High tech cognitive and acoustic enrichment for captive elephants

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Abstract

This paper investigates the potential for using technology to support the development of sensory and cognitive enrichment activities for captive elephants. It explores the usefulness of applying conceptual frameworks from interaction design and game design to the problem of developing species-specific smart toys that promote natural behaviours and provide stimulation. We adopted a *Research through Design* approach, and describe how scientific inquiry supported our design process, while the creation of artefacts guided our investigations into possible future solutions. Our fieldwork resulted in the development of an interactive prototype of an acoustic toy that elephants are able to control using interface elements constructed from a range of natural materials.

Keywords: elephant, cognitive enrichment, Research through Design, Animal-Computer Interaction, embedded technology, acoustic enrichment

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We present a qualitative study examining the potential for using technology to support the delivery of novel enrichment experiences for elephants kept in captivity, in order to provide them with meaningful choices and opportunities to control environmental features, thereby offering cognitive and sensory enrichment.

We have adopted a *Research through Design* approach in order to explore this problem space, allowing us to progressively gain insights through the process of making successive prototypes. *Research through Design* emphasises the physical aspects of producing novel artefacts and experimenting with materials, so that knowledge is gained through the process of designing. The evolution of the product is supported by both design logic and scientific research, and should "explain its own emergence" (Jonas, 2006, p2). We have investigated concepts for playful interactive systems that have an acoustic output by developing physical prototypes for elephants and using our experiences in the field to inform and inspire future iterations, moving from speculation to manifestation. We maintain that a playful system is a useful paradigm for exploring interaction design for elephants, because of the opportunities it affords for offering choice and control.

The new field of Animal Computer Interaction (Mancini, 2011) is investigating a range of approaches to the problem of designing user-centred systems for animals and this investigation into high-tech devices for elephants aims to contribute towards the development of a methodological approach for designing smart and playful enrichment for all species. However, this raises an important question – can technology-enabled environmental enrichment ever be appropriate for an undomesticated captive animal, which would never have cause to interact with such a system in the wild? We argue that technology can mitigate some of the limitations imposed by living in a restricted environment, by mimicking challenges that cannot be presented in captivity such that the cognitive exercise is similar to what would occur in the wild, even if the process is different and uses "unnatural" materials (French, Mancini, & Sharp, 2016). This idea has already been explored with a variety of species; for example, Kim-McCormack, Smith and Behie (2016) highlight the relevance of digital technology for providing dynamic and flexible enrichment in the context of captive primates, while Kingston-Jones, Buchanan-Smith and Marno (2005) endorse the use of technology to support enrichment for lions.

There are a number of different categories of environmental enrichment, relating to food provision as well as sensory, social, environmental and cognitive experience. Feeding-related enrichment is now common-place in UK zoos. As well as offering a nutritional reward, scattering food and using puzzle feeders stimulates physical activity that exercises the body and poses cognitive challenges that exercise the mind. Additionally, this kind of enrichment is an interesting way to expend time in an enclosed space where there are limited opportunities for stimulation; indeed, it well known that many animals prefer to work for their food (known as contra-freeloading - Osborne, 1977; Podelsnik & Jimenez-Gomez, 2016; Washburn & Rumbaugh, 1992).

However, feeding is only one aspect of a captive animal's life experience, even if it occupies a significant portion of their time. Mills, Dube and Zulch (2012) describe how a captive animal whose basic (physiological, safety-related, social) needs are met will be driven to seek cognitive stimulation and will need novel challenges to overcome. In the wild, an animal has complete autonomy and can make meaningful choices in a complex living environment; in contrast, captive animals lack control over many aspects of their lives, where routines are imposed on them for practical reasons and social dynamics are often compromised by enforced proximity to, or separation from, conspecifics.

Offering environmental control

Welfare experts have endorsed the idea of offering animals more control over aspects of the captive environment (Mills et al, 2012; Whitham & Wielebnowski, 2013; Young, 2003). In particular, Mills et al. (2012) explain why control is important in the context of homeostasis, whereby an animal is driven to respond to changes in its environment in order to reduce stress and maintain an optimal physiological or social condition. The ability to control something is an opportunity to respond to a stimulus, requiring the exertion of both physical and mental skills that animals have evolved to express. As a case in point, Buchanan-Smith and Badihi (2012) explored the idea that having control is enriching in a series of studies with captive marmosets during which some of them were provided with switches they could activate in order to increase the amount of light, and simultaneously the amount of heat, in their cages. A decrease in behaviours used as indicators of reduced welfare, such as the amount of time spent self-scratching and scent-marking, suggested that the animals given controls to use were less stressed. In an earlier experiment, Washburn, Hopkins and Rumbaugh (1991) confirmed that rhesus monkeys were able to exercise choice using a screen interface and moreover that they performed better in tasks they had chosen to do using this selection procedure than in tasks assigned to them by a keeper. The authors suggest that this shows the potential for offering choice and control as part of an enrichment programme.

Several researchers have explored how animals might exercise control by allowing them to make choices in a playful context. One such project was undertaken by Dutch interaction designers in conjunction with pig farmers (Alfrink & Lagerweij, 2012). The team used a computer game to improve farm animal welfare, as part of their “Playing with Pigs” project, aimed at reducing stress in barn-housed pigs. Lights on an interactive wall attracted the pigs’ attention and if they followed a light with their snout while a human simultaneously used an iPhone interface to follow the light with a finger, the light would become brighter and make an exciting display. Although such technological interventions are not part of pigs’ natural experience, they engaged with the installation quite actively. The Playing with Pigs project claimed to be successful both in entertaining pigs (thus reducing the incidence of tail biting behaviour) and in raising awareness of their existence among the meat-eating public.

The expression of playful behaviour is recognised as a highly positive behaviour in captive animals (Oliveira, Rossi, Silva, Lau, & Barreto, 2010). Burghardt’s surplus resource theory (2005) claims that four factors need to be present for play to emerge – (i) animals should have sufficient energy; (ii) they must be buffered from stress or danger; (iii) they must be in need of stimulation; (iv) the species lifestyle should be sufficiently complex. Zoo-housed animals tend to meet these factors well, as they are properly fed, kept free from danger, have time to be filled and many are species that would have a complex lifestyle in the wild.

Although it is relatively easy to identify, play is challenging to define because it is fluid and transient with no immediately obvious cause (Bekoff & Byers,1998; Sendova-Franks & Scott, 2012). None-the-less, researchers (Brown, 2010; Sicart, 2014; Burghardt, 2005) have attempted to characterise play, with the following attributes being commonly agreed: it is autotelic (offers intrinsic reward) and it is apparently non-functional (not directly related to fitness). However, there are a number of possible reasons for play behaviour, with current research favoring the idea that play prepares animals for their future lives by refining the control that the prefrontal cortex has over other parts of the brain, allowing the animal to become more adaptable (Pellis, Pellis, & Bell, 2010). Burghardt (2010) suggests that behavioural play is a precursor to mental play and may be an important factor in the evolution of cognitive and social abilities in different species.

Spinka, Newberry and Bekoff (2001) claim that toys are intrinsically cognitively enriching because any novel objects of interest provide animals with opportunities to "train for the unexpected," a skill that would develop naturally in the wild, but which is likely to be under-developed in captivity where the living environment is much simpler and routines are in place. Young (2003) points out that toys have been successfully introduced into animals' enclosures in order to stimulate play behaviour for several years and that particularly "mammal and bird species can benefit from the effects of toys" (p.149). On the other hand, Tarou and Bashaw (2016) propose that enrichment providing extrinsic reinforcement (such as food) is likely to have more long-term success in promoting behavioural change than intrinsically rewarding enrichment (such as toys).

Traditional toys are designed for freeform play, in contrast to games, which have a formal structure and require players to understand and accept a system of rules, a distinction discussed by Callois (1961). It appears that animal play more closely resembles freeform play, which is spontaneous and improvisational, rooted in physical sensation and role-play (Brown, 2010). On the surface, toys might appear to offer fewer opportunities than games for exercising control and choice. However, recent developments have seen a new trend emerging towards "enhanced" toys for captive animals (Hirskyj-Douglas & Read, 2014; Westerlaken & Gualeni, 2014; Wirman, 2014), which include embedded technology and offer a measure of interactivity. The integration of a toy with a formal system imposes some game-like qualities on the experience in that the player needs to understand how the system works in order to be able to play with it, thus providing a cognitive challenge and promoting physical engagement and meaningful choices on the part of the animal.

We chose elephants to be our users on account of their cognitive and social complexity (Plotnik, 2010; Poole & Granli, 2008) and because they are known to be playful, demonstrating loco-motor, object and social play all their lives (Lee & Moss, 2014). These behavioural characteristics imply that elephants might be both capable and willing to engage with a technologically enhanced toy. We argue that there may be welfare benefits for captive elephants (with minimal extended family, limited space and little need to forage) from interventions that give them a measure of control over their environment through engagement with a playful system that offers multisensory feedback. The Elephant Welfare Group (http://www.biaza.org.uk/animal-management/animal-welfare/elephant-welfare-group/) endorses the idea that captive elephants should be provided with substantial enrichment, including toys.

In order to begin to design a playful interactive system for an elephant, we needed to gain an appreciation of their cognitive abilities, as well as an understanding of how elephants typically interact with the world and their conspecifics.

Elephants

Bates, Poole and Byrne (2008) point out that elephants have the largest brain size of any mammal on earth, pointing out that there must be a good reason for this because brains require a lot of energy to maintain. Hart, Hart & Pinter-Wollman (2008) concluded that elephants could perform as well as apes in many cognitive feats. The measures of cognitive ability they used include determining whether an animal has a “theory-of-mind”, how well it performs on tasks requiring memory, the complexity of its social life and its spatial-temporal understanding.

With regard to “theory-of-mind”, elephants' responses to the death of a conspecific are pointers to an advanced mental capacity; their reactions seem to show grief, which suggests empathy, which is a prerequisite for an understanding of an "other" - thus, a sense of self (King, 2013). Experiments with mirrors add credence to this idea. Plotnik, de Waal, Moore and Weiss (2010) document a study of mirror self recognition (MSR) in three adult Asian elephants and claim that the cognitive evolution of elephants is similar to that of apes and dolphins, because of the stages the elephants went through on their way to recognising themselves in the mirror.

Memory, social complexity and spatial-temporal understanding have been shown to be highly developed in elephants. According to Poole and Granli (2008), wild elephants typically range over hundreds of kilometres with their large extended families, spending the majority of their time foraging. To survive, they need to develop good geographical memories, make decisions, take risks and use their trunks to smell the environment, manipulate objects and produce sounds. In addition, they need to develop excellent auditory perception. Elephants’ social networks are extensive and complex; their repertoire of vocalisations indicates a sophisticated communication system. They engage in antiphonal calling, a form of communication conducted at low frequencies within the herd for the purpose of maintaining group cohesion (McComb, Reby, Baker, Ross & Sayialel, 2003). The calls are all distinct, providing clues to identity. McComb, Moss, Sayialel & Baker (2000) determined that elephants can recognise up to 100 other elephants in their extended families, building up their knowledge as they grow older and encounter more family members. There is also evidence that elephants are highly aware of other sounds in their environment via their sense of hearing, for example, being able to perceive distant thunder and bees (King, Soltis, & Douglas-Hamilton, 2010). In a captive environment in Korea, a solitary Asian elephant has been documented attempting to communicate with its keepers by making sounds that resembled five Korean words – translated as ‘hello’, ‘sit down’, ‘no’, ‘lie down’, ‘good’ – by placing his trunk inside his mouth (Stoeger, Mietchen, Oh, de Silva & Herbst, 2012). The authors suggest that this is an example of an animal attempting to cement social bonds across species.

There are other indicators of intelligence, such as problem-solving and tool use, where elephants seem to score lower than apes, although Bates et al. (2008) point out that we typically emphasise these measures because humans excel at solving problems and using tools. Nevertheless, using a branch for fly-switching has been documented by Hart & Hart (2001). Plotnik, Lair, Suphachoksahakun & deWaal (2011) demonstrated that “elephants can learn to coordinate with a partner in a task requiring two individuals to simultaneously pull two ends of the same rope to obtain a reward.” Working simultaneously in order to accomplish a task that cannot be done by oneself is a specific kind of problem-solving, which requires an understanding of the other participant and the outcome of their actions. Finding a solution to a challenge also requires insight and demonstrates the ability to learn something new. Spontaneous novel behaviour is reported as being shown by an Asian elephant in the context of allomothering. Vidya (2014) describes how an auntie elephant dealt with a calf that kept trying to suckle – she gave it her trunk to suck instead of kicking it out of the way, a behaviour that had not been observed before.

Another example is provided by Foerder, Galloway, Barthel & Moore (2011), who provided a young male zoo-housed elephant with the equipment and motivation to prove his problem-solving abilities. The elephant showed insight by spontaneously moving a block to a position under some branch baited with food, so he could stand on the box and reach the food. When the block was removed and replaced with a tyre, he used that instead. The authors believe that this demonstrated tool use and tool generalisation, consistent with insightful problem-solving.

These examples demonstrate that there is scope for further research into elephant cognition and behaviour, and our work attempts to show how technology might be used to support future investigations by enabling systems that offer elephants the freedom to make decisions that produce a meaningful outcome.

Design characteristics

There are two aspects to this work – the conceptual model of the interactive toy and the design of the interface. These two aspects are deeply integrated, as the interface serves as a metaphor for the underlying functionality and the sensory feedback from the system is an inherent part of the playability of the toy, providing intrinsic motivation to continue playing. In order to play with a novel system, an animal will need to be able to make choices about what to do and use the necessary controls to achieve its aims. We argue that this presents both an interesting cognitive challenge and has the potential to offer appropriate sensory stimulation.

Because environmental enrichment aims to encourage species-appropriate behaviours across a range of categories, the interactive toy should aim to give the captive elephant an experience that reproduces some features of an experience enjoyed by a wild elephant, or which enables the elephant to practice some of the skills that a wild elephant would naturally deploy. Zoos and wildlife parks currently offer their elephants a wide range of low-tech enrichment; therefore our approach has focused on gaps in elephant experience that are not met using traditional enrichment, with the aim of using technology to offer something new.

Designing “something new” that technology can help to deliver is a distinct challenge in itself. What would an elephant find engaging? In order to tackle this, we needed to probe how an elephant might interact with a system by using a novel interface, and also imagine the kinds of systems that would stimulate interest from an elephant. Useful frameworks for developing games and toys for animals (Lawson, Kirman, & Linehan, 2016; Pons, Jaen, & Catala, 2015; Zamansky & Wirman, 2016) as well as participatory approaches to the design process (Robinson, Mancini, Van der Linden, Guest, & Harris, 2014) have recently been proposed by ACI researchers. The frameworks of Pons et al. and Lawson et al. are largely speculative; the former proposing the future development of an adaptive environment and the latter concerned with thought experiments to gain insights. Zamansky and Wirman take a more practical approach, describing a framework that includes performance and environmental measurement, animal sensors and device outputs.

The work presented here builds on their suggestions by emphasising the value of *Research through Design* as a structured approach for developing a future end product from an evolving concept – emphasising the need to underpin conceptual work with clear design goals relating to the theoretical and physical properties of the system – how it supports its purpose and how it manifests in the environment (Hengeveld, Frens and Deckers, 2016; Lim, Stolterman and Teneenberg, 2008).

Our aims were: (i) to explore the design of technology-enabled enrichment for elephants; (ii) to identify suitable enrichment goals that could be facilitated using technology; (iii) to develop an interface design that enabled choice and control; (iv) to identify outputs that offered suitable sensory stimulation; (v) to manufacture and test different playful systems with elephants. To accomplish this, we have adapted methodologies from interaction design, game design and ACI. The detailed methodology is discussed in the next section.

Methods

This section outlines the methods used as part of our *Research through Design* approach to the challenge of developing novel high tech enrichment.

Understanding elephants

User-centred (UX) design requires a thorough understanding of the design context (Rogers, Sharp, & Preece, 2011). It offers a range of possible approaches to the challenge of designing a novel interactive system, and one of the fundamental principles is to gather user requirements at the start of the design process in order to inform development through successive design iterations with the participation of users and other stakeholders. We gathered requirements in three different ways: by reviewing existing literature about elephants, by conducting ethnographic observations at zoological facilities and by developing and testing prototypes with an elephant.

Ethnographic study

The fieldwork began with an ethnographic study of four African elephants at Colchester Zoo, undertaken between January and March 2014. Observations carried out within the study revealed some of the playful behaviours of the animals, showed their range of movements and interests during discrete time periods and clarified hierarchies within the herd. Interviews with the Head Elephant keeper were useful for explaining the animal husbandry routines in place and for shedding light on the different characteristics of the animals. This information was supplemented by later observations of a small herd of African elephants at Howletts Wild Animal Park (Kent, England), two African females at Blair Drummond Safari Park (Stirling, Scotland), two African males at Noah's Ark Elephant Eden (Bristol, England) and our main user-tester, an Asian female at Skanda Vale Ashram (Carmarthenshire, Wales).

In order to motivate potential ideas for enrichment devices, we attempted to identify some of the gaps in experience of captive elephants compared to their wild counterparts. The behaviours observed in captivity were compared with behaviours recorded in communities of wild elephants (from the academic literature). Based on our findings, we identified the following experiences and associated behaviours as having potential for expression via high-tech enrichment (for some groups of elephants), in cases where a natural alternative was not attainable.

1. Acoustic experiences – e.g., antiphonal calling, opportunity to identify multiple family members, stimulation at appropriate frequencies. Such experiences are fundamental for establishing and maintaining social bonds.
2. Olfactory experiences – e.g., scents of multiple elephants in different physiological states, novel environmental features.
3. Cognitive challenges and the need to adapt – e.g., route-planning, foraging in unfamiliar terrain, dealing with conspecifics, exercising control over own behaviour, making meaningful choices about when and where to eat, drink, bathe, play etc.
4. Social experiences – e.g., being able to choose companions, fellowship within a herd, allomothering, play-fighting.
5. Physical exercise – e.g., opportunity and motivation to walk for long distances.

This information provided the basis for subsequent brainstorming and concept development, as we were aiming to design playful systems that would encourage the expression of evolved behaviour patterns (such as those recorded in wild elephants) in the zoo-housed animals.

Concept development

Our concepts evolved over several months as we discovered more about our potential users and began to test designs in the field. We quickly ruled out attempting to offer social or olfactory enrichment because we were not in a position to modify herd size nor have sufficient knowledge of chemical signalling in elephants. With regard to promoting exercise, we felt that this could be enabled for specific muscles (eg. trunk manipulations). Consequently, our initial aim was to develop an acoustic toy – one that encouraged free play rather than a structured game with rules, so that it might have similarities with wild elephant object play, yet still offer the kind of cognitive stimulation associated with understanding a new problem space and being able to discriminate between different sounds.

Although using acoustic stimulation as an aspect of environmental enrichment has been attempted with elephants before, in no instances have we found reports of elephants being given control over the audio production, thereby offering them a choice. Wells and Urwin (2008) observed that elephants showed less stereotypic behaviour when they were played "classical music" and anecdotal evidence (http://www.musicforelephants.com/ ; https://www.thedodo.com/elephant-zoo-classical-music-1206110193.html) suggests that some music does have elephant appeal. In these examples, humans have selected and played pieces of audio to elephants; in another case (http://www.stevetorok.com/elephant_music_project/), elephants were given the opportunity to control percussive elements. With this in mind, our goal has been to produce an interactive toy that allows an elephant to make selections about the kinds of sounds being produced. The fact that audio signals can be produced and altered programmatically means that they are a practical form of output for a technically enabled system.

Concepts that were informed by our investigations were initially formulated as labelled sketches, descriptions and miniature cardboard prototypes. When our ideas reached a usable stage (in terms of both suitability and feasibility), they were shared with keepers and animal behaviour experts. Alexander and Beus-Dukic (2009) remark how user requirements are often created by collaborative work. This collaboration – known as Participatory Design - is described by Muller (2003) as the third space in HCI - where developer and user can work together on fulfilling design expectations.

Participatory design

Initially, we undertook fieldwork with one female Asian elephant called Valli, living at Skanda Vale Ashram. Several iterations of prototyping with Valli resulted in a template concept for a toy that we were able to test with two African males, housed at Noah's Ark Zoo.

At Skanda Vale we worked with the keepers to design a bespoke system, so that they shared ownership of the concept, which fostered our collaboration. Indeed, the keepers became very engaged with the idea of offering Valli some technology-enabled enrichment. Yet the most important user in this scenario was the elephant – how could she participate in the design process? Usually, during the prototyping stage of UX Design, it is possible to obtain feedback from the user through self-reporting methods, such as questionnaires and focus groups. This is vital because concept development is an iterative process and feedback directly informs subsequent designs. In order to elicit Valli's feedback we adopted a method used by Robinson et al. (2014) that generated a series of 'quick and dirty' physical prototypes that we could place in her enclosure to assess her responses. This particular form of Participatory Design has been called “bodystorming” (Schleicher, Jones, & Kachur, 2010) and its goal is to be able to investigate users with their tools or systems in the context (physical space) in which they will be used. In this way, we were able to explore our design ideas in direct cooperation with the elephant as well as via the mediation of her keepers.

The evaluation of design concepts was an inherent part of the prototyping stage, so that we could make adjustments as elephant feedback was observed, recorded, logged and interpreted. To gauge the elephants’ reactions to our interventions, we used a variety of methods: (i) observational data and video recordings that showed how they interacted with a novel interface; (ii) data from the system itself that showed whether the controlling mechanism was effective or not; (iii) the expert opinions of keepers interpreting whether the responses were positive or negative by observing elephant body language.

Additionally, the “making” aspect of the work - constructing real objects - was conducive to gaining useful insights (French et al, 2016). For example, we were able to appreciate the qualities of the materials used in the design and reflect on how these qualities might influence Valli’s responses. Four of our prototypes are the subject of this paper and are described below.

Participatory Design (PD)1: Sound test.

Goals. Check whether Valli shows aversion or interest to low frequency audio samples.

Rationale. Rather than use samples of music, our initial intention was to synthesise some sounds with low frequencies (infrasound), so they had waveforms in common with elephant rumbles. The rationale for this was that while humans appreciate musical harmony, there is minimal evidence of other mammals finding it interesting. Uetake, Hurnik and Johnson (1997) report that “classical music” influenced cows in a positive manner prior to milking, but Ritvo and Macdonald (2016) discovered no benefits for orang-utans subjected to “music”, nor did Wells, Coleman and Challis (2006) note a significant effect of “classical music” on zoo-housed gorillas. On the other hand, dolphins have demonstrated the ability to learn new acoustic signals that resemble sounds made by their own species (Herzing, Delfour & Pack, 2012), while Snowden, Teie and Savage (2015) report that cats prefer “species-appropriate” music, based on sounds they hear in infancy.

Our initial participant, Valli, was orphaned at birth and has been living with human companions at Skanda Vale Ashram for over thirty years. Valli does not have the opportunity to communicate with other elephants, so we hypothesized that acoustic enrichment in a lower frequency range than human voice might provide her with some interesting auditory experiences. Advice from representatives of the EWG (Elephant Welfare Group) originally cautioned against playing the sounds of unknown elephants to captive animals, as wild elephants have a negative reaction to the sounds of unknown herds (Soltis, King, Douglas-Hamilton, Vollrath, & Savage, 2014). We therefore attempted to explore a range of alternative sounds, starting with synthesised sine waves and progressing to complex musical samples.

We knew that Valli had been exposed to different music styles because her main caregivers regularly played bluegrass and rock music through overhead speakers, while the ceremonies that took place at the temples included a lot of percussion and singing. From these experiences, we also knew that Valli had previously showed aversion to drums, so before introducing a device with novel acoustic feedback, we needed to check that this would not provoke a negative reaction.

Procedure. Speakers were placed on the balcony above Valli's enclosure. When Valli came in from her outdoor enclosure (part of her usual routine), we played nine 10 second long samples ranging in frequency from 10Hz to 90 Hz, consecutively with a short time gap in between. The researcher was on the balcony, while the keepers observed Valli's reaction from the ground. Then two longer samples of didgeridoo music were played while keepers monitored Valli's reaction.

Findings. We encountered the practical problem of not being able to hear sounds at the lower end of the spectrum ourselves, and therefore not being sure whether the Skanda Vale speakers were large enough to reproduce samples below 30 Hz.

Valli turned in the direction of the speakers and tilted her head when the samples were first played. Although keeper and researcher estimates concluded that she spent more time in this position when sounds were in the 60-80 Hz frequency range, the findings were inconclusive. According to Valli's keepers, during the playback period she displayed no signs of anxiety, nor was there evidence of any subsequent change in her behaviour. As a result, Valli's keepers were satisfied that hearing unusual sounds would not cause her any anxiety and they were consequently happy for us to continue to investigate acoustic feedback in our prototypes. We therefore achieved our goals and also identified questions for future research, such as what frequency audio Valli might choose to listen to, if she had control over the presentation.

The next stage involved constructing and testing a range of interface designs in order to understand what might be feasible for an elephant with regard to using controls - how might an elephant be physically and cognitively able to interact with a system? The physical aspect relates to the design of an object that an elephant can control using its evolved way of interacting with the world. What qualities would make such an interface easily usable for an elephant? The cognitive aspect relates to the design of a system that an elephant can understand. As Krippendorf (1989) notes, meaning is a cognitively constructed relationship connecting features of objects and features of their context into a coherent unity.

Sensible UX design for an animal would make use of its existing knowledge of the world and simplify the controls so that they are natural to activate. This is an important aspect of interface design known as affordance – the idea that an object offers its user an indication of how to interact with it and sometimes also its functionality through properties that the user can perceive, such as its form (Norman, 1988). Thus we might assume that a branch-like structure would suggest to an elephant that it could be tugged (and moreover that it would offer resistance). In fact, although our initial concept designs included such controls (bungee ropes as pulleys), there were insurmountable difficulties associated with mounting these safety from the roof of the elephant shed.

This highlights one of our major challenges – and therefore one of our goals – the construction of interfaces that were sufficiently robust to be safe, using materials that could be repurposed or bought relatively cheaply and which were easy to work with using our available equipment.

PD2: Acoustic pipe button.

Goals. Create and deploy an interface that offers Valli control over acoustic output; assess her willingness and ability to engage with device.

Rationale. Observations of elephants have shown that they often investigate crevices and other small spaces with their trunk tips, possibly to search for something edible, but also simply to explore the environment. For this reason, we used lengths of drainpipe as physical buttons that could offer Valli control of an acoustic experience. We placed capacitance sensors inside, hypothesising that Valli would be motivated to feel inside the pipe out of curiosity. Capacitance sensors are activated by the proximity of conductive objects (in this case Valli's trunk). No contact or force needs to be applied to the sensor, the advantage being that a trunk tip in the vicinity will activate the sensor and no special movements need to be made by the animal. The disadvantage is that the sensor itself provides no tactile feedback to show it has been activated, (unlike a toggle switch, for example, which changes position). Acoustic feedback was generated by the system – a small piezo buzzer vibrating at different speeds to produce different tones.

Procedure. Three sections of 300mm corrugated plastic drainpipe were mounted over three capacitance sensing buttons made from plywood and tinfoil on a wooden base. The buttons were located behind a browsing hole in the wall of Valli's enclosure, so she could only access them with her trunk tip, and not have the full use of her considerable strength which would have enabled her to easily pull them apart. When Valli came inside (part of her usual routine), Valli's keeper Brother Stefan initially used food to motivate her to put her trunk into a button (Fig 1). He held a banana on the device side of the wall (invisible to Valli); he also called her name. Valli's other keeper, Brother Peter, remained on the inside of the enclosure and directed her towards the browsing hole. The researcher remained with the pipe buttons, to observe Valli's trunk movement.

Findings. Valli explored the device with her trunk, finding a piece of fruit when she felt inside the pipe. When she had the fruit in her trunk, she withdrew it from the browsing hole to eat, and then pushed her trunk back through again. Researcher and keeper observed from the device side as Valli spent several minutes exploring the pipes with her trunk. She withdrew her trunk and we observed her for a further 30 minutes, during which time she remained close to the browsing hole, regularly checking it with her trunk, even though there were no more bananas on offer.

Martin and Niemitz (2003) found that Asian elephants are typically "right-trunkers" or "left-trunkers", which adds to the notion that the trunk can be compared in some ways with a human hand – it is used for caressing, feeding oneself and others, investigating novel objects and manipulating tools. The fact that a trunk is also simultaneously a nose and a sound producing organ greatly increases its utility, but also complicates matters when we try to design an interface for an elephant to use to control a system. Foeder, Galloway, Barthel, Moore and Reiss (2011) comment that unsuccessful attempts to demonstrate tool use in elephants may be due to a misplaced emphasis on the trunk as a kind of "hand" for holding a tool, whereas in fact it is primarily a sensory organ in the context of food.

This came to light when we tested the pipe buttons. In retrospect we realised that banana enticement was counter-productive with regard to assessing the viability of the interface design because her focus was always on food. When bananas were removed from the situation, the problem was not only that the association had already been made, but also the fact that the residual chemical properties of the banana were easy for an elephant to smell.

There has been a strong assumption from many keepers and welfare experts that food should be the motivator for elephant enrichment because of the large proportion of time that wild elephants spend foraging. However, because an elephant is so motivated by food, using food as an initial motivator means that it then becomes impossible to determine if the animal is performing an action for any other reason apart from the possibility of a food outcome. Food is also strongly associated with training activities, whereas our aim was to design a system that invoked playful behaviour, and play is characterised by being voluntary, not trained (Brown, 2010; Sicart, 2014).

Even without the addition of food as a distraction, it was problematic to assess the effect of individual aspects of the design, because of the integration of so many modalities. Whereas humans can be relied upon to try and separate perceptions into different categories – visual, tactile, acoustic etc – it seems likely that perception is a holistic experience for an animal.

We partially met our goals because this attempt was successful as a physical object and as a potential controller because of its shape, size and texture, which had some intrinsic appeal for Valli, evidenced by the amount of time she spent exploring the surface. The heavy duty plastic drainpipe had been lying around in the Welsh countryside, so it probably held some interesting scents as well, besides residual banana. However, it was not possible to determine whether Valli had any interest in the accompanying audio output. We could not reproduce the physical aspects of the pipe design in a more accessible location because it would have been too easy for Valli to pull apart, but we needed to move the next prototype from a browsing window so it was clearly visible and dissociated with food. Therefore we moved on to a more streamlined design.

PD3: Fence mounted acoustic push button

Goals. Design a robust button with stronger audible and tactile feedback and deploy it in a location where Valli can see and touch it without being able to destroy it.

Rationale. At some zoos we visited (when we were looking for collaborative partners), keepers suggested that any device the elephant could reach needed to be made from stainless steel. However, this was not a viable option, both in terms of cost and manufacturing capabilities. Indeed, our experiences show that our elephant testers did not attempt to destroy any of the wooden interfaces we provided, but instead targeted loose fittings such as hosepipes, when they were left unattended. We consider that it is worth emphasising that stainless steel boxes are not a natural part of a wild elephant’s environment.

We constructed a wooden frame containing a heavy duty sewing machine button with a spring-back mechanism and a rubber textured surface (Fig 2) which we hoped would offer feedback in the form of resistance to pressure. When activated, the button triggered the production of a tuba sample on the grounds that the harmonics generated from an instrument with a long bore might have something in common with noises generated by a trunk (Gilbert, Dalmont and Potier, 2010) and therefore have more interest for an elephant than a sine wave.

We had based our initial prototype (PD2) on research into elephant communication suggesting that modalities for interfacing with an object should focus on tactile, acoustic or chemical properties, rather than relying solely on a visual display. Plotnik and de Waal (2014) suggest that elephants live in a world that is largely acoustic and olfactory rather than visual. Yet it seems that vision does have a significant part to play in the design, so we changed the location of the device to a balcony beside Valli’s enclosure with a rail made of steel bars reinforced with a thick wire fence.

Procedure. Judging that Valli would not be able to pull down a device that was mounted on her balcony fence, we bolted the pedal button to the heavy wire netting while she was outside. When she came in (as part of her usual routine), one of her keepers showed her the button and tried to encourage her to push it (without banana inducement).

Findings. Valli moved directly towards the balcony where her keeper was standing, but she did not push the button. She explored the surface and felt round the edges of the new object with her trunk tip, but seemed reluctant to exert pressure on the pad. The keeper showed her what to do using his hand and the sound sample was played, but this did not make a difference to her behaviour. After multiple attempts to engage her with the button, Valli walked away.

We were satisfied that the location of the device on the fence was appropriate. The sewing machine pedal corresponded to our idea of what a button should be like, but on a larger scale. However, it was clear that the action of pushing small items was not a natural behaviour for Valli. Pushing is reserved for large, heavy objects such as suspended tyres and other elephants, and it is typically expressed as an all-body action, not performed with the tip of the trunk. For this reason, we decided to revert to using hidden sensors, but to emphasise the tactile qualities of the button in order to encourage trunk tip exploration.

PD4: Fence mounted control with acoustic and haptic feedback

Goals. Design and deploy buttons with tactile interest and acoustic output, using hidden sensors.

Rationale. Infrared technology is a cheap and simple solution for detecting movement, used in field cameras and often in buildings as part of an automated lighting circuit. Therefore, we decided to use IR sensors hidden in the button frames that mapped to outputs (acoustic and haptic) via a microcontroller. . As the button touch pads were securely constrained within the wooden frames, it was possible to experiment with the materials used for the surface, reasoning that textured surfaces might seem more natural and therefore hold more interest for an elephant than smooth manufactured ones. Consequently, we used natural fibres to knit textured surfaces for the button pads. Following this line of thought led to the development of haptic interfaces, implemented with small vibrating motors fixed behind the button pads.

The choice of rectangular frames for buttons was based on a need to simplify the design so that it could be manufactured quickly and easily, to facilitate rapid prototyping. Additionally, such a design offered clear affordance for keepers, such that it was easy to explain how it worked, and also allowed us to use hidden sensors.

Procedure. These buttons were deployed in a similar manner to the previous ones. A keeper was present on the balcony when Valli entered the enclosure, gesturing to the buttons to attract her attention. When she touched a button, two things happened – the button surface vibrated and a sound was played (brass sample).

Findings. This prototype (Fig 3) fulfilled our goals with regard to interface design and functionality. Valli reached up to explore the objects voluntarily. She was able to interact with the buttons and sShe spent a few minutes moving her trunk between the different buttons, which offered distinct surfaces and haptic feedback from different vibrating motors.

We wanted Valli to understand that she had activated the controls successfully by offering haptic feedback, but in fact this could have been confused with the system output, which was an audio signal. The keepers' consensus was that the design worked well, while the researchers felt it would be appropriate to disentangle the acoustic output and haptic feedback in a subsequent experiment, as it was not clear which sensation Valli found interesting.

PD5: Fence mounted elephant radio system

Goals. Design, deploy and evaluate an "elephant radio" for zoo-housed elephants.

Rationale. This prototype was developed for two African male elephants, Janu and Machanga, housed at Noah's Ark Zoo[1]. Janu and Machanga are usually housed together, but can be separated at night to manage any conflict. Their keepers wanted both elephants to have the opportunity to play with the enrichment, to avoid any competition that might provoke aggressive behaviour or bullying, so we were asked to provide two identical systems.

The system comprised two radios with three buttons each, offering a choice of acoustic output, so that the elephants could individually exhibit preference in controlling the sounds. The buttons were based on the previous successful design, but focused on controls triggering single actions (audio output) and omitting haptic feedback.When a button was touched, one of three audio clips was triggered – whalesong, a recording of a friendly elephant call (taken from elephantvoices.org site) and a classical track (Bach's D Minor for 2 violins). The audio choices were based on requests from the EWG, who wanted to test whether sounds that had previously been played to elephants by humans (with no response) would generate more interest when elephants were given control over their expression.Research surprisingly did not reveal which tracks had been deployed in previous studies of playing classical music to animals, as if the nature of the music was of little consequence. To inform our choice, we investigated anecdotal and video evidence of elephants apparently showing pleasure at the sound of classical music, notable in that it was always in an acoustic setting, not emanating from speakers.

Recordings of whales and elephants can be found on the Internet. With regard to elephants, it is known that their calls are context dependent and have meaning for other members of the herd. The Elephant Voices Organisation (https://www.elephantvoices.org/) has collected and categorised a wide range of elephant calls, providing information about each one to explain if it is a distress call, for example, or a request for play. For our purpose, we selected a "rumble-coo" noise, made by a mother to soothe her calf, as we wanted to ensure that the call had a positive association. Unfortunately, no such database of whale songs yet exists, although it seems likely that these calls also have meanings for other members of the species. We do not know the context of the whale song we used.

Procedure. We discussed the project with the elephant keeper at Noah's Ark Zoo and undertook a survey of the enclosure to find suitable locations for the device. We subsequently mounted two sets of radio buttons inside the elephant enclosure in separate locations while the animals were outside, bolting them to the fence at a height of 2.5m to ensure there was only trunk-tip access (Fig 4).

When the system was initially installed, we observed the elephants for half an hour and left instructions for keepers, showing how to reset the system in case it stopped or looped and how to change batteries.

Findings. When the elephants were released into the enclosure, it was part of a routine feeding and public demonstration in which the keeper talked with visitors. The loudspeaker meant that the keeper's voice was the dominant noise in the space at that time. None of the keepers drew attention to the buttons. At first, the elephants walked right past the device and we realised that the buttons were not at eye level. However, the elephants then spotted the devices from the other side of the shed and came back to investigate. They reached up and touched different buttons (Fig 5) to activate different sounds. Both elephants had an opportunity to play with the buttons. Although the elephants were not kept apart during the period of our prototyping, the fact they both tried to use the system at the same time validated the decision to provide two devices.

We also observed the night footage from that evening, which showed the elephants interacting with the buttons again. We subsequently noted that the capacitance sensing was affected by the heavy metal bars in the enclosure and this meant that the system did not work consistently. Also, the batteries needed to be replaced after 24 hours. However, the system was in place for five days in total and not destroyed during that time.

Prototyping in the Noah's Ark environment resolved some questions relating to experimental procedure, but also raised a number of issues that we had not encountered when working with Valli. The keepers at Noah's Ark and the EWG researchers emphasised that novel enrichment should be introduced to the elephants' enclosure and left for the animals to discover independently, in contrast to the keepers at Skanda Vale, who always personally introduced new systems to Valli. The problem with the latter approach is that it may have set up some expectations – Valli might have behaved differently without keepers present; it is possible that she interacted with the buttons in the hope of receiving a food reward or some positive encouragement, since her relationship with her keepers is very personal.

Janu and Machanga, on the other hand, have a PC (protected contact) relationship with their keepers, suggesting that they are less likely to seek approval. In any case, allowing the elephants to investigate novel features in their environment in their own time allowed us to confirm that they would be curious when they first noticed the devices using visual perception. In contrast to Valli, they were both actively engaged with testing buttons for several minutes (until the system failed to work as expected). Future interventions with any group of elephants will use a similar procedure.

Working with Noah's Ark was also productive in that it brought to our notice some of the challenges inherent in designing an acoustic toy to be used by more than one animal.

Summary

The findings from the prototypes PD2 – PD5 are collected in Table 1, which identifies the positive and negative aspects of each design, informing subsequent iterations.

The reactions of Valli and the two African elephants, Janu and Machanga, indicated a willingness to engage with novel devices, using trunks to investigate. Our wooden framed hidden sensor button design worked for both sets of elephants as a control mechanism for an acoustic system, and it was robust, portable and flexible enough to be used in different situations. We have begun to explore elephant choice with regard to acoustic stimulation, but there are still many interesting questions to investigate, with regard to interface design, underlying system functionality, quality of auditory output and how to enable elephants to show us their preferences.

Discussion

Our fieldwork has enabled us to investigate the design of an interactive toy that offers sensory and cognitive enrichment to captive elephants. We wanted to identify suitable enrichment goals, discover what might motivate an elephant to engage with a high-tech system and explore the physical properties of such a system. By using a *Research through Design* approach, we were able to project our thoughts into reality. Our prototypes were opportunistic, rather than finished products, and they were used to give direction and shape our ideas. Through a process of trial and error, we gained valuable insights into a previously unknown problem space.

Our initial ethnographic study identified some gaps in the experience of captive elephants that could potentially be filled using enrichment and we used these to motivate the concept designs, so that our interventions would have clear enrichment goals. Determining the ways in which an elephant might be able to interact with a device was approached by reviewing their natural behaviour and understanding how they usually interact with the world. However, designing a suitable toy for an elephant required a leap of imagination. Importantly, the interface design and the toy design were interrelated problems, with the evaluation of one feeding back into the design and development of the other. This symbiotic relationship between concept and implementation has meant that our design interventions have constantly evolved during the project.

With subsequent iterations, our designs began to focus on the aesthetic aspects as much as the practicalities – in other words, what an elephant might enjoy interacting with, as well as what was physically possible. We became interested in exploring the sensory qualities of the interface; therefore we developed a prototype button using wood and knitted textiles. Using embedded technology, we tested different kinds of sensors as input devices and various acoustic and haptic signals as outputs, mediated through a micro-controller. We tested different procedures for introducing enrichment devices and we learned about elephant preferences with regard to using controlling mechanisms. Our designs were limited in scope due to a number of species-related constraints and other factors such as time, financial investment and portability. We also experienced some technical challenges that need to be resolved, including issues of quality and consistency of system output.

Participatory design and the shared experience of “making” playful objects for an elephant facilitated good working relationships with the elephant keepers and their animals. Nevertheless, we did not succeed in overcoming one of the fundamental challenges of designing for and with animals – how to find out what the animal really thinks about the experience. Through the designed objects we constructed, we were able to offer Valli a range of options, but it was difficult to gauge her responses because of the conflation of the sound effects with other stimuli, such as the presence of strange human researchers, unusual smells emanating from a novel device and the recurring possibility of food rewards.

It should be pointed out that in its present form, the system is not scalable. In many zoos, elephants are kept in larger groups and it would be impossible to provide individual elephants with their own personal radios, In addition, acoustic output has the property of being pervasive, which means that it would affect all elephants in the vicinity, not only the elephant that used the control. Mancini (2014) highlights this problem in a discussion of smart controls for dog kennels: “For animals housed individually, smart controls seem practical, but for shared housing environments, there are challenges inherent in the design of a system that offers a personalised experience to one animal without imposing their choices on the other animals.” Indeed, we have begun to appreciate the individual characteristics of elephants, which have different preferences and roles within the hierarchy of their herd, suggesting that any solution could not be "one size fits all". McCormack et al (2016) support this notion with regard to enriching apes, who also exhibit individual characteristics. In other words, we should not expect enrichment to necessarily be identical for different elephants.

This preparatory work has succeeded in shaping designs for elephant interfaces and acoustic toys, prior to a more systematic study. In order to obtain quantitative experimental data in the context of an animal testing an interactive device, there needs to be a clear mapping between a single action on the animal's part to an unambiguous signal delivered by the system. To make that conceptual link, the feedback from the system should be immediate and consistent (as it was when we initially offered the elephant radio to Janu and Machanga at Noah's Ark).

Future directions

The provision of interactive acoustic enrichment within elephant enclosures raises many questions. For example, what kinds of output would be most interesting for an elephant? Is it feasible to offer acoustic enrichment to a group of animals? How is it possible to design a system for a herd such that environmental control is afforded equally to all the individuals? Might it be possible to design a toy that enables cooperative rather than competitive play?

Our plans are to collect data from future elephant radio experiments, demonstrating the frequency of selecting specific tracks. New priorities are to design a more stable system and build two separate versions so that the Noah's Ark elephants are not close together when they play, as well as using extra field cameras to capture sounds as well as videos. We then plan to extend the trial to include Valli as a participant, repurposing the buttons to offer her a wider range of acoustic effects. We hope to investigate how to implement a graduated control for analogue input in order to better determine her acoustic preferences, offering her an instrumental toy so she can control pitch and volume.

Our work has also revealed some possible motivations for future prototypes that might work in a shared environment, such as the idea of developing haptic interfaces. Although Valli always explored the physical aspect of our devices, she showed little engagement with any of the sounds we proposed to her. Yet a note-worthy observation from our fieldwork was the level of interest she demonstrated when she encountered the vibro-tactile button pads. Tiny ERM (eccentric rotating mass) motors produce a low volume sound wave when they vibrate, so they can be perceived aurally as well as felt through mechano-receptors under the skin. We speculate that auditory installations might be more interesting for elephants if the technology enabled a range of rotating physical devices that vibrated at different frequencies to produce sounds, rather than using samples of existing human instruments or orchestrations. With a suitable controller, an elephant would be able to alter the rotational speed / frequency at will, thus facilitating the user feedback that is inherent in participatory design.

Sicart (2014) argues that instead of using the term "game designer", which implies the consideration and construction of a system with pre-formulated objectives, we should use the expression "architect of play" to describe someone who deliberately creates a playful environment – a space that encourages the expression of playful behaviour. We can imagine a playful acoustic environment with multiple controls and multiple outputs – a space rather like Huizinga's magic circle (1938) that players (elephants) can choose to enter or leave at will; creating such a place depends on available space, consideration of animal husbandry requirements and the willingness of zoo keepers to allow high tech prototypes to be evaluated with their animals.

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Appendix

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Table 1: Comparison of system designs

CONTROL	SENSOR	OUTPUT	MATERIALS	PROCEDURE	LOCATION	RESULTS - positive	RESULTS - negative
PD2 Pipe button	Capacitance sensing (hidden)	Acoustic (sine wave buzz)	Drain pipe – large corrugated cylindrical shape	Keeper collaboration in build. Introduce with banana	Browse hole	Tactile – lots of trunk exploring, control in protected location.	Association with food in location, banana training required.
PD3 Pedal button	Push-to-make sewing machine pedal	Acoustic (brass sample) + spring mechanism feedback	Wooden frame, repurposed sewing machine pedal	Keeper on balcony directs attention	Balcony rail	Visible, tactile, interest in exploring surface and frame. Good location, firmly bolted at trunk tip height	Valli won't push, no interest in sound (mild aversion).
PD4 Vibro-tactile buttons	PIR (hidden)	Acoustic (samples) + vibromotor	Wooden frame, knitted rope textile surface + haptic feedback	Keeper on balcony directs attention	Balcony rail	Visible, tactile – lots of trunk exploring vibrating interface, easy to use. Good location, firmly bolted at trunk tip height	No apparent interest in sounds.
PD5 Elephant radio	Capacitance sensing (hidden)	Acoustic – whale song, classical music, elephant rumble-coo	Wooden frame, copper plate	Leave in place for elephants to find	High on fence	Visible, tactile, interest shown initially from both elephants. All buttons deployed multiple times during different periods of day/night. Good location, firmly bolted at trunk tip height	Technical issues - capacitance interference and batteries run out

Figure 1: PD2 Valli puts trunk through browsing hole in wall to retrieve banana from the pipe button

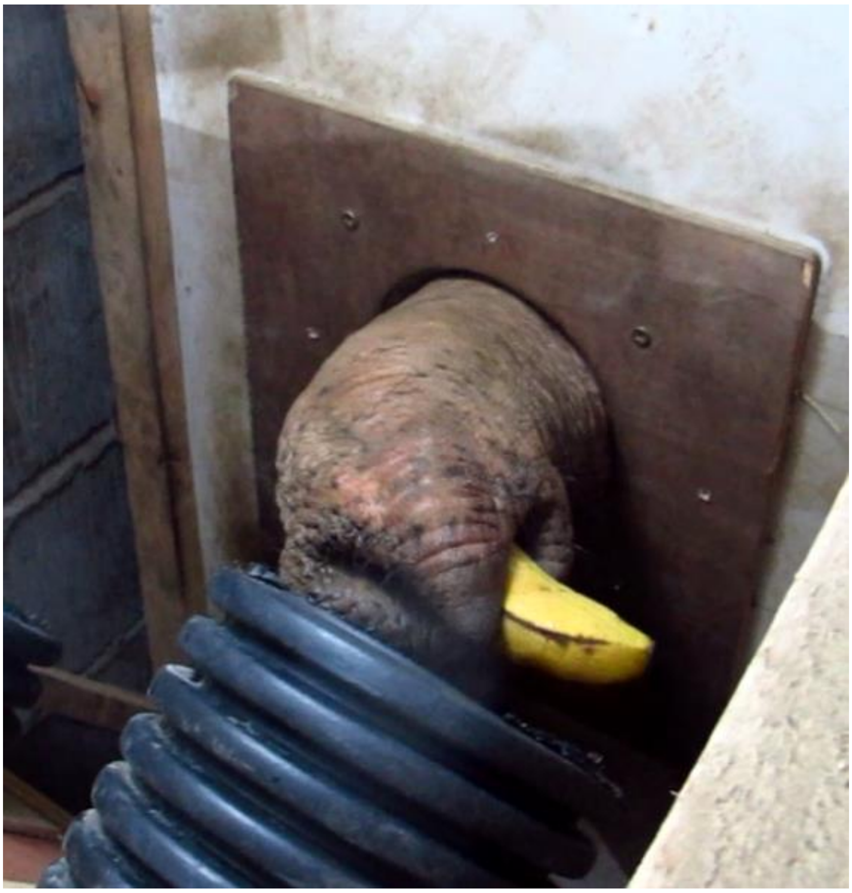

Figure 2: PD3 Sewing pedal button in wooden frame

Figure 3: PD4 Buttons with tactile and haptic feedback

Figure 4: PD5 Fitting radio buttons to the Noah's Ark elephant enclosure

Figure 5: PD5 Elephants at Noah's Ark playing with the radio buttons

Footnotes

[1] The project was a collaboration with Lisa Yon from EWG (Elephant Welfare Group: http://www.biaza.org.uk/animal-management/animal-welfare/elephant-welfare-group/) and Ashley Bryant, one of her students, who helped with the installation.