.37	.37
.46	.56
.25	.29
.43	.29
.16	.18
.40	.48
.40	.44
.46	.52
.30	.37
.47	.56
.45	.57
.37	.29
.35	.42
.37	.50
.40	.39

Tests of Normality

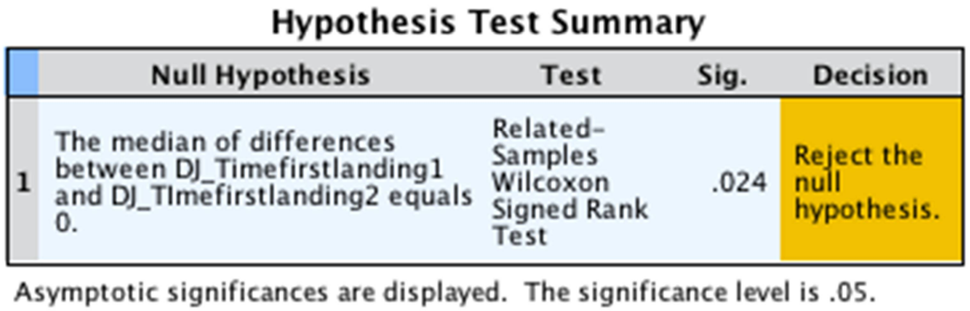
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Timefirstlanding1	.209	18	.037	.895	18	.047
DJ_TImefirstlanding2	.106	18	.200*	.950	18	.432

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Timefirstlanding1 - DJ_TImefirstlanding2	-.04278	.06781	.01598	-.07650	-.00906	-2.677	17	.016



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_Timefirstlanding1 and DJ_TImefirstlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.024	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NORMALITY TESTS 50:50 PARAMETRIC & NON-PARAMETRIC BOTH SIGNIFICANT*
DJ_Force Acel First Landing 1_2

29.28	25.57
44.03	37.22
29.21	29.42
41.56	41.51
28.99	26.30
46.78	38.12
42.78	41.29
65.79	57.92
27.43	26.44
39.41	30.04
24.33	24.73
35.14	37.02
25.58	24.72
25.85	27.96
39.07	37.06
34.91	32.89
28.84	25.17
35.23	36.74

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Accelfirstlanding1	.182	18	.118	.867	18	.016
DJ_Accelfirstlanding2	.156	18	.200*	.853	18	.009

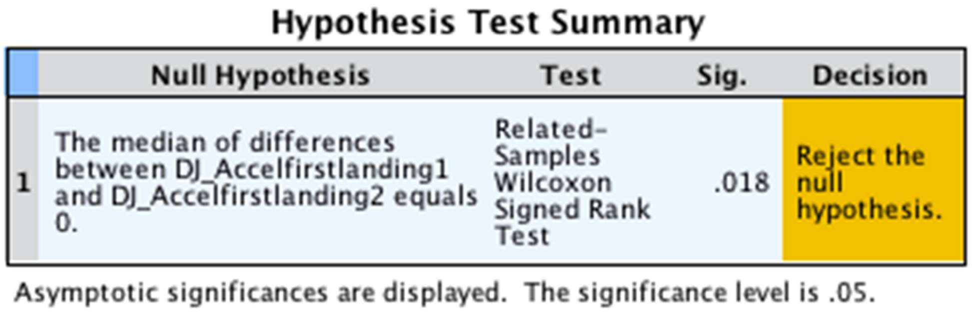
*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

	Paired Differences				t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference			

					Lower	Upper			
Pair 1	DJ_Accelfirstlanding1 - DJ_Accelfirstlanding2	2.44944	3.59830	.84813	.66005	4.23884	2.888	17	.010



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_Accelfirstlanding1 and DJ_Accelfirstlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.018	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NORMALITY TESTS 50:50 PARAMETRIC & NON-PARAMETRIC BOTH SIGNIFICANT*

DJ_Force Velocity First Landing 1_2

8.39	9.10
6.78	6.97

7.97	9.07
7.56	8.03
8.85	9.71
7.46	6.80
8.77	7.31
5.52	5.63
7.60	8.47
7.59	7.45
8.13	8.71
7.85	8.17
9.43	10.18
9.65	10.80
8.18	6.89
7.56	7.55
7.30	8.79
8.32	8.16

Tests of Normality

	Kolmogorov-Smirnov[a]	Shapiro-Wilk

	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Velocfirstlaning1	.141	18	.200*	.953	18	.481
DJ_Velocfirstlaning	.084	18	.200*	.988	18	.997

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Velocfirstlaning1 - DJ_Velocfirstlaning	-.27111	.80356	.18940	-.67071	.12849	-1.431	17	.170

PARAMETRIC NON SIG

DJ_Force Power First Landing 1_2

11905.00	12235.00
7684.07	7703.83
10276.33	10426.00
9062.53	9019.03

8559.40	**9301.03**
9621.53	**7426.67**
8798.97	**9515.17**
12347.67	**11934.17**
8546.33	**9270.40**
9567.83	**9757.90**
10558.33	**11623.00**
9634.93	**9210.72**
9496.47	**10603.67**
13604.67	**14317.17**
7263.53	**9778.33**
8836.00	**8058.03**
11850.33	**12104.17**
11297.33	**11291.67**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Powerfirstlanding1	.182	18	.117	.958	18	.566
DJ_Powerfirstlanding2	.148	18	.200*	.962	18	.634

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Powerfirstlanding1 - DJ_Powerfirstlanding2	-259.15056	957.24554	225.62494	-735.17756	216.87645	-1.149	17	.267

PARAMETRIC NON SIG

DJ_Force dfdt First Landing 1_2

70775.67	128095.17
110737.33	117755.67
127070.33	122553.17
198578.43	228353.00
113963.67	165959.67
129065.67	93713.83
285282.33	212087.50
270093.67	178415.33
45197.67	50226.82
209359.00	202249.83
66220.33	102714.83
123368.33	137928.33
132703.67	159158.33
153981.00	128930.17
192748.67	251968.00
115276.67	109163.17
110080.67	66868.67
125901.00	159986.33

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_dftdtfirstlanding1	.232	18	.012	.912	18	.094
DJ_dftdtfirstlanding2	.118	18	.200[*]	.980	18	.950

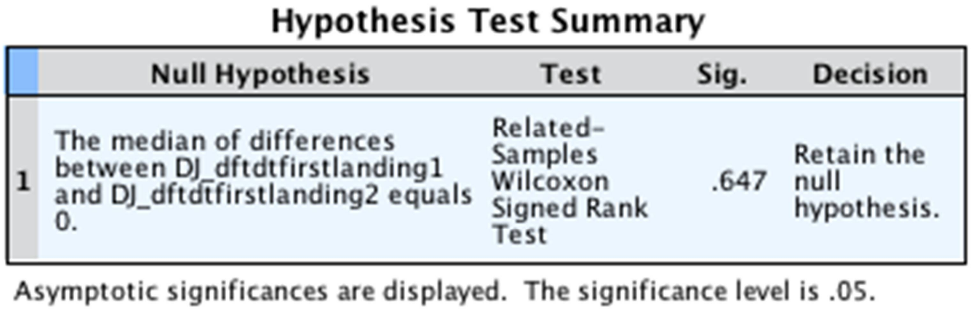
*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

	Paired Differences				t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference			

					Lower	Upper			
					Lower	Upper			
Pair 1	DJ_dftdtfirstlanding1 - DJ_dftdtfirstlanding2	-1984.65056	42982.21870	10131.00610	-23359.20505	19389.90394	-.196	17	.84



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_dftdtfirstlanding1 and DJ_dftdtfirstlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.647	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NORMALITY TESTS 50:50 PARAMETRIC & NON-PARAMETRIC BOTH NON-SIGNIFICANT

DJ_Force Flight Time First Landing 1_2

.48	.50
.38	.39
.47	.51
.45	.43
.42	.40
.47	.43
.47	.45
.37	.43

.42	.46
.34	.36
.42	.42
.50	.48
.47	.49
.57	.57
.45	.45
.32	.30
.49	.43
.47	.46

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Flighttme1	.176	18	.148	.944	18	.343
DJ_Flighttime2	.142	18	.200*	.971	18	.812

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Flighttme1 - DJ_Flighttime2	.00000	.03010	.00709	-.01497	.01497	.000	17	1.000

PARAMETRIC NON SIG

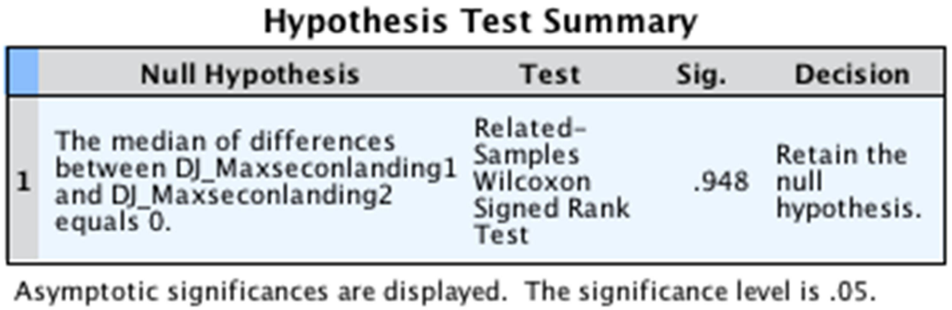
DJ_Force Max Second Landing 1_2

2816.27	**2071.60**
2693.03	**2983.30**
2986.23	**2632.87**
1578.57	**1847.43**
2964.30	**2371.93**
2621.13	**3232.93**
3088.03	**3337.80**
2299.93	**2325.00**
10701.20	**3070.88**
2738.63	**2634.78**
2265.63	**2222.03**
2145.60	**5521.53**
2878.70	**2757.38**
2375.93	**2413.70**
1732.83	**1808.40**
2330.90	**2445.08**
2671.50	**3005.30**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Maxseconlanding1	.421	18	.000	.447	18	.000
DJ_Maxseconlanding2	.174	18	.159	.773	18	.001

a. Lilliefors Significance Correction



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_Maxseconlanding1 and DJ_Maxseconlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.948	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NON-PARAMETRIC NON SIG

DJ_Force Accel Second Landing 1_2

39.29	34.64
55.02	37.91
44.73	48.65
53.36	46.51
26.29	30.39
61.32	47.00
46.59	56.19
48.82	51.34
40.97	41.36
51.53	45.07
38.21	35.71
43.99	41.76
38.00	39.39
40.43	38.72
40.09	39.47
27.02	27.79
31.21	35.64
37.67	39.37

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Accelsecondlanding 1	.137	18	.200*	.973	18	.853
DJ_Accelsecondlanding 2	.136	18	.200*	.982	18	.965

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Accelsecondlanding1 - DJ_Accelsecondlanding2	1.53500	6.58023	1.55097	-1.73727	4.80727	.990	17	.336

PARAMETRIC NON SIG

DJ_Force Power Second Landing 1_2

25712.67	24633.50
22001.33	16476.00
25290.33	30639.00
26983.33	23979.33
16005.67	19574.67
24392.00	19053.33
25561.00	28171.00
22265.33	23548.50

80632.00	23392.00
28945.33	26924.67
26219.33	26503.67
20846.33	21027.50
22887.00	26665.83
30213.67	32274.17
17924.00	19348.67
16008.33	16666.50
21388.67	26534.83
25776.00	27051.00

Tests of Normality

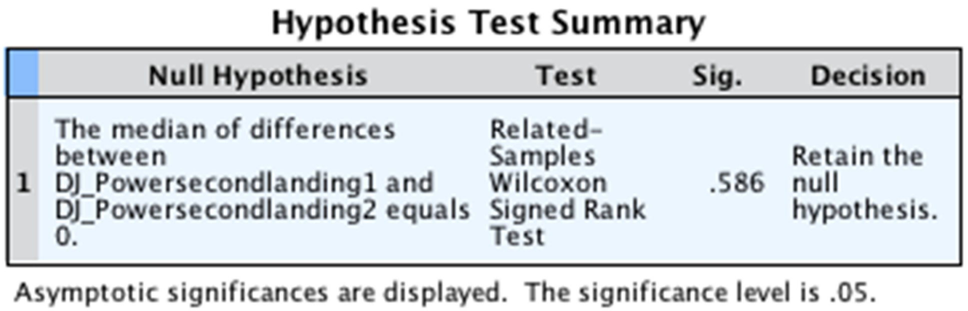
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Powersecondlanding1	.343	18	.000	.522	18	.000
DJ_Powersecondlanding2	.151	18	.200*	.959	18	.591

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	DJ_Powersecondlanding1 - DJ_Powersecondlanding2	2588.23056	13991.91803	3297.92671	-4369.78658	9546.24770	.785	17	.443



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_Powersecondlanding1 and DJ_Powersecondlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.586	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NORMALITY TESTS 50:50 PARAMETRIC & NON-PARAMETRIC BOTH NON-SIGNIFICANT

DJ_Force dfdt Second Landing 1_2

113140.00	130345.67
310382.00	172421.00
260002.60	288061.00
524810.00	300868.67
106737.00	138123.67
375714.30	167705.83
345302.00	216723.83
181294.00	179736.00
141174.00	113828.17
401677.00	249721.33
121356.60	115437.00
276780.60	237460.00
174686.30	197050.17
274074.60	289829.33
224205.30	155704.67
85566.67	75633.00

73458.00	**120899.00**
125432.60	**182427.00**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_dftdsecondlanding1	.146	18	.200*	.929	18	.184
DJ_dftdsecondlanding2	.127	18	.200*	.951	18	.437

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	DJ_dftdsecondlanding1 - DJ_dftdsecondlanding2	43545.45722	88576.92304	20877.78098	-502.81032	87593.72477	2.086	17	.05

PARAMETRIC NON SIG

SLVJ_L_Time Take Off 1_2

1.17	**.51**
.91	**.66**
.44	**.58**
.48	**.56**
.79	**.68**
.75	**.58**
.66	**.66**
.90	**.56**

.79	**.72**
.69	**.61**
.77	**.52**
1.20	**.43**
.73	**.58**
1.15	**.55**
.75	**.52**
.87	**.56**
.90	**.72**
.71	**.80**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_L_timetakeoff1	.158	18	.200*	.933	18	.218
SLVJ_L_timetakeoff2	.198	18	.060	.957	18	.551

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_L_timetakeoff1 - SLVJ_L_timetakeoff2	.21444	.25341	.05973	.08843	.34046	3.590	17	.002

PARAMETRIC SIG*

SLVJ_L_Max Take Off 1_2

1302.32	**1479.53**

750.83	831.26
1261.17	1246.43
1059.40	1020.73
1049.60	1061.37
843.85	890.83
1047.19	1127.83
1139.20	1306.53
994.18	997.48
995.30	1219.40
1202.83	1263.77
999.85	1069.67
1183.33	1034.97
1218.57	1289.50
1210.77	1202.80
930.34	1073.97
1368.93	1185.07
1366.60	1358.93

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_L_maxtakeoff1	.115	18	.200*	.968	18	.757
SLVJ_L_maxtakeoff2	.116	18	.200*	.987	18	.993

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_L_maxtakeoff1 - SLVJ_L_maxtakeoff2	-40.87833	104.81707	24.70562	-93.00264	11.24597	-1.655	17	.116

PARAMETRIC NON-SIG

SLVJ_L_acceltakeoff1_2

14.67	15.21
20.95	20.32
18.93	18.03
17.48	17.48
18.61	19.60
18.01	20.10
17.71	17.74
15.26	17.90
16.78	17.13
19.41	20.08
20.96	17.43
17.13	18.11
20.43	19.67
10.51	16.50
18.33	17.27
19.27	18.88

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_L_acceltakeoff1	.152	17	.200*	.895	17	.056
SLVJ_L_acceltakeoff2	.164	17	.200*	.970	17	.823

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

	Paired Differences				t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference			

					Lower	Upper			
Pair 1	SLVJ_L_acceltakeoff1 - SLVJ_L_acceltakeoff2	-.44647	1.97628	.47932	-1.46258	.56964	-.931	16	.365

PARAMETRIC NON-SIG

SLVJ_L_Velocitytakeoff 1_2

33.51	**28.42**
25.73	**31.34**
40.74	**37.44**
35.73	**41.51**
35.20	**30.51**
44.55	**26.16**
52.58	**36.68**
52.71	**27.04**
45.22	**22.17**
42.75	**32.01**
27.29	**22.52**
38.45	**29.36**
38.82	**40.12**
54.12	**24.77**
27.22	**43.16**
35.53	**33.92**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_L_velocitytakeoff 1	.116	17	.200[*]	.946	17	.403

SLVJ_L_velocitytakeoff2	.116	17	.200*	.955	17	.541

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_L_velocitytakeoff1 - SLVJ_L_velocitytakeoff2	7.50471	12.01246	2.91345	1.32847	13.68094	2.576	16	.020

PARAMETRIC SIG*(wrong direction)

SLVJ_L_Powertakeoff 1_2

22930.00	21369.00
30231.33	36441.33
41230.33	36707.33
35661.00	42515.67
34888.00	32629.33
49124.67	32149.00
51596.00	34492.00
51140.67	31310.33
51683.67	25799.00
41505.00	32631.00
30417.33	21946.33
44861.00	35908.67
44678.00	45919.00
48968.00	24914.33
35484.33	48751.33
46214.00	44535.00

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_Lpowertakeoff1	.160	17	.200*	.927	17	.193
SLVJ_Lpowertakeoff2	.109	17	.200*	.965	17	.730

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_Lpowertakeoff1 - SLVJ_Lpowertakeoff2	6887.84412	11070.35406	2684.95524	1195.99327	12579.69496	2.565	16	.02

PARAMETRIC SIG* (wrong direction)

SLVJ_L_dfdttakeoff 1_2

8164.90	10430.73
4687.20	6840.33
31660.43	8494.00
6445.27	3987.47
6905.50	6975.80
7886.27	8777.17
5814.10	8450.93
6385.27	6877.10
5787.63	6620.33
5965.73	6694.87
6283.30	6100.50

7820.50	**6907.27**
6819.70	**7606.77**
7954.10	**7876.87**
4496.50	**7052.23**
7177.00	**6775.30**
7027.20	**8773.33**

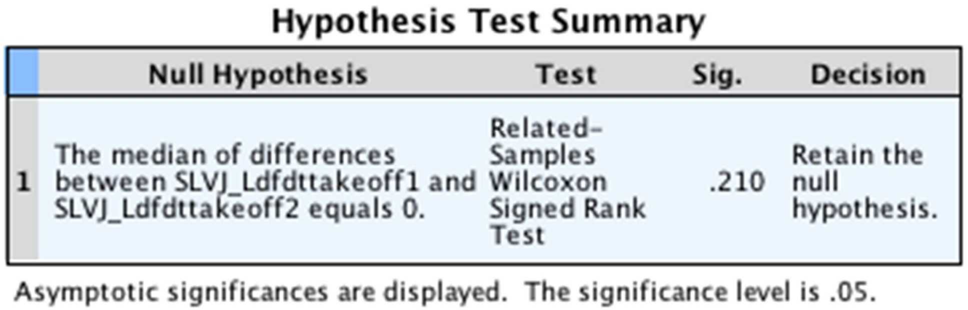
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_Ldfdttakeoff1	.435	17	.000	.422	17	.000
SLVJ_Ldfdttakeoff2	.180	17	.148	.930	17	.215

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_Ldfdttakeoff1 - SLVJ_Ldfdttakeoff2	708.21176	5939.38661	1440.51284	-2345.53905	3761.96258	.492	16	.630



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between SLVJ_Ldfdttakeoff1 and SLVJ_Ldfdttakeoff2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.210	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

50:50 NORMALITY NON-PARAMETRIC AND PARAMETRIC BOTH NON-SIG.

SLVJ_L_flighttime 1_2

.34	**.33**
.27	**.25**
.35	**.39**
.30	**.26**
.27	**.26**
.32	**.30**
.32	**.31**
.34	**.33**
.31	**.32**
.25	**.26**
.32	**.30**
.37	**.36**
.37	**.32**
.41	**.39**
.34	**.30**
.20	**.18**

.29	**.27**
.32	**.31**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_LFflighttime1	.143	18	.200*	.971	18	.813
SLVJ_LFflighttime2	.149	18	.200*	.952	18	.466

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_LFflighttime1 - SLVJ_LFflighttime2	.01389	.02033	.00479	.00378	.02400	2.898	17	.010

PARAMETRIC SIG*

SLVJ_L_max landing 1_2

1683.86	**1503.87**
2347.80	**1611.03**
1881.33	**2393.63**
2374.47	**1890.00**
1403.40	**1418.70**
2062.69	**1785.87**
2081.90	**2114.73**

2536.33	2281.73
1800.70	1828.67
2752.77	2106.90
1976.07	2012.60
1669.27	1979.13
2088.93	1706.90
2326.83	2637.43
1406.50	1296.73
1413.00	1336.03
1770.03	1758.97
1948.07	1917.73

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLCVJ_Lmaxlanding1	.106	18	.200[*]	.964	18	.671
SLCVJ_Lmaxlanding2	.080	18	.200[*]	.979	18	.945

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLCVJ_Lmaxlanding1 - SLCVJ_Lmaxlanding2	107.96111	323.77047	76.31343	-53.04616	268.96838	1.415	17	.175

PARAMETRIC NON-SIG

SLVJ_L_accel landing 1_2

24.59	22.08
45.87	29.48
31.25	39.03
42.43	33.39
23.38	22.21
37.00	36.75
40.10	35.10
32.07	32.53
42.21	30.93
27.57	27.28
32.41	37.15
36.99	28.75
32.68	37.03
23.74	21.20
22.04	20.53
23.70	25.64
27.47	26.18

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_L_acellanding1	.135	17	.200*	.931	17	.224
SLVJ_L_acellanding2	.124	17	.200*	.937	17	.283

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_L_acellanding1 - SLVJ_L_acellanding2	2.36706	6.12038	1.48441	-.77975	5.51387	1.595	16	.130

PARAMETRIC NON-SIG

SLVJ_L_power landing 1_2

56694.00	45233.33
80115.00	47519.00
50427.00	77480.33
99520.67	72803.33
52403.33	57522.33
75298.67	66785.67
112374.00	62381.67
95954.33	68498.67
147482.00	58856.33
90972.67	46797.00
70321.67	64894.67
58850.00	39307.67
128807.33	80320.67
54980.00	54855.67
77583.00	34435.33
51221.00	78546.00
71427.33	66674.00

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_L_powerlanding1	.157	17	.200*	.900	17	.067
SLVJ_L_powerlanding2	.113	17	.200*	.960	17	.632

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

	Paired Differences	t	df	Sig. (2-tailed)

					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_L_powerlanding1 - SLVJ_L_powerlanding2	20677.66647	29497.82159	7154.27260	5511.28608	35844.04686	2.890	16	.01

PARAMETRIC SIG*

SLVJ_L_dftdt landing 1_2

60436.00	155666.33
240140.33	78154.33
60036.33	52511.67
142342.67	131720.00
169516.00	92227.33
104563.67	108097.00
302769.00	210325.33
100763.67	74361.33
143797.00	162582.33
115462.67	73847.67
197927.33	201371.67
116986.00	34538.00
59685.00	37980.67
71127.00	79877.67
73950.33	68107.33

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_L_dftdt1	.174	17	.180	.879	17	.031

SLVJ_L_dftdt2	.201	17	.067	.900	17	.069

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_L_dftdt1 - SLVJ_L_dftdt2	32597.68647	63349.21012	15364.44027	26.52812	65168.84483	2.122	16	.05

PARAMETRIC NON-SIG (0.05)*

SLVJ_R_timetakeoff 1_2

1.24	.53
1.02	.82
.52	.70
.50	.45
.73	.67
.73	.56
.86	.61
1.03	.59
.88	.68
.84	.59
.74	.47
1.03	.53
.60	.48
.68	.58
.73	.45
.96	.57
1.02	.62
.78	.52

Tests of Normality

	Kolmogorov-Smirnov[a]	Shapiro-Wilk

	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_timetakeoff1	.115	18	.200*	.965	18	.707
SLVJ_R_timetakeoff2	.121	18	.200*	.946	18	.364

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_R_timetakeoff1 - SLVJ_R_timetakeoff2	.24833	.19785	.04663	.14995	.34672	5.325	17	.000

PARAMETRIC SIG*

SLVJ_R_maxtakeoff 1_2

1327.96	1468.63
698.00	770.87
1385.50	1311.13
993.96	1055.00
1021.01	1002.84
871.15	887.18
1077.53	1084.70
1177.30	1334.00
1006.06	1065.27
4564.03	1238.73
1152.83	1225.90
1068.87	1110.70
1099.88	1054.23
1270.50	1326.93
1202.73	1216.73
944.80	1044.07
1285.13	1227.83
1423.37	1358.20

Tests of Normality

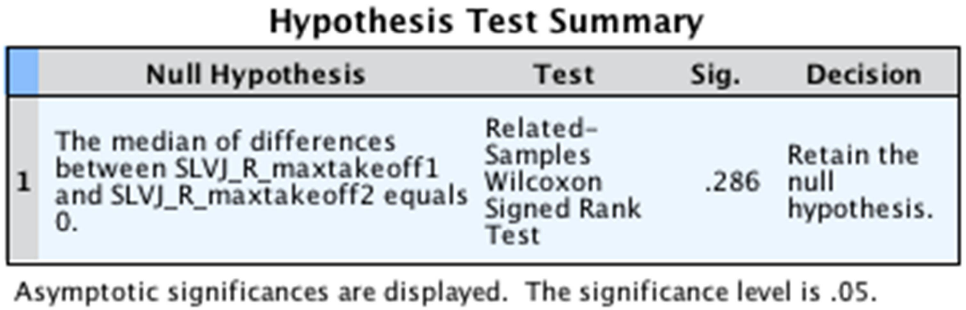
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_maxtakeoff1	.390	18	.000	.464	18	.000
SLVJ_R_maxtakeoff2	.137	18	.200*	.969	18	.781

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_R_maxtakeoff1 - SLVJ_R_maxtakeoff2	154.87056	794.05454	187.16045	-240.00348	549.74459	.827	17	.419



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between SLVJ_R_maxtakeoff1 and SLVJ_R_maxtakeoff2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.286	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

50:50 NORMALITY NON-PARAMETRIC AND PARAMETRIC BOTH NON-SIG.

SLVJ_R_aceltakeoff 1_2

19.51	**21.56**
13.64	**14.11**
23.01	**21.38**
17.76	**18.64**
17.01	**16.52**
19.15	**18.85**
18.61	**20.52**
17.92	**18.95**
17.03	**18.19**
16.08	**16.62**
20.76	**20.85**
17.84	**18.63**

20.29	**19.90**
14.73	**16.04**
17.21	**17.90**
20.07	**18.54**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_acceltakeoff1	.123	16	.200[*]	.986	16	.994
SLVJ_R_acceltakeoff2	.121	16	.200[*]	.959	16	.641

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	SLVJ_R_acceltakeoff1 - SLVJ_R_acceltakeoff2	-.41125	1.06903	.26726	-.98090	.15840	-1.539	15	.145

PARAMETRIC NON-SIG

SLVJ_R_velocitytakeoff 1_2

60.48	30.59
37.69	27.97
21.10	28.07
38.56	31.29
39.71	49.52
72.58	26.45
42.41	30.23
33.75	26.37
33.13	38.69
35.10	25.23
28.40	35.95
46.36	38.92
41.95	28.49
81.71	44.51
50.45	40.05
42.27	30.80

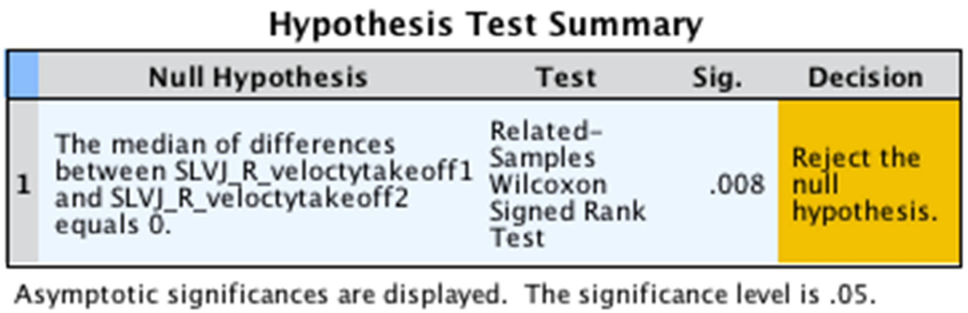
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_veloctytakeoff 1	.230	16	.023	.893	16	.063
SLVJ_R_veloctytakeoff 2	.237	16	.017	.891	16	.057

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_R_veloctytakeoff1 - SLVJ_R_veloctytakeoff2	10.78250	15.70897	3.92724	2.41178	19.15322	2.746	15	.015



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between SLVJ_R_veloctytakeoff1 and SLVJ_R_veloctytakeoff2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.008	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

50:50 NORMALITY NON-PARAMETRIC AND PARAMETRIC BOTH NON-SIG.

SLVJ_R_powertakeoff 1_2

24097.33	19009.33
26302.00	34070.33
36271.67	31346.67
38811.33	47961.00
74685.33	25753.00
47865.67	37850.00
33166.00	26359.67
35199.33	45720.00
37891.47	28414.33
28592.67	38257.33
57221.33	49635.33
48353.00	32465.00
75158.33	44117.33
62499.33	47021.33
64258.00	39768.67

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_powertakeoff1	.192	16	.117	.908	16	.107
SLVJ_R_powertakeoff2	.110	16	.200*	.959	16	.638

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_R_powertakeoff1 - SLVJ_R_powertakeoff2	11006.44625	16979.51659	4244.87915	1958.70052	20054.19198	2.593	15	.02

PARAMETRIC. SIG*

SLVJ_R_dfdttakeoff 1_2

8687.60	8957.43
4834.23	6104.30
10982.30	11252.97
6925.43	7581.67
6184.77	6947.23
7306.73	8034.37
6547.77	8292.40
6183.20	8224.93
8024.13	7156.57
22503.23	5854.00
8052.80	8552.83
6893.17	7716.47
8152.13	8270.03

5215.60	6677.27
6777.03	6987.10
7395.37	8908.57

Tests of Normality

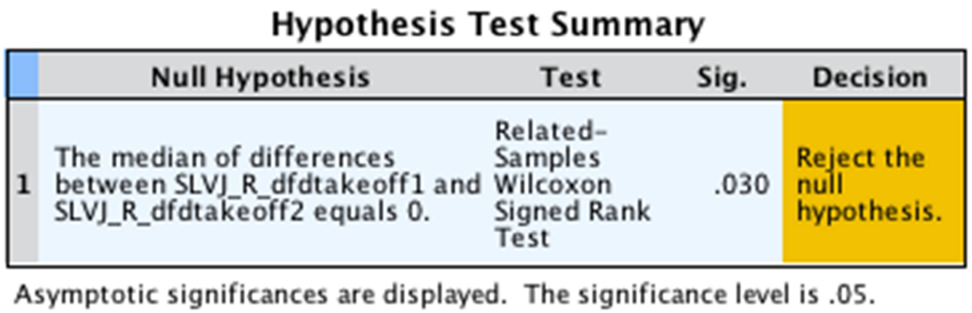
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_dfdtakeoff1	.324	16	.000	.597	16	.000
SLVJ_R_dfdtakeoff2	.134	16	.200*	.937	16	.310

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_R_dfdtakeoff1 - SLVJ_R_dfdtakeoff2	321.70937	4413.75656	1103.43914	-2030.21548	2673.63423	.292	15	.775



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between SLVJ_R_dfdtakeoff1 and SLVJ_R_dfdtakeoff2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.030	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

50:50 NORMALITY NON-PARAMETRIC SIG* (wrong direvction) AND PARAMETRIC NON-SIG.

SLVJ_R_flighttime 1_2

.34	.31
.22	.22
.38	.41
.31	.29
.28	.24
.32	.29
.28	.26
.37	.32
.32	.32
.28	.25
.31	.32
.36	.35
.36	.34
.43	.41
.33	.30
.23	.20
.24	.30
.36	.33

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_flighttime1	.111	18	.200*	.970	18	.800
SLVJ_R_flughttime2	.129	18	.200*	.961	18	.629

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_R_flighttime1 - SLVJ_R_flughttime2	.01444	.02662	.00627	.00121	.02768	2.302	17	.034

PARAMETRIC. SIG*

SLVJ_R_maxlanding 1_2

1759.59	1666.53
1759.23	1218.96
1940.47	2512.73
1928.07	1934.77
1436.10	1346.80
1418.00	1820.87
1968.47	2092.77
2433.67	2185.00
1670.43	1583.27
10450.33	2228.17
1999.80	2118.97
1478.83	1795.23
1849.11	1744.87
3005.50	2448.53

1480.73	**1491.57**
1701.83	**1352.23**
1537.70	**1734.23**
2582.73	**2185.57**

Tests of Normality

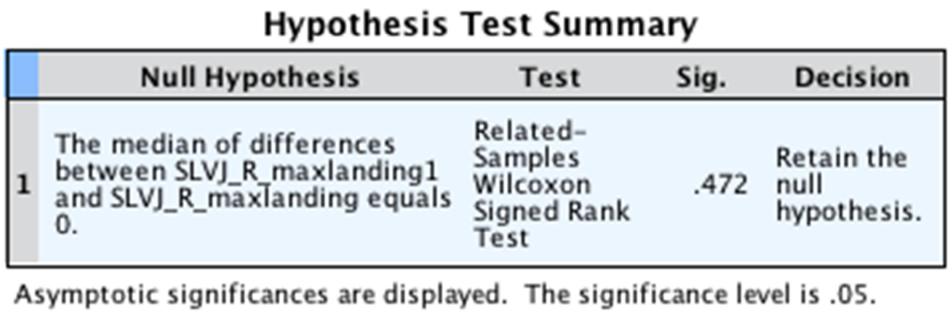
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_maxlanding1	.346	18	.000	.423	18	.000
SLVJ_R_maxlanding	.119	18	.200*	.968	18	.763

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_R_maxlanding1 - SLVJ_R_maxlanding	496.64000	1952.39706	460.18440	-474.26422	1467.54422	1.079	17	.296



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between SLVJ_R_maxlanding1 and SLVJ_R_maxlanding equals 0.	Related-Samples Wilcoxon Signed Rank Test	.472	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

50:50 NORMALITY NON-PARAMETRIC AND PARAMETRIC BOTH NON-SIG.

SLVJ_R_Acelanding 1_2

26.37	24.47
34.37	22.31
32.23	40.97
34.45	34.18
23.92	22.18
34.99	36.37
38.47	33.61
29.75	28.17
42.12	32.71
27.90	28.72
28.72	33.70
42.22	34.38
24.98	24.39
26.54	20.78
20.59	25.28
36.42	29.84

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_acellanding1	.109	16	.200[*]	.965	16	.760
SLVJ_R_acellanding2	.144	16	.200[*]	.951	16	.499

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_R_acellanding1 - SLVJ_R_acellanding2	1.99875	5.57941	1.39485	-.97431	4.97181	1.433	15	.172

PARAMETRIC. NON-SIG

SLVJ_R_Powerlanding 1_2

107844.00	53563.67
69056.67	35234.00
30938.12	73228.67
76335.00	61824.67
58840.67	68263.00
139801.67	57497.00
102115.67	69169.67
57255.33	43618.33
91522.33	88864.33
73052.67	55309.67
44409.67	66668.33
144020.33	97405.00
63662.33	43973.00
141720.00	60926.00
76200.67	71920.67
127671.33	70653.00

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJR_R_powerlanding1	.188	16	.135	.933	16	.274
SLVJR_R_powerlanding2	.150	16	.200[*]	.970	16	.831

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	SLVJR_R_powerlanding1 - SLVJR_R_powerlanding2	24145.46562	34708.90521	8677.22630	5650.39557	42640.53568	2.783	15	.01

PARAMETRIC. SIG*

SLVJ_R_dfdt 1_2

56988.00	75691.00
73904.33	29960.33
153443.33	208062.00
58253.56	111575.00
74792.67	48087.33
166668.67	186371.33
194202.00	99424.33
97355.67	85208.67
273078.33	183546.67
98842.00	95629.00
66742.00	96407.33
343923.67	133469.00
70502.67	55857.33
105364.67	38712.67
40356.00	77450.67
194016.00	73498.00

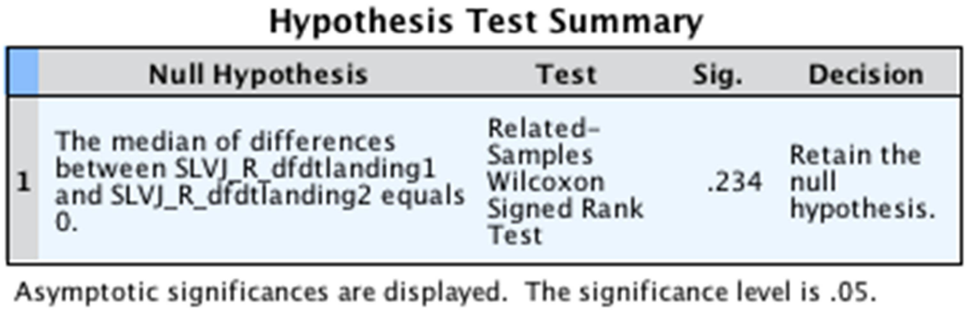
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SLVJ_R_dfdtlanding1	.234	16	.019	.849	16	.013
SLVJ_R_dfdtlanding2	.191	16	.120	.909	16	.110

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	SLVJ_R_dfdtlanding1 - SLVJ_R_dfdtlanding2	29342.68187	72257.92251	18064.48063	-9160.84715	67846.21090	1.624	15	.12



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between SLVJ_R_dfdtlanding1 and SLVJ_R_dfdtlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.234	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

50:50 NORMALITY NON-PARAMETRIC AND PARAMETRIC BOTH NON-SIG

SLVJ_velocitytakeoffTrain2_3

Post-hoc
Training Groups

Cross-ed Groups

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_VelocitytakeoffCrossed2 - SLVJ_VelocitytakeoffCrossed3	-.94222	7.94045	2.64682	-7.04579	5.16135	-.356	8	.731

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Training2 - SLVJ_VelocitytakeoffCrossed3	-2.04667	10.42025	3.47342	-10.05638	5.96305	-.589	8	.572

Detraining Groups

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			

Pair 1	SLVJ_VelocitytakeoffDetrain2 - SLVJ_VelocitytakeoffDetrain3	4.97556	8.21161	2.73720	-1.33645	11.28756	1.818	8	.107

NO POST HOC SIGNIFICANCE AS >0.017

SLVJ_PowertakeoffTrain2_3

Post-hoc
Training Groups

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_powertakeoff_Train_2 - SLVJ_powertakeoff_Train_3	-5960.66333	7599.15024	2533.05008	-11801.88729	-119.43938	-2.353	8	.046

Cross-ed Groups

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_powertakeoff_Crossed_2 - SLVJ_powertakeoff_Crossed_3	979.25778	10572.26070	3524.08690	-7147.30119	9105.81675	.278	8	.788

Detraining Groups

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLVJ_powertakeoff_Detraining_2 - SLVJ_powertakeoff_Detraining_3	5902.00444	9441.92631	3147.30877	-1355.70259	13159.71148	1.875	8	.098

NO POST HOC SIGNIFICANCE AS >0.017

DJ_Force Max First Landing 2_3

1741.37	**1771.50**
2033.60	**2061.27**
1804.42	**2170.32**
2349.93	**1979.60**
1799.40	**1439.40**
1923.85	**2184.95**
2375.87	**2334.47**
3598.73	**4056.82**
1486.13	**1354.15**
1879.38	**2347.07**
1824.47	**2061.93**
1972.58	**2066.20**
1468.22	**1348.95**
1991.20	**2094.42**
2266.57	**2003.40**
2140.42	**1847.50**
1726.93	**1827.92**
2690.93	**3037.52**

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Trial_2	Training Group	.138	9	.200*	.987	9	.991

	Detraining Group	.289	9	.029	.713	9	.002
Trial_2	Training Group	.181	9	.200*	.950	9	.694
	Detraining Group	.360	9	.001	.740	9	.004

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	23174.480	1	23174.480	.601	.450
	Greenhouse-Geisser	23174.480	1.000	23174.480	.601	.450
	Huynh-Feldt	23174.480	1.000	23174.480	.601	.450
	Lower-bound	23174.480	1.000	23174.480	.601	.450
TrialGroups * Group	Sphericity Assumed	6366.178	1	6366.178	.165	.690
	Greenhouse-Geisser	6366.178	1.000	6366.178	.165	.690
	Huynh-Feldt	6366.178	1.000	6366.178	.165	.690
	Lower-bound	6366.178	1.000	6366.178	.165	.690
Error(TrialGroups)	Sphericity Assumed	617260.682	16	38578.793		
	Greenhouse-Geisser	617260.682	16.000	38578.793		
	Huynh-Feldt	617260.682	16.000	38578.793		
	Lower-bound	617260.682	16.000	38578.793		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	23174.480	1	23174.480	.601	.450
TrialGroups * Group	Linear	6366.178	1	6366.178	.165	.690
Error(TrialGroups)	Linear	617260.682	16	38578.793		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	156505896.354	1	156505896.354	245.890	.000
Group	972.712	1	972.712	.002	.969
Error	10183790.842	16	636486.928		

PARAMETRIC & NON SIG (0.991, 0.690, 0.969)

DJ_Force Time First Landing 2_3

.46	**.52**
.31	**.34**

.48	.46
.37	.40
.56	.61
.29	.27
.29	.33
.18	.15
.48	.57
.44	.41
.52	.44
.37	.41
.56	.57
.57	.55
.29	.42
.42	.43
.50	.46
.39	.42

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Timefirstlanding2	Training Group	.148	9	.200*	.940	9	.578
	Detraining Group	.278	9	.044	.884	9	.171
DJ_Timefirstlanding3	Training Group	.260	9	.079	.900	9	.254
	Detraining Group	.185	9	.200*	.957	9	.765

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	.002	1	.002	1.597	.224

	Greenhouse-Geisser	.002	1.000	.002	1.597	.224
	Huynh-Feldt	.002	1.000	.002	1.597	.224
	Lower-bound	.002	1.000	.002	1.597	.224
TrialGroups * Group	Sphericity Assumed	.000	1	.000	.073	.790
	Greenhouse-Geisser	.000	1.000	.000	.073	.790
	Huynh-Feldt	.000	1.000	.000	.073	.790
	Lower-bound	.000	1.000	.000	.073	.790
Error(TrialGroups)	Sphericity Assumed	.022	16	.001		
	Greenhouse-Geisser	.022	16.000	.001		
	Huynh-Feldt	.022	16.000	.001		
	Lower-bound	.022	16.000	.001		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	.002	1	.002	1.597	.224
TrialGroups * Group	Linear	.000	1	.000	.073	.790
Error(TrialGroups)	Linear	.022	16	.001		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	6.452	1	6.452	256.808	.000
Group	.009	1	.009	.372	.551
Error	.402	16	.025		

PARAMETRIC & NON SIG (0.224, 0.790, 0.551)

DJ_Accelfirstlanding_2_3

25.57	25.72
37.22	37.37
29.42	34.36
41.51	35.43
26.30	24.82
38.12	43.33
41.29	41.07
57.92	59.09
26.44	24.45
30.04	34.22
24.73	37.46
37.02	37.68
24.72	23.18
27.96	28.62
37.06	32.52
32.89	28.24
25.17	26.21
36.74	41.28

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.

DJ_Accelfirstlanding_2	Training Group	.160	9	.200*	.921	9	.403
	Detraining Group	.225	9	.200*	.797	9	.019
DJ_Accelfirstlanding_3	Training Group	.181	9	.200*	.931	9	.488
	Detraining Group	.207	9	.200*	.883	9	.170

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	6.192	1	6.192	.641	.435
	Greenhouse-Geisser	6.192	1.000	6.192	.641	.435
	Huynh-Feldt	6.192	1.000	6.192	.641	.435
	Lower-bound	6.192	1.000	6.192	.641	.435
TrialGroups * Group	Sphericity Assumed	10.595	1	10.595	1.096	.311
	Greenhouse-Geisser	10.595	1.000	10.595	1.096	.311
	Huynh-Feldt	10.595	1.000	10.595	1.096	.311
	Lower-bound	10.595	1.000	10.595	1.096	.311
Error(TrialGroups)	Sphericity Assumed	154.624	16	9.664		
	Greenhouse-Geisser	154.624	16.000	9.664		
	Huynh-Feldt	154.624	16.000	9.664		
	Lower-bound	154.624	16.000	9.664		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	6.192	1	6.192	.641	.435
TrialGroups * Group	Linear	10.595	1	10.595	1.096	.311
Error(TrialGroups)	Linear	154.624	16	9.664		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	41017.726	1	41017.726	274.017	.000
Group	23.056	1	23.056	.154	.700
Error	2395.049	16	149.691		

PARAMETRIC & NON SIG (0.435, 0.311, 0.700)

DJ_Velocfirstlaning_2_3

8.39	**9.90**
6.78	**7.33**
7.97	**8.48**

7.56	8.40
8.85	9.90
7.46	6.86
8.77	7.53
5.52	5.30
7.60	8.81
7.59	7.79
8.13	10.87
7.85	8.28
9.43	10.06
9.65	10.61
8.18	8.65
7.56	7.58
7.30	7.80
8.32	8.68

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Velocfirstlaning_2	Training Group	.177	9	.200*	.881	9	.161
	Detraining Group	.182	9	.200*	.935	9	.528
DJ_Velocfirstlaning_3	Training Group	.194	9	.200*	.889	9	.195
	Detraining Group	.139	9	.200*	.988	9	.992

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	2.734	1	2.734	7.352	.015
	Greenhouse-Geisser	2.734	1.000	2.734	7.352	.015

	Huynh-Feldt	2.734	1.000	2.734	7.352	.015
	Lower-bound	2.734	1.000	2.734	7.352	.015
TrialGroups * Group	Sphericity Assumed	.174	1	.174	.467	.504
	Greenhouse-Geisser	.174	1.000	.174	.467	.504
	Huynh-Feldt	.174	1.000	.174	.467	.504
	Lower-bound	.174	1.000	.174	.467	.504
Error(TrialGroups)	Sphericity Assumed	5.949	16	.372		
	Greenhouse-Geisser	5.949	16.000	.372		
	Huynh-Feldt	5.949	16.000	.372		
	Lower-bound	5.949	16.000	.372		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	2.734	1	2.734	7.352	.015
TrialGroups * Group	Linear	.174	1	.174	.467	.504
Error(TrialGroups)	Linear	5.949	16	.372		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	2429.504	1	2429.504	997.740	.000
Group	4.107	1	4.107	1.687	.212
Error	38.960	16	2.435		

PARAMETRIC & SIG* (Trial Groups: 0.015)

PARAMETRIC & NON SIG (0.504, 0.212)

DJ_Powerfirstlanding_2_3

12235.00	12652.50
7703.83	7348.40
10426.00	9932.23
9019.03	9109.35
9301.03	8515.15
7426.67	8304.83
9515.17	8702.13
11934.17	12898.17
9270.40	9132.07
9757.90	10042.32
11623.00	14027.83
9210.72	8951.35
10603.67	9708.20
14317.17	14556.33
9778.33	10526.17
8058.03	8279.35
12104.17	10573.93
11291.67	11536.00

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Powerfirstlanding2	Training Group	.195	9	.200[*]	.931	9	.491
	Detraining Group	.166	9	.200[*]	.923	9	.414

DJ_Powerfirstlanding3	Training Group	.233	9	.173	.879	9	.153
	Detraining Group	.199	9	.200*	.937	9	.555

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	41368.170	1	41368.170	.102	.754
	Greenhouse-Geisser	41368.170	1.000	41368.170	.102	.754
	Huynh-Feldt	41368.170	1.000	41368.170	.102	.754
	Lower-bound	41368.170	1.000	41368.170	.102	.754
TrialGroups * Group	Sphericity Assumed	129841.312	1	129841.312	.319	.580
	Greenhouse-Geisser	129841.312	1.000	129841.312	.319	.580
	Huynh-Feldt	129841.312	1.000	129841.312	.319	.580
	Lower-bound	129841.312	1.000	129841.312	.319	.580
Error(TrialGroups)	Sphericity Assumed	6504219.790	16	406513.737		
	Greenhouse-Geisser	6504219.790	16.000	406513.737		
	Huynh-Feldt	6504219.790	16.000	406513.737		
	Lower-bound	6504219.790	16.000	406513.737		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	41368.170	1	41368.170	.102	.754
TrialGroups * Group	Linear	129841.312	1	129841.312	.319	.580
Error(TrialGroups)	Linear	6504219.790	16	406513.737		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	3769392480.693	1	3769392480.693	501.480	.000
Group	1254217.073	1	1254217.073	.167	.688
Error	120264529.239	16	7516533.077		

PARAMETRIC & NON SIG (0.754, 0.580, 0.688)

DJ_dftdtfirstlanding_2_3

128095.17	118881.50
117755.67	146638.50
122553.17	138020.83
228353.00	225865.50
165959.67	138702.67
93713.83	101621.00
212087.50	195165.33
178415.33	306380.50
50226.82	49943.00
202249.83	275649.83

102714.83	102216.83
137928.33	155379.17
159158.33	131325.17
128930.17	111511.83
251968.00	159899.50
109163.17	92181.00
66868.67	58319.83
159986.33	207826.33

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
DJ_dftdtfirstlanding_2	Training Group	.194	9	.200[*]	.919	9	.383
	Detraining Group	.200	9	.200[*]	.942	9	.605
DJ_dftdtfirstlanding_3	Training Group	.171	9	.200[*]	.946	9	.645
	Detraining Group	.252	9	.104	.848	9	.071

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	274457205.563	1	274457205.563	.244	.628
TrialGroups * Group	Linear	387058.180	1	387058.180	.000	.985
Error(TrialGroups)	Linear	17989511984.655	16	1124344499.041		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	789626588755.547	1	789626588755.547	122.902	.000
Group	10948791551.637	1	10948791551.637	1.704	.210
Error	102797473189.764	16	6424842074.360		

PARAMETRIC & NON SIG (0.628, 0.985, 0.210)

DJ_Flighttme_2_3

.50	.51
.39	.37
.51	.42
.43	.44
.40	.37
.43	.44
.45	.42
.43	.45
.46	.48
.36	.37
.42	.42
.48	.46
.49	.44
.57	.57
.45	.44
.30	.29
.43	.37
.46	.45

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Flighttme_2	Training Group	.184	9	.200[*]	.951	9	.697
	Detraining Group	.229	9	.191	.920	9	.395
DJ_Flighttme_3	Training Group	.183	9	.200[*]	.958	9	.782
	Detraining Group	.218	9	.200[*]	.889	9	.193

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
TrialGroups	Pillai's Trace	.193	3.817[b]	1.000	16.000	.068
	Wilks' Lambda	.807	3.817[b]	1.000	16.000	.068
	Hotelling's Trace	.239	3.817[b]	1.000	16.000	.068
	Roy's Largest Root	.239	3.817[b]	1.000	16.000	.068
TrialGroups * Group	Pillai's Trace	.018	.299[b]	1.000	16.000	.592
	Wilks' Lambda	.982	.299[b]	1.000	16.000	.592
	Hotelling's Trace	.019	.299[b]	1.000	16.000	.592
	Roy's Largest Root	.019	.299[b]	1.000	16.000	.592

a. Design: Intercept + Group

Within Subjects Design: TrialGroups

b. Exact statistic

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	.002	1	.002	3.817	.068
	Greenhouse-Geisser	.002	1.000	.002	3.817	.068
	Huynh-Feldt	.002	1.000	.002	3.817	.068
	Lower-bound	.002	1.000	.002	3.817	.068
TrialGroups * Group	Sphericity Assumed	.000	1	.000	.299	.592
	Greenhouse-Geisser	.000	1.000	.000	.299	.592
	Huynh-Feldt	.000	1.000	.000	.299	.592
	Lower-bound	.000	1.000	.000	.299	.592
Error(TrialGroups)	Sphericity Assumed	.007	16	.000		
	Greenhouse-Geisser	.007	16.000	.000		
	Huynh-Feldt	.007	16.000	.000		
	Lower-bound	.007	16.000	.000		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.

Intercept	6.821	1	6.821	940.170	.000
Group	.003	1	.003	.368	.553
Error	.116	16	.007		

PARAMETRIC & NON SIG (0.068, 0.592, 0.553)

DJ_Maxseconlanding_2_3

2359.38	**1960.52**
2071.60	**2134.25**
2983.30	**2271.45**
2632.87	**2705.20**
1847.43	**1410.53**
2371.93	**2466.32**
3232.93	**2447.02**
3337.80	**3159.12**
2325.00	**2349.28**
3070.88	**2593.25**
2634.78	**2428.35**
2222.03	**2793.85**
5521.53	**1705.00**
2757.38	**2989.33**
2413.70	**1856.12**
1808.40	**1701.85**
2445.08	**2274.87**
3005.30	**2580.50**

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Maxseconlanding_2	Training Group	.286	9	.032	.801	9	.021

	Detraining Group	.208	9	.200[*]	.951	9	.703
DJ_Maxseconlanding_3	Training Group	.217	9	.200[*]	.885	9	.177
	Detraining Group	.221	9	.200[*]	.935	9	.528

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	1445809.848	1	1445809.848	3.337	.086
	Greenhouse-Geisser	1445809.848	1.000	1445809.848	3.337	.086
	Huynh-Feldt	1445809.848	1.000	1445809.848	3.337	.086
	Lower-bound	1445809.848	1.000	1445809.848	3.337	.086
TrialGroups * Group	Sphericity Assumed	259055.551	1	259055.551	.598	.451
	Greenhouse-Geisser	259055.551	1.000	259055.551	.598	.451
	Huynh-Feldt	259055.551	1.000	259055.551	.598	.451
	Lower-bound	259055.551	1.000	259055.551	.598	.451
Error(TrialGroups)	Sphericity Assumed	6932153.004	16	433259.563		
	Greenhouse-Geisser	6932153.004	16.000	433259.563		
	Huynh-Feldt	6932153.004	16.000	433259.563		
	Lower-bound	6932153.004	16.000	433259.563		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	1445809.848	1	1445809.848	3.337	.086
TrialGroups * Group	Linear	259055.551	1	259055.551	.598	.451
Error(TrialGroups)	Linear	6932153.004	16	433259.563		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	229361584.714	1	229361584.714	500.286	.000
Group	782136.828	1	782136.828	1.706	.210
Error	7335371.449	16	458460.716		

PARAMETRIC & NON SIG (0.086, 0.451, 0.210)

DJ_Accelsecondlanding_2_3

34.64	**28.47**
37.91	**38.77**
48.65	**35.96**
46.51	**48.42**
30.39	**24.32**
47.00	**48.91**

56.19	37.72
51.34	46.02
41.36	42.42
45.07	37.81
35.71	44.12
41.76	50.96
39.39	29.29
38.72	40.85
39.47	30.13
27.79	26.01
35.64	32.62
39.37	35.07

Tests of Normality

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
DJ_Accelsecondlanding_2	Training Group	.162	9	.200*	.966	9	.855
	Detraining Group	.147	9	.200*	.955	9	.750
DJ_Accelsecondlanding_3	Training Group	.153	9	.200*	.940	9	.586
	Detraining Group	.146	9	.200*	.970	9	.894

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	96.826	1	96.826	3.657	.074
	Greenhouse-Geisser	96.826	1.000	96.826	3.657	.074
	Huynh-Feldt	96.826	1.000	96.826	3.657	.074

	Lower-bound	96.826	1.000	96.826	3.657	.074
TrialGroups * Group	Sphericity Assumed	3.145	1	3.145	.119	.735
	Greenhouse-Geisser	3.145	1.000	3.145	.119	.735
	Huynh-Feldt	3.145	1.000	3.145	.119	.735
	Lower-bound	3.145	1.000	3.145	.119	.735
Error(TrialGroups)	Sphericity Assumed	423.624	16	26.477		
	Greenhouse-Geisser	423.624	16.000	26.477		
	Huynh-Feldt	423.624	16.000	26.477		
	Lower-bound	423.624	16.000	26.477		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	96.826	1	96.826	3.657	.074
TrialGroups * Group	Linear	3.145	1	3.145	.119	.735
Error(TrialGroups)	Linear	423.624	16	26.477		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	55600.068	1	55600.068	561.924	.000
Group	1.247	1	1.247	.013	.912
Error	1583.135	16	98.946		

PARAMETRIC & NON SIG (0.074, 0.735, 0.912)

DJ_Powersecondlanding_2_3

24633.50	22343.67
16476.00	17904.50
30639.00	21881.50
23979.33	25494.33
19574.67	15797.00
19053.33	19494.83
28171.00	21196.00
23548.50	23091.83
23392.00	53533.67
26924.67	24398.00
26503.67	30742.33
21027.50	26188.00
26665.83	19326.67
32274.17	34124.17
19348.67	18305.33
16666.50	16261.67
26534.83	22289.17
27051.00	25230.33

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Powersecondlanding_2	Training Group	.179	9	.200[*]	.954	9	.731
	Detraining Group	.204	9	.200[*]	.948	9	.669
DJ_Powersecondlanding	Training Group	.210	9	.200[*]	.946	9	.644

_3	Detraining Group	.336	9	.004	.706	9	.002

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	733543.716	1	733543.716	.021	.887
	Greenhouse-Geisser	733543.716	1.000	733543.716	.021	.887
	Huynh-Feldt	733543.716	1.000	733543.716	.021	.887
	Lower-bound	733543.716	1.000	733543.716	.021	.887
TrialGroups * Group	Sphericity Assumed	26351367.778	1	26351367.778	.743	.401
	Greenhouse-Geisser	26351367.778	1.000	26351367.778	.743	.401
	Huynh-Feldt	26351367.778	1.000	26351367.778	.743	.401
	Lower-bound	26351367.778	1.000	26351367.778	.743	.401
Error(TrialGroups)	Sphericity Assumed	567404020.553	16	35462751.285		
	Greenhouse-Geisser	567404020.553	16.000	35462751.285		
	Huynh-Feldt	567404020.553	16.000	35462751.285		
	Lower-bound	567404020.553	16.000	35462751.285		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	733543.716	1	733543.716	.021	.887
TrialGroups * Group	Linear	26351367.778	1	26351367.778	.743	.401
Error(TrialGroups)	Linear	567404020.553	16	35462751.285		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	21028246675.328	1	21028246675.328	323.737	.000
Group	5324948.532	1	5324948.532	.082	.778
Error	1039277001.759	16	64954812.610		

PARAMETRIC & NON SIG (0.887, 0.401, 0.778)

DJ_dftdsecondlanding_2_3

130345.67	135302.00
172421.00	154780.33
288061.00	294897.67
300868.67	307963.50
138123.67	94247.67
167705.83	294981.33
216723.83	248912.83
179736.00	172153.67
113828.17	206457.50
249721.33	118921.17
115437.00	98349.50

237460.00	360055.50
197050.17	87960.83
289829.33	734430.33
155704.67	108947.33
75633.00	69720.67
120899.00	109829.00
182427.00	151254.67

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
DJ_dftdsecondlanding_2	Training Group	.136	9	.200[*]	.959	9	.790
	Detraining Group	.255	9	.095	.805	9	.023
DJ_dftdsecondlanding_3	Training Group	.231	9	.183	.799	9	.020
	Detraining Group	.221	9	.200[*]	.841	9	.060

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	4834656377.801	1	4834656377.801	.594	.452
	Greenhouse-Geisser	4834656377.801	1.000	4834656377.801	.594	.452
	Huynh-Feldt	4834656377.801	1.000	4834656377.801	.594	.452
	Lower-bound	4834656377.801	1.000	4834656377.801	.594	.452

TrialGroups * Group	Sphericity Assumed	1760289713.051	1	1760289713.051	.216	.648
	Greenhouse-Geisser	1760289713.051	1.000	1760289713.051	.216	.648
	Huynh-Feldt	1760289713.051	1.000	1760289713.051	.216	.648
	Lower-bound	1760289713.051	1.000	1760289713.051	.216	.648
Error(TrialGroups)	Sphericity Assumed	130178616708.628	16	8136163544.289		
	Greenhouse-Geisser	130178616708.628	16.000	8136163544.289		
	Huynh-Feldt	130178616708.628	16.000	8136163544.289		
	Lower-bound	130178616708.628	16.000	8136163544.289		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	4834656377.801	1	4834656377.801	.594	.452
TrialGroups * Group	Linear	1760289713.051	1	1760289713.051	.216	.648
Error(TrialGroups)	Linear	130178616708.628	16	8136163544.289		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1392848766553.219	1	1392848766553.219	66.498	.000
Group	34103018749.067	1	34103018749.067	1.628	.220
Error	335129467638.250	16	20945591727.391		

PARAMETRIC & NON SIG (0.452, 0.648, 0.220)

DJ_Force Max First Landing 1_2

1941.37	**1741.37**
2253.47	**2033.60**
1758.47	**1804.42**
2325.70	**2349.93**
1740.17	**1799.40**
2259.00	**1923.85**
2407.00	**2375.87**
4161.77	**3598.73**
1540.23	**1486.13**
2570.13	**1879.38**
1744.03	**1824.47**
1981.23	**1972.58**
1444.70	**1468.22**
1840.53	**1991.20**
2315.87	**2266.57**
2238.40	**2140.42**
2372.23	**1726.93**
2498.10	**2690.93**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.

DJ_Maxfirstlanding1	.206	18	.043	.794	18	.001
DJ_Maxfirstlanding2	.188	18	.093	.835	18	.005

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	DJ_Maxfirstlanding1 - DJ_Maxfirstlanding2	128.80000	265.87665	62.66773	-3.41735	261.01735	2.055	17	.056

PARAMETRIC NON SIG

DJ_Force Time First Landing 1_2

.39	.46
.28	.31
.40	.48
.37	.37
.46	.56
.25	.29
.43	.29
.16	.18
.40	.48
.40	.44
.46	.52
.30	.37
.47	.56
.45	.57
.37	.29
.35	.42
.37	.50
.40	.39

Tests of Normality

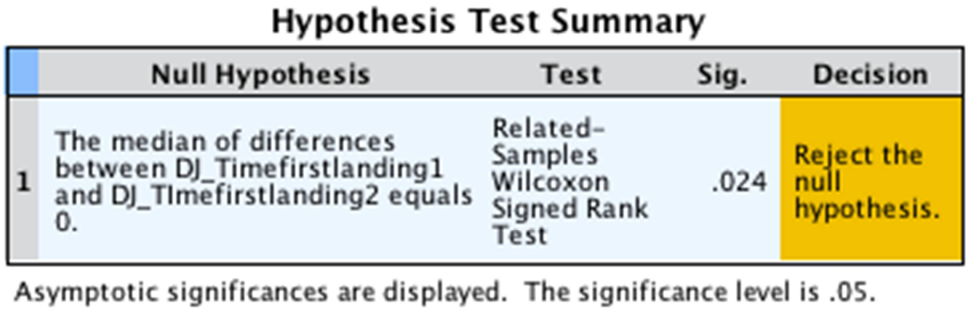
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Timefirstlanding1	.209	18	.037	.895	18	.047
DJ_TImefirstlanding2	.106	18	.200*	.950	18	.432

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Timefirstlanding1 - DJ_TImefirstlanding2	-.04278	.06781	.01598	-.07650	-.00906	-2.677	17	.016



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_Timefirstlanding1 and DJ_TImefirstlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.024	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NORMALITY TESTS 50:50 PARAMETRIC & NON-PARAMETRIC BOTH SIGNIFICANT*

29.28	25.57
44.03	37.22
29.21	29.42
41.56	41.51
28.99	26.30
46.78	38.12
42.78	41.29
65.79	57.92
27.43	26.44
39.41	30.04
24.33	24.73
35.14	37.02
25.58	24.72
25.85	27.96
39.07	37.06
34.91	32.89
28.84	25.17
35.23	36.74

Tests of Normality

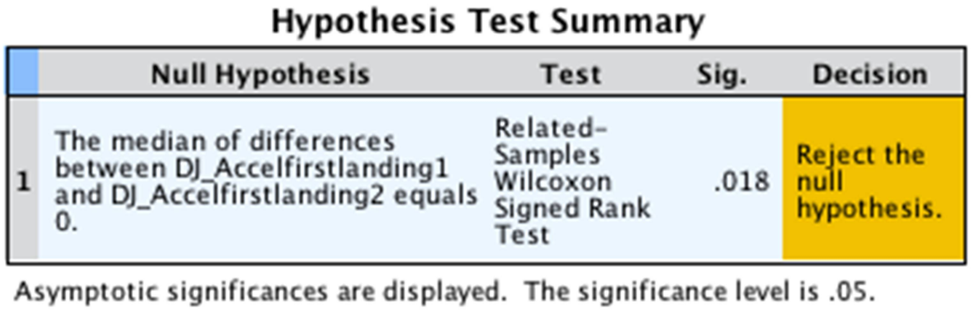
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Accelfirstlanding1	.182	18	.118	.867	18	.016
DJ_Accelfirstlanding2	.156	18	.200[*]	.853	18	.009

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Accelfirstlanding1 - DJ_Accelfirstlanding2	2.44944	3.59830	.84813	.66005	4.23884	2.888	17	.010



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_Accelfirstlanding1 and DJ_Accelfirstlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.018	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NORMALITY TESTS 50:50 PARAMETRIC & NON-PARAMETRIC BOTH SIGNIFICANT*

DJ_Force Velocity First Landing 1_2

8.39	9.10
6.78	6.97
7.97	9.07
7.56	8.03
8.85	9.71
7.46	6.80
8.77	7.31

5.52	5.63
7.60	8.47
7.59	7.45
8.13	8.71
7.85	8.17
9.43	10.18
9.65	10.80
8.18	6.89
7.56	7.55
7.30	8.79
8.32	8.16

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Velocfirstlaning1	.141	18	.200*	.953	18	.481
DJ_Velocfirstlaning	.084	18	.200*	.988	18	.997

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	DJ_Velocfirstlaning1 - DJ_Velocfirstlaning	-.27111	.80356	.18940	-.67071	.12849	-1.431	17	.170

PARAMETRIC NON SIG

DJ_Force Power First Landing 1_2

11905.00	12235.00
7684.07	7703.83
10276.33	10426.00
9062.53	9019.03
8559.40	9301.03
9621.53	7426.67
8798.97	9515.17
12347.67	11934.17
8546.33	9270.40
9567.83	9757.90
10558.33	11623.00
9634.93	9210.72
9496.47	10603.67
13604.67	14317.17
7263.53	9778.33
8836.00	8058.03
11850.33	12104.17
11297.33	11291.67

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Powerfirstlanding1	.182	18	.117	.958	18	.566
DJ_Powerfirstlanding2	.148	18	.200*	.962	18	.634

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	DJ_Powerfirstlanding1 - DJ_Powerfirstlanding2	-259.15056	957.24554	225.62494	-735.17756	216.87645	-1.149	17	.267

PARAMETRIC NON SIG

DJ_Force dfdt First Landing 1_2

70775.67	128095.17
110737.33	117755.67
127070.33	122553.17
198578.43	228353.00
113963.67	165959.67
129065.67	93713.83

285282.33	212087.50
270093.67	178415.33
45197.67	50226.82
209359.00	202249.83
66220.33	102714.83
123368.33	137928.33
132703.67	159158.33
153981.00	128930.17
192748.67	251968.00
115276.67	109163.17
110080.67	66868.67
125901.00	159986.33

Tests of Normality

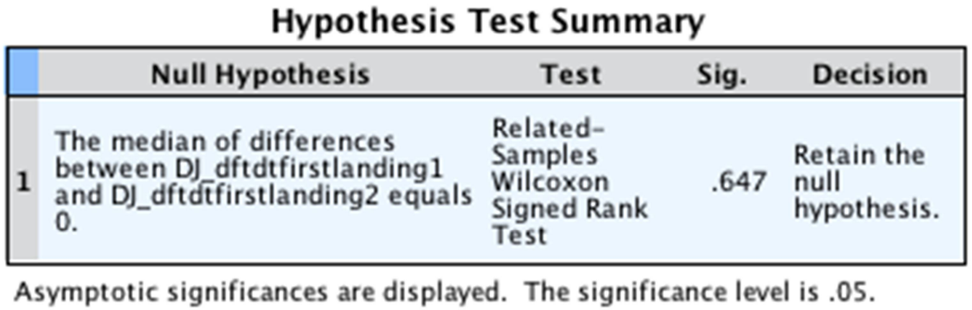
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_dftdtfirstlanding1	.232	18	.012	.912	18	.094
DJ_dftdtfirstlanding2	.118	18	.200*	.980	18	.950

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_dftdtfirstlanding1 - DJ_dftdtfirstlanding2	-1984.65056	42982.21870	10131.00610	-23359.20505	19389.90394	-.196	17	.84



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_dftdtfirstlanding1 and DJ_dftdtfirstlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.647	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NORMALITY TESTS 50:50 PARAMETRIC & NON-PARAMETRIC BOTH NON-SIGNIFICANT

DJ_Force Flight Time First Landing 1_2

.48	.50
.38	.39
.47	.51
.45	.43
.42	.40
.47	.43
.47	.45
.37	.43
.42	.46
.34	.36
.42	.42
.50	.48
.47	.49
.57	.57
.45	.45
.32	.30

.49	.43
.47	.46

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Flighttme1	.176	18	.148	.944	18	.343
DJ_Flighttime2	.142	18	.200*	.971	18	.812

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Flighttme1 - DJ_Flighttime2	.00000	.03010	.00709	-.01497	.01497	.000	17	1.000

PARAMETRIC NON SIG

DJ_Force Max Second Landing 1_2

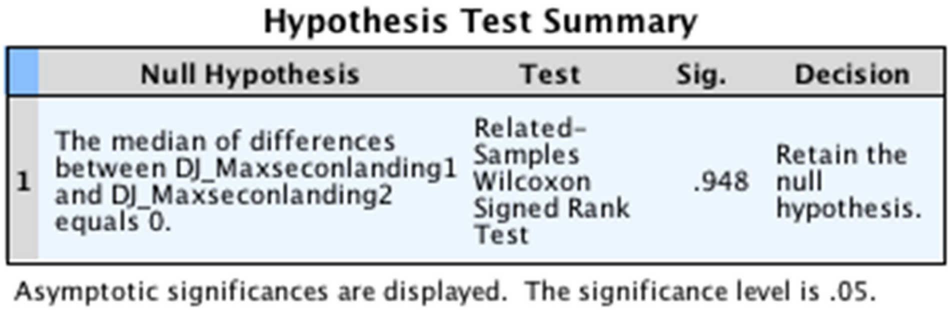
2816.27	2071.60
2693.03	2983.30
2986.23	2632.87
1578.57	1847.43
2964.30	2371.93

2621.13	**3232.93**
3088.03	**3337.80**
2299.93	**2325.00**
10701.20	**3070.88**
2738.63	**2634.78**
2265.63	**2222.03**
2145.60	**5521.53**
2878.70	**2757.38**
2375.93	**2413.70**
1732.83	**1808.40**
2330.90	**2445.08**
2671.50	**3005.30**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Maxseconlanding1	.421	18	.000	.447	18	.000
DJ_Maxseconlanding2	.174	18	.159	.773	18	.001

a. Lilliefors Significance Correction



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_Maxseconlanding1 and DJ_Maxseconlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.948	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NON-PARAMETRIC NON SIG

DJ_Force Accel Second Landing 1_2

39.29	34.64
55.02	37.91
44.73	48.65
53.36	46.51
26.29	30.39
61.32	47.00
46.59	56.19
48.82	51.34
40.97	41.36
51.53	45.07
38.21	35.71
43.99	41.76
38.00	39.39
40.43	38.72
40.09	39.47
27.02	27.79
31.21	35.64
37.67	39.37

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Accelsecondlanding1	.137	18	.200*	.973	18	.853
DJ_Accelsecondlanding2	.136	18	.200*	.982	18	.965

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	DJ_Accelsecondlanding1 - DJ_Accelsecondlanding2	1.53500	6.58023	1.55097	-1.73727	4.80727	.990	17	.336

PARAMETRIC NON SIG

DJ_Force Power Second Landing 1_2

25712.67	24633.50
22001.33	16476.00
25290.33	30639.00
26983.33	23979.33
16005.67	19574.67
24392.00	19053.33
25561.00	28171.00
22265.33	23548.50

80632.00	**23392.00**
28945.33	**26924.67**
26219.33	**26503.67**
20846.33	**21027.50**
22887.00	**26665.83**
30213.67	**32274.17**
17924.00	**19348.67**
16008.33	**16666.50**
21388.67	**26534.83**
25776.00	**27051.00**

Tests of Normality

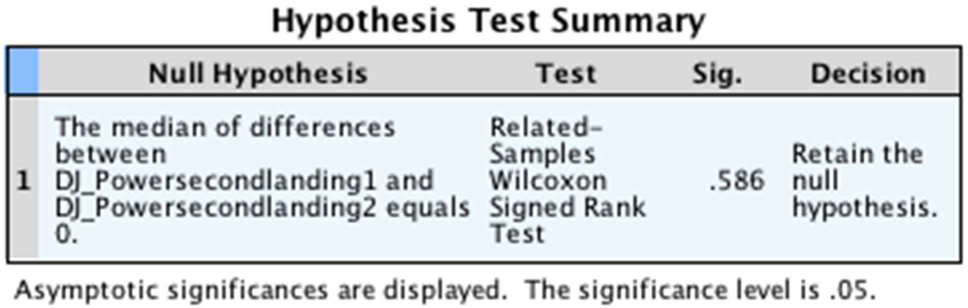
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_Powersecondlanding1	.343	18	.000	.522	18	.000
DJ_Powersecondlanding2	.151	18	.200*	.959	18	.591

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_Powersecondlanding1 - DJ_Powersecondlanding2	2588.23056	13991.91803	3297.92671	-4369.78658	9546.24770	.785	17	.44



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between DJ_Powersecondlanding1 and DJ_Powersecondlanding2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.586	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

NORMALITY TESTS 50:50 PARAMETRIC & NON-PARAMETRIC BOTH NON-SIGNIFICANT

DJ_Force dfdt Second Landing 1_2

113140.00	**130345.67**
310382.00	**172421.00**
260002.60	**288061.00**
524810.00	**300868.67**
106737.00	**138123.67**
375714.30	**167705.83**
345302.00	**216723.83**
181294.00	**179736.00**
141174.00	**113828.17**
401677.00	**249721.33**
121356.60	**115437.00**
276780.60	**237460.00**
174686.30	**197050.17**
274074.60	**289829.33**
224205.30	**155704.67**
85566.67	**75633.00**

73458.00	**120899.00**
125432.60	**182427.00**

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DJ_dftdsecondlanding1	.146	18	.200*	.929	18	.184
DJ_dftdsecondlanding2	.127	18	.200*	.951	18	.437

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DJ_dftdsecondlanding1 - DJ_dftdsecondlanding2	43545.45722	88576.92304	20877.78098	-502.81032	87593.72477	2.086	17	.052

PARAMETRIC NON SIG

SLVJ_Kneevalgus_Video_2_3

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Groups	Statistic	df	Sig.	Statistic	df	Sig.

SLVJ_Kneevalgus_Video_2	Training	.124	9	.200*	.968	9	.879
	Cross-ed	.198	9	.200*	.956	9	.758
	Detraining	.186	8	.200*	.973	8	.918
SLVJ_Kneevalgus_Video_3	Training	.147	9	.200*	.947	9	.655
	Cross-ed	.192	9	.200*	.933	9	.509
	Detraining	.233	8	.200*	.927	8	.486

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Sphericity Assumed	1.242	1	1.242	1.173	.290
	Greenhouse-Geisser	1.242	1.000	1.242	1.173	.290
	Huynh-Feldt	1.242	1.000	1.242	1.173	.290
	Lower-bound	1.242	1.000	1.242	1.173	.290
TrialGroups * Groups	Sphericity Assumed	.006	2	.003	.003	.997
	Greenhouse-Geisser	.006	2.000	.003	.003	.997
	Huynh-Feldt	.006	2.000	.003	.003	.997
	Lower-bound	.006	2.000	.003	.003	.997
Error(TrialGroups)	Sphericity Assumed	24.367	23	1.059		
	Greenhouse-Geisser	24.367	23.000	1.059		

	Huynh-Feldt	24.367	23.000	1.059		
	Lower-bound	24.367	23.000	1.059		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TrialGroups	Type III Sum of Squares	df	Mean Square	F	Sig.
TrialGroups	Linear	1.242	1	1.242	1.173	.290
TrialGroups * Groups	Linear	.006	2	.003	.003	.997
Error(TrialGroups)	Linear	24.367	23	1.059		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	255.872	1	255.872	36.599	.000
Groups	1.749	2	.875	.125	.883
Error	160.800	23	6.991		

PARAMETRIC & NON SIG (0.290, 0.997, 0.883)

APPENDIX I

Data reduction for sEMG

Variable	Jump No.	Absolute Start Time	Max	Start_finish	Average	% MVIC Average	Sum	Time	Integrated	% MVIC Integrate	
MVIC R Q Dec Joss	x	x	121.38	12.13	17.47	x	110556.76	6.326	110.55	x	
MVIC L Q Dec Joss	x	x	80.8	8.08	20.24	x	121465.53	5.999	121.458	x	
MVIC R HS Dec Joss	x	x	885.43	88.54	302.38	x	1728387.18	5.715	1728.29	x	
MVIC L HS Dec Joss	x	x	928.79	92.879	282.02	x	2712444.9	9.617	2711.92	x	
MVIC R GM Dec Joss	x	x	96.37	9.637	22.01	x	135770.59	6.167	135.76	x	
MVIC L GM Dec Joss	x	x	500.92	50.09	157.93	x	8695868.45	5.505	869.54	x	
MVIC R Q Feb Joss	x	x	872.54	87.25	220.93	x	1249997.13	5.657	1249.92	x	
MVIC L Q Feb Joss	x	x	1406.53	140.65	171.22	x	307340.28	1.794	307.15	x	
MVIC R HS Feb Joss	x	x	1388.56	138.86	230.75	x	207216.83	0.897	207.06	x	
MVIC L HS Feb Joss	x	x	762.68	76.27	143.63	x	133864.63	0.931	133.78	x	
MVIC R GM Feb Joss	x	x	x	x	x	x	x	x	x	x	**Channe fault 80**
MVIC L GM Feb Joss	x	x	x	x	x	x	x	x	x	x	**Channe fault 80**
BASED ON PENG'S STUDY											
DJ R Q Dec Landing 1 Joss	2	44171	591.3	59.13	197.99	163.22	314612.88	1.59	314.56	284.45	
DJ R Q Dec Take Off Joss	2	47047	899.53	90	246.14	1408.92	249098.62	1.01	249.07	225.3	
DJ R Q Dec Landing 2 Joss	2	48838	825.82	82.58	255.61	1463.14	246407.3	0.96	492.66	445.64	
DJ L Q Dec Landing 1 Joss	2	44516	536.29	53.63	231.77	1145.11	348357.18	1.5	348.31	286.77	
DJ L Q Dec Take Off Joss	2	46697	494.66	49.47	229.14	1132	182627.62	0.78	182.57	150.31	
DJ L Q Dec Landing 2 Joss	2	49021	678.65	67.87	168.95	834.73	171482.21	1.02	171.42	141.13	
BASED ON PENG'S STUDY											
DJ R Q Feb Landing 1 Joss	2	47359	534.57	53.45	164.73	74.56	308216.11	1.87	308.16	24.65	
DJ R Q Feb Take Off Joss	2	49707	506.61	50.66	213.45	96.61	354126.4	1.65	354.07	28.33	
DJ R Q Feb Landing 2 Joss	2	51789	510.7	51.07	197.15	89.24	406727.32	2.063	406.67	32.54	
DJ L Q Feb Landing 1 Joss	2	47073	1164.54	116.45	328.58	191.91	754430.23	2.29	754.31	245.38	
DJ L Q Feb Take Off Joss	2	49593	696.62	69.66	308.83	180.37	842814.94	2.72	842.74	274.37	
DJ L Q Feb Landing 2 Joss	2	53057	913.13	91.31	271.02	158.29	162614.83	0.6	162.52	52.91	
BASED ON PENG'S STUDY											
DJ R HS Dec Landing 1 Joss	2	44702	501.37	50.13	167.7	55.46	138856.15	0.83	138.81	8.03	
DJ R HS Dec Take Off Joss	2	46781	681.24	68.12	198.26	65.57	130456.44	0.66	130.39	7.54	
DJ R HS Dec Landing 2 Joss	2	49670	534.49	53.45	147.31	48.72	102966.88	0.7	102.92	5.96	
DJ L HS Dec Landing 1 Joss	2	44640	677.4	67.74	191.15	67.78	209687.85	1.1	209.63	7.73	
DJ L HS Dec Take Off Joss	2	46790	943.25	94.33	294.05	104.27	343455.86	1.17	343.37	12.66	
DJ L HS Dec Landing 2 Joss	2	47958	619.12	61.91	254.79	90.34	469838.11	1.84	810.99	29.9	
BASED ON PENG'S STUDY											

DJ R HS Feb Landing 1 Joss	2	47288	191.98	19.2	44.74	19.39	64468.94	1.44	64.45	31.13
DJ R HS Feb Take Off Joss	2	51359	170.13	17.01	63.95	27.71	73287.84	1.15	73.27	35.39
DJ R HS Feb Landing 2 Joss	2	53299	174.51	17.45	41.31	17.9	29166.69	0.71	29.15	14.01
DJ L HS Feb Landing 1 Joss	2	47090	142.65	14.27	58.82	40.95	145101.22	2.7	145.09	108.45
DJ L HS Feb Take Off Joss	2	51054	170.26	17.03	55.95	38.95	77206.6	1.38	51.59	38.56
DJ L HS Feb Landing 2 Joss	2	52599	117.64	11.76	44.3	30.84	57821.13	1.31	57.99	43.35

BASED ON CARCIA'S + DAI'S STUDY

DJ R GM Dec Landing 1 Joss	2	44655	194.13	19.41	53.68	243.89	50516.04	0.94	50.5	37.2
DJ R GM Dec Take Off Joss	2	46117	209.74	21	52.31	237.66	61620.32	1.18	61.6	45.37
DJ R GM Dec Landing 2 Joss	2	48870	126.39	12.64	47.17	187.05	37074.65	0.79	37.06	27.3
DJ L GM Dec Landing 1 Joss	2	44366	102.49	10.25	34.84	22.06	41599.72	1.19	41.59	4.78
DJ L GM Dec Take Off Joss	2	46301	131.32	13.13	37.94	24.01	31827.56	0.84	31.82	3.66
DJ L GM Dec Landing 2 Joss	2	49186	90.09	9.01	30	19	14217.56	0.47	14.21	1.63

DJ R GM Feb Landing 1 Joss	2	x	x	x	x	x	x	x	x	x
DJ R GM Feb Take Off Joss	2	x	x	x	x	x	x	x	x	x
DJ R GM Feb Landing 2 Joss	2	x	x	x	x	x	x	x	x	x
DJ L GM Feb Landing 1 Joss	2	x	x	x	x	x	x	x	x	x
DJ L GM Feb Take Off Joss	2	x	x	x	x	x	x	x	x	x
DJ L GM Feb Landing 2 Joss	2	x	x	x	x	x	x	x	x	x

BASED ON MORITZ AND FARLEY STUDY

SLVJ R Q Dec Take off Joss	2	70483	671.52	67.15	131.25	751.29	464351.38	3.54	464.29	419.98
SLVJ R Q Dec Landing Joss	2	74154	260.03	26	43.72	250.26	43672.52	1	43.65	39.48
SLVJ L Q Dec Take off Joss	1	28112	266.73	26.67	51.05	252.22	150560.83	2.95	150.54	123.94
SLVJ L Q Dec Landing Joss	1	31108	124.6	12.46	15.95	78.8	174609.44	10.95	174.6	143.75

BASED ON MORITZ AND FARLEY STUDY

SLVJ R Q Feb Take off Joss	1	15483	86.95	8.7	25.51	11.55	107832.38	4.23	107.82	8.63
SLVJ R Q Feb Landing Joss	1	20548	110.62	11.06	29.34	13.28	42838.58	1.46	42.83	3.43
SLVJ L Q Feb Take off Joss	1	15568	549.03	54.9	193.21	112.84	437611.55	2.27	437.56	142.46
SLVJ L Q Feb Landing Joss	1	21661	510.39	61.03	164.15	95.87	243108.81	1.48	243.06	79.13

BASED ON PADULO'S STUDY

SLVJ R HS Dec Take off Joss	2	70753	770.15	77.015	167.15	55.28	518356.3	3.101	518.28	29.99
SLVJ R HS Dec Landing Joss	2	74077	347.81	34.781	63.5	21	43310.61	0.682	43.27	2.5
SLVJ L HS Dec Take off Joss	1	28388	317.29	31.73	49.09	17.41	83164.75	1.69	83.13	3.07
SLVJ L HS Dec Landing Joss	1	30076	243.42	24.34	58.48	20.74	53858.66	0.92	53.84	1.99

BASED ON PADULO'S STUDY

SLVJ R HS Feb Take off Joss	1	15452	717.33	71.73	249.44	108.1	614886.07	2.46	614.81	2.97
SLVJ R HS Feb Landing Joss	1	21532	853.48	85.34	223.82	97	360577.19	1.61	360.49	174.1
SLVJ L HS Feb Take off Joss	1	15425	166.31	16.63	50.36	35.06	362307.6	7.19	362.29	270.81
SLVJ L HS Feb Landing Joss	1	20038	153.68	15.34	54.17	37.71	116158.49	2.12	116.14	86.81

BASED ON STRUMINGER'S STUDY

SLVJ R GM Dec Take off Joss	2	71111	663.25	66.33	128.53	583.96	310796.96	2.42	310.73	228.88
SLVJ R GM Dec Landing Joss	2	74068	162.79	16.28	23.58	107.13	24973.73	1.06	24.96	18.39
SLVJ L GM Dec Take off Joss	1	29549	676.11	67.61	133.89	84.78	63597.89	0.48	63.53	7.31
SLVJ L GM Dec Landing Joss	1	31010	217.88	21.79	41.12	26.04	34950.04	0.85	34.93	4.02

SLVJ R GM Feb Take off Joss	1	x	x	x	x	x	x	x	x	x
SLVJ R GM Feb Landing Joss	1	x	x	x	x	x	x	x	x	x
SLVJ L GM Feb Take off Joss	1	x	x	x	x	x	x	x	x	x