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Using a trans-disciplinary and trans-institutional team approach and co-design principles to develop an accessible serious gaming system for children with limited hand function

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Abstract

This paper describes the design process that was used to design and develop a stand-alone, home-based, customised and accessible 'serious gaming' (SG) system for children with hand impairments. Hand impairments, typically resulting from conditions such as cerebral palsy (CP), prevent access and the appropriate use of the full range of control options available from commercially available controllers for gaming systems such as the Microsoft Xbox or Sony PlayStation. This lack of engagement and participation in a popular mainstream activity can lead to feelings of frustration and annoyance and a sense of peer exclusion.

The aim of this project was to design and develop an accessible SG system that was engaging, fun to use, and provided a new form of therapy. A trans-disciplinary and trans-institutional team incorporating Biomedical Engineering, Industrial Design, Computer Science, Information Technology, Digital Media, Rehabilitation Medicine and Allied Health provided professional expertise through a co-design process involving children with and without hand impairments.

The design and development process took just over thirty months from problem analysis through to the finished product. Known as the 'OrbIT Gaming System', the final product provides an integrated software and hardware solution for children with hand impairments who want to play computer games. The System includes fifteen two and three dimensional games, an integrated menu system, and full data-logging capability. A structured stage-gate product development process was used to produce a novel 'orb' shaped controller (nicknamed 'Orby') that players use to control their game character.

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The overall design was guided by team members experienced in Universal Design and accessibility, with therapy and rehabilitation requirements integrated into the design decisions. A co-design philosophy was adopted for both the hardware and software aspects of the project, using a combination of focus group sessions and in-home trials. Teenagers with hand impairments described the games as "exciting and mostly creative", while the controller 'Orby' was described as "creative", "natural" and "intuitive". The System is undergoing further design refinement and adaptation in response to market feedback, with future research involving other user-groups where hand function and accessibility are barriers to engagement.

This paper forms part of a doctoral research project from Flinders University, Adelaide, Australia.

Keywords: accessible, Universal Design, medical device design, multi-disciplinary, trans-institutional, serious game, cerebral palsy, participatory research, design approaches, rehabilitation

Introduction

Many children with cerebral palsy (CP) face obstacles when engaging in activities of daily living due to their upper limb impairment (Van Zelst *et al*, 2006). This not only prevents or hinders their independence, but places them at risk for lower participation in social and leisure activities critical in fostering friendships, developing interests, and promoting well-being (Shikako-Thomas *et al*, 2008). As the most common form of childhood physical disability affecting approximately one in every 400 live births per year in both United Kingdom and Australia (Cerebral Palsy; Cerebral Palsy Australia, 'The Facts'), CP is a life-long condition with no current cure.

As a condition, CP can be broadly categorised depending on the parts of the body that are affected, such as *hemiplegia* (one side of the body is affected), *diplegia* (both sides of the body are affected, typically the legs more than the arms) or *quadriplegia* (all four limbs are affected, sometimes including the face and mouth), as shown in Figure 1. The consensus definition for CP now also recognises that the "*motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication, and behaviour, by epilepsy, and by secondary musculoskeletal problems*" (Rosenbaum *et al*, 2007).

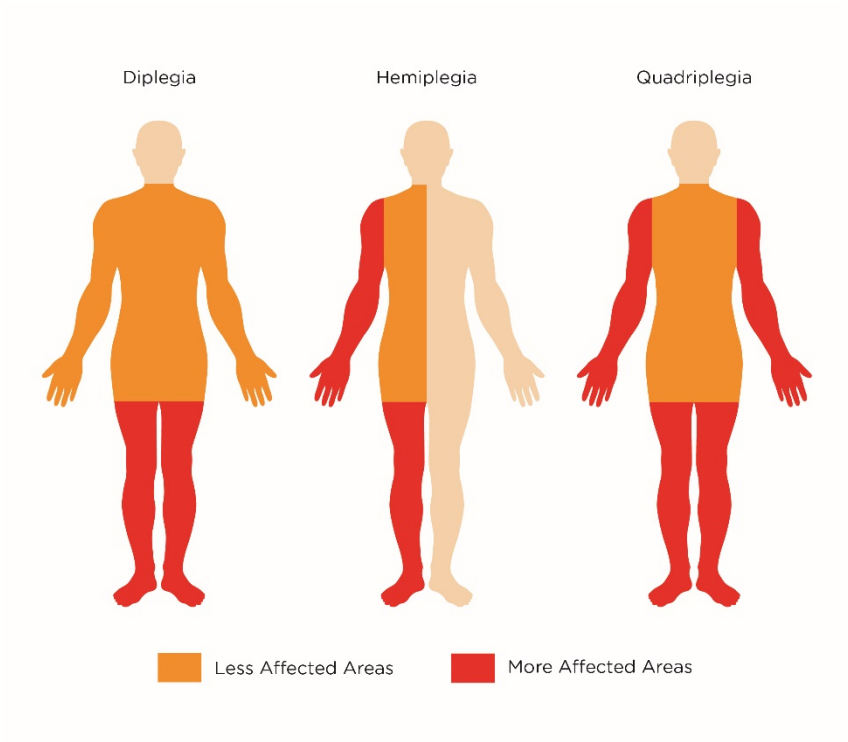

Figure 1: Types of cerebral palsy and how they affect the body

(Image credit: http://www.cpl.org.au/research/cp/types-of-cerebral-palsy)

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A focus of current technology is to engage and motivate children with CP using computer games, harnessing their attractive and mainstream nature to augment or replace conventional therapy. In this context, the games are known as a 'serious game' (SG), the industry term for a computer game where the primary purpose of the game is *not* pure entertainment (e.g. such as games for health, education or management). A recent review of the literature concluded that "*SG shows enough evidence to be included within conventional treatment of CP children since it proved to be efficient for increasing patients' motivation*" (Bonnechere *et al*, 2014). Recent applications of SG for children with CP include to improve postural control (Wade & Porter, 2012) and to improve upper limb motor outcomes (Zoccolillo *et al*, 2015).

The specific aim of this project was to use a transdisciplinary team and a co-design approach to design and develop an accessible SG system as an alternative therapeutic intervention for children with a confirmed diagnosis of CP aged between 5 and 15 years. However, our SG approach was not to target the motor impairment known to affect this population, but rather to address the often neglected issue of tactile sensory impairment common in the hands of children with CP (Hobbs *et al*, 2014). This research aimed to determine if contextually appropriate vibrations that reinforce game play can aid in improving tactile sense in the hands of children with CP with a known sensory loss, with the hypothesis being tested through an in-home randomised controlled trial (RCT).

Problem Statement

To conceptualise, develop, prototype, test, manufacture and trial a custom-made accessible SG system that is capable of engaging children with an impaired sense of touch through interactive and challenging game play, for the purposes of providing tactile sensory training via controlled and integrated afferent feedback to their hands.

The project included the design and integration of all necessary hardware and software components required to log and record activity, and enable an independent home-based RCT to occur to assess the use and performance of each trial participant.

Design Features and Therapy Requirements of the Gaming System

Incorporating the preferred rehabilitation and therapy requirements into the desired system required an understanding of what the participant was required to do, what their limitations might be, and what was possible within the framework of the hardware and software for the project. Given the heterogeneous nature of hand impairment due to CP, team members with specialist clinical experience were able to provide design insight and direction to achieve an outcome that would be suitable for the trial. Accordingly, team members possessing specialist design and technology experience were able to match clinical requirements with appropriate form and function. Given that the intention of the System was to provide vibration stimulation to the hands of children who engaged with it, physical accessibility (being able to independently use the

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system) and cognitive buy-in (to ensure re-playability and longevity) were key design foci. From a participant perspective, children with hand impairment who could not voluntarily open their hand and extend their fingers to expose their palm were excluded from the study, due to an inability to assess and hence quantify their level of tactile hand sensation.

The following features and design rationale were incorporated into the gaming system:

• The System was designed and developed to maximise accessibility, and as such incorporates all 7 Principles of Universal Design (Story, 1998) for greater access.

Design rationale: the controller needed to be simple and intuitive to use and operable by children with an existing hand impairment aged between five and fifteen years old. The final solution that was adopted was inspired by a computer trackball and incorporated a spherical or 'orb' form that measured 200mm in diameter (Figure 2). Movement of the controller caused a unique and intuitive 'rolling dome' motion to play each game. Textured oval pads of a contrasting colour in comparison to the orb surface implied where the user's hands needed to be placed in order to use the controller (Figure 3). Due to the distinctive form of the controller it was nicknamed 'Orby' by the design team, which resonated with children during the trial. 'Orby' was 3D printed for the trial using a *ProJet® HD 3500 plus* printer, which provided additional texture (as can be seen in Figures 2 and 3). The overall system was called the 'OrbIT' Gaming System (combining the 'orb' controller with a laptop IT interface) and was fully automated to start at the press of a button, log all player and game activity, and shutdown easily.

Figure 2: The final 'Orby' controller

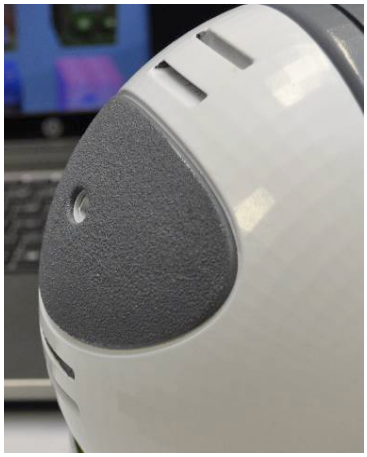

Figure 3: An up-close view of the controller's textured oval pad

• Adopting a control mechanic within each game where only joystick movements (forward, backward, left and right) controlled the main character for in-game movement and control, meaning that no in-game button actions were required.

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Design rationale: a computer game can be inaccessible due the physical hardware (game controller), the software, and/or a combination of both. Most children with hand impairments find commercial gaming controllers difficult or impossible to use because of the size and location of the in-game buttons that require a controlled and coordinated finger/thumb press to progress in the game. Eliminating all in-game buttons and relying on joystick movements only for game control meant participants didn't require fine motor control to succeed in a given game.

• Providing an engaging experience, where each relevant game action (such as progressing to the next level or collecting a bonus within the game) produced a corresponding vibration event that was felt via the controller, thereby reinforcing the action in-game (Geerdink *et al*, 2004). The vibration events were tailored to a particular game event, meaning the participant experienced a range of vibration intensities and durations during play and not a single repetitive burst of vibration each time.

Design rationale: it was important that a range of vibration levels were provided by the system, so each child had the opportunity to experience light (potentially sub-threshold) vibrations as well as stronger vibrations, meaning they were exposed to a range of different afferent stimuli. Tailoring of the specific game event to the vibration level provided via the controller was regulated to avoid a mismatch between what occurred in the game and what they felt in terms of mechanical feedback.

• Promoting bimanual hand use and encouraging children with CP to use and engage their more involved hand and limb.

Design rationale: Most children with CP have a preferred or dominant hand, using this upper limb in isolation for most daily living tasks and leading to a condition known as 'learned non-use' for the more impaired hand and limb as they are neglected. Current therapy interventions aim to encourage or force hand use, either individually (as in constraint induced upper limb therapy) or together with the less or non-involved upper limb (such as with bimanual therapy) in an effort to get the more impaired hand used in general tasks and activities. Through the use of proximity sensors built into the textured oval pads of the controller (which can be seen in Figure 3) and software that monitors the sensor activity, the system effectively 'senses' when a child's hands are in contact with the controller surface and pauses game play if a hand is removed. This introduces an aspect of forced bimanual use, meaning the child is required to place their hand correctly on 'Orby's' surface and pay attention to their more involved hand's position.

Co-Design Process

An important aspect of the design process was the involvement and input of children with and without disabilities. A co-design process was utilised for both aspects of the System – testing the appeal and engagement of the games, and testing and validating that the controller design was accessible, enabling and appropriate.

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Typically developing children of both genders were recruited from local schools to provide feedback and critique on the games at two time points twelve months apart during the software development process (n=49, ages 4-16 years old). Given that most children with a hand impairment cannot access or play a commercial gaming system, an able-bodied cohort was chosen for the evaluation due to their ability to not only rate the games as a standalone item, but because of their ability to contextualise and compare them to familiar commercial games.

Additionally, two teenagers with CP volunteered to evaluate the games in an in-home setting for an extended time period (minimum two weeks) at two different time points, providing critique and feedback that was incorporated into the software development cycle. One of the participants noted that the games she played "…*were exciting and mostly creative*" and "*were quite fun to play*", as reported earlier (Henschke *et al*, 2012).

Development and evaluation of the System controller also adopted a co-design process, where two teenagers with CP engaged with the design team during the prototype building and testing phase, prior to the selection of the controller for the trial (Walker & Hobbs, 2014). During the focus group sessions the 'Orby' controller was described as "*creative*", "*natural*" and "*intuitive*". The design team encouraged users to suggest improvements in order to make the final result more appropriate to meet their needs, recognising that the quality of design increases if the users' interests are considered within the design process.

Figure 4: A functional prototype controller being trialled during one of the focus group sessions with children with hand impairments.

OrbIT Gaming System Summary

The OrbIT Gaming System (Figure 5) features an integrated suite of fifteen custom-made 2D and 3D computer games, with full data logging and monitoring capability, in conjunction with a novel, accessible controller. The games were developed with an emphasis on cognitive engagement to ensuring player buy-in and system longevity to encourage long term and repeat play. Rehabilitation medicine and allied health experience guided the required clinical and rehabilitation goals; computer science, IT, digital media and engineering was used to design,

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develop and deliver a range of accessible games for the system; and engineering and industrial design expertise was used to ideate, conceptualise, design, prototype and manufacture the accessible controller, where the focus was on accessibility, the form of the device, and intuitive use. A Patent Cooperation Treaty (PCT) has been filed for the System, recognising the design novelty and application.

The System was the subject of a 6-week home-based RCT with 18 children with CP, which recently concluded. Preliminary feedback from parents and trial participants post-trial indicates that the System was rated highly, liked and enjoyed. Parents reported instances of improved participation levels and social interactions amongst siblings during the trial. The system has attracted significant interest from allied health therapists, rehabilitation professionals, families of children with CP, and the media, and won a number of industry design and innovation awards.

The overall System is undergoing further design refinement and adaptation based on market feedback to remove current barriers to commercialisation. Future studies include trialling the System with an adult user-group where hand function and accessibility are barriers to engagement.

Figure 5: The trial OrbIT Gaming System

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