Nintendo Wii versus Resistance Training to Improve Upper-Limb Function in Children Ages 7 to 12 with Spastic Hemiplegic Cerebral Palsy: A Home-Based Pilot Study

By

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CERTIFICATE OF APPROVAL

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Abstract

This pilot, home-based study compared a Nintendo Wii intervention to a single-joint upper-limb resistance training of a similar intensity, in n=6 children ages of 7 to 12 with spastic hemiplegic CP with respect to upper limb function, compliance and motivation levels. The main results of this study found that all participants in the Wii intervention group (n=3) experienced positive changes in more than one assessment from pre-test to follow-up, and these changes were on average greater than those experienced by the resistance training group (n=3). Also, the Nintendo Wii group was found to have a higher compliance rate with the study's protocols, and higher parent-reported motivation levels throughout the study, as compared to the resistance-training group. This suggests that Nintendo Wii interventions for the upper limbs may be a more effective home-based rehabilitation strategy than the single-joint upper limb resistance training program used in this study for this population, primarily due to greater participant motivation to comply with Nintendo Wii training. These findings warrant further research with larger sample sizes.

Keywords: spastic hemiplegic cerebral palsy, upper-limb function, Nintendo Wii, resistance training, home study

Caroline Kassee (2015)

STATEMENT OF ORIGINALITY

I, Caroline Kassee, hereby declare that this thesis is, to the best of my knowledge, original, except as acknowledged in the text. I further declare that the material contained in this thesis has not been previously submitted, either in whole or in part, for a degree at this, or any other university.

Caroline Kassee (2015)

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LIST OF ABBREVIATIONS USED

AVG	Active Video Games
boNT-A	Botulinum neurotoxin-A
CP	Cerebral Palsy
GMFCS	Gross Motor Function Classification System
HIE	Hypoxic Ischemic Encephalopathy
MA2	Melbourne Assessment of Unilateral Upper Limb Function-2
MACS	Manual Ability Classification System
PVL	Periventricular Leukomalacia
ROM	Range of Motion
SD	Standard Deviation
SDT	Self-Determination Theory
VR	Virtual Reality

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SECTION 1: INTRODUCTION

Introduction to Thesis

Overview of Cerebral Palsy

Cerebral palsy (CP) refers to a range of childhood syndromes of posture and motor impairment, that arise as a result of a static (non-progressive) lesion in the developing brain (Hoon & Tolley, 2013; Koman, Smith, & Shilt, 2004; Rosenbaum, 2003). CP is the most common cause of physical disability in children, with a prevalence of about 2 to 2.5 per 1000 live births in Western countries (Hirtz et al., 2007; Rosenbaum, 2003). Causes and associated risk factors for the development of CP include prematurity, with its associated complications, such as intraventricular haemorrhage (IVH), periventricular leukomalacia (PVL); along with complications in term infants, such as hypoxic ischemic encephalopathy (HIE), perinatal stroke, maternal and fetal infections, genetic defects, and early childhood brain trauma (Miller, 2005; Miller & Clark, 1998; Rosenbaum & Rosenbloom, 2012). CP is also associated with a variety of other motor and medical conditions, including the persistence of primitive reflexes, intellectual disabilities, epilepsy, speech language and communication delays, visual and sensory impairments, feeding difficulties and even the co-occurrence of other disabilities such as autism spectrum disorder (ASD), or attention-deficit hyperactivity disorder (ADHD) (Hoon & Tolley, 2013; Miller, 2005; Rosenbaum & Rosenbloom, 2012). There are several subtypes of CP, the most common being spastic CP, which occurs in approximately 77.4% of all children with CP (Christensen et al., 2014; Koman, Smith, & Shilt, 2004). Spastic CP can be further sub-divided into different phenotypes, according to the distribution of the spasticity, and the limbs most affected (Rosenbaum & Rosenbloom, 2012). One of these phenotypes is spastic hemiplegic CP. Spastic hemiplegic CP involves spasticity on one side of the body, and occurs in approximately 23% of children with spastic CP (Hagberg, Hagberg, Beckung, & Uvebrant, 2001; Koman, Smith, & Shilt, 2004).

Spastic Hemiplegic Cerebral Palsy

Spastic hemiplegic CP involves unilateral static lesions in the regions of the brain, such as the primary motor cortex associated with upper limb movement (Hoon & Tolley, 2013). Clinically, this manifests as spasticity generally in one upper limb, that can include elbow flexion with forearm pronation, wrist and finger flexion, and thumb adduction into the palms, under the flexed fingers, depending on the level of severity (Arner, Eliasson, Nicklasson, Sommerstein, & Hägglund, 2008; Miller, 2005). Some individuals also experience spasticity in the muscles of the ipsilateral shoulders and hip as well (Brown, Rensburg, Lakie, & Wrigh, 1987; Uvebrant, 1988). This leads to a variety of motor impairments, including range of motion restrictions (Koman et al., 2008; Uvebrant, 1988), fine motor coordination deficits (Arner et al., 2008), disrupted sensory mechanisms in stereognosis and propriopception (Cooper, Majnemer, Rosenblatt, & Birnbaum, 1995), and muscle weakness (Damiano, Dodd, & Taylor, 2002). These motor impairments have a significant impact on the upper limb function of children with spastic hemiplegic CP (Arner et al., 2008; Braendvik, Elvrum, Vereijken, & Roeleveld, 2010; Klingels et al., 2012), and can severely compromise a child's ability to perform upper limb functions such as reaching, grasping, and manipulating objects. It can also limit their ability to perform many of the activities of daily living, such as eating, dressing and bathing (Nieuwenhuijsen, Donkervoort, Nieuwstraten, Stam, & Roebroeck, 2009).

Therefore, it is important for children with spastic hemiplegic CP to acquire upper limb functional abilities, so as to enable them to participate fully in daily life.

Management of Upper Limb Spastic Hemiplegic Cerebral Palsy

The range of management options available for upper limb impairments in spastic CP includes medical, surgical and rehabilitative strategies (Papavasiliou, 2009). With respect to rehabilitative interventions, options include traditional physiotherapy and occupational therapy along with approaches such as constraint-induced movement therapy, hand-arm bimanual intensice training, aquatherapy, and resistance training (Hoon & Tolley, 2013). However, systematic reviews have proven largely inconclusive as to which rehabilitative approaches are superior for children CP who have upper limb impairments, and under what conditions, intensities and durations they are most effective (Anttila, Autti-Rämö, Suoranta, Mäkelä, & Malmivaara, 2008; Boyd, Morris, & Graham, 2001; Sakzewski, Ziviani, & Boyd, 2009; Sakzewski, Ziviani, & Boyd, 2013).

Furthermore, the majority of studies in the published literature involve rehabilitative interventions that take place in clinical settings, rather than the home environment, which can pose some challenges for the integration of these programs into the daily lives of children with CP and their families. Although clinical programs can be incorporated into the lifestyles of children with CP, it is probable that home-based programs might achieve lifestyle integration with even greater ease, since they provide many opportunities for convenient, repeated practice, in a non-stressful environment. In addition, home –based therapy programs can allow families to bypass issues associated with lengthy waitlists and limited treatment centres (King, Law, King, & Rosenbaum, 1998), which helps children with CP to receive additional therapy, in combination with clinical treatments and rehabilitation. Therefore, in order to expand the range of available treatment options for children with CP, it is necessary to validate new approaches to rehabilitation, that can be used in the home environment, as an adjunct to conventional therapy based in treatment centres.

Motivation and Rehabilitation

In order for home therapies to be effective in this population, they need to be motivating for children, and easy to implement for families. Studies show that children with CP have significantly lower levels of motivation related to the mastery of tasks, when compared to children of typical development (Jennings, Connors, & Stegman, 1988; Majnemer, Shevell, Law, Poulin, & Rosenbaum, 2010; Tatla et al., 2013). Researchers speculate that children with CP experience barriers in free environmental exploration, which may be made worse by overly protective parents and caregivers, leading these children to avoid challenge and prefer les complex tasks, when compared to children of typical development (Jennings, Connors, & Stegman, 1988). Furthermore Majnemer et al. (2010) found that higher motivation levels in children with CP were associated with lower levels of disability, in terms of functional and activity limitations, and cognitive abilities.

Low levels of motivation can adversely affect a child's functional abilities, and decrease the effectiveness of therapeutic interventions (Maclean & Pound, 2000). Motivation is an essential component of motor learning, which refers to a permanent change in movement behaviour due to practice (Magill, 2007). In a study by Bartlett and Palisano (2002) that examined the factors that influence the acquisition of motor abilities in children, as perceived by physiotherapists, motivation was rated to be the single most influential personal characteristic that determines motor and functional outcomes in physiotherapy. Moreover, motivation is also important to parents, when evaluating functional therapy programs for their children (Law et al., 1998). As treatment non-compliance is one of the greatest barriers in medicine and rehabilitation, to patient recovery and well-being (DiMatteo & DiNicola, 1982), it is hoped that greater levels of motivation in patients will lead to greater levels of compliance with prescribed treatments, which will in turn lead to greater functional outcomes (Maclean & Pound, 2000).

Nintendo Wii Training in Pediatric Cerebral Palsy

One novel rehabilitation strategy that has the potential to address the need for motivating therapeutic interventions, which is also easy to implement, and can improve motor and functional outcomes, is Nintendo Wii training. The Nintendo Wii is a subset of virtual reality (VR) technologies known as active video games (AVGS), which are games that require physical activity beyond that of conventional hand-held controller games (Holden, 2005; Riener & Harders, 2012). The Nintendo Wii has been used in therapy programs for a wide range of clinical populations (Brichetto, Spallarossa, de Carvalho, & Battaglia, 2013; Cho, Lee, & Song, 2012; DeMatteo, Greenspoon, Levac, Harper, & Rubinoff, 2014; Esculier, Vaudrin, Beriault, Gagnon, & Tremblay, 2012; Williams, Doherty, Bender, Mattox, & Tibbs, 2011; Yohannan et al., 2012), with generally positive clinical and functional outcomes. With respect to pediatric CP, the Wii is a relatively novel rehabilitative strategy (Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008), but it has been studied in a variety of motor function domains, such as exercise intensity, balance, postural control, and muscle activation patterns (Ballaz, Robert, Lemay, &

Prince, 2011; Gordon, Roopchand-Martin, & Gregg, 2012; Jelsma, Pronk, Ferguson, & Jelsma-Smit, 2013; Robert, Ballaz, Hart, & Lemay, 2013; Tarakci, Ozdincler, Tarakci, Tutuncuoglu, & Ozmen, 2013). However, only three studies to date have focused on the effects of Wii training on upper limb quality of movement and function in children with CP (Chiu, Ada, & Lee, 2014; Howcroft et al., 2012; Winkels, Kottink, Temmink, Nijlant, & Buurke, 2013).

Despite the lack of strong evidence for upper limb interventions using the Nintendo Wii for this population, researchers and clinicians believe that the Wii does have the ability to target specific domains of motor function in the upper limbs, such as unimanual and bimanual coordination, muscular endurance, movement fluency, dexterity, and even general fitness, depending on the duration and intensity of the interventions, and the games used (Deutsch et al., 2011)Furthermore, the ability of the Nintendo Wii to provide motivating training and solicit high compliance rates is supported by empirical evidence (Chiu, Ada, & Lee, 2014; Gordon, Roopchand-Martin, & Gregg, 2012; Howcroft et al., 2012; Jelsma, Pronk, Ferguson, & Jelsma-Smit, 2013), along with theories of motivation such as self-determination theory (SDT), which has been applied to VR game play by social scientists in the last decade (Przybylski, Rigby, & Ryan, 2010; Ryan, Rigby, & Przybylski, 2006).

Resistance Training in Pediatric Cerebral Palsy

By contrast to Nintendo Wii training, which is novel, resistance training is a more conventional approach to the rehabilitation of children with spastic hemiplegic CP. Resistance training, which is also referred to as strength training in the literature pertaining to children with CP (Bernhardt et al., 2001), is a systematic program of exercises designed to cause the muscles to contract against external resistance, in order to increase the strength and endurance of targeted muscle groups (Fleck & Kraemer, 2014). Resistance training is a well-studied therapeutic approach for children and adolescents with CP (Damiano, 2009), and has been the subject of several systematic reviews(Darrah, Fan, Chen, Nunweiler, & Watkins, 1997; Dodd, Taylor, & Damiano, 2002; Haney, 1998; Mockford & Caulton, 2008; Scianni, Butler, Ada, & Teixeira-Salmela, 2009). While the majority of these systematic reviews do provide preliminary support for the use of resistance training for pediatric CP, most of the studies were primarily concerned with the lower limbs. For resistance training in the upper limbs for pediatric CP, there are six studies in the published literature that focus exclusively on the upper limbs (Elvrum et al., 2012; Kim et al., 2012; Lee, You, Lee, Oh, & Cha, 2009; Lee et al., 2013; O'Connell & Barnhart, 1995; Vaz et al., 2008), with generally positive outcomes. With respect to motivation, several studies have found that motivation to complete an exercise program is an important element of compliance in home based resistance training interventions (Chen, Neufeld, Feely, & Skinner, 1999; Taylor, Dodd, McBurney, & Graham, 2004). Although no identified studies have measured the motivation levels of children with spastic hemiplegic CP when completing home-based resistance training programs, it is likely that they experience the same level of motivation as other clinical populations do in conventional exercise programs and therapy (Sluijs, Kok, & van der Zee, 1993)

Summary

Children with spastic hemiplegic CP involving the upper limbs experience challenges in daily life, due to limitations that compromise their ability to perform upper limb functions. For this reason, it is necessary to explore novel therapeutic techniques such as Nintendo Wii training, which are motivating for children, and can be easily integrated into the lifestyles of these children, in order to determine whether it is able to promote upper limb functional improvements. Also, resistance training is a well-studied therapeutic approach for this population, which allows it to serve as a comparison to a more novel rehabilitation strategy such as the Wii. Consequently, there is a need in the published literature for more studies concerning upper limb interventions in children with hemiplegic CP, for both Nintendo Wii training and resistance training.

This study involved a Nintendo Wii intervention experimental group, with a resistance training control group, for children ages 7 to 12 with spastic hemiplegic CP. It examined these two interventions in the home environment, in terms of upper limb quality of movement, performance of daily activities, and factors relating to motivation and overall compliance with the study's protocols.

Proposed Research Framework: Dynamic Systems Theory

Dynamic Systems Theory and Therapeutic Interventions

Dynamic systems theory was first put forward in the field of developmental psychology by Esther Thelen in the 1980s, in order to describe how movement arises in children as they develop. Dynamic systems postulates that movement in complex organisms such as humans is produced from the interaction of multiple subsystems within the person, the task and the environment (Thelen, 1989). These sub-systems, which can be either internal or external, spontaneously self-organize to produce the most energy-efficient movement for a specific task, which is known as the attractor state for a particular movement (Kamm, Thelen, & Jensen, 1990). This process of self-organization into new attractor states is induced by shifts in control parameters, which are factors that either inhibit, or promote the development of new motor behaviours. A slight change in one of the control parameters that constitute a sub-system can cause the whole system to shift, which can produce new motor behaviours (Thelen, 1989). These control parameters can be highly specific, such as the central nervous system's reorganization or a change in a particular muscle's strength, or non-specific, such as emotional or psychological states (Kamm, Thelen, & Jensen, 1990).

Control Parameters in Nintendo Wii and Resistance Training

This study aims to manipulate control parameters that produce motor behaviours in the upper limbs, in order to shift atypical motor behaviours that may have developed in these children to more efficient attractor states, by promoting functional outcomes. Children with spastic hemiplegic CP tend to produce abnormal movements in their affected arms, due to spasticity and muscle weakness (Hoon & Tolley, 2013). This causes physiological strain in the upper extremities, which leads to the re-organization of various sub-systems, and promotes atypical upper limb movements, in order to compensate for the impairments. Ultimately, this leads to the development of an attractor state, or stable, preferred movement patterns, which are not energy-efficient or functional, given human anatomical proportions. One example of this is a child with a spastic impairment characterized by wrist and finger flexion in one limb. This child may be able to swing a baseball bat by rotating the shoulders and the torso, but might be unable to do the same swing if the affected hand was used in a more functional position (i.e. with the wrist extended and finger joints flexed), due to weakness, fatique, or a lack of coordination. Therefore, improving motor performance control parameters through therapeutic interventions could improve upper limb functionality in a child with spastic hemiplegia.

Control parameters of upper limb motor performance targeted by the Nintendo Wii include bimanual coordination, range of motion and muscular strength and endurance (Deutsch et al., 2011). In Wii Sports Resort, the game used in this study, this is done through a variety of games that simulate the motion used in sports such as tennis, swordplay and archery. In addition, because activation of the Wii Remote requires pressing a series of buttons, and the Remote also vibrates in response to successful game play, it is possible that fine motor coordination skills and sensory mechanisms such as stereognosis (haptic perception) are also targeted. Furthermore, as players progress through levels that increase in difficulty, greater accuracy and fluency of movement is required to score points, which forces participants to become more skilled. With respect to resistance training, control parameters of muscular strength and endurance are targeted (Fleck & Kraemer, 2014), and possibly also bimanual coordination, as the majority of exercises in this intervention involve simultaneous use of both hands

Finally, another important control parameter that may influence functional outcomes in this study is motivation. Motivating interventions are more likely to promote motor learning and neuroplasticity, as participants are more willing to undergo training (Bartlett & Palisano, 2002; Law et al., 1998). The Nintendo Wii is a video game console, designed for children, with the primary aim of providing recreation. Children can therefore be motivated by the game itself, and will likely play for fun and to advance through different levels, without the need for parents/guardians to force compliance with the intervention. By contrast, resistance training is designed to target specific functional deficits, and although it is possible that some children may be goal-oriented, and motivated by the desire to improve upper limb function, it is likely that they may not see the importance of such therapy and /or find it boring, and therefore need more parent/guardian direction in completing the intervention. In essence, motivating interventions can lead to more compliance with the programs aims. This can lead to more opportunities for motor learning, which ultimately leads to larger neuroplastic effects, which have the potential to permanently change the attractor states that are responsible for upper limb movement.

Summary

Dynamic systems theory postulates that movement is produced from the interaction of multiple subsystems within the person, the task and the environment, which self organize to produce energy efficient states of movement, known as attractor states. A slight change in one the control parameters that organize a subsystem cause the whole movement behaviour to shift, producing a new attractor state. All therapeutic interventions aim to manipulate control parameters, in order to produce more efficient attractor states for movement in a specific clinical population, such as children with spastic hemiplegic CP. In Nintendo Wii training, using the game of Wii Sports Resort, control parameter manipulation is done through a variety of games that simulate the motion used in sports such as tennis, swordplay and archery. Control parameters targeted include bimanual coordination, range of motion, and muscular strength and endurance. Also, fine motor coordination, sensory deficit are likely targeted through pressing buttons and vibrational feedback from the Wii Remote. With respect to resistance training, muscular strength and endurance are also targeted, along with bimanual coordination, as many of exercises in this study require the use of both hands in order to complete. Finally motivation is a control parameter that is also targeted in this study, with the hopes of greater motivation producing greater motor learning in this population.

Significance of the Research

This study contributes to the published literature in several ways. Firstly, it adds to research concerning Nintendo Wii interventions for the upper limbs in children with spastic hemiplegic CP, which represents a relatively novel approach to upper limb rehabilitation for this population (Deutsch et al., 2008). With respect to Wii training for the upper limbs, there are only 3 studies in the published literature that included an examination of upper limb movement (Chiu, Ada, & Lee, 2014; Howcroft et al., 2012; Winkels et al., 2013). It will also add to the published literature concerning resistance training for the upper limbs in this population, as there are only six studies examining this (Elvrum et al., 2012; Kim et al., 2012; Lee et al., 2009; Lee et al., 2013; O'Connell & Barnhart, 1995; Vaz et al., 2008). Furthermore, this study adds to the published literature concerning home studies for children with CP (Novak & Cusick, 2006; Piggot, Paterson, & Hocking, 2002), and can contribute to validating the Wii for use in the home as an adjunct to conventional therapy programs.

Justification of Methodology

This study examined the effectiveness of a Nintendo Wii intervention, as compared to resistance training, in improving upper limb functionality in children ages 7 to 12 with spastic hemiplegic CP, in the home environment. ‘ Upper –limb functionality’ in this study is defined as clinically relevant changes in upper limb movement quality that translate into improvements in functional tasks such as reaching, grasping or manipulating objects. This is in contrast to more 'biomechanical' measures of upper limb function, such as changes in the degree of range of motion of specific joints, or timed improvements in limb acceleration and decelerations, etc.

The Nintendo Wii intervention group was considered the experimental group, due to its relatively novel status as a rehabilitative strategy in the published literature for this population (Deutsch et al., 2008). The resistance training intervention group was considered to be the control, as in a small community-based study like this one, it was not considered ethical to deprive the control group of an intervention. Nevertheless, resistance training is a well-established therapeutic approach for this population (Damiano, 2009), which targets muscle weakness, an important element of motor dysfunction in children with spastic hemiplegic CP (Damiano, Dodd, & Taylor, 2002).

The age range of 7 to 12 years was chosen, as it was considered to be the optimal age for the Nintendo Wii, since games for this video game console are designed for children that are old enough to follow basic instructions, but is likely not challenging enough for teenagers, and especially those that are higher functioning. Also, this age range was considered to be appropriate for the resistance training group as well, since resistance training is safest for children that are old enough to follow basic instructions, as not to injure themselves (Bernhardt et al., 2001).

The duration and intensity of these interventions were chosen based on other studies with a similar design. For VR home studies in the published literature for this population, the duration and intensity of the interventions varied from 4 to 6 weeks, at 20 to 40 minutes a day (Chiu, Ada, & Lee, 2014; Sandlund, Dock, Häger, & Waterworth, 2012). In this study, the Wii intervention, was set for 6 weeks, 5 days a week, for 40 minutes a day. This was considered to be intense enough to measure improvements, but flexible enough to accommodate the schedules of busy families. For the resistance intervention, in this study 6 weeks, and 5 days a week was also set as the duration. However, rather than set a time frame for exercise completion each day, participants were told to do 6 exercises, 12 times each as one set, for two sets a day (i.e. a total of each of the 6 exercises performed 24 times each day). Prescribing resistance training programs in terms of sets is recommended by the American College of Sports Medicine (American College of Sports Medicine, 2009), where 1 to 2 sets, at 10 to 12 repetitions per exercise, is set as a minimum intensity(Myers, Herbert, & Humphrey, 2002). Furthermore, single-joint resistance exercises of a mild intensity were specifically chosen in this intervention so as to not overload children with CP with a complicated, and intense training program, especially since participants and their parents were completing this program at home on their own, without the supervision of a therapist. Also, an intense, demanding resistance-training intervention would have made a comparison between the compliance rates of the two interventions more difficult. As the Wii training program was designed to only take approximately 40 minutes a day, the resistance training program was designed with a similar intensity and duration in mind.

Finally, both interventions in this study took place in the home environment, as home program have the potential to be integrated into the daily lives of children with CP, and are more reflective of the real-world conditions in which children with CP and their families live on a daily basis(Novak & Cusick, 2006; Piggot, Paterson, & Hocking, 2002). Furthermore, home programs can be more convenient for families, and allow parents and guardians the opportunity to direct the therapy that their children receive, which can produce greater outcomes for these children (King, Law, King, & Rosenbaum, 1998). Also, there is a need to validate cost-effective, and relatively simple therapeutic interventions for use in the home, as an adjunct to conventional therapy.

Purpose and Overall Contribution

The overall purpose of this study is to determine whether there are benefits to children with spastic hemiplegic CP, in terms of improvements in upper limb functionality, after a novel rehabilitative approach such as a Nintendo Wii intervention, as compared to a more well-studied rehabilitative approach such as resistance training (Damiano, 2009). Several studies have established positive outcomes for upper limb Wii training in this population (Chiu, Ada, & Lee, 2014; Howcroft et al., 2012; Winkels et al., 2013), but more research is needed to clarify this relationship. A secondary objective of this study is to add to the published literature concerning resistance training for the upper limbs in this population, as there are few studies that examine this in detail (Elvrum et al., 2012; Lee et al., 2009; Lee et al., 2013; O'Connell & Barnhart, 1995; Vaz et al., 2008).

Objectives and Hypotheses

Objectives of the Research

1. To determine whether there are benefits to children between the ages of 7 to 12 with spastic hemiplegic CP, in terms of improvements in upper limb quality of movement (i.e. range of motion, accuracy, fluency and dexterity), grip strength, and the performance of daily activities requiring the use of the upper limbs, after a Nintendo Wii U intervention using Wii Sports Resorts, to improve upper limb function

2. To determine to determine the comparative effectiveness of a Nintendo Wii intervention, when compared to a single-joint resistance training program for the upper limbs, with respect to these outcomes.
3. To explore differences in compliance rates, and parent and participant perceptions of enjoyment, exertion and overall feasibility of a Nintendo Wii and resistance training intervention for this population

Specific Hypotheses of the Research

1. There will be benefits to children between the ages of 7 to 12 with spastic hemiplegic CP, in terms of improvements in upper limb quality of movement (i.e. range of motion, accuracy, fluency and dexterity), grip strength, and the performance of daily activities requiring the use of the upper limbs, after a Nintendo Wii U intervention using Wii Sports Resorts, to improve upper limb function
2. Participants in the Nintendo Wii U group will have greater positive outcomes with respect these outcome measures, as compared to the resistance training group
3. The Nintendo Wii intervention group will have higher compliance, enjoyment levels, and overall feasibility ratings, as compared to the resistance training group, but that both intervention groups will experience similar levels of exertion and use of their affected (spastic) upper limb.

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SECTION 2: LITERATURE REVIEW

Cerebral Palsy

Overview

Cerebral Palsy (CP) refers to a range of non-progressive, childhood syndromes of motor development, that result from an insult or lesion to the developing central nervous system (Hoon & Tolley, 2013). CP is primarily a disorder of movement, characterized by abnormal posture, and/or walking, muscle spasticity, weakness, limited or involuntary motion, and exaggerated reflexes (Koman, Smith, & Shilt, 2004; Rosenbaum, 2003; Rosenbaum & Rosenbloom, 2012). CP is the most common cause of physical disability in children, with a prevalence rate of about 2 to 2.5 per 1000 live births in Western countries (Hirtz et al., 2007; Koman, Smith, & Shilt, 2004; Rosenbaum, 2003). There are four main subtypes of CP: spastic, dyskinetic, ataxic, and mixed (Hoon & Tolley, 2013). *Spastic CP* refers to an abnormal increase in muscle tone, resulting from an increased, velocity-dependent resistance to muscle stretch and lengthening (termed *spasticity*). *Dyskinetic CP* describes abnormalities in muscle tone that involve the whole body, and is often associated with movement anomalies such as chorea, which are rapid and jerky movements; athetosis, which are slow writing movements; and dystonia, which are twisted movements that distort posture (Hoon & Tolley, 2013; Miller & Clark, 1998). *Ataxic CP* is characterized by impairments in voluntary movements, balance and posture, and involves jerky uncoordinated motion, along with abnormalities in muscle tone (Hoon & Tolley, 2013; Miller & Clark, 1998; Rosenbaum & Rosenbloom, 2012). Finally *mixed CP,* refers to the presence of more than one motor pattern, and does not easily fit into the other 3 categories (Hoon & Tolley, 2013; Miller & Clark, 1998).

Causes of Cerebral Palsy

A diagnosis of CP simply means that a child has motor impairments that arise from a static (non-progressive) brain lesion (Miller, 2005). Therefore, the etiology of CP is necessarily multi-factorial, since there are several different causal pathways from which this lesion can arise (Miller, 2005; Miller & Clark, 1998). These causal pathways all disrupt the development of the neuronal networks associated with movement (Meberg & Broch, 2004; Nelson & Grether, 1999).

One of the most significant risk factors in the development of CP is prematurity (Rais-Bahrami & Short, 2013). Premature (or pre-term) infants, especially those born prior to 28 weeks of gestation, or with a birth weight of less than 1, 500 grams, account for almost half of all individuals with CP (Hagberg, Hagberg, Beckung, & Uvebrant, 2001; Marlow, Wolke, Bracewell, & Samara, 2005). This is due to the vulnerability of the pre-term brain to injury, especially in specific areas, or during specific periods of development (Johnston, 1998). Furthermore, other body structures, such as the respiratory and cardiovascular systems, are also underdeveloped in pre-term infants, which can adversely affect brain and motor development (Rais-Bahrami & Short, 2013). One type of brain injury in pre-term infants, that can cause CP is intraventricular haemorrhage (IVH), which is defined as bleeding into the ventricular space within the brain hemispheres (Volpe, 1989, 2008). IVH is strongly correlated with the development of CP (Sarkar, Bhagat, Dechert, Schumacher, & Donn, 2009). Furthermore, severe IVH can develop into a condition known as periventricular leukomalacia (PVL), which refers to necrosis and the subsequent development of focal or diffuse cystic lesion in the periventricular white matter of the brain, closest to the ventricles (Rezaie & Dean, 2002).

PVL occurs in approximately 4 to 15 % of premature infants (Perlman, Risser, & Broyles, 1996), and is also strongly correlated with the development of CP(de Vries, Eken, Groenendaal, van Haastert, & Meiners, 1993; Sarkar et al., 2009). In addition, PVL has several causes outside of IVH, including cardiac or pulmonary disease, a drastic fall in systemic blood pressure, or hypoxic events (Perlman, Risser, & Broyles, 1996). Hypoxic events (events that deprive the brain of oxygen) are particularly common in premature infants(Rais-Bahrami & Short, 2013). These events can result in severe oxygen desaturation, and can lead to bleeding in the periventricular space, neurological impairments (Janvier et al., 2004), or to a condition known as hypoxic ischemic encephalopathy (HIE), which refers to brain injury caused by inadequate oxygen and/or inadequate blood circulation to the brain (Gaitatzes, Chang, & Baumgart, 2013). Furthermore, maternal health issues such hypertension, diabetes, or preeclampsia can also cause hypoxic events, and lead to HIE (Rosenbaum & Rosenbloom, 2012). In addition, severe HIE has also been known to cause PVL in some infants (Rezaie & Dean, 2002). Overall, the risk of brain injury and associated complications generally increases with the degree of prematurity (Rais-Bahrami & Short, 2013).

CP can also develop in full-term infants during the perinatal and post-natal periods. For instance, HIE can result from a short period of acute oxygen deprivation during delivery(Rosenbaum & Rosenbloom, 2012), which occurs in approximately 10-20% of children with CP (Nelson & Grether, 1999; Speer & Hankins, 2003). HIE –induced brain injuries in full-term infants typically manifest as border zone infarcts (Rutherford, 2002), which are small, localized lesions of dead tissue, between the junctions of major arteries, lesions in the basal ganglia and/or thalamus(Krägeloh-Mann et al., 2002), subcortical leukomalacia, which refer to cystic lesions underneath the cortex(Takashima, Armstrong, & Becker, 1978), and multicystic encephalomalacia, which refers to the degeneration of brain tissue, and the formation of large cavities in the cortex and white matter (Frigieri et al., 1996). Other causal pathways for the development of CP in full-term infants include perinatal stroke, which occurs when a major cerebral blood vessel is obstructed (Lynch, Hirtz, DeVeber, & Nelson, 2002); kernicterus, which occurs when too much bilirubin (produced as red blood cells breakdown) in the blood leads to brain dysfunction (Ikonen, Janas, Koivikko, Laippala, & Kuusinen, 1992);and infections in the fetus or the mother, such as bacterial meningitis (Galiza & Heath, 2009; Hermansen & Hermansen, 2006) or chorioamnionitis, which is an inflammation of the fetal membranes due to bacterial infection (Leviton & Dammann, 2004; Shatrov et al., 2010; Wu, 2002; Yoon, Park, & Chaiworapongsa, 2003).

There is also some evidence to suggest that genetic defects can lead to the development of CP (Hughes & Newton, 1992) – one study has even identified a gene on chromosome 2q24-25, that is implicated in the development of CP (McHale et al., 1999). However, other genetic defects that manifest as congenital brain anomalies can also lead to the development of CP (Croen, Grether, Curry, & Nelson, 2001; Rosenbaum & Rosenbloom, 2012). Congenital brain anomalies result from an interruption in the normal development of the nervous system, and lead to brain malformations (Pharoah, 2007). Some congenital anomalies that lead to CP include schizencephaly (clefts in the brain), lissencephaly (cerebral cortex that lacks cerebral gyri), cortical dysplasia (neurons that fail to migrate to their proper location), agenesis of the corpus callosum (the failure of the fibers of the corpus callosum to connect the cerebral hemispheres), and the Dandy-

Walker malformation (characterized by the underdevelopment, or absence of the cerebellar vermis)(Burton, 2008a, 2008b; Croen, Grether, Curry, & Nelson, 2001; Krägeloh-Mann & Cans, 2009; Miller, 2005). Congenital brain anomalies can also be caused by environmental stressors as well(Pharoah, 2007).

Finally other risk factors for the development of CP include multiple gestations, which predispose infants to premature birth and low birth weigh (Pharoah & Cooke, 1996), trauma that leads to brain injury such as blows to the head, or near-drowning experiences (Miller, 2005; Miller & Clark, 1998), and exposure to teratogens that disrupt normal brain development (Hoon & Tolley, 2013).

CP is a heterogeneous disorder that has multiple causal pathways. However, since the underlying brain lesion that causes CP is static, management options for CP rarely need to take into account the etiology of the disorder to provide effective treatment. Still though, knowing the etiology of CP is often important to parents and families, as well as being medically relevant.

Associated Impairments in Cerebral Palsy

CP is also associated with a variety of other impairments in sensation, communication and behaviour, along with other medical and motor conditions (Koman, Smith, & Shilt, 2004; Rosenbaum, 2003; Rosenbaum & Rosenbloom, 2012). One of these associated impairments is the persistence of primitive reflexes, which are exhibited by infants, but not by neurotypical adults (Zafeiriou, 2004). For individuals with CP, primitive reflexes persist as involuntary movements, which can lead to delayed or absent postural reactions that interfere with their motor abilities (Hoon & Tolley, 2013; Payne & Isaacs, 2012). Intellectual disabilities are also closely associated with CP, where approximately 40 to 50 % of children with CP also have an intellectual disability (Centers for Disease Control and Prevention [CDC], 2015), and many with typical intellectual abilities have a learning disability (Centers for Disease Control and Prevention [CDC], 2015; Nordmark, Hägglund, & Lagergren, 2001). Epilepsy occurs in approximately 35 to 41% of children with CP (Centers for Disease Control and Prevention [CDC], 2015; Christensen et al., 2014; Nordmark, Hägglund, & Lagergren, 2001), where partial (focal) seizures are most common (Carlsson, Hagberg, & Olsson, 2003). Speech, language, and communication delays are also common in children with CP, where approximately 36% have some form of speech impairment, and 42% experience communication difficulties (Lewis, Shapiro, & Church, 2013; Parkes, Hill, Platt, & Donnelly, 2010; Sigurdardottir & Vik, 2011). Moreover, visual impairments occur in about 15 % of children (Centers for Disease Control and Prevention [CDC], 2015), and include both ocular impairments and cortical visual impairments (Geddie, Bina, & Miller, 2013; Repka, 2002). In addition, feeding difficulties and nutritional problems are also fairly common in children with CP, generally due to motor impairments of the mouth and tongue (Hoon & Tolley, 2013), and some experience low bone density, caused by a lack of weight being activities with impaired limbs(Hough, Boyd, & Keating, 2010). Finally, some children with CP have other , co-occuring disabilities such as autism spectrum disorder (Christensen et al., 2014; Nordin & Gillberg, 1996) or attention deficit hyperactivity disorder (Gross-Tsur, Shalev, Badihi, & Manor, 2002). It is important to note, however, that due to the heterogeneous nature of CP, many other associated conditions and impairments are also possible(Koman, Smith,

& Shilt, 2004). Generally speaking, the more severe motor impairments are in CP, the higher the likelihood of associated conditions (Hoon & Tolley, 2013).

Spastic Cerebral Palsy

The most common subtype of CP is spastic CP, which occurs in approximately 77.4 % of all children with CP (Centers for Disease Control and Prevention [CDC], 2015; Christensen et al., 2014). Spasticity is defined as increased muscle tone, that causes velocity-dependant resistance to passive stretching and restrictions to voluntary movement (Barnes & Johnson, 2008; Phadke, Balasubramanian, Ismail, & Boulias, 2013). A complete explanation for the origins of spasticity does not currently exist (Barnes & Johnson, 2008; Miller, 2005). However, it is believed to arise from a distribution in either the motor cortex, a region of the frontal lobe involved in voluntary movement, and/or the pyramidal and parapyramidal tracts that connect the motor cortex to the spinal cord (Yaun, Keating, & Gropman, 2013). This type of disruption is known as upper motor neuron syndrome (Hoon & Tolley, 2013), which also leads to spasticity in children and adults with multiple sclerosis, acquired brain injury, or stroke(Barnes & Johnson, 2008). Due to its prevalence in CP, and other motor function disorders and conditions, spasticity is likely an attractor state for motor organization in humans with static brain lesions. This may be because there are some functional benefits to spasticity in humans, over other possible motor configurations that can occur in damaged motor systems. For instance, research into the biomechanics of spasticity indicate that spastic muscle contraction is actually constant and dynamic, which leads some researchers to suggest that spasticity is more accurately termed 'muscle over-activity'(Esquenazi, Cioni, & Mayer, 2010; Mayer & Esquenazi, 2003). Therefore, if CNS motor function damage results in muscle hyper-activity, it is possible that spasticity may be a way for a damaged motor system to constrain the limbs, and thereby recover at least some functional motion, rather than allow excessive movement variability. In addition, there is some evidence to suggest that spasticity can increase in response to physiological or environmental related triggers, such as bowel and bladder issues, menstruation, mental stress, and cold weather (Phadke, Balasubramanian, Ismail, & Boulias, 2013), which reinforces the dynamic nature of spastic muscle contraction.

Spasticity also leads to physiological abnormalities in the muscles, joints and bones (Miller, 2005). It can cause muscle contractures, which refer to a permanent shortening of a muscle or joint (O'Dwyer, Neilson, & Nash, 1989). If a muscle is passively immobilized in a shortened position for a prolonged period of time, the actin and myosin filaments that make up the sarcomere (the basic functional unit of the skeletal muscle) no longer overlap, which prevents optimum force generation. The muscle responds by losing sarcomeres, which reduces the overall length and cross-sectional area of muscle fibres (Fridén & Lieber, 2003; O'Dwyer, Neilson, & Nash, 1989). Spasticity also results in immature subunits in the neuromuscular junctions (Theroux et al., 2005), which causes individuals with spastic CP to be resistant to certain muscle relaxants used in anaesthesia (Wongprasartsuk & Stevens, 2002). Finally, spasticity-induced muscular changes can lead to bone deformities, such as scoliosis (twisting of the spine), foot deformities and hip dislocations, or elbow, shoulder, and wrist joint contractures (Graham & Selber, 2003).

Spastic CP can be sub-dived into 3 phenotypes, according to the distribution of the spasticity, and the limbs most affected. These phenotypes are diplegia, quadriplegia and hemiplegia. In spastic diplegia, both legs are affected more than the arms (Hoon & Tolley, 2013), which occurs in approximately 33% of children with spastic CP (Hagberg, Hagberg, Beckung, & Uvebrant, 2001; Koman, Smith, & Shilt, 2004) In spastic quadriplegia, all four limbs, and usually the trunk, and muscles that control the mouth, tongue and pharynx are all affected(Hoon & Tolley, 2013). Quadriplegic CP occurs in 44% of children with spastic CP(Hagberg, Hagberg, Beckung, & Uvebrant, 2001; Koman, Smith, & Shilt, 2004) And finally, in spastic hemiplegia, one side of the body is more affected than the other, and usually the arms are more affected than the legs (Hoon & Tolley, 2013). Hemiplegic CP occurs in approximately 23% of children with spastic CP (Hagberg, Hagberg, Beckung, & Uvebrant, 2001; Koman, Smith, & Shilt, 2004).

Spastic Hemiplegic Cerebral Palsy

Spastic hemiplegic CP involves unilateral static lesions, which are lesions that involve only one cerebral hemisphere(Hoon & Tolley, 2013). This leads to one side of the body being more affected than the other, and the arms are usually more affected than the legs (Hoon & Tolley, 2013). Spastic hemiplegia is highly correlated with perinatal stroke (Lynch, Hirtz, DeVeber, & Nelson, 2002; Rosenbaum & Rosenbloom, 2012), although neonatal stroke, congenital brain anomalies, genetic defects and PVL can also lead to spastic hemiplegia (Boardman et al., 2005; Miller, 2005; Nelson & Grether, 1999; Okumura, Kato, Kuno, Hayakawa, & Watanabe, 1997). The most common location for stroke to occur in individuals with hemiplegic CP is the middle cerebral artery (Rosenbaum & Rosenbloom, 2012). This leads to focal infarcts (small lesions of dead brain tissue) in regions of the brain that are irrigated by this artery (Krägeloh-Mann & Horber, 2007), which include the motor cortex, which controls voluntary motion; the basal ganglia, which modulates signals from the motor cortex to produce smooth, coordinated movements; the sensory cortex, which controls sense perception and integration; and Broca's and Wernicke areas, which are involved in language production (Donkelaar, 2011; Yaun, Keating, & Gropman, 2013). In addition the brain region affected, the hemisphere in which these lesions are distributed affects overall functionality for individuals with spastic hemiplegia (Goto et al., 2009). The motor and sensory impacts of the static lesions are experienced on the opposite side of the body to that of the lesion, so that left hemispheric lesions lead to right side body impairments, and vice versa (Yaun, Keating, & Gropman, 2013). Furthermore, evidence suggests that the left and right hemispheres are responsible for controlling different features of upper limb movements. Several studies involving adult stroke patients suggest that damage to the left hemisphere selectively impairs the acceleration phase, while right hemisphere damage impairs the deceleration phase of unilateral upper limb motion (Haaland & Harrington, 1989; Schaefer, Haaland, & Sainburg, 2007; Winstein & Pohl, 1995). A similar pattern may be present in children with hemiplegic CP as well, although much more research is needed.

Motor Impairments in Spastic Hemiplegic Cerebral Palsy

The presence of lesions in the motor and sensory control regions of the brain manifests clinically as spasticity on one upper limb, that can include elbow flexion with forearm pronation, wrist and finger flexion, and thumb adduction into the palms, underneath flexed fingers (called spastic thumb-in-palm deformity), depending on the level of severity (Arner, Eliasson, Nicklasson, Sommerstein, & Hägglund, 2008; Miller, 2005). Some individuals with more severe forms of hemiplegic CP may also experience spasticity in the muscles of the ipsilateral shoulder, hip and leg as well (Brown, Rensburg, Lakie, & Wrigh, 1987; Uvebrant, 1988). This leads to a variety of motor impairments in this population. Generally speaking, the upper limb with the most spasticity is typically referred to as the affected hand, while the upper limb with the least spasticity is referred to as the non-affected. Individuals with hemiplegic CP typically use their non-affected hand as their dominant hand (Arner et al., 2008; Brown, Rensburg, Lakie, & Wrigh, 1987; Uvebrant, 1988).

Range of motion (ROM) restrictions are the most noticeable impairments in spastic hemiplegic CP, in both active and passive ROM. Restriction of movement generally increases towards the periphery of the affected (spastic) arm, where both active and passive supination of the forearm, wrist extension and radial deviation and the functions are affected (Uvebrant, 1988). Internal rotation of the shoulders is also common, which can impair movement as well (Koman et al., 2008). Spasticity also causes fine motor coordination (dexterity) deficits, due to thumb – in-palm deformities or general spasticity in the hand(Arner et al., 2008), and also disrupted sensory mechanisms in stereognosis (the perception of tactile sensation) in the fingers and palms (Cooper, Majnemer, Rosenblatt, & Birnbaum, 1995; Eliasson, Gordon, & Forssberg, 1995; Gordon & Duff, 1999), as well as proprioception(the perception of body position and motion in three dimensional space) of the fingers and arms (Cooper, Majnemer, Rosenblatt, & Birnbaum, 1995; Goble, Hurvitz, & Brown, 2009; Smorenburg, Ledebt, Deconinck, & Savelsbergh, 2012). Furthermore, individuals with hemiplegic CP may also have sensory and motor impairments in their non-affected (non-spastic) arm (Brown et al., 1989; Mercuri et al., 1999), which can limit fluent, accurate and controlled bimanual (two-arm) movement between the upper limbs, an important component of efficient functional movement (Hung, Charles, & Gordon, 2004).

Finally, muscle weakness is an important element of motor dysfunction in children with CP (Brown, Rensburg, Lakie, & Wrigh, 1987; Damiano, Dodd, & Taylor, 2002; Uvebrant, 1988). In children with hemiplegic CP, weakness occurs in wrist flexors and extensors (Klingels et al., 2012; Vaz, Cotta, Fonseca, & De Melo Pertence, 2006), supinators and pronators (Klingels et al., 2012), and in grip strength, in both the affected and non-affected hand(Smits-Engelsman, Rameckers, & Duysens, 2005). An explanation as to why spastic muscles are also weak unclear in the literature, although several mechanisms have been put forward to explain this (Mockford & Caulton, 2010). One possibility is that spastic muscles are intrinsically weak, due to fewer and/or abnormal sarcomeres, which reduces muscle cross-sectional area and length (Fridén & Lieber, 2003; O'Dwyer, Neilson, & Nash, 1989). Another possibility is that weakness results from active or passive resistance from opposing muscle groups, which leads to an overall lower net force generated by a spastic muscle (Ross & Engsberg, 2002; Sahrmann & Norton, 1977). Finally, spastic muscle weakness may be due to reduced output from the brain itself, due to damage in the pyramidal or parapyramidal tracts, or abnormalities in muscle innervation (Filloux, 1996).

Upper-Limb Impairments and Functionality in Spastic Hemiplegic Cerebral Palsy

Motor impairments in range of motion, fine motor and bimanual coordination, and muscle strength have a significant impact on the upper-limb functionality of children with hemiplegic CP. For instance, Klingels et al. (2012) conducted a correlation study using a stepwise multiple regression model, and determined that the most significant predictors for unimanual functionality as measured by the Melbourne Assessment-2 (MA2) were wrist strength, stereognosis and proprioception, which together explained 76% of the variance in MA2 scores. For bimanual function, wrist strength and grip strength explained 76% of the variance in the Assisting Hand Assessment , and wrist strength and stereognosis predicted 46% of the variance in the ABILHAND-Kids questionnaire. The Assisting Hand Assessment measures the contributions of the non-affected (or assisting) hand to bimanual coordination in children with upper limb disabilities (Krumlinde-Sundholm, Holmefur, Kottorp, & Eliasson, 2007), and the ABILHAND-Kids is a parent report questionnaire that assesses parent perceptions of bimanual functionality as it relates to the performance of daily activities in children with upper limb CP (Arnould, Penta, Renders, & Thonnard, 2004). A similar stepwise regression study was conducted by Braendvik, Elvrum, Vereijken, and Roeleveld (2010). They found that active range of motion forearm supination, and total strength (a combined measure that included elbow flexion and extension torque, forearm supination and pronation torque, and grip strength) contributed to 74% of the variance in the Assisting Hand Assessment, and active range of motion and total force control (measured through force modulation tasks of the hand and arm) contributed to 74% of the variance in the MA2. Finally, another study by Arnould, Penta, and Thonnard (2007) found that gross manual dexterity (measured by the maximum number of blocks transported individually from one compartment of a box to another in one minute), and grip strength of the non-affected limb predicted 58% of the variance in the ABILHAND-Kids.

Correlation studies demonstrate that upper limb impairments can severely compromise a child's ability to complete upper limb functional tasks. Furthermore, these impairments can also limit a child's ability to perform many of the activities of daily living, such as eating, dressing and bathing, all of which has a significant impact on the quality of life of children with CP (Nieuwenhuijsen, Donkervoort, Nieuwstraten, Stam, & Roebroeck, 2009).

Rehabilitation in Pediatric Cerebral Palsy

Management of Upper Limb Spastic Cerebral Palsy

The range of management options available for upper limb impairment in CP (which includes both hemiplegic and quadriplegic populations) are based on level of severity. They can be generally divided into medical, surgical, and rehabilitative strategies (Papavasiliou, 2009). Medical treatments are most commonly aimed at reducing spasticity and rigidity, and include baclofen, diazepam, and botulinum-neurotoxin A (boNT-A) (Hoon & Tolley, 2013). Surgical interventions for upper limb CP typically include soft tissue releases, tendon transfers, and bone/joint stabilization (Van Heest, House, & Cariello, 1999). Rehabilitative interventions include traditional physiotherapy and occupational therapy along with approaches such as constraint-induced movement therapy, hand-arm bimanual intensive training, aquatherapy, and strength training (Hoon & Tolley, 2013).

Systematic reviews have proven largely inconclusive as to which rehabilitative interventions are superior for children with upper limb CP (Anttila, Autti-Rämö, Suoranta, Mäkelä, & Malmivaara, 2008; Boyd, Morris, & Graham, 2001; Sakzewski, Ziviani, & Boyd, 2009), or have provided only modest evidence for the superiority of specific, intensive, activity-based rehabilitative approaches (Sakzewski, Ziviani, & Boyd, 2013). However, even if intensive interventions have the greatest measurable outcomes for this population, these types of programs are often difficult for children and families, as they generally take place in treatment or rehabilitation centres, with a very demanding schedule that requires a considerable commitment from children and families. Furthermore, it is often unclear under what conditions and intensity levels the programs are most effective for this population (Dettmers et al., 2005).

Research into the perceptions of parents/guardians of children's rehabilitation programs suggest that there are higher rates of family satisfaction, compliance and therapeutic outcomes when programs are designed with a family-centred focus (King, Law, King, & Rosenbaum, 1998; Rosenbaum, King, Law, King, & Evans, 1998). Although clinical programs can be family-focused, home programs in particular are conducive to a family-focused rehabilitation model, since they provide many opportunities for repeated practice for new tasks, in a non-stressful environment. A large part of the physical training for children with CP is conducted at home, in the course of daily live, and under the guidance and supervision of parents and guardians. In addition, home programs provide an adjunct to clinic-based therapy, that can help to alleviate some family dissatisfactions associated with lengthy wait-lists, and limited treatment centres(King, Law, King, & Rosenbaum, 1998). Home programs are used extensively as a rehabilitation strategy for children with CP(King, Law, King, & Rosenbaum, 1998), and several studies have concluded that these programs able to promote functional outcomes in children with CP as programs in clinical settings (Novak & Cusick, 2006; Piggot, Paterson, & Hocking, 2002). Moreover, studies that have explored family perceptions of virtual reality (VR) home therapy programs for children with CP have found favourable responses from children and parents, in terms of overall enjoyment, motivation, feasibility of use and positive functional outcomes (Bryanton et al., 2006; Chiu, Ada, & Lee, 2014; Sandlund, Dock, Häger, & Waterworth, 2012). In order to expand the range of available treatment options for children with CP, it is necessary to validate new approaches to rehabilitation, which can be easily integrated into the home lives of children with CP.

Motivation and Rehabilitation in Pediatric Cerebral Palsy

Studies show that children with CP have significantly lower levels of motivation related to the mastery of tasks, when compared to children of typical development (Jennings, Connors, & Stegman, 1988; Majnemer, Shevell, Law, Poulin, & Rosenbaum, 2010; Tatla et al., 2013). Motivation related to the mastery of a task is defined as an intrinsic psychological force that encourages an individual to attempt to master a skill that is challenging to that person (Majnemer et al., 2010). With respect to motivation in rehabilitation, motivational interventions can be defined as those that promote the initiation and persistence of goal-directed motor behaviour (Tatla et al., 2013), and is usually not a constant factor, but a dynamic process that is difficult to cleary predict for each individual child. Researchers speculate that children with CP experience barriers in free environmental exploration, which may be made worse by overly protective parents and caregivers, leading these children to avoid challenge and prefer less complex tasks, when compared to children of typically development (Jennings, Connors, & Stegman, 1988). This finding was confirmed by Majnemer et al. (2010), in their study that aimed to identify factors associated with motivation in children with CP. Majnemer et al. (2010) found that higher motivation levels in children with CP were associated with higher levels of functional and cognitive abilities.

Low levels of motivation can adversely affect a child's functional abilities and potential, and decrease the effectiveness of therapeutic interventions. Motivation is a critical element of pediatric rehabilitation (Maclean & Pound, 2000), and a crucial element of motor learning (Magill, 2007). In a study by Bartlett and Palisano (2002) that examined the factors that influence the acquisition of motor abilities in children with CP as perceived by physiotherapists, motivation was rated to be the single most influential personal characteristic that determines motor and functional outcomes in physiotherapy. Moreover, motivation was also considered to be extremely important to parents, when evaluating functional therapy programs in children with CP (Law et al., 1998). It is hoped that greater levels of motivation in patients will lead to greater levels of compliance with prescribed treatments, which will in turn lead to greater functional outcomes (Maclean & Pound, 2000). Treatment non-compliance is one of the greatest barriers in medicine and rehabilitation (DiMatteo & DiNicola, 1982) , with some physiotherapists speculating that only 64% of their patients comply with short-term exercise prescriptions, while only 23% comply with long-term exercise prescriptions (Sluijs, Kok, & van der Zee, 1993). Therefore, improving motivation may ultimately be one of the most meaningful ways to improve compliance, and actualize the goals of treatment for clinical populations, including children with CP.

Experimental Group: Nintendo Wii Rehabilitation and Cerebral Palsy

Introduction to Virtual Reality and Rehabilitation

The Nintendo Wii is a subset of virtual reality (VR) technologies known as active video games (AVG). VR is a simulation of the real world, using computer graphics, which enables a person to interact with an artificial, three-dimensional environment by utilizing senses such as vision, hearing, tactile sensation, and proprioception (Holden, 2005; Riener & Harders, 2012). Active video games (AVGS), which are also known as 'exergames' are games and gaming consoles that require physical activity beyond that of conventional hand-held controller games (Holden, 2005; Riener & Harders, 2012). AVGS make use of handsets, controllers, headsets, and specialized platforms or exercise broads, that track body movement, position and reaction times of the player, and integrate this information into the gaming console (Biddiss & Irwin, 2010; Peng, Crouse, & Lin, 2012). This allows the participant to move and exercise in the real world, and in doing so affect actions and outcomes within the structure of the virtual world within the game. Although AVGS are only able to promote low to moderate levels of physical activity for typically developing children and adults (LeBlanc et al., 2013; Peng, Lin, & Crouse, 2011), AVGs offer many practical advantages over real-world rehabilitation exercise, especially for clinical populations that may find conventional exercise programs difficult, or even dangerous (Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008; Riener & Harders, 2012). Modifications to the timing and equipment can be easily done to most consoles, and there is less need for specialized equipment outside of the AVG platform itself (Holden, 2005; Riener & Harders, 2012). Furthermore, commercially-available AVG consoles are often user friendly and low-costing, which makes them easier for families to use in the home, and requires less clinician oversight to operate(Holden, 2005; Riener & Harders, 2012).

The creation of AVG commercial consoles such as the Wii that can be used for exercise in non-clinical settings was dependant on the development of inexpensive and ways to track body movements, positions and reaction times. Previous VR technologies used for exercise rehabilitation were expensive, confined to laboratories or clinical research centers, and often required highly specialized expertise to operate (Deutsch et al., 2008). However, recent advances in the past decade have made low-cost, user-friendly AVG technologies possible, and allowed them to become commercially available. Some of these commercially available gaming platforms include the Sony EyeToy, Microsoft Xbox Kinect, and Konami Dance Dance Revolution, along with the Nintendo Wii. All of these platforms have been used in rehabilitation research, however the majority of AVG rehabilitation studies have used the Nintendo Wii (Taylor, McCormick, Impson, Shawis, & Griffin, 2011). The Nintendo Wii is one of the most commercially successful gaming consoles currently on the market, having sold approximately 101.44 million home systems worldwide, as of January 28th 2015 (Nintendo Co., 2015).

Nintendo Wii Technology

In the Nintendo Wii and its upgrade system, the Nintendo Wii U, movement can be controlled by the Wii Remote, and the Nunchuck. The motion of the remote is detected by a series of accelerometers, that are placed at right angles to each other to detect motion in a series of planes. The remote then sends this information to the infrared light emitting diode sensor bar, that estimates the remote's position and integrates this information into the structure of the game (Tanaka et al., 2012). The Remote also provides audio and vibration feedback to the user. Moreover, a recent expansion of the Wii Remote, called the Wii MotionPlus, uses gyro sensors, which are devices that can sense angular velocity, to more accurately capture three-dimensional and rotational motion of the remote (Tanaka et al., 2012; Vaughan-Nichols, 2009). Another extension for the Wii and Wii U is called the Wii Fit balance board, which is a 51.6 x 31.6 centimeter board that contains multiple pressure sensors to detect a player's centre of gravity and load transition (Clark et al., 2010; Tanaka et al., 2012).

Nevertheless, there are some drawbacks to the Nintendo Wii's technology, in terms of exercise facilitation. For instance, since the gaming console only detects motion through signals sent from the remote, and not from the actual position and orientation of the player's limbs, it is possible to adopt motion strategies that are not conducive to rehabilitation aims. For instance, players can utilize movements such as a wrist snap in place of an arm swing for a virtual tennis racquet, and still be successful in virtual game play (Deutsch et al., 2011). However, this type of motion is more difficult to do with the Wii MotionPlus expansion. The Wii MotionPlus remote has more advanced motion detection capabilities, especially for three-dimensional and rotational motion, which can force players to perform more realistic movements in order to score points within the games (Vaughan-Nichols, 2009).

Ultimately, the Nintendo Wii does have the technological capabilities a to detect motion with enough speed and accuracy to facilitate exercise (Tanaka et al., 2012). This allows the Wii to be used for rehabilitation (Deutsch et al., 2011). Furthermore, although the Wii was not specifically designed for rehabilitation, it is possible to make adaptations to its accessories in order to make it more accessible. For instance, it is possible to modify the Wii settings in order to change which buttons on the remote control certain functions, so that the console can be controlled with easier to reach buttons. Also, it is possible to use specialized gloves, or tensure bandages to modify grip around the remote (Gordon, Roopchand-Martin, & Gregg, 2012).

In addition to this, Nintendo has made available the Wii and Wii U software development kits to programmers and game designers (Tanaka et al., 2012), which allows laboratories that specialize in AVGs for rehabilitation to modify the games and the console, to make it more suitable for rehabilitation aims. Several studies have modified the Wii console to suit exercise programs for specific clinical populations. For instance Dowling, Hone, Brown, Mastick, and Melnick (2013) modified the Wii balance board to be compatible with an already existing classroom balance and dance program, while Gregory, Howard, and Boonthum-Denecke (2012) created a toy robot controlled by the Wii Remote that can dance with children with CP, when they wave the remote. Although modified Wii games and equipment studies typically take place in treatment or clinical centres, it is likely that as research in Wii rehabilitation expands, some of these modifications will become available in the home setting as well.

Overview of Nintendo Wii Rehabilitation Studies in Pediatric Cerebral Palsy

The majority of rehabilitation studies using commercially available AVG platforms have made use of the Wii (Taylor et al., 2011). This is perhaps due to the Wii' console's user friendly interface, family-friendly games, and widespread commercial success (Deutsch et al., 2011; Nintendo Co., 2015). The Wii has been used for rehabilitation in a wide range of clinical populations. These include elderly people (Williams, Doherty, Bender, Mattox, & Tibbs, 2011), stroke patients (Cho, Lee, & Song, 2012), people with acquired brain injuries (DeMatteo, Greenspoon, Levac, Harper, & Rubinoff, 2014), and even people with chronic conditions such as Parkinson's disease(Esculier, Vaudrin, Beriault, Gagnon, & Tremblay, 2012), multiple sclerosis(Brichetto, Spallarossa, de Carvalho, & Battaglia, 2013), and even acute burn rehabilitation (Yohannan et al., 2012). These studies have found largely positive rehabilitation outcomes in patients, although more detailed evidence is needed to make firm conclusions.

With respect to pediatric CP, the Wii has been studied in a variety of motor function domains. Robert, Ballaz, Hart, and Lemay (2013) examined the exercise intensity levels in 10 children with spastic diplegic CP aged 7 to 12, using a typically developing control. Participants were asked to exercise for 40 minutes, using jogging, cycling, snowboarding or skiing games on the Wii Fit, and heart rate and lower extremity motion analysis was used to determine outcomes. No significant differences in any measured variables or analysis was found between the experimental and control groups, which suggests that children with CP are able to obtain exercise-related benefits similar to those obtained by typically developing children while playing the Wii. The results of this study are reinforced by Howcroft et al. (2012), who measured energy expenditure, upper limb kinematics and muscle activation, and self-reported enjoyment in 17 children with a mean age of 9.43(±1.51) years, using Wii bowling, boxing, tennis and Dance Dance Revolution, for approximately 8 minutes each game (with a 5 minute rest period between games). Moderate levels of physical activity were achieved during Dance Dance Revolution, and boxing, and a high level of enjoyment was reported. Jelsma, Pronk, Ferguson, and Jelsma-Smit (2013) examined the effects of Wii Fit training on 14 children aged 7 to 14 with spastic hemiplegic CP with respect to standing balance, running speed and agility, and timing up and down stairs. Wii Fit training was used in place of conventional physiotherapy at a treatment centre for 3 weeks. The results indicated that while balance scores significantly improved, running agility and time going up and down the stairs did not have significant improvements. However, 10 out of 14 children in the study reported preferring Wii training over conventional physiotherapy exercises. Tarakci, Ozdincler, Tarakci, Tutuncuoglu, and Ozmen (2013) examined the effectiveness of Wii balance board training on improving the balance and postural control of 14 children with a mean age of 12.07(±3.36) years with cerebral palsy. Participants performed balance activities using the Wii with physiotherapist 2 times a week, for 12 weeks. Statistically significant improvements were found in static and dynamic balance, as well as trunk control through left and right transfer of body weight. Ballaz, Robert, Lemay, and Prince (2011) examined aerobic solicitation and postural movements induced by Wii Fit jogging, snowboarding, skiing and biking, in children ages 7 to 11 with diplegic CP, as compared to a typically developing control group. Participants played each of the four games for 10 minutes, and various motor functions were examined, such as isometric strength in the hip, knee and ankle joints, and flexion and extension in the upper limbs. Postural sway and balance were also assessed, along with energy expenditure. Energy expenditure levels were similar in both groups, which indicated that motor function impairments, postural sway and balance were not limiting factors in children with CP playing AVGS. Finally, Gordon, Roopchand-Martin, and Gregg (2012) conducted a study to determine whether Wii Sports could be used to improve gross motor function of 7 children aged 6 to 12 years with dyskinetic CP. Average gross motor function, as measured by the Gross Motor Function Measure, improved pre to post test assessments in the children, and high levels of compliance and enjoyment were reported.

The Nintendo Wii has shown mainly positive outcomes when used for the rehabilitation of clinical populations, including children with CP. Only one study, by

Ramstrand and Lygnegård (2012) found no significant improvements in children with CP for a home-based balance intervention using the Nintendo Wii. However, the authors of the study did not conclude that the Wii was ineffective, but rather, that the intensity and duration of their intervention was insufficient to promote measureable changes.

Wii Rehabilitation of the Upper Limbs in Pediatric Cerebral Palsy

To date, there have only been three studies in the published literature to specifically examine Wii rehabilitation in the context of upper limb function in children with CP. Two studies specifically examined the effects of an upper limb Wii intervention for children with hemiplegic CP in terms of functionality (Chiu, Ada, & Lee, 2014; Winkels, Kottink, Temmink, Nijlant, & Buurke, 2013), and one study included an upper limb kinematic analyses during Wii play as part of larger study design(Howcroft et al., 2012).

Chiu, Ada, and Lee (2014) conducted a randomized, single-blind trial with children ages 6 to 13 with hemiplegic CP. 32 children were placed in the experimental group, and underwent 6 weeks of Wii training at home plus usual therapy, 3 times a week, for 40 minutes each session. The Wii Sports Resort games of bowling, air sports, Frisbee and basketball were used, and participants were instructed to play each of the 4 games for 10 minutes. The control group, of 30 children underwent usual therapy only, which included both upper and lower limb training. Outcome measures included coordination, strength, hand function and carer's perception of hand function, at baseline, at 6 weeks, and at the 12 week follow up. Coordination was measured using a tracking task developed by the researchers, which consisted of following a moving target on a computer screen with a finger. This coordination task was previously used to measure coordination in adults with hemiplegic CP, in a previous study by the researchers (Chiu, Ada, Butler, & Coulson, 2010). Strength was measured as the maximum voluntary isometric contraction with the hand in a power grip using a dynamometer. Hand function was measured using the Nine-hold Peg Test, and the Jebsen-Taylor Test of Hand Function. The carer's perception of hand function was measured using the Functional Use Survey. Strength and carer's perception of hand function were greater in the experimental group by the 6 week and the 12 week point, but there was no significant difference by 6 or 12 weeks for hand function or coordination between the control and experimental groups. However, the researchers note that the compliance rate was 96% for the experimental group, and that children and their families were able to integrate Wii training into their daily lives(Chiu, Ada, Butler, & Coulson, 2010).

Winkels et al. (2013) conducted a pre to post test explorative clinical trial, with 15 children aged 6 to 14 with hemiplegic CP, who played Wii Sports boxing and tennis for 6 weeks, twice a week for 30 minutes each session (15 minutes each game), in a clinical rehabilitation centre. The outcome measures used were the ABILHAND-Kids questionnaire, which measures parent/guardian's perceptions of the child's performance of daily activities that require the use of the upper limbs, and the Melbourne Assessment-2(MA2), which measures unilateral upper limb quality of movement. Results were not significant for the MA2 assessment at post-test, but were significant for the ABILHAND-Kids questionnaire. However, the researchers note that many of the participants scored relatively high on the MA2 assessment at pre-test, which limits the potential for a change in score at the post-test (Winkels et al, 2013).

Finally, in addition to energy expenditure and physical activity enjoyment, Howcroft et al. (2012) also conducted an upper limb kinematics assessment of 13 of the children with hemiplegic CP, during their single game play session with Wii sport boxing, tennis and Dance Dance Revolution. The largest range of movements elicited by the AVGs was recorded, for shoulder flexion and abduction, elbow flexion and extension, wrist flexion and extension, and wrist medial and lateral deviation. The highest angular velocities and accelerations for wrist movement was also measure, and whether or not participants adopted an adapted (non-realistic) movement style to play the game was also noted. Results indicated that Wii tennis elicited higher wrist activity than Wii boxing, but Wii boxing elicited higher angular velocities and accelerations than Wii tennis. Also, about 8 participants used an adapted movement style while playing the games. The authors also observed that movement complexity increases as the players advanced through different levels (Howcroft et al., 2012).

While these studies provide promising preliminary results, more studies are needed to make definitive conclusions as to the ideal games, duration and program design for the Wii, in order to maximize upper limb functionality in children with CP.

Domains of Upper Limb Function Targeted by the Nintendo Wii

Despite the paucity of research Wii upper limb interventions for children with CP, researchers and clinicians believe that the Wii does have the ability to target specific domains of motor function in the upper limbs. Deutsch et al. (2011) conducted a game analysis of Nintendo Wii games, to determine the game elements that can be used for rehabilitation. Although the focus of the study was on the rehabilitation of stroke patients, CP and stroke patients share common clinical manifestations (Hoon & Tolley, 2013), so their findings are generalizable to populations with CP. Deutsch et al. (2011) found that the Nintendo Wii can target balance, coordination of upper and lower limbs, cardiovascular and neuromuscular endurance, upper and lower limb strength, and upper extremity control. Deutsch et al. (2011)'s game analysis only involved the Wii Sports and Wii Fit games, so the rehabilitation potential of other Wii games, such as Wii Sports Resort, is not clear, but it is likely to be similar to Wii Sports.

The types of motion elicited Wii Sports Resort will likely vary based on the game. In general, games do attempt to mimic real-word motions of the sport they are stimulating. For example, in Swordplay, the player is required to hold the Wii Motion Plus Remote like a sword, and swing it left, right, forwards and backwards, in order to strike blows on an virtual opponent. In Tennis, players are required to use overhand and underhand swinging motions to hit a virtual tennis ball across the court, and in Archery, the player uses the Wii Motion Plus Remote as a bow, and the Nunchuck as a bowstring, in order to fire arrows at a game target. The upgraded technology in the Wii U and the Wii Motion Plus Remote, is better at detecting three-dimensional rotational motion than previous versions of the technology (Tanaka et al., 2012), which aids at motion realism, and limits the potential for using adapted motion such as a wrist snap, to elicit game responses. Wii Sports Resort therefore allows players to develop skills such as bimanual coordination in games where both hands are engaged, range of motion from swings and wrist motions, and strength and endurance in order to keep pace with the game. Moreover, as a player progresses through the different levels of the game, greater skill, accuracy and fluency in movement is required from players to score points, which promotes a refinement of learned motor abilities in the context of the game. Also, it is possible that these games can also target some fine motor coordination skills, since a player must press a series of buttons on the Remote and the Nunchuck in order to activate them for game play. In addition, the Wii Remote also vibrates in response to successful game play, which may target some sensory (sterognosis) deficits in these children as well.

Motivation and Virtual Reality in Self Determination Theory

The ability of VR to provide motivation for players is also supported by motivation theory. Although there are several different theories of motivation in the published literature (Bandura, 1977; Jackson & Csikszentmihalyi, 1999; Wentzel, Wigfield, & Miele, 2009), Self-determination theory has been most successfully applied to VR game theory, by Ryan, Rigby, and Przybylski (2006). Self-determination theory (SDT) addresses the factors that facilitate or undermine motivation, both intrinsic (that is, arising from within the person), or extrinsic (that is, arising from outside, the person, in terms of social or environmental pressures), although the focus is mostly on intrinsic motivation (Ryan & Deci, 2000). SDT posits that the core type of motivation underlying sport, recreation, and by extension AVG, is intrinsic motivation, which refers more specifically to the inherent tendency to seek out novelty and challenges, to extend and exercise one's capacities, and to explore and learn (Ryan & Deci, 2000).

According to SDT, there are three main contextual factors that can support or thwart intrinsic motivation: autonomy, competence, and relatedness (Ryan & Deci, 2000) *Autonomy* describes a situation where a person is allowed to make choices in the context of the activity, and their choices represent a sense of volition, interests and/or willingness to do the task. *Competence* describes a person's need for challenge and feeling effective in a task that allows them to acquire new skills or abilities, and receive positive feedback. *Relatedness* is experienced when a person feels connected to others who are doing the same activity, generally in a group setting(Ryan & Deci, 2000). In addition to these three factors, when explaining intrinsic motivation in the context of VR activities, another two factors apply: presence, and intuitive control (Przybylski, Rigby, & Ryan, 2010; Ryan, Rigby, & Przybylski, 2006). *Presence* refers to the immersive aspects of an activity or game; the sense that one is within the game as a player, rather than an outside observer. *Intuitive control* refers to the extent to which the game activities or movements are logical in the context of the activity, are easily mastered, and do not interfere with one's sense of being within the game. In other words, the actions required to play the game make sense to the player, and are logically related to game outcomes (Ryan, Rigby, & Przybylski, 2006).

In their application of SDT theory to VR technologies, Ryan, Rigby, and Przybylski (2006) discuss how VR games in general can fulfil these five components needed for intrinsic motivation. Furthermore, their discussion can be extended to an analysis of AVG consoles such as the Nintendo Wii in the context of The Nintendo Wii, and games such as Wii Sports Resort, can address the need for autonomy in intrinsic motivation, by allowing players a high degree of choice in the selection of games to play. Wii Sports Resort provides players with a choice of 12 games, 8 of which solicit a high degree of upper-limb movements. The Nintendo Wii can also address the need for competence in intrinsic motivation, by constantly challenging players, first allowing them to begin game tasks at easier level, and then advance to more difficult levels as their abilities progress. This gives players the chance to develop new abilities and skills as game tasks change, all the while providing positive feedback in the form of an infinite number of chances to master a task, and in-game rewards such as points or extra capabilities that are unlocked as a player advances. As these capabilities are unlocked, the player gets to explore new territories within the game, which adds to its novelty. Moreover, presence and intuitive control in intrinsic motivation are enhanced by the Nintendo Wii's Wii MotionPlus technology (Tanaka et al., 2012), which aids in motion realism in games i.e. by allowing players to swing the remote like a real-world tennis racquet in tennis, while also providing relatively realistic and appropriate visual, tactile, and auditory feedback (Deutsch et al., 2011). Furthermore, the Nintendo Wii allows for the creation of a Mii avatar, which is an in game character that is inserted into the virtual world, which is created by the player and is customizable to their individual preference. Research into game psychology suggests that being able to choose and customize the character that represents them in a game leads to greater immersion in the game (Lim & Reeves, 2009), which in this case, may lead to more play, and possibly greater functional outcomes. Finally, relatedness is a possibility in the Nintendo Wii, when it is played with multiple players, group settings, or even online, in Internet communities. Based on these features, it is therefore possible for the Nintendo Wii to provide intrinsic motivation to participants, which can he harnessed for rehabilitation, in order to increase motor and functional outcomes for clinical populations such as children with CP.

Motivation and Nintendo Wii Interventions

In many ways, the potential of AVGs as tools for rehabilitation is connected to their ability to provide motivating therapeutic interventions, especially for children

(Deutsch et al., 2008). With respect to motivation in the context of upper limb Nintendo Wii interventions, three studies in the published literature measured motivation or discussed motivation, or an aspect of motivation, in the context of their results (Chiu, Ada, & Lee, 2014; Howcroft et al., 2012; Winkels et al., 2013). Winkels et al. (2013) measured the user satisfaction and motivation of 15 children with CP ages 6 to14, as part of their 6-week Nintendo Wii upper limb interventions study, that took place at a rehabilitation centre. They used a user satisfaction questionnaire to determine the children's perception of the Wii, and a visual analog scale, to quantify their level of enjoyment and motivation throughout the study. Overall, the results indicated that the enjoyment and motivation levels were high for most children, and the majority of children were satisfied with their experiences playing the Nintendo Wii. Howcroft et al. (2012) conducted a study to evaluate the potential of the Nintendo Wii to promote physical activity and upper limb kinematics conductive to rehabilitation in 17 children with CP with a mean age of 9.43± 1.51 years, during only one session of Nintendo Wii play at a rehabilitation centre. With respect to the motivation and enjoyment aspect of their study, they used the Physical Activity Enjoyment Scale to determine the level of enjoyment during the study, and found the average score to be 4.50 (±0.30), out of a possible 5 points, which indicates a high level of enjoyment. Finally, Chiu, Ada, and Lee (2014) compared a 6-week home based Nintendo Wii intervention to improve the upper limb to a control group receiving usual therapy, in sixty two children with CP ages 6 to 13. Although they did not measure motivation directly in their study, they reported a compliance rate of 96% for the children in the Nintendo Wii intervention group, which they attributed to increased motivation levels, due to engagement in the game.

Several other studies in the published literature measured or discussed some aspect of motivation for Nintendo Wii interventions in children with CP, to improve motor and functional outcomes. Robert, Ballaz, Hart, and Lemay (2013) examined the exercise intensity and lower limb kinematics of 10 children with CP ages 7 to 12, when playing Nintendo Wii Fit games in a single session, at a rehabilitation centre, as compared to children with typical development. With respect to motivation, participants were asked to rate their levels of motivation on a numeric scale from 1 to 10, and found that the average motivation score for the Wii Fit games was constant, and ranged from 7.38 to 7.90, which represents a moderately high level of motivation. Jelsma, Pronk, Ferguson, and Jelsma-Smit (2013) examined the effects of Nintendo Wii training on 14 children with CP ages 7 to 14, on standing balance, running speed and agility, and timing going up and down the stairs, in a 3 week study at a rehabilitation centre. In terms of motivation, 10 out of the 14 children said that they preferred Wii Fit training to conventional physiotherapy, leading the authors to suggest that Nintendo Wii training might be a positive adjunct to conventional therapy for children with CP. Ballaz, Robert, Lemay, and Prince (2011) examined the exercise intensity and postural kinematics induced by the Nintendo Wii Fit in 11 children ages 7 to 11 with CP, in one training centre in a rehabilitation centre, as compared to a typically developing control. With respect to motivation outcomes, participants were asked to rate their levels of enjoyment during the study on a 10 point scale, and found that the average motivation levels for all the games, were moderate to high (range 6.9 to 8.4). Finally, Gordon, Roopchand-Martin, and Gregg (2012) conducted a study to determine whether the Nintendo Wii could be used to improve gross motor function of 6 children ages 6 to 12, over a 6 week study in a treatment centre. Although motivation was not directly measured, the authors reported a 100% attendance rate for all the children in the study, which attributed to high motivation and engagement levels.

Several other studies in the published literature have measured motivation levels, along with functional outcomes for VR interventions in general (not using the Wii) in children with CP (Brutsch et al., 2011; Brütsch et al., 2010; Bryanton et al., 2006; Harris & Reid, 2005; Jannink et al., 2008; Sandlund, Dock, Häger, & Waterworth, 2012). One notable study, by Sandlund, Dock, Häger, and Waterworth (2012), aimed to explore parent's perceptions of home based commercial VR interventions (in this case, the Sony EyeToy) for children with CP, in a qualitative study using semi-structured interviews with 15 parents. Overall, the parent perceptions of the study and its methods were very positive, and many parents expressed the view that the increased motivation levels of their children in the study made the program much easier to facilitate at home. Although this study used the Sony EyeToy rather than the Nintendo Wii, the authors generalize their results to low-cost, commercially available AVG consoles, and conclude that the increased motivation levels of children when playing AVGS can help to increase independent training in the home environment, which will lead to greater functional outcomes.

Motor Learning in Virtual Reality Interventions

The Nintendo Wii is also able to promote motor learning in clinical populations. Motor learning refers to permanent change in movement behaviour, due to practice, that is measured after a retention period (Magill, 2007). The key components needed for motor learning to occur are repetitive, purposeful, task specific training, multi-sensory feedback and motivation for participants .Deutsch et al. (2011) provided several observations pertaining to the type of interface, and the nature of the feedback in Wii games. According to their analysis, the Wii can provide tactile, visual and auditory feedback for users, which reinforces specific movements in the context of the game. The majority of games in Wii Sports, Wii Sport Resort, and Wii Fit require combinations of movements to be executed at the appropriate time and speed, in order to score well. This promotes coordination and controlled motor responses, which reinforces motor learning (Magill, 2007). Also Wii Sport and Wii Fit games tend involve both unimanual and bimanual upper limb involvement, and have multiple repetitions of tasks within the game that are longer than three minutes, which promotes prolonged rhythmical exercise and neuromuscular endurance (Deutsch et al., 2011), and also reinforces motor learning (Magill, 2007). Furthermore, evidence also shows that motor learning in virtual environments can be translated into real-world motor task (Holden, 2005). In addition, several systematic reviews also lend support to this conclusion, and provide preliminary evidence that AVGS, are able to promote motor learning in children with neurodevelopmental disabilities including CP (Laufer & Weiss, 2011; Mitchell, Ziviani, Oftedal, & Boyd, 2012; Parsons, Rizzo, Rogers, & York, 2009; Snider, Majnemer, & Darsaklis, 2010; Wang & Reid, 2010; Weiss, Tirosh, & Fehlings, 2014). Finally, the end result of motor learning is neuroplasticity. Neuroplasticity refers to the reorganization of the central nervous system, which causes a relatively permanent change in movement behaviour, as a result of practice (Raskin, 2011). This gives the brain the potential to compensate for the damage caused to it, which is the underlying motivation for all therapeutic interventions in rehabilitation (Raskin, 2011).

Control Group: Resistance Training and Cerebral Palsy

Introduction to Resistance Training

Resistance training is a systematic program of exercises designed to cause the muscles to contract against external resistance, in order to increase the strength and endurance of targeted muscle groups (Fleck & Kraemer, 2014). Although there are certain differences between the terms 'resistance training' and 'strength training', they are often used interchangeably, especially in the literature concerning children and adolescents (Bernhardt et al., 2001).

Resistance training is a well-studied therapeutic approach for people with CP. Although it was previously believed that resistance training would increase spasticity (Bobath, 1990), this theory was not supported by evidence (Damiano, Dodd, & Taylor, 2002). After this was demonstrated empirically, resistance training flourished as a therapeutic intervention (Damiano, 2009), since muscle weakness and/or impaired force generation is an important element of motor dysfunction in children with CP (Brown, Rensburg, Lakie, & Wrigh, 1987; Damiano, Dodd, & Taylor, 2002; Klingels et al., 2012; Smits-Engelsman, Rameckers, & Duysens, 2005; Uvebrant, 1988; Vaz, Cotta, Fonseca, & De Melo Pertence, 2006), and is significantly correlated with upper limb functionality in this population (Arnould, Penta, & Thonnard, 2007; Braendvik, Elvrum, Vereijken, & Roeleveld, 2010; Klingels et al., 2012). Furthermore, according to a policy statement issued by the American Academy of Pediatrics, resistance training is safe for children, including those with disabilities, as long as ability appropriate guidelines are followed, which include preventing joint overload, and the need for slow, controlled movements, and a gradual progression of intensity(Council on Sports & Fitness, 2008; Damiano, Dodd, & Taylor, 2002; Myers, Herbert, & Humphrey, 2002). Finally, similar to other types of physical activity, resistance training has been shown to improve cardiovascular fitness, body composition, bone mineral density, blood lipid profiles and mental health (Damiano, 2009).

Overview of Resistance Training Studies in Pediatric Cerebral Palsy

Resistance (or strength) training for pediatric CP has been the subject of several systematic reviews (Darrah, Fan, Chen, Nunweiler, & Watkins, 1997; Dodd, Taylor, & Damiano, 2002; Haney, 1998; Mockford & Caulton, 2008; Scianni, Butler, Ada, & Teixeira-Salmela, 2009) which are useful, since they aggregate the findings of multiple studies. The earliest systematic reviews in the published literature, Darrah et al. (1997) and Haney (1998) reviewed 7 and 8 studies respectively concerning children with CP. While they noted that all studies reported improvements in strength, few were deemed to be of high quality evidence, due to small sample sizes and lack of control groups. Dodd, Taylor, and Damiano (2002) included all resistance training studies for people with CP, both children and adults, in their systematic review, and found that strength can be increased in this population, in a properly designed short term program. Mockford and Caulton (2008) reviewed all studies pertaining to strength training in children and adolescents with CP, with respect to lower limb functionality and gait, and found functional benefits for strength training in some, but not all studies.

However, despite the general agreement of the other systematic reviews, Scianni, Butler, Ada, and Teixeira-Salmela (2009) reached the opposite conclusion when reviewing strength training studies in pediatric CP, and determined that there was no evidence for the effectiveness of strength training for this population. However, there are several factors that affect the interpretation of this review. Firstly, in their discussion, Scianni, Butler, Ada, and Teixeira-Salmela (2009) suggested that one possible reason for their conclusions was that the studies they reviewed did not have programs of a sufficient duration or intensity to have a functional effect. Other possible reasons for this conclusion were discussed in a published response to Scianni, Butler, Ada, and Teixeira-Salmela (2009), by Taylor (2009). Taylor (2009) suggests that the decision of Scianni, Butler, Ada, and Teixeira-Salmela (2009) to only include controlled trials in their review, and to calculate effect size using post-intervention score means, rather than from baseline, provides an explanation for their anomalous findings. Furthermore, Taylor (2009) points out that the strength interventions included in the review were very distinct from each other, and perhaps should not have been combined in a meta-analysis.

Given these considerations, the majority of systematic reviews do support for the use of resistance interventions for pediatric CP. However, the majority of these studies focus on lower-limb spastic CP, not upper limb CP. While it is true that there is a lack of strong evidence in the form of high-quality randomized control trials, preliminary evidence suggests that it can provide some benefit for these children. Finally, it is important to note that no adverse effects of resistance training in this population have been reported in any studies in the published literature.

Resistance training for the Upper Limbs in Pediatric Cerebral Palsy

There were only six identified studies in the published literature that include a resistance (strength) training intervention for the upper limbs for children with pediatric CP (Elvrum et al., 2012; Kim et al., 2012; Lee, You, Lee, Oh, & Cha, 2009; Lee et al., 2013; O'Connell & Barnhart, 1995; Vaz, Cotta, Fonseca, & De Melo Pertence, 2006).

Three of these studies were validating a specific rehabilitation technique, two included other therapeutic techniques alongside resistance training(Elvrum et al., 2012; Vaz, Cotta, Fonseca, & De Melo Pertence, 2006), and the final study only included 3 subjects with CP(O'Connell & Barnhart, 1995).

Lee et al. (2013), Kim et al. (2012) and Lee et al. (2009) evaluated the effectiveness of the Comprehensive Hand Repetitive Intensive Strength Training Technique, which was developed by Lee et al. (2009). It makes use of a low speed treadmill, with a body weight suspension belt in order to facilitate stepping motion with the hands. Stimulation is also provided to the hands, shoulder, elbow, wrist, palm and finger join by a specialized glove with sensors that the child wears during therapy. All of these studies have measured statistically significant improvements in upper limb movement quality and functionality. However, its use of specialized equipment, combined with the clinical expertise needed to conduct the intervention make it unsuitable for a home study setting. Furthermore, this form of intensive treatment may be difficult to integrate into the daily lifestyles of children with hemiplegic CP, and it remains unclear whether it can translate into improvements in functional tasks.

Vaz, Cotta, Fonseca, and De Melo Pertence (2006) and Elvrum et al. (2012) investigated the effects of strength training on the upper extremities, combined with electrical stimulation and botulinum-toxin A injections respectively. Both of these studies found statistically significant improvements in outcome measures, which included grip, flexor, and extensor strength, range of motion, and functionality assessments. However, although these studies do explore the effects of strength training for upper limbs in children with CP, their utilization of other clinical therapeutic techniques obscure a direct measure of the effectiveness of strength interventions for this population.

Finally, O'Connell and Barnhart (1995) examined the effects of an upper limb strength training program in improving wheelchair propulsion. Six wheelchair-using subjects were included in the study, 3 with CP, and 3 with spina bifida. Subjects performed three sets of six repetition maximum upper body strength exercises, three times a week, for 30 minutes each session, and quantitative measures of muscle strength were taken before and after the intervention. All subjects participated in a 50-metre dash and 12metre distance test in wheelchairs before and after the intervention, where time completion was used as an outcome measure. Subjects were found to improve significantly in all muscular strength measures, and in the 12 metre distance test. Also, there was a trend towards improvement in the 50 metre dash, although this change was not significant.

Overall, the only study that featured a straightforward strength intervention, with a focus on functionality is O'Connell and Barnhart (1995). However, there were only 3 participants in this study with hemiplegic CP, and other aspects of functionality, such as object control, manipulation, or performance on the tasks of daily living, was not examined. Therefore, more studies are needed in order to explore this further.

Resistance Training and Motivation in Pediatric Cerebral Palsy

Very little research in the published literature has examined motivation in the context of resistance training in populations with pediatric CP.A study by Taylor, Dodd, McBurney, and Graham (2004) on the factors influencing the compliance rates of young people with CP to home based strength programmes found that the main personal factors involved were motivation, autonomy, and the amount of effort it required to complete the program. These findings were reiterated in on the compliance rates in home based studies to improve upper extremity function by Chen, Neufeld, Feely, and Skinner (1999), who found that volition, or motivation levels of participants was a significant predictor of compliance rates. It is likely that motivation levels of children with CP in resistance training exercises, is similar motivation levels of other clinical populations in conventional exercise programs and therapy (Sluijs, Kok, & van der Zee, 1993).

Summary

Cerebral palsy (CP) is the most common cause of physical disability in children, (Hirtz et al., 2007; Koman, Smith, & Shilt, 2004). Of these children, approximately 23% of children with the spastic subtype of CP have spastic hemiplegic CP (Christensen et al., 2014). Spastic hemiplegic CP involves spasticity in one side of the body, usually with the arms more affected than the legs (Hoon & Tolley, 2013). Children with spastic hemiplegic CP experience a variety of motor impairments, that can severely compromise a child's ability to perform upper limb functions (Nieuwenhuijsen et al., 2009). Therefore, it is necessary to intervene in this area and use innovative and effective rehabilitation strategies, so as to enable children with spastic hemiplegic CP to participate fully in adult life. Specifically, it is important to validate new approaches to upper limb rehabilitation that are motivating for children, and easy to integrate into the home lives of families of children with CP and their families. Also, it is important to contrast novel rehabilitation strategies to more established therapeutic approaches, so as to promote greater knowledge and understanding of the functional and therapeutic gains of these interventions. One novel rehabilitation strategy that can address the need for effective and motivating therapy is the Nintendo Wii. By contrast, resistance training is conventional and a well –established approach to the rehabilitation of children with spastic CP. This study involves a Nintendo Wii intervention experimental group, compared to a resistance training control group, for children ages 7 to 12 with spastic hemiplegic CP.

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SECTION 3: MANUSCRIPT 1

Abstract

The purpose of this pilot study was to determine whether there are benefits to children between the ages of 7 to 12, with spastic hemiplegic CP, in terms of improvements in upper limb quality of movement, grip strength, and the performance of daily activities requiring the use of the upper limbs, after a Nintendo Wii U intervention for upper limb function. A secondary objective was to determine the comparative effectiveness of a Nintendo Wii intervention, when compared to single-joint resistance training, with respect to upper limb quality of movement and grip strength. A total of n=6, participants aged 7 to 12, diagnosed with spastic hemiplegic CP were recruited, and randomized to either the Nintendo Wii group (n=3), or the resistance training group (n=3). Participants trained at home for 6 weeks, and pre, post and 4 week follow-up measures were conducted. Overall this study found that there were benefits to children with spastic hemiplegic CP with respect to the improvements in upper limb quality of movement, grip strength and the performance of upper limb daily activities after a Nintendo Wii U intervention to improve upper limb function, as all Wii participants improved from baseline in at least 2 or more assessment measures. However, although the Nintendo Wii group did experience greater positive changes on average in most assessments as compared to the resistance training group, it is not possible to make conclusions about the comparative effectiveness of these two interventions, with respect to these outcome measures, due to small sample size and participant variability.

Caroline Kassee (2015)

Introduction

Cerebral Palsy

Cerebral palsy (CP) refers to a range of permanent motor disorders of early childhood, characterized by poor coordination, spasticity, muscle weakness, movement and posture abnormalities, and delays in motor development (Hoon & Tolley, 2013; Koman, Smith, & Shilt, 2004). There are several sub-types of CP, one of which is spastic hemiplegic CP. Spastic hemiplegic CP involves spasticity on one side of the body, usually with the arm affected more than the leg (Hoon & Tolley, 2013), and occurs in approximately 23% of children with CP (Koman, Smith, & Shilt, 2004). Spastic hemiplegic CP is caused by unilateral static lesions in the regions of the brain that control motor function, and generally manifests clinically as elbow flexion with forearm pronation, wrist and finger flexion, and thumb adduction into the palms, underneath flexed fingers, depending on the level of severity (Arner, Eliasson, Nicklasson, Sommerstein, & Hägglund, 2008; Miller, 2005). Some individuals also experience spasticity in the muscles of the ipsilateral shoulder, leg and hip as well (Brown, Rensburg, Lakie, & Wrigh, 1987).

Children with spastic hemiplegia experience a variety of motor impairments, including range of motion and coordination deficits (Arner et al., 2008; Koman et al., 2008; Uvebrant, 1988), sensory impairments (Cooper, Majnemer, Rosenblatt, & Birnbaum, 1995), and muscle weakness (Damiano, Dodd, & Taylor, 2002). These impairments can significantly compromise a child’s ability to perform upper limb functions such as reaching, grasping and manipulating objects (Nieuwenhuijsen, Donkervoort, Nieuwstraten, Stam, & Roebroeck, 2009). Therefore, it is necessary to intervene in this area, and help children with spastic hemiplegic CP acquire upper limb functional abilities, so as to enable them to participate fully in daily life. The range of management options for upper limb impairments include medical, surgical, and rehabilitative strategies (Papavasiliou, 2009); however with respect to rehabilitative approaches, systematic reviews have proven largely inconclusive as to which rehabilitation approaches are superior for this population (Anttila, Autti-Rämö, Suoranta, Mäkelä, & Malmivaara, 2008; Boyd, Morris, & Graham, 2001; Sakzewski, Ziviani, & Boyd, 2009; Sakzewski, Ziviani, & Boyd, 2013). In order to expand the range of available treatment options for children with CP, it is important to validate new approaches to rehabilitation, which can be easily integrated into the home lives of children and their families, so as to promote greater functional and therapeutic gains. One novel rehabilitation strategy,that has the potential to address these aims is Nintendo Wii training.

Nintendo Wii Training in Pediatric Cerebral Palsy

The Nintendo Wii is a subset of virtual reality (VR) technologies known as active video games (AVGS), which are games that require physical activity beyond that of conventional hand-held controllers games (Holden, 2005; Riener & Harders, 2012). In pediatric CP, the Wii has been studied in a variety of motor function domains, including exercise intensity, lower extremity kinematics, balance, agility and overall gross motor function (Ballaz, Robert, Lemay, & Prince, 2011; Gordon, Roopchand-Martin, & Gregg, 2012; Jelsma, Pronk, Ferguson, & Jelsma-Smit, 2013; Robert, Ballaz, Hart, & Lemay, 2013; Tarakci, Ozdincler, Tarakci, Tutuncuoglu, & Ozmen, 2013). With respect to Wii rehabilitation and upper limb function, there have only been three studies in the published literature to examine the effects of a Wii intervention for children with hemiplegic CP (Chiu, Ada, & Lee, 2014; Howcroft et al., 2012; Winkels, Kottink, Temmink, Nijlant, & Buurke, 2013). Chiu, Ada, and Lee (2014) conducted a randomized, single-blind trial to determine whether Wii training was effective in improving limb function in children ages 6 to 13 with hemiplegic CP. 32 children in the experimental group underwent Wii training at home for 6 weeks, while 30 children in the control group underwent usual therapy for 6 weeks. The study concluded that Wii training did not improve hand function, coordination or strength, but caregivers perceived that the children used their hands more for functional tasks. Also, the compliance rate for the experimental group was 96%, and children and their families reported that they were able to integrate Wii training into their daily lives.

Winkels et al. (2013) conducted a pre post explorative clinical trail with 15 children ages 6 to 14, who played the Wii for 6 weeks, twice a week, for 30 minutes each session, in a clinical rehabilitation centre. While results were not statistically significant for improvements in quality of upper limb movement (which may have been due to low intensity for the intervention), parent/caregiver perception of the children's hand function did improve, and high levels of enjoyment were reported. Finally, in addition to energy expenditure and physical activity enjoyment,

Howcroft et al. (2012) also conducted an upper limb kinematics assessment of 13 children with hemiplegic CP, during a single game play session with the Wii. The results indicated that there was considerable variability in the wrist and arm movements elicited between Wii games, and that movement complexity increased as the players advanced through the levels, suggesting that the games have the potential to promote motor learning. However, the authors observed that some players used an adapted movement style to elicit game responses while playing the games. While these studies provide promising preliminary results, more research is needed, in order to determine the ideal games, duration and program design to maximize upper limb functionality in children with CP.

Domains of Upper Limb Function Targeted by the Nintendo Wii

Despite the lack of research in the published literature for upper limb Wii interventions, researchers and clinicians believe that the Wii does have the ability to target specific domains of motor function in the upper limbs, such as coordination, cardiovascular and neuromuscular endurance, upper extremity control, along with controlled arm movements, dexterity, and general fitness (Deutsch et al., 2011). The Wii does this by requiring players to mimic the real-world motions of the sport the game is simulating. For example, in Wii Tennis in the Wii Sports Resort game, players are required to use overhand and underhand swinging motions of the Wii Remote in order to hit a virtual tennis ball, which is similar to the real-world motion of hitting a tennis ball. This ability to promote motor function is enhanced by Wii U's upgraded technology, which can detect three-dimensional and rotational motion with greater accuracy (Tanaka et al., 2012; Vaughan-Nichols, 2009). Also, the Wii is able to promote motor learning (Deutsch et al., 2011). Motor learning refers to a permanent change in movement behaviour, which requires repetitive, purposeful, task-specific training, multi-sensory feedback, and motivation for participants (Magill, 2007). Furthermore, evidence suggests that motor learning in virtual environments for people with disabilities is transferrable to real-world motor equivalent motor tasks in most cases, and in some cases even generalizable to untrained tasks as well (Holden, 2005).

Resistance Training and Pediatric Cerebral Palsy

By contrast to Nintendo Wii training, which is a novel rehabilitative approach, resistance training is a more conventional and established approach for the rehabilitation of children with spastic CP (Damiano, 2009). Resistance training, which is also referred to as strength training in the literature pertaining to children with CP (Bernhardt et al., 2001) is a systematic program of exercises designed to cause the muscles to contract against external resistance, in order to increase the strength and endurance of targeted muscle groups (Fleck & Kraemer, 2014). It specifically targets muscle weakness, which is an important element of motor dysfunction in children with spastic hemiplegic CP (Damiano, Dodd, & Taylor, 2002). With respect to the published literature, there are six studies in the published literature that focus exclusively on the upper limbs (Elvrum et al., 2012; Kim et al., 2012; Lee, You, Lee, Oh, & Cha, 2009; Lee et al., 2013; O'Connell & Barnhart, 1995; Vaz et al., 2008), with generally positive, but inconclusive results. In order to expand the range of approaches to rehabilitation for this population, it is necessary to compare and contrast novel approaches to conventional therapeutic techniques, so as to yield a meaningful comparison, and validate new approaches for use in different settings. In this study, the experimental group underwent a Nintendo Wii intervention, while the non-equivalent control group underwent a resistance training intervention, to improve upper limb functionality.

Purpose

The purpose of this pilot study was to determine whether there are benefits to children between the ages of 7 to 12, with spastic hemiplegic CP, in terms of improvements in upper limb quality of movement, grip strength, and the performance of daily activities requiring the use of the upper limbs, after a Nintendo Wii U intervention for upper limb function. A secondary objective is to determine the comparative effectiveness of a Nintendo Wii intervention, when compared to single joint resistance training, with respect to upper limb quality of movement and grip strength.

Methods

Study Design

This study employed a quasi-randomized, pre-test, post-test experimental design, with a 4-week follow-up, and a non-equivalent control group. Ethics approval was received from the University Research Ethics Board, and Grandview Children's Centre (GCC)'s research committee, in Oshawa Ontario (Appendices 1 and 2, respectively), and all parents provided informed consent (Appendix 3), and all participants provided child assent (Appendix 4) prior to beginning the study. Participants were randomly assigned to the experimental Wii group (n=3) or the resistance control group (n=3), based on the order in which they were contacted by the researchers, and underwent pre-test assessments, a 6-week intervention, post-test assessments, and a 4-week follow-up assessment, regardless of group assignment.

Recruitment

Children between the ages of 7 and 12 with a diagnosis of spastic hemiplegic CP were contacted through the client database at GCC, and a recruitment letter was sent to their homes, inviting them to participate in the study (Appendix 5). Recruitment posters for the study were also placed on bulletin boards at GCC, inviting potential participants to contact the researchers if interested in participating (Appendix 6). Due to low recruitment rates from these methods, additional ethics approval was granted in order to expand the method of recruitment to include phone calls to the homes of potential participants. Only one initial phone call was made to each home, and if the families did not answer the phone, a message was left on their answering machine, asking them to contact the researchers if interested in the study. Phone calls were made at random, based on the inclusion criteria, by the medical and research director of GCC, according to a verbal recruitment script approved by the University Ethics Board (Appendix 7), and were discontinued once a total of n=6 participants were recruited. If the families expressed interest in the study, their contact information was given to the principal investigator, who then arranged an initial pre-test meeting at the home of the participant, where informed consent was obtained, and the child began the intervention the same day.

Participants

Inclusion criteria for the study required that all participants be between the ages of 7 to 12, with a diagnosis of spastic hemiplegic CP. Exclusion criteria for the study was: (1) having undergone any major surgeries in the upper extremities in the past year, (2) medical complications, such as seizures, breathing difficulties etc., that make exercise or virtual reality participation unsafe, (3) regular, weekly play of the Nintendo Wii U Wii

Sports Resort game, and (4) lack of informed consent to participate in the study. Group assignment was generated using an online random assignment tool, which generated a series of six numbers, either 0 or 1, where 0 represented the control group, and 1 the experimental group. Then participants were assigned sequentially to these numbers. A total of 6 participants were recruited and signed up for the study by their parents.

Procedures

Participant Demographic and Descriptive Information

Once group assignment was determined, the principal investigator and a trained research assistant visited the homes of all participants, in order to enrol them into the study, obtain informed consent from parents and child assent from participants, and conduct pre-test assessments. Parents also completed a supplemental data form, in order to provide demographic data and relevant medical information for each child (Appendix 8). Information regarding boNT-A treatments for each participant was verified by the developmental paediatrician at GCC, with the consent of all parents and participants in the study.

In addition, parents were also asked to report their child's overall level of functioning according to the Manual Ability Classification System (MACS) and the Gross Motor Function Classification System (GMFCS). MACS describes how children with CP use their hands in daily life, by assigning each child to one of five levels, where Level I represents the highest functionality, and Level V, the lowest (Eliasson et al., 2006). GMFCS is also a five level classification system for children with cerebral palsy, that describes a child's movement and locomotion ability, where Level I represents the highest functionality, and Level V the lowest (Rosenbaum, Palisano, Bartlett, Galuppi, & Russell, 2008).

Interventions

Experimental Group - Nintendo Wii Training

Participants assigned to the Wii intervention experimental group were given a Nintendo Wii U system, one Wii MotionPlus Remote controller, a Wii Nunchuck, and the Wii Sports Resort game, to be played at home (Figure 1). All the equipment was returned to the researcher at the end of the study. Participants were instructed to play their choice of games, out of a specific set of games shown in Table 1, for 40 minutes each day, 5 days a week, for a total of 6 weeks, using their affected hand and arm as much as possible. In total, this was 30 days of Wii training, for a total of 1200 minutes of playing time.

Table 1. Wii Intervention Wii Sport Resort Games

Games to Play	Games to Exclude
Tennis	Power cruising
Archery	Cycling
Swordplay	Wakeboarding
Basketball	Air Sports
Bowling	
Canoeing	
Golf	
Frisbee	

Figure 1. Nintendo Wii U equipment

Participants and their parents were also asked to fill out an intervention log each day, that asked participants to state the time they exercised, and what games they played, and also rate on a scale of 0 to 5, how much they used their affected arm, how hard they exercised, and how much fun they had (Appendix 9).

Non-Equivalent Control Group-Resistance Training

Participants in the resistance training control group were given a set of equipment to use at home, consisting of a TheraBand Soft Gel hand-held ball weight, an Elite resistance band, and a gel-filled squeeze ball. The ball weights were of 0.5 kilograms, 1 kilogram, or 1.5 kilograms sizes, and the resistance bands were of Light (yellow) or Medium (green) resistance (Figure 2). Each child was given one ball weight, and one resistance band for the duration of the study. The size of the ball weight and resistance band level was based on the parent's perception of the child's initial strength level at the beginning of the study, and their MACS level. A series of 6 exercises, with a set duration, intensity (repetitions and sets) was given to the control group (Table 2), and they were instructed to exercise 5 days a week, for a period of 6 weeks (30 days in total).

Table 2. Resistance Training group exercises

Exercises	Repetitions	Sets
1. Bicep curls with resistance band	12	2
2. Triceps extensions with hand-held weight	12	2
3. Grip strength, with squeeze ball	12	2
4. Shoulder flexion, with hand-held weight	12	2
5. Shoulder abduction, with resistance bands	12	2
6. Shoulder extension, with resistance band	12	2

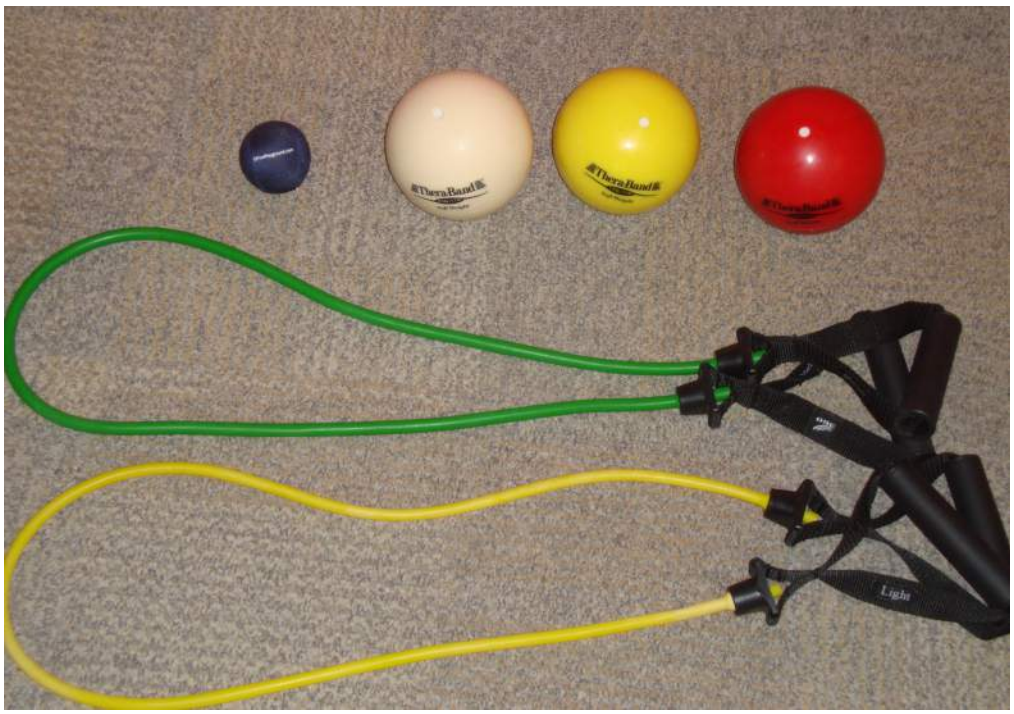


Figure 2. Resistance training equipment

Each exercise was demonstrated to participants and their parents by the principal investigator and research assistant, and participants were given a booklet of the 6 exercises, that consisted of a picture and clear description of how to do each exercise (Appendix 10). Participants and their parents were also asked to fill out an intervention log each day, that asked participants to state the time they exercised, how many sets they did, and how long it took them, and also rate on a scale of 0 to 5, how much they used their affected arm, how hard they exercised, and how much fun they had (Appendix 11).

Assessments

Pre, post and 4 week follow up assessments were taken for each group in the study. The following assessments were conducted during the pre, post, and follow-up assessment periods:

Melbourne Assessment of Unilateral Upper Limb Function-2

The Melbourne Assessment of Unilateral Upper Limb Function-2 (MA2), was used to quantify the quality of upper limb movement for all participants. The MA2 is a criterion referenced test that measures the upper limb quality of movement, of a child's affected (or spastic) hand, with respect to four sub-skill categories: range of motion, accuracy, dexterity and fluency. It contains 14 test items that involve reaching, grasping, releasing and manipulating simple objects, and each child's performance on the test is video recorded, in order to score more accurately. For each of the 14 test items, scores are awarded on a 2, 3 or 4 point scale, depending on the item, and the sub-skill categories that the item tests. For example, for a task such as reaching forwards to press a button (Item 1, in the MA2), a child can score up to 3 points for range of motion, 3 points for accuracy, and 3 points for fluency. A task such as picking up a small pellet (Item 6) is only evaluated in the dexterity category, where a child can score up to 4 points. In addition, some test items, such as Item 4, which evaluates a child's drawing grasp, is not tested, if the child's affected hand is not their dominant hand (The Royal Children's Hospital Melbourne, 2011). With each category of range of motion, accuracy, dexterity and fluency, the item scores are summed, to provide a total score for each section. This total is then divided by the maximum score possible for each sub-skill category, and multiplied by 100, in order to give a percentage score. The greater the percentage score, the higher the child's overall level of functioning for a specific sub-skill category (The Royal Children's Hospital Melbourne, 2011). A child's final score on the MA2 is therefore four separate scores, one for each of range of motion, accuracy, dexterity and fluency.

The Melbourne Assessment of Unilateral Upper Limb Function was developed to be a valid, reliable and easy- to -administer clinical tool to evaluate the most important components of upper limb function in children (Randall, Johnson, & Reddihough, 1999). It was later revised to address identified problems in measuring younger children, and became the Melbourne Assessment of Unilateral Upper Limb Function -2 (Randall, Imms, & Carey, 2008). The MA2 has been found to be valid and reliable for children with CP (Bourke-Taylor, 2003; Randall, Carlin, Chondros, & Reddihough, 2001), with strong interrater reliability (Cusick, Vasquez, Knowles, & Wallen, 2005), including for children with spastic hemiplegic CP (Spirtos, O'Mahony, & Malone, 2011). Furthermore, according to several systematic reviews, the MA2 is considered to be the most effective activity-based measure for quantifying upper limb capacity in children with upper extremity CP, between the ages of 5 to 16 years (Gilmore, Sakzewski, & Boyd, 2010; Klingels et al., 2010). It has also been shown to correlate highly with other assessment tools used to quantify upper limb function in children with CP, such as the Pediatric Evaluation Disability Inventory (Bourke-Taylor, 2003), and the dissociated movement domains of the Quality of Upper Extremity Skills Test (Klingels et al., 2008).

Grip Strength

Maximal hand grip strength was measured in both hands for all participants, using a baseline pneumatic (squeeze bulb) dynamometer, with a range of 0 to 15 pounds per square inch (psi) units. This device consists of a hand-held pump containing water, which is connected to a pressure gauge. Participants were seated, with the shoulders in neutral position, and the elbow flexed at 90 degrees. They were instructed to squeeze the bulb as hard as they could for 2 seconds, and the highest value attained was recorded. Two successive measurements were taken on each hand, with an approximately 10 seconds rest period between measures. Measuring grip strength in both hands served as a comparison to determine the grip strength capacity of the individual participant, and established baseline measures in order to determine improvements as a result of the intervention. Furthermore, this identical method of assessing grip strength has been used for children with spastic hemiplegic CP in the published literature (Thompson, Chow, Vey, & Lloyd, 2015).

ABILHAND-Kids Questionnaire

The ABILHAND-Kids questionnaire was used to quantify each participant's performance of daily activities that require the use of the upper limbs. The ABILHAND-Kids questionnaire is a parent-reported measure that quantifies the manual ability of children with upper limb impairments, in terms of their ability to manage daily activities that require the use of the upper limbs. The questionnaire is filled out by the child's parents/guardians, and is focused on the child's difficulty, as perceived by the parents, in completing a list of 21 tasks in daily life, that require upper limb involvement. The child can receive a score on each task of 0 for impossible to complete, 1 for difficult to complete, or 2 for easy to complete. The score on each task is then summed to calculate a total individual raw score. This raw score is then transformed into a linear measure, known as a logit, according to the Rasch model of analysis. The logit expresses the odds of success of the patient on any given item, taking into account the child's ability level, based on the raw score, and the intrinsic difficulty level of each task, as ranked by the researchers (Arnould, Penta, Renders, & Thonnard, 2004). Therefore, the logit score on the ABILHAND-Kids questionnaire provides an estimate of the child's total manual ability. The lowest logit score possible is -6.753 and the highest score possible is 6.684 (Arnould, Penta, Renders, & Thonnard, 2004).

The ABILHAND-kids questionnaire has been validated for children with CP between the ages of 6 and 15 (Arnould, Penta, Renders, & Thonnard, 2004; Penta, Thonnard, & Tesio, 1998; Vandervelde, Van den Bergh, Penta, & Thonnard, 2010). Several systematic revises have concluded that the ABILHAND-Kids questionnaire is the most effective activity-based measure for quantifying functional upper limb ability in this population (Gilmore, Sakzewski, & Boyd, 2010; Klingels et al., 2010).

Parent Feedback Form

Parents were asked to provide their feedback on their perceptions of the intervention, in the form of 4 rate-response questions, and 4 written response questions (Appendix 12). Please refer to Manuscript 2 for more a more detailed discussion of this part of the study.

Intervention Daily Logs

Participants in the Wii and resistance training groups were asked to fill out daily participation logs, that asked participants to record the details of their daily exercise, and also to rate on a scale of 0 to 5, how much they used their affected arm, how hard they exercised, and how much fun they had (Appendices 9 and 11). Please refer to Manuscript 2 for a more detailed discussion of this part of the study.

Statistical Analyses

Several methods were used to analyze the results of this pilot study. Part 1 of the results section provides a case- by- case description of pre-test, post-test , followy-up and change scores for the MA2, grip strength and the ABILHAND-Kids questionnaire for all participants in the study. Part 2 compares the experimental and non-equivalent control group to each other. An independent-samples two-tailed t-test at $\alpha = 0.05$, in order to determine if there were any statistically significant differences between the Nintendo Wii group and the resistance group at baseline. Also, a line graph analysis was used to visualize major trends in the means of the two groups at each assessment period, and the mean change score was calculated for all assessments, in order to determine and quantify intervention gains, by group. In addition to this, a mixed-design analysis of variance (mixed ANOVA) model was used to determine whether assessment scores at pre, post and follow-up were dependant on intervention group. In order to conduct the mixed ANOVAs with missing follow-up data from Wii Participant-1 (W1), the mean value of W1's pre and post-test scores was substituted as his follow-up score, for all assessments. Although it is acknowledged that this method is flawed (Schafer & Graham, 2002), it was considered to be appropriate in this case, due to the small sample sizes in this study, and W1's relatively high level of functioning at baseline and post-test, which made score variability at different assessment periods less likely for this participant.

Results

Part 1: Participant Case Descriptions

Table 3 displays participant demographic information for all participants in the study. All 6 were male, between the ages of 7 to 12. The MACS, and GMFCS level of participants ranged from 1 to 2, and 5 out of 6 participants were left-handed. None of the participants had the main location of spasticity in their dominant hand.

Table 3. Participant demographic information

Participant Designation	Age (years)	Sex	Main Location of Spasticity (Arm)	Dominant Hand	Parent-reported MACS Level	Parent-reported GMFCS Level
Wii Participant-1	7	Male	Right	Left	1	2
Wii Participant-2	8	Male	Right	Left	2	2
Wii Participant-3	12	Male	Left	Right	2	2
Resistance Participant-1	10	Male	Right	Left	1	1
Resistance Participant-2	7	Male	Right	Left	2	1
Resistance Participant-3	12	Male	Right	Left	2	2

Experimental Group- Nintendo Wii Training

Wii Particpant-1

Wii Participant-1 (W1) is a 7-year old male, with spastic hemiplegic CP centred in his right upper and lower extremities. He is left- hand dominant, and his parent-reported MACS and GMFCS level is 1 and 2, respectively. He did not receive boNT-A in the 6 months prior to his enrolment in the study, but he did receive boNT-A during the study, in his right lower extremities; in the gastrocnemius (60 units) and soleus (40 units).

Table 4 displays W1's total scores for each sub-skill category on the Melbourne Assessment-2 (MA2), for the pre and post-test assessment periods. He was not assessed at the 4-week follow-up, due to withdrawal from the study at post-test over a scheduling conflicts. W1 scored above 50.00% on all sub-skill categories of the MA2 at baseline. Overall W1 improved by 1.12 % on the MA2, from pre to post-test.

Table 4. MA2 Summary table and change scores for Wii Participant-1

Sub-Skill Category	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
*ROM(%)	96.30	96.30	n/d	0	n/a	n/a
Accuracy(%)	92.00	92.00	n/d	0	n/a	n/a
Dexterity(%)	87.50	93.75	n/d	6.25	n/a	n/a
Fluency(%)	95.24	95.24	n/d	0	n/a	n/a
Total(%)	93.26	94.38	n/d	1.12	n/a	n/a

**ROM :Range of motion; n/d is 'no data'; n/a is 'not applicable'*

Table 5 displays W1's average maximal grip strength for his affected hand (right) and non-affected (left) hand. At baseline, his non-affected (dominant) hand was stronger than his affected hand, which was maintained at post-test. Overall, W1 improved by 2.25

psi units in his affected hand, and 1.50 psi units in his non-affected hand, from pre to post-test.

Table 5. Average maximal grip strength summary table and change scores for Wii Participant-1

Hand	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Left (psi)	3.00	4.50	n/d	1.50	n/d	n/d
*Right(psi)	2.00	4.25	n/d	2.25	n/d	n/d

*Notes: Measures shown are the average of two trials; psi is 'pounds per square inch', n/d is 'no data', * indicates main location of spasticity*

Table 6 displays W1's raw score, and overall upper-limb manual ability logit score for the ABILHAND-kids questionnaire at pre and post-test assessments. Overall, W1 improved in upper-limb manual ability by 2.797 logits, from pre to post-test. For the complete raw data tables for this participant, please see Appendix 13.

Table 6. ABILHAND-Kids summary table and change scores for Wii Participant-1

	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Raw Score	37	42	n/d	5	n/a	n/a
Logit Score(SE)	3.887 (±0.666)	6.684 (±1.685)	n/d	2.797	n/a	n/a

Notes: minimum raw score is 0, maximum is 42; minimum logit score is -6.753 (±1.691), maximum is 6.684(±1.685); SE: standard error; n/d is 'no data', n/a is 'not applicable'

Wii Participant-2

Wii Participant-2 (W2) is an 8 -year old male with spastic hemiplegic CP centred in his right upper and lower extremities. He is left-hand dominant, and his parent - reported MACS and GMFCS level is 2 for both. He received boNT-A in the 6 months prior to his enrolment in the study, in his right lower extremities: in the hip abductor longus (25 units), gracilis (25 units), medial hamstrings (100 units) and gastrocnemius (50 units). He did not receive boNT-A injections during the study.

Table 7 displays W2's total scores for each sub-skill category of the MA2, for the pre, post and follow-up assessment periods. W2 scored below 50.00% on the fluency sub-skill category of the MA2 at baseline, and above 50.00% on all other categories. Overall, W2 improved by 11.24% on the MA2 from pre –test to follow-up

test to follow-up, and remained constant in all other sub-skill categories.

Table 7. MA2 summary table and change scores for Wii Participant-2

Sub-Skill Category	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
*ROM(%)	74.07	74.07	74.07	0	0	0
Accuracy(%)	76.00	96.00	92.00	20	-4	16.00
Dexterity(%)	62.50	68.75	62.50	6.25	-6.25	0
Fluency(%)	47.62	66.66	76.19	19.04	9.53	28.57
Total (%)	66.29	77.53	77.53	11.24	0	11.24

**ROM: Range of motion*

Table 8 displays W2's average maximal grip strength, for his affected (right) hand, and non-affected (left) hand. At baseline, his non-affected hand (dominant) was stronger than his affected hand, which was maintained at the post-test and follow-up. Overall, W2 did not improve in maximal grip strength from pre to follow-up.

Table 8. Average maximal grip strength summary table and change scores

Hand	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Left (psi)	2.75	3.25	2.75	0.50	-0.50	0
*Right(psi)	1.50	2.25	1.50	0.75	-0.75	0

*Notes: Measures shown are the average of two trials; psi is 'pounds per square inch';*indicates the main location of spasticity*

Table 9 displays W2's raw score, and overall upper-limb manual ability logit score for the ABILHAND-kids questionnaire at pre, post and follow-up assessments.

Overall, W2 improved in upper-limb manual ability by 0.504 logits from pre-test to follow-up. For the complete raw data tables for this participant, please see Appendix 13.

Table 9. ABILHAND-Kids summary table and change scores for Wii Participant-2

	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Raw Score	19	23	22	4	-1	-3
Logit Score(SE)	–0.332 (±0.412)	0.340 (±0.412)	0.172 (±0.411)	0.672	-0.168	0.504

Notes: minimum raw score is 0, maximum is 42; minimum logit score is -6.753 (±1.691), maximum is 6.684(±1.685); SE: standard error

Wii Participant-3

Wii Participant-3 (W3) is a 12- year old male with spastic hemiplegic CP centred in his left upper and lower extremities. He is right-hand dominant, and his parent-reported MACS and GMFCS level is 2 for both. He did not receive boNT-A in the 6 months prior to his enrolment in the study, or during the study.

Table 10 displays W3's total scores for each sub-skill category of the MA2, for the pre, post and follow-up assessment periods. W3 scored at 50.00% for the dexterity sub-skill category at baseline, and above 50.00% for all other sub-skill categories. Overall, W3 improved by 12.36% in the MA2, from pre-test to follow-up.

Table 10. MA2 summary table and change scores for Wii Participant-3

Sub-Skill Category	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
*ROM (%)	74.07	92.59	92.59	18.52	0	18.52
Accuracy(%)	96.00	100	100	4.00	0	4.00
Dexterity(%)	50.00	81.25	75.00	31.25	-6.25	25.00
Fluency(%)	71.43	80.95	76.19	9.52	-4.76	4.76
Total(%)	75.28	89.89	87.64	14.61	-2.25	12.36

**ROM: Range of motion*

Table 11 displays W3's average maximal grip strength for his affected (left) hand, and his non-affected (right) hand. At baseline, his non-affected hand was stronger than his affected hand, which was maintained at post-test and follow-up. Overall W3 improved by 1.00 psi units in his affected hand, and 0.75 units in his non-affected hand, from pre-test to follow-up.

Table 11. Average maximal grip strength summary table and change scores for Wii Participant-3

Hand	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
*Left(psi)	2.50	2.75	3.50	0.25	0.75	1.00
Right(psi)	4.50	5.25	5.25	0.75	0	0.75

Notes: Measures shown are the average of two trials; psi is 'pounds per square inch'; indicates the main location of the spasticity*

Table 12 displays W3's raw score, and overall upper-limb manual ability logit score for the ABILHAND-kids questionnaire at pre, post and follow-up assessments. Overall, W3 decreased in upper-limb manual ability by -0.392 logits from pre-test to follow-up. For the complete raw data tables for this participant, please see Appendix 13.

Table 12. ABILHAND-Kids summary table and change scores for Wii Participant-3

	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Raw Score	32	31	30	-1	-1	-2
Logit Score(SE)	1.963 (±0.456)	1.763 (±0.456)	1.571 (±0.438)	-0.200	-0.192	-0.392

Notes: minimum raw score is 0, maximum is 42; minimum logit score is -6.753 (±1.691), maximum is 6.684(±1.685); SE: standard error

<u>Non-Equivalent Control Group-Resistance Training</u>

Resistance Participant-1

Resistance Participant-1 (R1) is a 10-year old male with spastic hemiplegic CP centred in his right upper and lower extremities. He is left hand-dominant, and his parent-reported MACS and GMFCS level is 1 for both. He did not receive boNT-A injections in the 6 months prior to enrolment in the study, or during the study. R1 used a TheraBand Soft Gel hand-held ball weight of 1.5 kilograms, and a Light tension Elite resistance band in the study.

Table 13 display's ROM's total scores for each sub-skill category of the MA2, for the pre, post and follow-up assessment periods. R1 scored above 50.00% on all sub-skill categories of the MA2 at baseline. Overall, R1 decreased his total score by 1.12 % on the MA2 from pre-test to follow-up.

Table 13. MA2 summary table and change scores for Resistance Participant-1

Sub-Skill Category	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
*ROM(%)	96.30	96.30	96.30	0	0	0
Accuracy(%)	100	100	96.00	0	-4.00	-4.00
Dexterity(%)	87.50	87.50	87.50	0	0	0
Fluency(%)	90.48	95.24	90.48	4.76	-4.76	0
Total (%)	94.38	95.51	93.26	1.13	-2.25	-1.12

**ROM: Range of motion*

Table 14 displays R1's average maximal grip strength for his affected (right) hand and his non-affected (left) hand. At baseline his non-affected hand was stronger than his affected hand, which was maintained at post-test and follow-up. Overall, R1 decreased by 0.50 psi units in his non-affected hand, and decreased by1.00 psi units in his affected hand, from pre-test to follow-up.

Table 14. Average maximal grip strength summary table and change scores for Resistance Participant-1

Hand	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Left (psi)	6.75	6.00	6.25	-0.75	0.25	-0.50
*Right(psi)	4.25	2.75	3.25	-1.50	0.50	-1.00

*Notes: Measures shown are the average of two trials; psi is 'pounds per square inch', * indicates the main location of spasticity*

Table 15 display's R1's total raw score, and overall upper-limb manual ability logit score for the ABILHAND-kids questionnaire at pre, post and follow-up assessments. Overall, R1 improved in upper-limb manual ability by 0.088 logits from pre-test to follow-up. For the complete raw data tables for this participant, please see Appendix 13.

Table 15. ABILHAND-Kids summary table and change scores for Resistance Participant-1

	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Raw Score	38	38	39	0	1	1
Logit Score(SE)	3.512 (±0.602)	3.512 (±0.602)	3.900 (±0.663)	0.088	0.088	0.088

Notes: minimum raw score is 0, maximum is 42; minimum logit score is -6.753 (±1.691), maximum is 6.684(±1.685); SE: standard error

Resistance Participant-2

Resistance Participant-2 (R2) is a 7-year old male, with spastic hemiplegic CP centred in his right upper and lower extremities. He is left-hand dominant, and his parent-reported MACs and GMFCS level is 2, and 1, respectively. He received boNT-A 6 months prior to enrolment in the study, and during the study, in his right upper extremities in the flexor carpi ulnaris (15 units), flexor carpi radialis (15 units), pronator teres; and in the right lower extremities, in the gastrocnemius (85 units). R2 used a

TheraBand Soft Gel hand-held ball weight of 0.5 kilograms, and a Light tension Elite resistance band in the study.

Table 16 displays R2's total scores for each sub-skill category of the MA2, for the pre, post, and follow-up assessment periods. R2 scored above 50.00% on all sub-skill categories of the MA2 at baseline. Overall, R2 improved by 8.98% in the MA2, from pre-test to follow-up.

Table 16. MA2 summary table and change scores for Resistance Participant-2

Sub-Skill Category	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
*ROM(%)	62.96	74.07	74.07	11.11	0	11.11
Accuracy(%)	80.00	96.00	100	16.00	4.00	20.00
Dexterity(%)	68.75	62.50	62.50	-6.25	0	-6.25
Fluency(%)	57.14	61.90	61.90	4.76	0	4.76
Total (%)	67.42	75.28	76.40	7.86	1.12	8.98

**ROM: Range of motion*

Table 17 displays R2's average maximal grip strength for his affected (right) hand and his non-affected (left) hand. At baseline, his non-affected hand was stronger than his affected hand, which was maintained at post-test and follow-up. Overall R2 increased by 0.25psi units in his affected hand, and decreased by 0.75 units in his non-affected hand, from pre-test to follow-up.

Table 17. Average maximal grip strength summary table and change scores for Resistance Participant-2

Hand	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Left (psi)	6.00	4.75	5.25	-1.25	0.50	-0.75
*Right(psi)	1.75	1.50	2.00	-0.25	0.50	0.25

Notes: Measures shown are the average of two trials; psi is 'pounds per square inch'; indicates the main location of spasticity*

Table 18 display's R2's total raw score, and overall upper-limb manual ability logit score for the ABILHAND-kids questionnaire at pre, post and follow-up assessments. Overall, R2 improved in upper-limb manual ability by 0.106 logits from pre-test to follow-up. For the complete raw data tables for this participant, please see Appendix 13.

Table 18. ABILHAND-Kids summary table and change scores for Resistance Participant-2

	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Raw Score	23	21	22	-2	1	-1
Logit Score(SE)	0.340 (±0.412)	0.004 (±0.411)	0.446 (±0.422)	-0.336	0.442	0.106

Notes: minimum raw score is 0, maximum is 42; minimum logit score is -6.753 (±1.691), maximum is 6.684(±1.685); SE: standard error

Resistance Participant-3

Resistance Participant-3 (R3) is a 12-year old male, with spastic hemiplegic CP centred in his right upper and lower extremities. He is left-hand dominant, and his parent-reported MACS and GMFCS level is 2 for both. He did not receive boNT-A 6 months prior to enrolment in the study, or during the study. R2 used a TheraBand Soft Gel hand-held ball weight of 0.5 kilograms, and a Light tension Elite resistance band in the study.

Table 19 display's R3's total scores for each sub-skill category of the MA2, for the pre, post and follow-up assessment periods. R3 scored above 50.00% on all sub-skill categories of the MA2 at baseline. Overall, R3 did not improve on the MA2 from pre-test to follow-up.

Table 19. MA2 summary table and change scores Resistance Participant-3

Sub-Skill Category	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
*ROM(%)	74.07	81.48	81.48	7.41	0	7.41
Accuracy(%)	96.00	96.00	88.00	0	-8.00	-8.00
Dexterity(%)	81.25	87.50	87.50	6.25	0	6.25
Fluency(%)	85.71	80.95	80.95	-4.76	0	-4.76
Total (%)	84.27	86.52	84.27	2.25	-2.25	0

**ROM: Range of motion*

Table 20 displays R3's maximal grip strength for his affected (right) hand and his non-affected (left) hand. Only one trial was conducted for each measurement, due to difficulties in compliance with this participant. At baseline, his non-affected hand was stronger than his affected hand, which was maintained at post-test, but reversed at the follow-up. Overall, R3 increased by 2.50 psi units in his affected hand, and remained constant from pre-test to follow up.

Table 20. Average maximal grip strength summary table and change scores for Resistance Participant-3

Hand	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Left (psi)	4.00	5.50	4.00	1.50	-1.50	0
*Right(psi)	2.50	3.50	5.00	1.00	1.50	2.50

Notes: Measures shown here represent one trial; psi is 'pounds per square inch'; indicates the main location of spasticity*

Table 21 display's R3's total raw score, and overall upper-limb manual ability logit score for the ABILHAND-kids questionnaire at pre, post and follow-up assessments. Overall, R3 decreased in upper-limb manual ability by 0.152 logits from pre-test to follow-up. For the complete raw data tables for this participant, please see Appendix 13.

Table 21. ABILHAND-Kids summary table and change scores for Resistance Participant-3

	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Raw Score	16	20	18	4	-2	2
Logit Score(SE)	0.653 (±0.427)	0.614 (±0.411)	0.501 (±0.414)	-0.039	-0.113	-0.152

Notes: minimum raw score is 0, maximum is 42; minimum logit score is -6.753 (±1.691), maximum is 6.684(±1.685); SE: standard error

Part 2: Group Analyses, by Assessment

Range of Motion Sub-skill - Melbourne Assessment-2

Table 22 presents the means and standard deviations at pre, post and follow-up for the Nintendo Wii and resistance groups for the range of motion sub-skill of the MA2. The Nintendo Wii group's mean pre-test range of motion score on the MA2 was 3.70 % higher than the resistance training group's mean score (95% CI, -30.41 to 37.82). However, this difference was not statistically significant, $t(4)=0.301$, $p= 0.778$. The mean scores of each group at pre, post and follow-up for this measure are also depicted graphically in Figure 3.

Table 22. MA2 Range of motion sub-skill means and standard deviations, by group

Assessment Period	Nintendo-Wii Group Mean (Standard Deviation)	Resistance Training Group Mean (Standard Deviation)
Pre-test(%)	81.48 (±12.83)	77.78 (±16.98)
Post-test(%)	87.65 (±11.91)	83.95 (±11.32)
4-week Follow-up(%)	*83.33 (±13.10)	83.95(±11.32)

*Notes: * The n=2 participants with data were used to calculate the follow-up mean for the Nintendo Wii Training group*

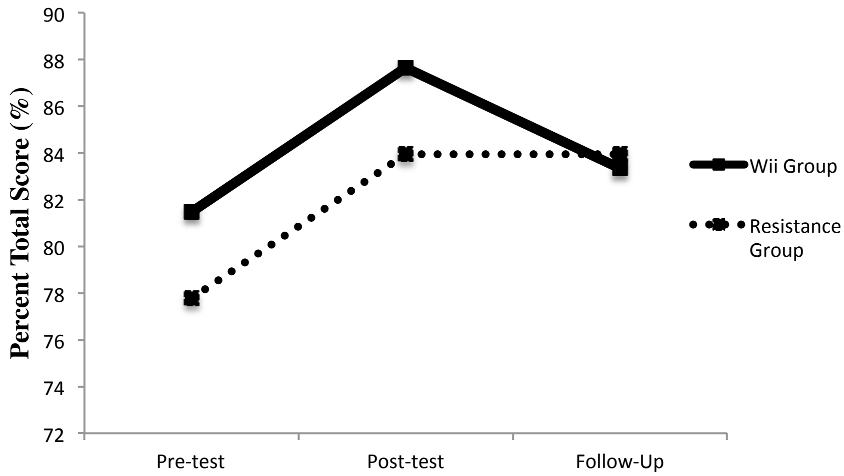


Figure 3. MA2 Range of motion sub-skill means, by group

<u>Accuracy Sub-Skill- Melbourne Assessment -2</u>

Table 23 presents the means and standard deviations at pre, post and follow-up assessments for the Nintendo Wii and resistance groups, or the accuracy sub-skill of the MA2. The Nintendo Wii group's mean pre-test accuracy score on the MA2 was 4.00 % lower than the resistance training group's mean score (95% CI, -27.99 to 19.99). However, this difference was not statistically significant, $t(4)=-0.463$, $p= 0.667$. The mean of each group at pre, post and follow-up for this measure are also depicted graphically in Figure 4.

Table 23. MA2 Accuracy sub-skill means and standard deviations, by group

Assessment Period	Nintendo-Wii Group Mean (Standard Deviation)	Resistance Training Group Mean (Standard Deviation)
Pre-test(%)	88.00 (±10.58)	92.00(±10.58)
Post-test(%)	96.00 (±4.00)	97.33(±2.31)
4-week Follow-up(%)	*96.00 (±5.66)	94.67(±6.11)

*Notes: * The n=2 participants with data were used to calculate the follow-up mean for the Nintendo Wii Training group*

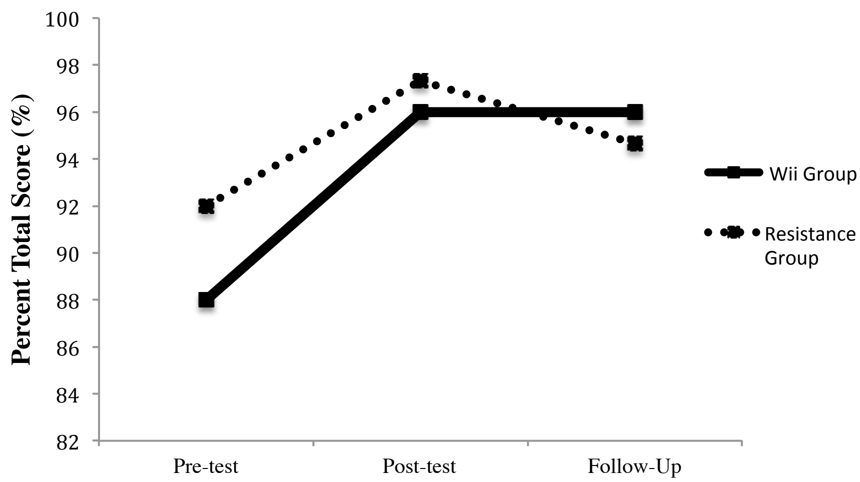


Figure 4. MA2 Accuracy sub-skill means , by groups

Dexterity Sub-skill- Melbourne Assessment –2

Table 24 shows the means and standard deviations at pre, post and follow-up assessments for the Nintendo Wii and resistance groups, for the dexterity sub-skill of the MA2. The Nintendo Wii group's mean pre-test dexterity score on the MA2 was 12.50 percent lower than the resistance training group's mean score (95% CI, -46.72 to 21.72). However, this difference was not statistically significant $t(4)=-1.014$, $p= 0.368$ .The mean of each group at pre, post and follow-up for this measure are also depicted graphically in Figure 5.

Table 24. MA2 Dexterity sub-skill means and standard deviations, by group

Assessment Period	Nintendo-Wii Group Mean (Standard Deviation)	Resistance Training Group Mean (Standard Deviation)
Pre-test(%)	66.67(±19.09)	79.17(±9.55)
Post-test(%)	81.25(±12.50)	79.17(±14.43)
4-week Follow-up(%)	* 68.75(±8.84)	79.17(±14.43)

*Notes: * The n=2 participants with data were used to calculate the follow-up mean for the Nintendo Wii Training group*

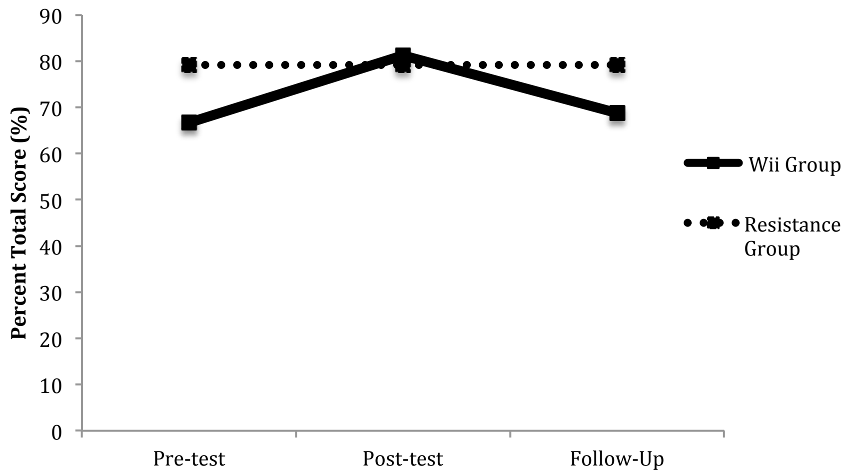


Figure 5. MA2 Dexterity sub-skill means, by group

Fluency Sub-Skill- Melbourne Assessment -2

Table 25 displays the means and standard deviations at pre, post and follow-up assessments for the Nintendo Wii and resistance groups, for the fluency sub-skill of the MA2. The Nintendo Wii group's mean pre-test fluency score on the MA2 was 6.17 % lower than the resistance training group's mean score (95% CI,-53.93, to 41.60). However, this difference was not statistically significant, $t(4)= -0.358$, $p=0.738$. The mean of each group at pre, post and follow-up for this measure are also depicted graphically in Figure 6.

Table 25. MA2 Fluency sub-skill means and standard deviations, by group

Assessment Period	Nintendo-Wii Group Mean (Standard Deviation)	Resistance Training Group Mean (Standard Deviation)
Pre-test (%)	71.43(±23.81)	77.78(±18.03)
Post-test(%)	80.95 (±14.29)	79.36(±16.73)
4-week Follow-up(%)	*76.19 (±0.00)	77.78(±14.55)

*Notes: * The n=2 participants with data were used to calculate the follow-up mean for the Nintendo Wii Training group*

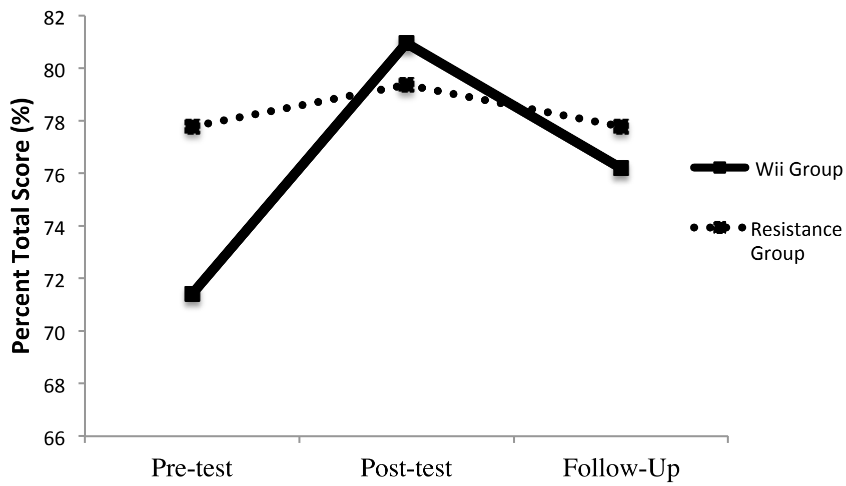


Figure 6. MA2 Fluency sub-skill means, by group

<u>Melbourne Assessment 2-Total Scores</u>

Table 26 displays the means and standard deviations at pre, post and follow-up assessment for the Nintendo Wii and the resistance training groups, for the total MA2 score. The Nintendo Wii's pre-test total MA2 score was 3.74 (95% CI,-34.75, to 27.26) percent lower than the resistance training group's mean score. However, this difference was not statistically significant, $t(4)=-0.336$, $p=0.754$. The means of each group at pre, post and follow-up for this measure are also depicted graphically in Figure 7.

Table 26. MA2 Total sub-skill means and standard deviations, by group

Assessment Period	Nintendo-Wii Group Mean (Standard Deviation)	Resistance Training Group Mean (Standard Deviation)
Pre-test (%)	78.28(±13.73)	82.02(±13.62)
Post-test(%)	87.27(±8.73)	85.77(±10.14)
4-week Follow-up(%)	* 82.59(±7.15)	84.64(±8.44)

*Notes: * The n=2 participants with data were used to calculate the follow-up mean for the Nintendo Wii Training group*

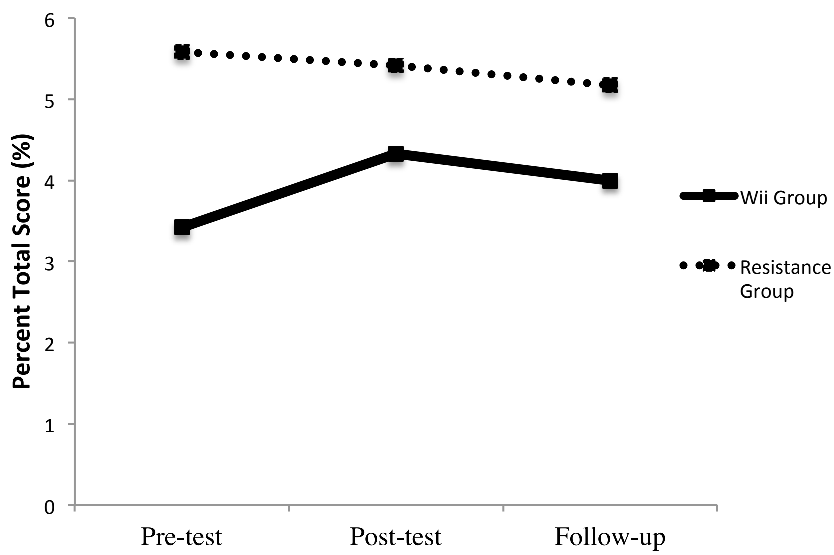


Figure 7. MA2 Total score means, by group

<u>Average Maximal Grip Strength - Affected Hand</u>

Table 27 displays the means and standard deviations at pre, post and follow-up assessments for the Nintendo Wii and resistance groups, for the average maximal grip strength in the affected hand.The Nintendo Wii group's mean pre-test affected hand grip strength measure was 0.71 psi units lower than the resistance training group's mean score (95% CI, -3.04 to 1.37). However, this difference was not statistically significant, $t(4)=-1.048$, $p=0.354$. The means of each group at pre, post and follow-up for this measure are also depicted graphically in Figure 8.

Table 27. Affected Hand average grip strength means and standard deviations, by group

Assessment Period	Nintendo-Wii Group Mean (Standard Deviation)	Resistance Training Group Mean (Standard Deviation)
Pre-test (psi)	2.00(±0.50)	2.83(±1.28)
Post-test (psi)	3.08(±1.04)	2.58(±1.01)
4-week Follow-up (psi)	* 2.50(±1.41)	3.25(±1.25)

*Notes: * The n=2 participants with data were used to calculate the follow-up mean for the Nintendo Wii Training group*

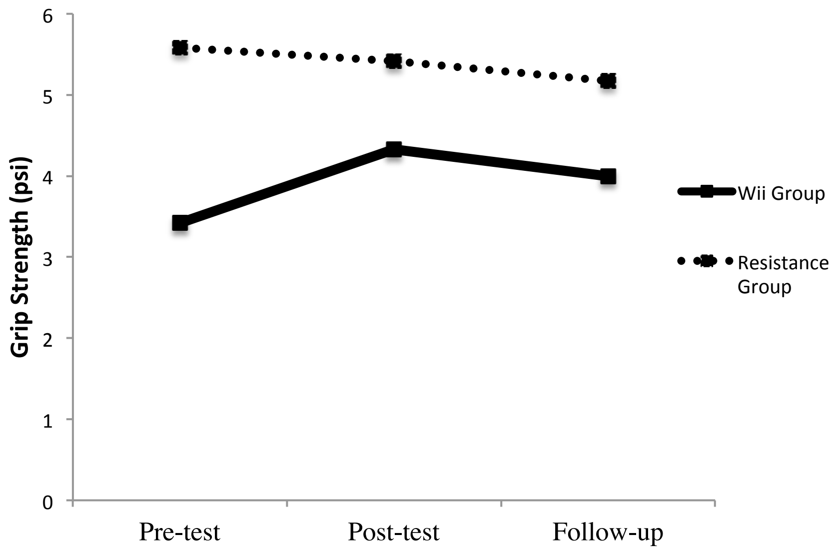


Figure 8. Affected hand maximal grip strength means, by group

<u>Average Maximal Grip Strength - Non-Affected Hand</u>

Table 28 displays the means and standard deviations at pre, post and follow-up assessments for the Nintendo Wii and resistance groups, for the average maximal grip strength in the non-affected hand. The Nintendo Wii group's mean pre-test non-affected hand grip strength measure was 2.16 psi units lower than the resistance training group's mean score(95% CI, -4.90 to 0.57). However, this difference was not statistically significant, t(4)=-2.197, p= 0.093. The means of each group at pre, post and follow-up for this measure are also depicted graphically in Figure 9.

Table 28. Non-affected hand average maximal grip strength means and standard deviations, by group

Assessment Period	Nintendo-Wii Group Mean (Standard Deviation)	Resistance Training Group Mean (Standard Deviation)
Pre-test (psi)	3.42(±0.95)	5.58(±1.42)
Post-test (psi)	4.33(±1.01)	5.42(±0.629)
4-week Follow-up (psi)	* 4.00((±1.77)	5.17(±1.13)

*Notes: * The n=2 participants with data were used to calculate the follow-up mean for the Nintendo Wii Training group*

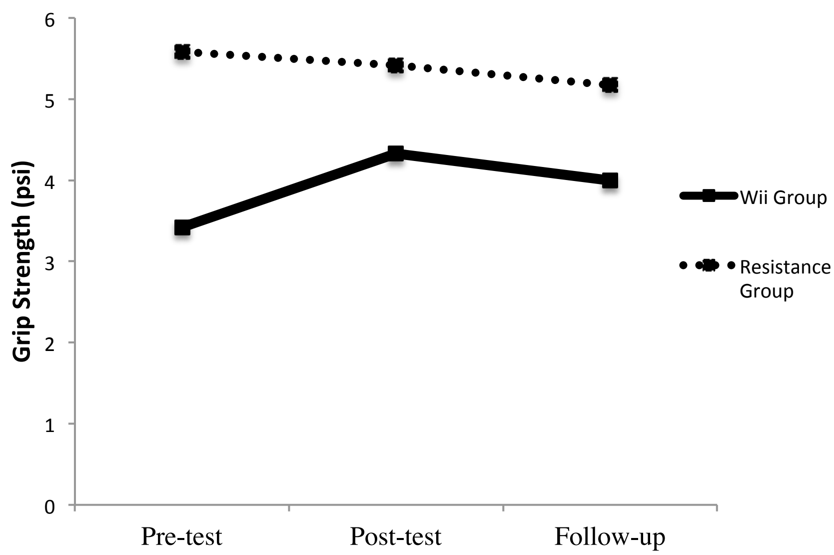


Figure 9. Non-affected hand means, by group

ABILHAND-Kids Questionnaire

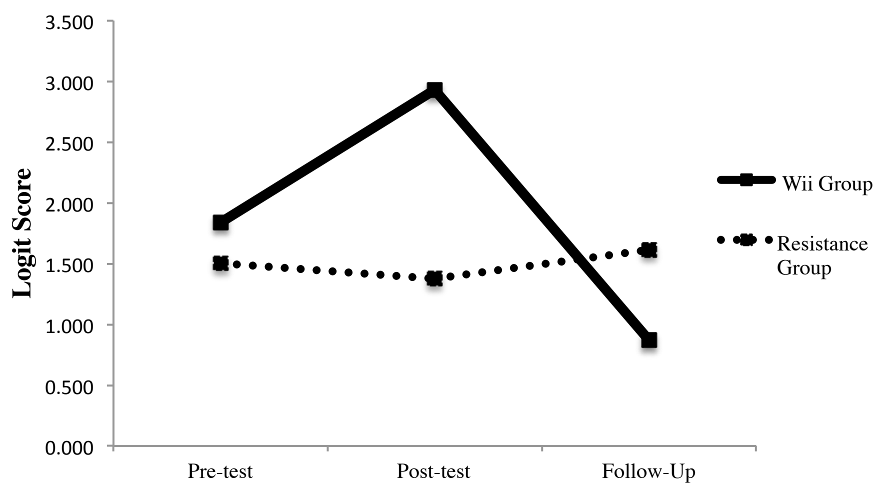
Table 29 displays the means and standard deviations at pre, post and follow-up assessments for the Nintendo Wii and resistance groups, for the ABILHAND-Kids assessment. The Nintendo Wii group's mean pre-test ABILHAND-Kids questionnaire was 0.338 logits higher than the resistance training group's mean score(95% CI, -4.057 to 4.733). However, this difference was not statistically significant, t(4)=-0.213, p= 0.842.. The means of each group at pre, post and follow-up for this measure are also depicted graphically in Figure 10.

Table 29. ABILHAND-Kids questionnaire means and standard deviations, by group

Assessment Period	Nintendo-Wii Group Mean (Standard Deviation)	Resistance Training Group Mean (Standard Deviation)
Pre-test(%)	1.839 (±2.112)	1.502 (±1.748)
Post-test(%)	2.929 (±3.329)	1.377 (±1.874)
4-week Follow-up(%)	*0.871 (±0.9892)	1.616(±1.978)

*Notes: * The n=2 participants with data were used to calculate the follow-up mean for the Nintendo Wii Training group*

Figure 10. ABILHAND-Kids means, by group



Mixed-design Analysis of Variance

Table 30 displays the results of the mixed analysis of variance, for all assessment variables used in the study. The analyses found no statistically significant interactions between intervention group and time, for any assessment variable. However, one statistically significant interaction was found with respect to time in the MA2 total score variable.

Table 30. Mixed-design analysis of variance, for all assessment variables

Variable	Intervention Group	Pre-test (mean±SD)	Post-test (mean±SD)	Follow-up (mean±SD)	Group-Time Interaction	Time Interaction	Group Interaction	Group-Time Effect size (Partial eta)
MA2: Range of Motion (%)	Nintendo Wii	81.48±12.83	87.65±11.91	87.65±11.91	F(2,8)=3.125 p=0.099	F(2,8)=0.0001 p=1.00	F(1,4)=0.138 p=0.729	0.0001
	Resistance	77.78±16.98	83.95±11.32	83.95±11.32				
MA2: Accuracy (%)	Nintendo Wii	88.00±10.58	96.00±4.00	94.67±4.62	F(2,8)=0.139 p=0.873	F(2,8)=1.564 p=0.267	F(1,4)=0.229 p=0.658	0.033
	Resistance	92.00±10.58	97.33±2.31	94.67±6.11				
MA2-Dexterity (%)	Nintendo Wii	66.67±19.09	81.25±12.50	76.04±14.09	F(2,8)=2.069 p=0.189	F(2,8)=2.069 p=0.189	F(1,4)=0.172 p=0.700	0.341
	Resistance	79.17±9.55	79.17±14.43	79.17±14.43				
MA2: Fluency (%)	Nintendo Wii	71.43±23.81	80.95±14.29	82.54±11.00	F(2,8)=1.316 p=0.321	F(2,8)=1.768 p=0.231	F(1,4)=0.0001 p=0.997	0.248
	Resistance	77.60±17.91	79.36±16.73	77.78±14.55				
MA2 Total Score(%)	Nintendo Wii	78.28±13.73	87.27±8.73	86.33±8.22	F(2,8)=1.218 p=0.345	F(2,8)=5.896 p=0.026	F(1,4)=0.0001 p=0.983	0.233
	Resistance	82.02±13.62	85.77±10.14	84.64±8.44				
Affected Hand Grip Strength (psi)	Nintendo Wii	2.00±0.50	3.08±1.04	3.75±2.38	F(2,8)=0.733 p=0.510	F(2,8)=1.942 p=0.205	F(1,4)=0.001 p=1.00	0.155
	Resistance	2.83±1.28	2.58±1.01	3.42±1.51				

Table 30. Continued

Non-Affected Hand Grip Strength(psi)	Nintendo Wii	3.42±0.95	4.33±1.01	3.92±1.26	F(2,8)=1.500 p=0.280	F(2,8)=0.745 p=0.505	F(1,4)=3.476 p=0.136	0.273
	Resistance	5.58±1.42	5.42±0.63	4.92±1.53				
ABILHAND-Kids (logits)	Nintendo Wii	1.839±2.112	2.929±3.329	2.343±2.643	F(2,8)=1.788 p=0.228	F(2,8)=1.110 p=0.376	F(1,4)=0.216 p=0.666	0.309
	Resistance	1.502±1.748	1.377±1.874	1.616±1.978				

Overall Change Scores

Table 31 presents the overall mean change score and standard deviations from pre-test to follow-up, for MA2, grip strength and the ABILHAND-Kids questionnaire respectively (note that the post-test change score was used for W1, due to missing follow-up data). Overall, the Nintendo Wii group achieved greater changes than the resistance group over the study for all assessments. In addition, the resistance training group experienced no changes in the dexterity and fluency sub-skill categories of the MA2, and a negative change with respect to grip strength in the non-affected hand.

Table 31. Overall mean pre-test to follow-up change scores and standard deviations, by group

Intervention Group	MA2 Range of Motion % (±SD)	MA2 Accuracy % (±SD)	MA2 Dexterity% (±SD)	MA2 Fluency% (±SD)	MA2 Total % (±SD)	Affected Hand Grip Strength psi (±SD)	Non-Affected Hand Grip Strength psi (±SD)	ABIL-HAND Kids logits (±SD)
*Nintendo Wii	6.17(±10.69)	6.67(±8.32)	10.42(±13.01)	11.11(±15.31)	8.24(±6.19)	1.08(±1.13)	0.75(±0.75)	0.970(±1.644)
Resistance	6.17(±5.67)	2.67(±15.14)	0(±6.25)	0(±4.76)	2.62(±5.54)	0.58(±1.77)	-0.42 (±0.38)	0.014(±0.144)

** W1's post-test data was used to calculate the Nintendo Wii group's average change scores*

Discussion

The primary objective of this study was to determine whether there are benefits to children with spastic hemiplegic CP, between the ages of 7 to 12, in terms of improvements in upper limb quality of movement, grip strength, and performance of upper limb daily activities, after a Nintendo Wii U intervention for upper limb function. A secondary objective was to determine the comparative effectiveness of a Nintendo Wii intervention, when compared to single-joint resistance training, with respect to quality of movement, grip strength, and performance of upper limb daily activities.

Benefits of Nintendo Wii Training for the Experimental Group

The results of this study suggest that there are benefits to children with spastic hemiplegic CP from a Nintendo Wii intervention to improve upper limb functionality. Overall, the line graph analyses of pre, post and follow-up mean scores on the MA2 and grip strength scores reveal a positive treatment effect, since there were no mean decreases in score back to baseline scores for these assessments at the 4 week follow-up (Figures 3 to 9). The mean ABILHAND-Kids scores did decrease from pre-test to follow-up for the Wii group; however, this can be attributed to a lack of follow-up data for W1, and the variability both between participants, and within participants, that affect small sample sizes.

With respect to overall change scores, all individual participants in the Nintendo Wii group demonstrated improvements on the Melbourne Assessment-2 (MA2), which was used to quantify improvements in the quality of upper limb movement, from pre-test measures to their final assessment (Table 31). The Wii participants that made the greatest improvements in total score (W3 and W2, respectively), also had lower scores on the

MA2 at baseline (Tables 7 and 10), and were both categorised as a MACS level II. By contrast, the Wii participant that made the least amount of improvements (W1) was a MACS level I, and scored very high on the MA2 at baseline (Table 4). This finding is in line with the results of Winkels et al. (2013) who found that children with CP with lower MA2 scores at baseline showed greater improvements after a Nintendo Wii intervention to improve upper limb function. Similarly, Jannink et al. (2008) found that the children with CP that achieved the highest improvements on the MA2 after an upper-limb Sony EyeToy, were also at MACS level II. Therefore, the results of this study suggest that Nintendo Wii training may be most appropriate for children with greater functional impairments. MACS level I describes a child that handles objects easily and successfully, with at most, limitations in the ease of performing manual tasks requiring speed and accuracy, which does not restrict independence in daily activities (Eliasson et al., 2006). By contrast, MACS II describes a child that can handle most objects successfully, but with somewhat reduced quality and/or speed of achievement. Children at MACS level II may avoid certain activities and tasks, or achieve them with some difficulty, and alternate forms of performance might be used (Eliasson et al., 2006). Since a progressive level of optimal challenge is necessary for motor and functional improvements in exercise rehabilitation (Frontera, Slovik, & Dawson, 2006), it is likely that children with CP at MACS level I do not experience Nintendo Wii training with the Wii Sports Resort game as challenging enough to facilitate functional improvements, while children at MACS level II do experience the game as challenging. Therefore, high functioning children with CP may require more challenging games than Wii Sports

Resort, in order to experience functional improvements in the quality of upper limb movement.

With respect to improvements in the MA2 sub-skills by the Nintendo Wii group, fluency was the MA2 category where Wii participants experienced the greatest change overall (Figure 11, Table 31). These improvements were experienced by W2 and W3, while W1 remained constant on this measure, which was likely due to high baseline scores (Table 4). Fluency with respect to movement is defined as the ability of the movement to flow smoothly and freely without jerkiness or tremor (The Royal Children's Hospital Melbourne, 2011), which is assessed in the MA2 in tasks such as reaching and manipulating objects. According to Deutsch et al. (2011)'s game analysis study of the clinical applications of the Nintendo Wii, the Wii has the ability to target this aspect of movement, especially in games that require combinations of moves at specific times in order to play. For instance, in the Swordplay game in Wii Sports Resort, the player is required to hold the Wii Motion Plus Remote like a real world sword, and swing it left, right, forwards and backwards, in order to strike blows on an virtual opponent, that must be accurately angled in order to maximum score points in the game. Furthermore, in Tennis, players are required to use overhand and underhand swinging motions with the Wii Remote, in order to hit a virtual tennis ball across the court, and must position their upper limbs correctly in order to return the ball to their virtual opponent. Therefore, these improvements were anticipated in the study design.

The MA2 category with the second greatest levels of change for the Nintendo Wii group was dexterity (Figure 11, Table 30), which is the coordination of finger and thumb movements when manipulating objects (The Royal Children's Hospital Melbourne, 2011). Improvements in this category were experienced by all three Wii participants, and are somewhat surprising, as games in Wii Sports Resort mainly rely on gross upper limb movements in order to play. It is possible that pressing buttons on the Wii Remote, and manipulating the thumb-controlled joystick on the Wii Nunchuck led to these improvements, since most games in Wii Sports Resort require some of these actions in-game in order to play. For instance, to block a hit in Swordplay, or strike the ball in Tennis, the player is required to orient their limbs at the correct angle, and press one or two buttons together on the Wii Remote at the right time. These actions call for a certain amount of dexterity on the part of players, along with coordination. Interestingly, some studies report Nintendo Wii training improves the surgical skills of laparoscopic surgeons (Boyle, Kennedy, Traynor, & Hill, 2011), and that laparoscopic skill is correlated with Nintendo Wii gaming ability (Badurdeen et al., 2010), which lends support to the potential of the Nintendo Wii to promote dexterity improvements in other populations, at least for certain games. However, more research as to why Wii Sports Resort game play has an influence on manual dexterity in children with spastic hemiplegic CP is needed.

Overall positive improvements in maximal average grip strength were also observed in Wii participants, in both the affected and non-affected hand (Figure 12, Table 30). These improvements were experienced by W1 (Table 5) and W3 (Table 11), while W2 reverted back to baseline on this measure at follow-up. This finding is also interesting, because Wii Sports Resort game does not include any games that primarily target strength, nor does Wii Motion Plus Remote contain any pressure sensors that could detect the strength of the participant's grip. However, Deutsch et al. (2011) found that the Nintendo Wii is able to target neuromuscular endurance, which they define as the ability of a muscle to sustain forces repeatedly, or to generate forces over a period of time. It is possible that the action of holding the limb suspended during arm movements in the game was enough to elicit strength improvements in the Wii participants, as children with CP generally have a considerable degree of weakness in their spastic limbs (Damiano, Dodd, & Taylor, 2002; Klingels et al., 2012; Smits-Engelsman, Rameckers, & Duysens, 2005; Uvebrant, 1988). Furthermore, Chiu, Ada, and Lee (2014) also reported a trend towards improvement in grip strength in their Nintendo Wii upper limb intervention for children with CP, using Wii Sports Resort. They attributed these findings to forced use, especially of the affected hand, and argue that because children with spastic hemiplegic CP generally favour the use of their less affected upper limb in everyday activities, they might not have the chance to learn and develop motor skills in their affected hand, and are therefore more likely to show rapid improvements when they are specifically asked to use their affected limb. The results of this study somewhat contradict this, as W1, the participant with the greatest improvements in grip strength, also reported using his affected arm less than W3, the only other Wii participant with improvements in grip strength (Manuscript 2). However, it is possible that this discrepancy is due to the personal characteristics of the participants. For instance, W1 is a MACS level I who receives 100 units of boNT-A injections in his lower extremities, while W3 is a MACS level II, who does not receive boNT-A injections. Although spastic hemiplegic CP tends to involve the upper extremities more than the lower extremities, it is possible that the main location of W1's spasticity is in his lower limbs. However, it should be noted that grip strength has been shown to be strongly correlated with total muscular strength in children and adolescents with typical development (Wind, Takken, Helders, & Engelbert, 2010). Therefore, the improvements in grip strength found in this study may indicate improvements in overall strength for these participants, although this relationship would have to be verified as being true for populations with spasticity, and measured in future studies.

Finally, positive overall improvements were also observed in the ABILHAND-Kids questionnaire for the Nintendo Wii group (Table 31). W1 and W2 both experienced a positive increase in ABILHAND-Kids scores (Tables 6 and 9, respectively), however, W3 experienced a decrease in total score from pre-test to follow-up (Table 12). This decrease in pre-test to follow-up change score on the ABILHAND-Kids measure is surprising, as W3 experienced the greatest overall improvement in total MA2 scores (Table 10) and also improved in grip strength (Table 11), so it was expected that these changes would translate into functional improvements in the performance of daily activities, as measured by the ABILHAND-Kids. However, as the ABILHAND-Kids questionnaire is a parent-reported assessment tool, it is possible that there was some subjective bias involved in this measure, especially since the difference in raw score values was relatively small (Please see Appendix 13, for raw data tables). Winkels et al. (2013) also reported a decrease in ABILHAND-Kids scores in their study on Nintendo Wii training and upper limb function, and attributed this finding to subjective bias in the measure as well.

Ultimately, all participants in the Nintendo Wii group experienced positive changes throughout the course of the study in at least one assessment, with only one instance of a decrease in score below baseline, in the ABILHAND-Kids scores of W3. W1 improved on MA2 dexterity, grip strength both the affected and non affected hand,

and the ABILHAND-Kids measure, with no decreases below baseline measures in other categories. W2 improved in MA2 accuracy and fluency, and the ABILHAND-kids measure, with no decreases below baseline measures in other categories. Finally, W3 improved in all categories of the MA2 and grip strength in both the affected and non-affected hand, with a slight decrease below baseline on the ABILHAND-kids measure. The results of this study demonstrate that there are benefits to children with spastic hemiplegic CP, from a Nintendo Wii intervention to improve upper limb function.

Benefits of Resistance Training for the Non-Equivalent Control Group

Although not one of the primary objectives of this study, these results also indicate that there are some benefits to children with spastic hemiplegic CP from a single joint resistance training intervention, designed to improve upper limb function. This finding is not surprising, as resistance training is a well-established approach to rehabilitation in populations with pediatric CP (Damiano, 2009; Dodd, Taylor, & Damiano, 2002; Mockford & Caulton, 2008); however, given the paucity of studies in the published literature on upper limb resistance interventions for children with CP, the results are worth discussing in greater detail. Overall, the line graph analyses of the pre, post and 4-week follow-up means for the resistance training group reveal positive treatment effects for MA2 range of motion, accuracy, and total scores, along with grip strength in the affected had, and the ABILHAND-Kids measure. The mean trend lines for MA2 dexterity and fluency reveal no treatment effects, as the mean scores at pre-test were the same at the 4-week follow-up. However the mean trend line for grip strength in the non-affected hand did decrease to below pre-test scores at the 4 –week follow-up.

This is possibly related to the large degree of variation between participants in the resistance group, as well as variation within individual participants.

With respect to overall change scores, there was a mean improvement in MA2 total scores for the resistance group from pre-test to follow-up (Table 31). However, although these improvements are clinically relevant, they only reflect the gains of one participant, R2, as R1 decreased in total MA2 scores (Table 13), and R3 remained unchanged (Table 19). Possible explanations for this are related to in the individual characteristics of each participant. For instance, R1 was classified as both a MACS level I and a GMFCS level I, and does not receive boNT-A. This makes him the highest functioning participant in the study, a fact which is reinforced by his very high MA2 scores at baseline (Table 13). Therefore, given his high performance on this assessment, there is very little room for him to improve further on the MA2, which makes it more likely that variations in his score are due to idiosyncrasies at each assessment period, rather than true changes. It is possible that a more sensitive clinical assessment tool than the MA2 would be able to detect changes in high functioning participants after a resistance training intervention. With respect to R3, his unchanged total MA2 scores does not reflect the gains made in individual sub-skill categories from pre-test to follow-up (Table 19), as MA2 total score is a composite measure of all the gains and decreases for this participant, in the measure as a whole. Furthermore, R3 was the only participant in the study with a notable intellectual disability, along with his diagnosis of spastic hemiplegic CP, which may have increased his intrinsic variability between assessment periods (i.e. within-participant variability). Finally, for R2, it is possible that since he was the only participant to receive boNT-A injections in the upper limbs, before and during the study, this combination of treatments impacted his results. Several studies in the published literature have examined the combined effects of therapy and boNT-A for children with spastic hemiplegic CP (Rameckers, Speth, Duysens, Vles, & Smits-Engelsman, 2009; Speth, Leffers, Janssen-Potten, & Vles, 2005), including one study by Elvrum et al. (2012) that investigated the effects of a boNT-A on resistance training for the upper limbs Although the results of these studies are inconsistent as to whether boNT-A positively or negatively contributes to the outcomes of rehabilitative interventions, when taken together, it is clear that boNT-A in combination with therapy does have a distinct effect (either positive or negative) on participant results. Therefore, the fact that R2 had boNT-A injections during the study, obscures a direct interpretation of his results, and the findings of this study more generally.

Nevertheless, due to participant variation, an examination of the individual sub-skill categories of the MA2 is more relevant to this discussion. With respect to improvement in the individual MA2 sub-skill categories, range of motion was the MA2 category where resistance participants experienced the greatest mean change overall (Table 31). These improvements were experienced by both R2 and R3 (Tables 16 and 19, respectively), while R1 remained unchanged in this measure (Table 13). Although not a lot is known about the extent of range of motion improvements with respect to resistance training in the upper limbs, there is no evidence that resistance training decreases range of motion or flexibility in populations of with spasticity (Damiano, Dodd, & Taylor, 2002; Dodd, Taylor, & Damiano, 2002), and that there is actually some evidence that resistance training can increase range of motion (or flexibility) in the lower limbs of people with CP (Dodd, Taylor, & Damiano, 2002). Therefore, it is possible that the resistance exercises used in this program, which were bimanual, and engaged muscles in the shoulders as well as the arms, was able to solicit improvements in range of motion, that were able to be captured by the range of motion tasks in the MA2.

The MA2 category with the second greatest levels of mean improvements for the resistance group was accuracy (Table 31). However, it is important to note that these positive improvements were only experienced by R2 (Table 16). Similarly, with respect to dexterity and fluency, although the mean improvements for these categories was 0 (Table 31), R3 did improve in dexterity from pre-test to follow-up (Table 19), while R2 improved in fluency from pre-test to follow-up (Table 16). This high degree of variation is expected in studies in this population, with small sample sizes. Furthermore, according to Verschuren et al. (2011), not all children with CP respond the same to resistance training, since selective motor control (which describes the performance of specific isolated joints in voluntary movement), age, and severity can all affect participant results. Therefore it is likely that some children with CP will benefit from resistance training more than others, in different domains of movement, and this intrinsic variability will compound the variability that already exists between participants, and within participants as well.

With respect to overall change scores for grip strength, the resistance training group increased in this measure from pre-test to follow-up in the affected hand, while decreased in the non-affected hand (Table 31). The increases in affected hand grip strength were experienced by R2 (Table 17) and R3 (Table 20), while R1 (Table 14) decreased on this measure. For the non-affected hand, the decreases in overall change scores were experienced by all three participants. It is certainly not surprising to find increases in strength after resistance training, since resistance training targets muscular strength and endurance (Fleck & Kraemer, 2014), However the decreases experienced by participants despite the exercise program's design to improve strength, and its inclusion of grip strength exercises is a somewhat surprising finding. One possible explanation for this is low compliance rates with the study's protocols (Manuscript 2), which would make the variations in grip strength scores more likely to be due to random variation between trials in participants, rather than a reflection of true changes. Also, it is possible that boNT-A injections in R2 skewed the results. Studies show that boNT-a injections can result in strength decreases immediately after it is administered (Hoare et al., 2010), so it is possible that this played a role in the results. Finally, it may be that this is the result of a confounding variable(s) that were not measured or controlled for in this study.

With respect to overall change scores in the ABILHAND-Kids measure, positive overall improvements were also observed in the ABILHAND-Kids questionnaire for the resistance training group (Table 31). These improvements were experienced by R1 and R2, while R3 decreased on this measure. As was previously mentioned, the ABILHAND-Kids questionnaire is a parent-reported assessment tool, so it is possible that there was some subjective bias involved in this measure, especially since the difference in raw score values was relatively small.

Ultimately, all participants in the resistance group experienced positive changes in at least one assessment throughout the course of the study, although all participants also decreased in follow-up scores to below baseline measures in at least one assessment category. However, given the small sample size, it is likely that variation between participants, and within participants from one assessment period to another, can account for at least some of these decreases. R1 improved on the ABILHAND-Kids measure, decreased in MA2 accuracy and grip strength in both hands, and remained at baseline in all other measures. R2 improved in MA2 range of motion, accuracy and fluency, grip strength in the affected hand and the ABILHAND Kids measures with decreases in dexterity and non-affected grip strength. R3 improved in MA2 range of motion and dexterity, and grip strength in the affected hand, and decreased in MA2 accuracy, fluency, grip strength in the non-affected hand, and ABILHAND- kids measures. The results of this study demonstrate that there are benefits to the single-joint, upper-limb resistance training program used in this study, for children with spastic hemiplegic CP.

Nintendo Wii versus Resistance Training Comparison

With respect to the secondary objective of the study, it is not possible to make definitive conclusions about the comparative effectiveness of the Nintendo Wii intervention versus the resistance training. Although the mixed design analyses of variance revealed no statistically significant interactions between intervention groups and time on any assessment variable (the significant time interaction in the MA2 Total score variable is not meaningful to the objectives of the study), this is likely due to small sample sizes, which increases the likelihood of a Type II error occurring. Therefore, descriptive statistics and participant characteristics are more relevant to understanding the results of this study.

The participant case descriptions reveal that there were some notable differences between the groups. For instance, as was discussed above, R1 was the highest functioning participant in the study, at both MACS level I and GMFCS level I. In addition to this, R2 was the only participant to receive boNT-A injections in his upper extremities, in the 6 months prior to the study, and during the study. Also, R3 was the only participant with noted co-occuring intellectual disability along with a diagnosis of CP. When taken together, these factors confound a straightforward interpretation of the data. In addition to this, two out of the 3 resistance group participants (R2 and R3), did not follow the study's timeline 6 weeks of intervention, and 4 week follow up, due to illnesses (Manuscript 2), and W3 exceeded his intervention dosage by 95%. Therefore, there is a real possibility that these factors render a straightforward interpretation of the data difficult. Nevertheless, as long as these differences are taken into account, it is still possible to make some broad, nuanced comparisons between groups.

Overall change scores from pre-test to follow-up reveal that while both groups made positive improvements, participants in the Nintendo Wii group made greater changes in all assessments, with the exception of ROM in the MA2, which was equal to the changes made by the resistance training group. Furthermore, participants in the Nintendo Wii group experienced fewer decreases below baseline scores than participants in the resistance training group. If this difference in change scores reflects the true differences between the Nintendo Wii and resistance training group, and are not skewed by the baseline characteristics of each group's participants; then one possible explanation for these results is the higher compliance rate of the Nintendo Wii group with the study's protocols, as compared to the resistance group (discussed in Manuscript 2). Low compliance with prescribed treatments is one of the greatest barriers in exercise rehabilitation and medicine (DiMatteo & DiNicola, 1982), and diminishes functional outcomes in therapeutic programs (Maclean & Pound, 2000). Furthermore, this compliance rate is linked to more sustained levels of enjoyment, and higher levels of motivation for participants in the Nintendo Wii group (discussed in Manuscript 2). Another possible explanation for differences in change scores between groups, is that resistance training may only target only one specific parameter of functionality (namely strength and endurance), while the Nintendo Wii has the potential to target a more comprehensive, or all-inclusive range of parameters affecting functionality. It is interesting to note, that with respect to the MA2, the resistance training group showed the greatest changes in the range of motion category, which were experienced by 2 participants (R2 and R3) out of 3; while the Nintendo Wii group experienced the greatest changes in MA2 fluency, which were experienced by 2 participants (W2 and W3), followed by dexterity, which was also experienced by 2 participant (W1 and W3), out of 3. It may be that throughout the course of its many games, the Nintendo Wii draws on a wider repertoire of movements and skills, in both gross motor and fine motor domains, while resistance training exercises for the upper limbs are limited to a specific set of movements and functional outcomes; a conclusion which is supported by Nintendo Wii game analysis (Deutsch et al., 2011), and the wide range of research that use the Nintendo Wii to target different domains of function, in diverse clinical populations(Bower, Clark, McGinley, Martin, & Miller, 2014; Williams, Doherty, Bender, Mattox, & Tibbs, 2011; Yohannan et al., 2012). However, it is also possible that a resistance training program with different exercises, of a greater intensity and duration would have solicited greater functional changes in multiple motor domains as well, if participants were to comply with that program in the home environment. However, this hypothesis would need to be confired by further research.

Ultimately, the results of this study found that there were greater overall improvements from pre-test to follow-up in the Nintendo Wii group, as compared to the resistance training group, and fewer decreases to below baseline measures on assessments, for individual participants in the Wii group. Although differences in baseline characteristics of the two groups make it difficult to make a straightforward pronouncement as to which intervention is ultimately more effective for upper limb rehabilitation in children with CP, this study provides some preliminary evidence for the further investigation of Nintendo Wii training, as compared other forms of rehabilitation in the home environment for this population.

Strengths and Limitations

The findings of this study have both strengths and limitations. One strength of this study is that it is, to the best of our knowledge, the first study to compare Nintendo Wii training to resistance training for the upper limbs, in children with spastic hemiplegic CP. Therefore, this study fills a gap in the published literature, adding to the research on both Nintendo Wii interventions and resistance training interventions for the upper limbs in this populations. A second strength of this study is that it attempts to validate home-based therapeutic approach, which can be a useful adjunct to conventional physiotherapy for children with CP. Additionally, a third strength of this study is that it is community-based, and was run with minimal funding. Therefore, this study could be replicated with relative ease by other researchers and clinicians, who are interested in affirming or expanding upon its findings.

The primary limitation with this study its small sample size, which reduces our statistical power to detect true changes between groups. Other limitations include the lack of a representative sample of children with spastic hemiplegic CP – in this study, all participants were male, which is not reflective of the1.5 to 1, male to female distribution of CP (Christensen et al., 2014). Also, we were unable to compare both groups to true control, that received standard treatment centre based physiotherapy, and no home intervention. It was also not possible for us to control for the effects of boNT-A, cognitive and/or co-occuring disabilities, the use of other active video gaming consoles by participants, or their participation in other exercise programs during the course of the study. Finally, researchers in this study were not blind to group randomization, which may have introduced bias into the findings. However, despite these limitations, the results of this study were able to clearly demonstrate differences in overall changes scores between treatment groups, and explore in some detail both individual and group differences with respect the outcome measures used.

Future Research

Future research should expand upon these findings by the increasing sample size, and its male to female distribution. It would also improve the validity of the group comparisons if participants were matched in each group by age, ability, and MACS level, and a randomized control trial, with blinded assessors was conducted. Also, in order to account for within- participant variability from one assessment period to another, multiple baseline assessments should be conducted, on all measures where possible. Furthermore, a larger number of clinical assessment tools to quantify other dimensions of upper limb functionality should be used, in order to determine the functional outcomes of these interventions in more detail. Specifically, it would be useful to directly measure changes in both passive and active range of motion in the upper extremities, bimanual functionality, muscular strength of flexors and extensors, and conduct kinematic and EMG analyses. The effects of different intervention intensities and dosage on the variables measured in this study are also warranted, along with an exploration of the functional outcomes of different Wii games, other AVG gaming consoles such as the Sony EyeToy or the Microsoft Kinect, and different resistance training exercises and intesitites. Finally, a longer follow-up period would allow researchers to more clearly ascertain the effects of these interventions on this population with more certainty.

Conclusions

Overall our study found that there were benefits to children with spastic hemiplegic CP with respect to the improvements in upper limb quality of movement, grip strength and the performance of upper limb daily activities after a Nintendo Wii U intervention to improve upper limb function; but that it is not possible to make conclusions about the comparative effectiveness of the experimental Nintendo Wii group and the resistance training non-equivalent control group with respect to these outcome measures, due to small sample size and participant variability. However, the Nintendo Wii group did experience greater positive changes from pre-test to follow-up, and fewer decreases to below baseline scores, on most assessment measures, as compared to the resistance training group

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SECTION 4: MANUSCRIPT 2

Abstract

The purpose of this pilot study was to explore differences in compliance rates, and parent and participant perceptions of enjoyment, exertion and overall feasibility of a Nintendo Wii and resistance training intervention for children ages 7 to 12 with spastic hemiplegic CP, with respect to a Nintendo Wii and single-joint resistance training intervention to improve upper limb function. A total of n=6 participants aged 7 to 12, diagnosed with spastic hemiplegic CP were recruited, and randomized to either the Nintendo Wii group (n=3), or the resistance training group (n=3). Participants trained home for 6 weeks, and pre, post and 4 week follow-up measures were conducted. Overall, the Nintendo Wii group was found to have a higher compliance rate with the study's protocols, where every participant in the Wii group had a higher compliance rate than the resistance group participant with the highest compliance rate. The Nintendo Wii group also demonstrated sustained enjoyment levels, exertion, and use of a their affected limb, and parent perceptions of participant motivation levels throughout the study were, on average higher for the Wii group, than the resistance group. Finally, on average, parent's rated the Nintendo Wii intervention as more feasible to accommodate in their schedules, and easier for children to follow, as compared to the resistance training group.

Introduction

Cerebral Palsy

Cerebral Palsy (CP) is a childhood disability of movement, defined by poor coordination, spasticity, muscle weakness, movement and posture abnormalities, and delays in motor development (Hoon & Tolley, 2013; Koman, Smith, & Shilt, 2004; Rosenbaum & Rosenbloom, 2012). CP is caused by a static (non-progressive) lesion in the developing brain, as is the most common cause of physical disability in children, with a prevalence of about 2.5 per 1000 live births in Western countries (Hirtz et al., 2007; Rosenbaum, 2003). There are several sub-types of CP, one of which is spastic hemiplegic CP. Spastic hemiplegic CP involves spasticity on one side of the body, usually with the arm more affected than the leg (Hoon & Tolley, 2013), and occurs in approximately 23% of children with CP (Christensen et al., 2014; Koman, Smith, & Shilt, 2004). Spastic hemiplegic CP generally presents as elbow flexion with forearm pronation, wrist and finger flexion, and thumb adduction into the palms, underneath flexed fingers (Arner, Eliasson, Nicklasson, Sommerstein, & Hägglund, 2008). Some individuals also experience spasticity in the muscles of the ipsilateral hip, shoulder and leg as well (Brown, Rensburg, Lakie, & Wrigh, 1987). Children with spastic hemiplegic CP experience a variety of motor impairments that can compromise a child's ability to perform many of the activities needed for daily living. Therefore, it is necessary to intervene, in order to assist children with spastic hemiplegic CP to acquire upper limb functional abilities, so as to enable them to participate fully in daily life.

Motivation and Rehabilitation in Children with Cerebral Palsy

Studies show that children with CP have significantly lower levels of motivation related to the mastery of tasks, when compared to children of typical development (Jennings, Connors, & Stegman, 1988; Majnemer, Shevell, Law, Poulin, & Rosenbaum, 2010; Tatla et al., 2013). Motivation related to the mastery of a task is defined as an intrinsic psychological force that encourages an individual to attempt to master a skill that is challenging to that person (Majnemer et al., 2010). With respect to motivation in rehabilitation, motivational interventions can be defined as those that promote the initiation and persistence of goal-directed motor behaviour (Tatla et al., 2013), and is usually not a constant factor, but a dynamic process that is difficult to cleary predict for each individual child. Researchers speculate that children with CP experience barriers in free environmental exploration, which may be made worse by overly protective parents and caregivers, leading these children to avoid challenge and prefer less complex tasks, when compared to children of typically development (Jennings, Connors, & Stegman, 1988). This finding was confirmed by Majnemer et al. (2010), in their study that aimed to identify factors associated with motivation in children with CP. Majnemer et al. (2010) found that higher motivation levels in children with CP were associated with higher levels of disability of functional and cognitive abilities.

Low levels of motivation can adversely affect a child's functional abilities and potential, and decrease the effectiveness of therapeutic interventions. Motivation is a critical element of pediatric rehabilitation (Maclean & Pound, 2000), and a crucial element of motor learning (Magill, 2007). In a study by Bartlett and Palisano (2002) that examined the factors that influence the acquisition of motor abilities in children with CP as perceived by physiotherapists, motivation was rated to be the single most influential personal characteristic that determines motor and functional outcomes in physiotherapy. Moreover, motivation was also considered to be extremely important to parents, when evaluating functional therapy programs in children with CP (Law et al., 1998). It is hoped that greater levels of motivation in patients will lead to greater levels of compliance with prescribed treatments, which will in turn lead to greater functional outcomes (Maclean & Pound, 2000). Treatment non-compliance is one of the greatest barriers in medicine and rehabilitation (DiMatteo & DiNicola, 1982), with some physiotherapists speculating that only 64% of their patients comply with short-term exercise prescriptions, while only 23% comply with long-term exercise prescriptions (Sluijs, Kok, & van der Zee, 1993). Therefore, improving motivation may ultimately be one of the most meaningful ways to improve compliance, and actualize the goals of treatment for clinical populations, including children with CP. One novel approach to rehabilitation, which has the potential to enhance motivation is the virtual reality (VR) technologies such as the Nintendo Wii.

Nintendo Wii Interventions and Motivation

The Nintendo Wii is a subset of VR technologies known as active video games (AVGS), which are games that require physical activity beyond that of conventional hand-held controller games (Holden, 2005; Riener & Harders, 2012). In many ways, the potential of AVGs as tools for rehabilitation is connected to their ability to provide motivating therapeutic interventions, especially for children (Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008). With respect to motivation in the context of upper limb Nintendo Wii interventions, three studies in the published literature measured motivation or discussed motivation, or an aspect of motivation, in the context of their results (Chiu, Ada, & Lee, 2014; Howcroft et al., 2012; Winkels, Kottink, Temmink, Nijlant, & Buurke, 2013). Winkels et al. (2013) measured the user satisfaction and motivation of 15 children with CP ages 6 to 14, as part of their 6-week Nintendo Wii upper limb interventions study, that took place at a rehabilitation centre. They used a user satisfaction questionnaire to determine the children's perception of the Wii, and a visual analog scale, to quantify their level of enjoyment and motivation throughout the study. Overall, the results indicated that the enjoyment and motivation levels were high for most children, and the majority of children were satisfied with their experiences playing the Nintendo Wii. Howcroft et al. (2012) conducted a study to evaluate the potential of the Nintendo Wii to promote physical activity and upper limb kinematics conductive to rehabilitation in 17 children with CP with a mean age of 9.43± 1.51 years, during only one session of Nintendo Wii play at a rehabilitation centre. With respect to the motivation and enjoyment aspect of their study, they used the Physical Activity Enjoyment Scale (PACES) to determine the level of enjoyment during the study, and found the average score to be 4.50 (±0.30), out of a possible 5 points, which indicates a high level of enjoyment. Finally, Chiu, Ada, and Lee (2014) compared a 6-week home based Nintendo Wii intervention to improve the upper limb to a control group receiving usual therapy, in sixty two children with CP ages 6 to 13. Although they did not measure motivation directly in their study, they reported a compliance rate of 96% for the children in the Nintendo Wii intervention group, which they attributed to increased motivation levels, due to engagement in the game.

Several other studies in the published literature measured or discussed some aspect of motivation for Nintendo Wii interventions in children with CP, to improve motor and functional outcomes. Robert, Ballaz, Hart, and Lemay (2013) examined the exercise intensity and lower limb kinematics of 10 children with CP ages 7 to 12, when playing Nintendo Wii Fit games in a single session at a rehabilitation centre, as compared to children with typical development. With respect to motivation, participants were asked to rate their levels of motivation on a numeric scale from 1 to 10, and found that the average motivation score for the Wii Fit games was constant, and ranged from 7.38 to 7.90, which represents a moderately high level of motivation. Jelsma, Pronk, Ferguson, and Jelsma-Smit (2013) examine the effects of Nintendo Wii training on 14 children with CP ages 7 to 14, on standing balance, running speed and agility, and timing going up and down the stairs, in a 3 week study at a rehabilitation centre. In terms of motivation, 10 out of the 14 children said that they preferred Wii Fit training to conventional physiotherapy, leading the authors to suggest that Nintendo Wii training might be a positive adjunct to conventional therapy for children with CP. Ballaz, Robert, Lemay, and Prince (2011) examined the exercise intensity and postural kinematics induced by the Nintendo Wii Fit in 11 children ages 7 to 11 with CP, in one training centre in a rehabilitation centre, as compared to children of typical development. With respect to motivation outcomes, participants were asked to rate their levels of enjoyment during the study on a 10 -point scale, and found that the average motivation levels for all the games, were moderate to high (range 6.9 to 8.4). Finally, Gordon, Roopchand-Martin, and Gregg (2012) conducted a study to determine whether the Nintendo Wii could be used to improve gross motor function of 6 children ages 6 to 12, over a 6 week study in a treatment centre. Although motivation was not directly measured, the authors reported a 100% attendance rate for all the children in the study, which was attributed to high motivation and engagement levels.

Several other studies in the published literature have measured motivation levels, along with functional outcomes for VR interventions in general (not using the Wii) in children with CP (Brutsch et al., 2011; Brütsch et al., 2010; Bryanton et al., 2006; Harris & Reid, 2005; Jannink et al., 2008; Sandlund, Dock, Häger, & Waterworth, 2012). One notable study, by Sandlund, Dock, Häger, and Waterworth (2012), aimed to explore parent's perceptions of home based commercial VR interventions (in this case, the Sony EyeToy) for children with CP, in a qualitative study using semi-structured interviews with 15 parents. Overall, the parent perceptions of the study and its methods were very positive, and many parents expressed the view that the increased motivation levels of their children in the study made the program much easier to facilitate at home. Although this study used the Sony EyeToy rather than the Nintendo Wii, the authors generalize their results to low-cost, commercially available AVG consoles, and conclude that the increased motivation levels of children when playing AVGS can help to increase independent training in the home environment, which will lead to greater functional outcomes.

Motivation and Virtual Reality in Self Determination Theory

Along with empirical evidence, the ability of VR to provide motivation for players is also supported by motivation theory. Although there are several different theories of motivation in the published literature (Bandura, 1977; Jackson & Csikszentmihalyi, 1999; Wentzel, Wigfield, & Miele, 2009), self-determination theory has been most successfully applied to VR game theory, by Ryan, Rigby, and Przybylski (2006). Self-determination theory (SDT) addresses the factors that facilitate or undermine motivation, both intrinsic (that is, arising from within the person), or extrinsic (that is, arising from outside, the person, in terms of social or environmental pressures), although the focus is mostly on intrinsic motivation (Ryan & Deci, 2000). SDT posits that the core type of motivation underlying sport, recreation, and by extension AVG, is intrinsic motivation, which refers more specifically to the inherent tendency to seek out novelty and challenges, to extend and exercise one's capacities, and to explore and learn (Ryan & Deci, 2000).

According to SDT, there are three main contextual factors that can support or thwart intrinsic motivation: autonomy, competence, and relatedness (Ryan & Deci, 2000) *Autonomy* describes a situation where a person is allowed to make choices in the context of the activity, and their choices represent a sense of volition, interests and/or willingness to do the task. *Competence* describes a person's need for challenge and feeling effective in a task that allows them to acquire new skills or abilities, and receive positive feedback. *Relatedness* is experienced when a person feels connected to others who are doing the same activity, generally in a group setting(Ryan & Deci, 2000). In addition to these three factors, when explaining intrinsic motivation in the context of VR activities, another two factors apply: presence, and intuitive control (Przybylski, Rigby, & Ryan, 2010; Ryan, Rigby, & Przybylski, 2006). *Presence* refers to the immersive aspects of an activity or game; the sense that one is within the game as a player, rather than an outside observer. *Intuitive control* refers to the extent to which the game activities or movements are logical in the context of the activity, are easily mastered, and do not interfere with one's sense of being within the game. In other words, the actions required to play the game make sense to the player, and are logically related to game outcomes (Ryan, Rigby, & Przybylski, 2006).

Ryan, Rigby, and Przybylski (2006) discuss how VR games in general can fulfil these five components needed for intrinsic motivation. Furthermore, their discussion can be extended to an analysis of AVG consoles such as the Nintendo Wi. The Nintendo Wii, and games such as Wii Sports Resort, can address the need for autonomy in intrinsic motivation, by allowing players a high degree of choice in the selection of games to play. Wii Sports Resort provides players with a choice of 12 games, 8 of which solicit a high degree of upper-limb movements. The Nintendo Wii can also address the need for competence in intrinsic motivation, by constantly challenging players, first allowing them to begin game tasks at easier level, and then advance to more difficult levels as their abilities progress. This gives players the chance to develop new abilities and skills as game tasks change, all the while providing positive feedback in the form of an infinite number of chances to master a task, and in-game rewards such as points or extra capabilities that are unlocked as a player advances. As these capabilities are unlocked, the player gets to explore new territories within the game, which adds to its novelty. Moreover, presence and intuitive control in intrinsic motivation are enhanced by the Nintendo Wii's Wii MotionPlus technology (Tanaka et al., 2012), which aids in motion realism in games i.e. by allowing players to swing the remote like a real-world tennis racquet in tennis, while also providing relatively realistic and appropriate visual, tactile, and auditory feedback (Deutsch et al., 2011). Furthermore, the Nintendo Wii allows for the creation of a Mii avatar, which is an in game character that is inserted into the virtual world, which is created by the player and is customizable to their individual preference. Research into game psychology suggests that being able to choose and customize the character that represents them in a game leads to greater immersion in the game (Lim &

Reeves, 2009), which in this case, may lead to more play, and possibly greater functional outcomes. Finally, relatedness is a possibility in the Nintendo Wii, when it is played with multiple players, group settings, or even online, in Internet communities. Based on these features, it is therefore possible for the Nintendo Wii to provide intrinsic motivation to participants, which can he harnessed for rehabilitation, in order to increase motor and functional outcomes for clinical populations such as children with CP.

Resistance Training and Pediatric Cerebral Palsy

By contrast to Nintendo Wii training, which is a novel rehabilitative approach, resistance training is a more conventional and established approach for the rehabilitation of children with spastic CP (Damiano, 2009). Resistance training, which is also referred to as strength training in the literature pertaining to children with CP (Bernhardt et al., 2001) is a systematic program of exercises designed to cause the muscles to contract against external resistance, in order to increase the strength and endurance of targeted muscle groups (Fleck & Kraemer, 2014). A study by Taylor, Dodd, McBurney, and Graham (2004) on the factors influencing the compliance rates of young people with CP to home based strength programmes found that the main personal factors involved were motivation, autonomy, and the amount of effort it required to complete the program. These findings were reiterated in on the compliance rates in home based studies to improve upper extremity function by Chen, Neufeld, Feely, and Skinner (1999), who found that volition, or motivation levels of participants was a significant predictor of compliance rates. It is likely that motivation levels of children with CP in resistance training exercises, is similar motivation levels of other clinical populations in conventional exercise programs and therapy (Sluijs, Kok, & van der Zee, 1993).

In order to enhance compliance and motivation in rehabilitation for this population, it is necessary to compare and contrast novel approaches such as the Nintendo Wii, to more established interventions the field. In this study, the experimental group underwent a Nintendo Wii intervention, while the non-equivalent control group underwent a resistance training intervention.

Purpose

The purpose of this pilot study was to explore differences in compliance rates, and parent and participant perceptions of enjoyment, exertion and overall feasibility of a Nintendo Wii and a single-joint resistance training intervention for children ages 7 to 12 with spastic hemiplegic CP, with respect to a Nintendo Wii and resistance training intervention to improve upper limb function.

Methods

Study Design

This study employed a quasi-randomized, pre-test-post-test experimental design, with a 4-week follow-up, and a non-equivalent control group. Ethics approval was received from the University Research Ethics Board, and Grandview Children's Centre (GCC), in Oshawa Ontario (Appendices 1 and 2, respectively), and all parents provided informed consent (Appendix 3), and all participants provided child assent (Appendix 4) prior to beginning the study. Participants were randomly assigned to the experimental Wii group (n=3), or the resistance control group (n=3), based on the order in which they were contacted by the researchers, and underwent pre-test assessments, a 6-week intervention, post-test assessments, and a 4-week follow-up assessment, regardless of group assignment.

Recruitment

Children between the ages of 7 and 12 with a diagnosis of spastic hemiplegic CP were contacted through the client database at GCC, and a recruitment letter was sent to their homes, inviting them to participate in the study (Appendix 5). Recruitment posters for the study were also placed on bulletin boards at GCC, inviting potential participants to contact the researchers if interested in participating (Appendix 6). Due to low recruitment rates from these methods, additional ethics approval was granted in order to expand the method of recruitment to include phone calls to the homes of potential participants. Only one initial phone call was made to each home, and if the families did not answer the phone, a message was left on their answering machine, asking them to contact the researchers if interested in the study. Phone calls were made at random, based on the inclusion criteria, by the medical and research director of GCC, according to a verbal recruitment script approved by the University Ethics Board (Appendix 7), and were discontinued once a total of n=6 participants were recruited. If the families expressed interest in the study, their contact information was given to the principal investigator, who then arranged an initial pre-test meeting at the home of the participant, where informed consent was obtained, and the child began the intervention the same day.

Participants

Inclusion criteria for the study required that all participants between the ages of 7 to 12, with a diagnosis of spastic hemiplegic CP. Exclusion criteria for the study was: (1) having undergone any major surgeries in the upper extremities in the past year, (2) medical complications, such as seizures, breathing difficulties etc., that make exercise or virtual reality participation unsafe, (3) regular, weekly play of the Nintendo Wii U Wii

Sports Resort game, and (4) lack of informed consent to participate in the study. Group assignment was generated using an online random assignment tool. Then participants were assigned to their group, based on the order in which they contacted the principal investigator (based on the recruitment letters), or the order in which they agreed to participate (from phone call recruitment). A total of 6 participants were recruited and signed up for the study by their parents.

Procedures

Participant Demographic and Descriptive Information

Once group assignment was determined, the principal investigator and a trained research assistant visited the homes of all participants, in order to enrol them into the study, obtain informed consent from parents and child assent from participants, and conduct pre-test assessments. A supplemental data form was also completed by parents, in order to provide demographic data and relevant medical information for each child (Appendix 8). Information regarding boNT-A treatments for each participant was verified by the developmental paediatrician at GCC.

In addition, parents were also asked to report and/or determine their child's overall level of functioning according to the Manual Ability Classification System (MACS) and the Gross Motor Function Classification System (GMFCS). MACS describes how children with CP use their hands in daily life, by assigning each child to one of five levels, where Level I represents the highest functionality, and Level V, the lowest (Eliasson et al., 2006). GMFCS is also a five level classification system for children with cerebral palsy, that describes a child's movement and locomotion ability, where Level I represents the highest functionality, and Level V the lowest (Rosenbaum, Palisano, Bartlett, Galuppi, & Russell, 2008).

Interventions

Experimental Group – Nintendo Wii Training

Participants assigned to the Wii intervention experimental group were given a Nintendo Wii U system, one Wii MotionPlus Remote controller, a Wii Nunchuck, and the Wii Sports Resort game (Figure 11) , to be played at home. They were instructed to play their choice of games, out of a specific set of games shown in Table 32, for 40 minutes each day, 5 days a week, for a total of 6 weeks, using their affected hand and arm as much as possible. In total, this was 30 days of Wii training, for 40 minutes each day.

Table 32. Wii Intervention Wii Sports Resort Games

Games to Play	Games to Exclude
Tennis	Power cruising
Archery	Cycling
Swordplay	Wakeboarding
Basketball	Air Sports
Bowling	
Canoeing	
Golf	
Frisbee	

Figure 11. Nintendo Wii U equipment

Participants and their parents were also asked to fill out an intervention log each day, that asked participants to state the time they exercised and what games they played, and also rate on a scale of 0 to 5, how much they used their affected arm to exercise, how hard they exercised, and how much fun they had (Appendix 9).

Non-Equivalent Control Group - Resistance Training

Participants in the resistance training control group were given a set of equipment to use at home, consisting of a TheraBand Soft Gel hand-held ball weight, an Elite resistance band, and a gel-filled squeeze ball. The ball weights were of 0.5 kilograms, 1 kilogram, or 1.5 kilograms sizes, and the resistance bands were of Light (yellow) or Medium (green) resistance (Figure 12). Each child was given one ball weight, and one resistance band for the duration of the study. The size of the ball weight and resistance band level was based on the child's initial strength and endurance at the beginning of the study, and their MACS level. A series of 6 exercises, with a set duration, intensity (repetitions and sets), and piece of equipment to use, were given to the control group (Table 33), and they were instructed to exercise 5 days a week, for a period of 6 weeks (30 days in total).

Table 33. Resistance training group exercises

Exercises	Repetitions	Sets
1.Bicep curls with resistance band	12	2
2. Triceps extensions with hand-held weight	12	2
3. Grip strength, with squeeze ball	12	2
4. Shoulder flexion, with hand-held weight	12	2
5. Shoulder abduction, with resistance bands	12	2
6. Shoulder extension, with resistance band	12	2

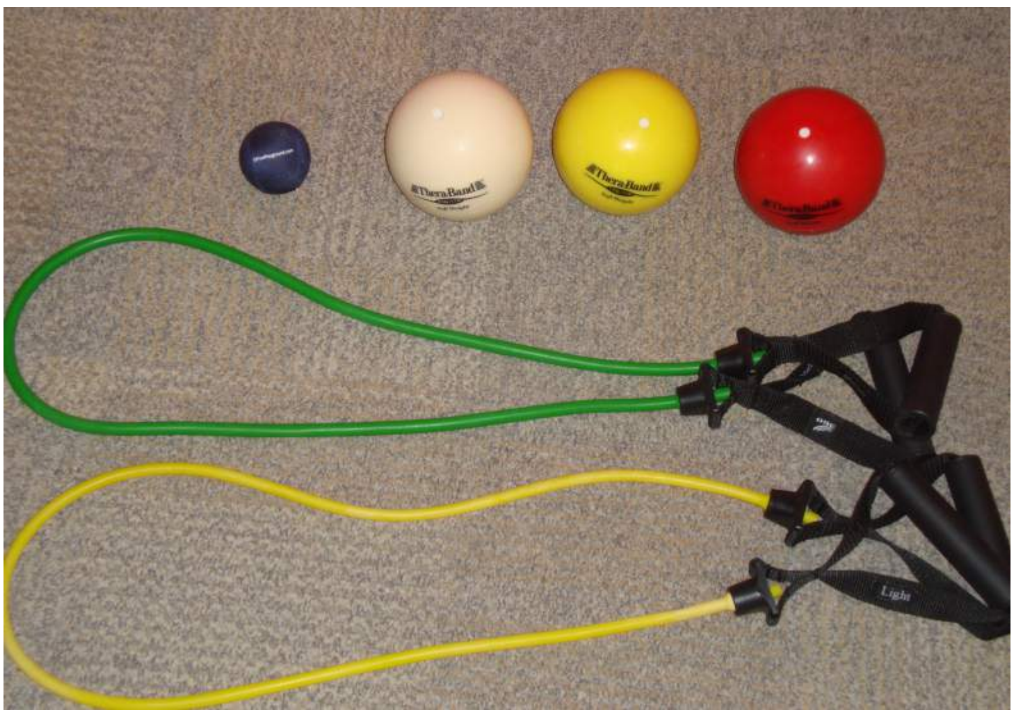

Figure 12. Resistance training equipment

Each exercise was demonstrated to participants and their parents by the principal investigator and research assistant, and participants were given a booklet of the 6 exercises, that consisted of a picture and clear description of how to do each exercise (Appendix 10). Participants and their parents were also asked to fill out an intervention log each day, that asked participants to state the time they exercised, how many sets they did, and how long it took them, and also rate on a scale of 0 to 5, how much they used their affected arm to exercise, how hard they exercised, and how much fun they had (Appendix 11).

Assessments

Pre, post and 4 week follow up assessments were taken for each group in the study. The following assessments were conducted during the pre, post, and follow-up assessment periods:

Intervention Daily Logs

Participants in the Wii and resistance training groups were asked to fill out daily participation logs, that asked participants to record the details of their daily exercise (Appendices 9 and 11). Nintendo Wii participants were asked to state the date, time and duration of the exercise, and circle how many of the recommended games they played that day. Resistance training participants were asked to state the date, time, duration and number of sets completed each day. The total number of days with complete log entries was used as a measure of compliance with the study's protocols. In total, each group required 30 days of exercise. The Wii intervention group required the completion of 1200 minutes of Wii play (40 minutes x 30 days), and the resistance intervention required the completion of 4320 exercises (6 exercises x 12 repetitions x 2 sets for 30 days), in order to be considered 100% compliant with the study's protocol. In addition, all participants were asked to rate their responses to three questions each day, which are displayed in Table 34.

Parent Feedback Form

Parents were asked to provide their feedback on their perceptions of the intervention, in the form of 4 rate-response questions, and 4 written response questions. The four rate response questions are displayed in Table 34. The four written response questions were: “do you feel that your child benefited from this exercise program?”, “was there anything that got in the way of your child doing the exercise program on a daily basis (i.e. daily chores, appointments, etc.)? If so, what was it?”, “what would you change about the exercise program, or the study, to make it more beneficial for your child, or easier to do at home?”, and “do you have any further comments or suggestions as to how to improve home-based therapy programs for children with cerebral palsy?” (Appendix 12).

Melbourne Assessment of Unilateral Upper Limb Function-2

The Melbourne Assessment of Unilateral Upper Limb Function-2 (MA2) is a criterion-referenced test that measures the upper limb quality of movement, of a child’s affected (or spastic) hand, with respect to four sub-skill categories: range of motion, accuracy, dexterity, and fluency. Please refer to Manuscript 1, for a more detailed discussion of this part of the study.

Grip Strength

Maximal hand grip strength was measured in both hands for all participants using a baseline pneumatic (squeeze bulb) dynamometer, with a range of 0 to 15 pounds per square inch (psi) units. Please refer to Manuscript 1 for a more detailed discussion of this part of the study.

ABILHAND-Kids Questionnaire

The ABILHAND-Kids questionnaire is a parent-reported measures that quantifies the manual ability of children with upper limb impairments, in terms of their ability to manage daily activities that require the use of the upper limbs. Please refer to Manuscript 1 for more information

Table 34. Daily intervention log and parent feedback rate-response questions and response scales

Participant Daily Intervention Log Questions	0	1	2	3	4	5
1.How much did you use your affected arm to exercise today?	Not at all	Once or twice	A few times	Half the time	Most of the time	All the time
2.How hard did you exercise today?	Not at all	A little	Some	Medium Hard	Hard	Very Hard
3. Did you have fun exercising today?	No	A little	Some	It was okay	I had fun	I had a lot of fun

Parent Feedback Rate Response Questions	0	1	2	3	4	5
1.Overall, how much fun do you think your had during the exercise program?	None	A little	Some	Average	Fun	A lot of fun
2.How easy was it to motivate your child to do the exercise program?	Very Difficult	Difficult	Somewhat Difficult	Neutral	Not Difficult	Easy
3.Was your exercise program hard to do five days a week, with your child's schedule?	Very Hard	Hard	Somewhat Hard	Neutral	Not Hard	Easy
4.How easy were the instructions for your exercise program to follow for your child?	Very Difficult	Difficult	Somewhat Difficult	Neutral	Not difficult	Easy

Statistical Analysis

Descriptive statistics were used to analyse the results of this pilot study. Part 1 of the results sections provides a case- by-case description of each assessment, for each participant in the study, by group, which includes a description of each participants compliance rates, their daily log responses, parent feedback form rate responses and parent written commments. Part 2 of the results section compares the experimental and non-equivalent control group to each other, in terms of each assessment. Compliance with the study's protocols was quantified by calculating the average compliance rate, in terms of intervention dosage, which is the total number of minutes completed in the study for the Nintendo Wii group, out of the prescribed 1200 minutes, and the total number of exercises completed by the resistance training group, out of 4320. For the daily intervention log questions, the weighted mean and weighted standard deviation was calculated for each participant in the case descriptions section in Part 1, and the mean and standard deviation of these scores was calculated the question, by group. Although rate-response scales are generally considered to be ordinal, or ordered categories, and therefore not suitable for mean calculations, or parametric statistics in general (Jamieson, 2004), the mean calculations were done in order to compare participants and groups to each other for the purposes of discussion. Also, it should be noted that the underlying concept of the rate response scales used in this study was designed to be continuous, with approximately equal intervals between each response.

Results

Part 1: Participant Case Descriptions

Table 35 displays participant demographic information for all participants in the study. All 6 were male, between the ages of 7 to 12. The MACS, and GMFCS level of participants ranged from 1 to 2, and 5 out of 6 participants were left-handed. None of the participants had the main location of spasticity in their dominant hand.

Table 35. Participant demographic information

Participant Designation	Age	Gender	Main Location of Spasticity (Arm)	Dominant Hand	Parent-reported MACS Level	Parent-reported GMFCS Level
Wii Participant-1	7	Male	Right	Left	1	2
Wii Participant-2	8	Male	Right	Left	2	2
Wii Participant-3	12	Male	Left	Right	2	2
Resistance Participant-1	10	Male	Right	Left	1	1
Resistance Participant-2	7	Male	Right	Left	2	1
Resistance Participant-3	12	Male	Right	Left	2	2

<u>Experimental Group - Nintendo Wii Training</u>

Wii Participant 1

Wii Participant-1 (W1) is a 7-year old male, with spastic hemiplegic CP centred in his right upper and lower extremities. He is left- hand dominant, and his parent-reported MACS and GMFCS level is 1 and 2, respectively.

W1 completed the 6-week training, and the post-test on schedule. He withdrew from the 4 week follow-up assessments due to scheduling conflicts. In total, W1 completed 19 daily exercise log entries, out of a prescribed 30, which represents a study compliance rate of 19/30 x100 = 63.3%. In terms of the Nintendo Wii intervention dosage, W1 completed 520 minutes of exercise, out of a prescribed 1200, which represents a treatment compliance rate of 520/1200 x100 = 43.3%.

W1 responded to the three daily log intervention questions displayed in Table 3, 18 times each. For question 1, which was "how much did you use your affected arm to exercise today?", his responses ranged from 1 ("once or twice") to 3 ("half the time"), with a weighted mean response of 2.61 (SD± 0.61). For question 2, which was" how hard did you exercise today?", his responses ranged from 0 ("not at all") to 3 ("medium hard"), with a weighted mean response of 2.28 (SD± 1.07). Finally, for question 3, which was "did you have fun exercising today?", his responses ranged from 0 ("No") to 5 ("I had a lot of fun"), with a weighted mean response of 2.44 (SD±1.34).

Figure 13 displays W1's frequency of play (the number of times each game was recorded as being played by W1) for each of the prescribed Nintendo Wii Sports Resort games. Overall, W1 showed an equal preference for all games except golf, which was his least preferred game. Please see Appendix 14 for the complete daily intervention logs for this participant.

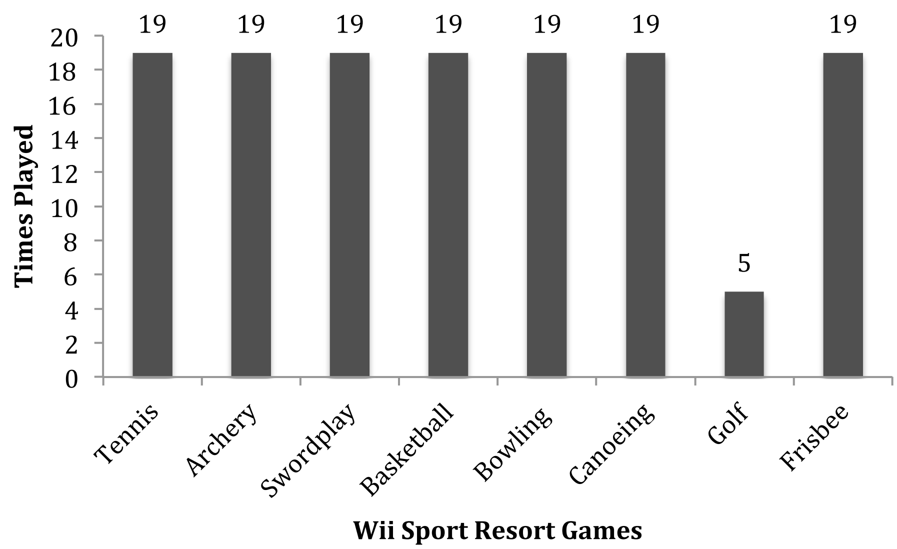

Figure 13. Frequency of play for prescribed Wii Sports Resort games, for Wii Participant-1

W1's parent responded to all 4 of the parent feedback form rate response questions displayed in Table 34. For question 1, which was "overall, how much fun do you think your child had during the exercise program?", the response was 2 ("some"). For question 2, which was "how easy was it to motivate your child to do the exercise program?", the response was 1 ("difficult"). For question 3 which was "was your exercise program difficult to do five days a week with your child's schedule?" the response was 0 ("very hard"), and for question 4, which was "how easy were the instructions for your exercise program to follow for your child?", the response was 5 ("easy"). Table 36 depicts the verbatim answers of W1's parent to the four written response questions on the parent feedback form.

Table 36. Parent feedback form written responses for Wii Participant-1

1. Do you feel that your child benefited from this exercise program?	2. Was there anything that got in the way of your child doing the exercise program on a daily basis? (i.e. daily chores, appointments, etc). If so, what was it?	3. What would you change about the exercise program, or the study, to make it more beneficial for your child, or easier to do at home?	4. Do you have any further comments, or suggestions as to how to improve home-based therapy programs for children with cerebral palsy?
"I think that my child got bored of the games, and after that wasn't even trying"	"I don't get home till after 6 pm so their just didn't seem enough time to work it in to a schedule, and when he would fight over it, I just couldn't fight with him"	"I think more games would of kept his interest"	"More variety of games"

Wii Participant 2

Wii Participant-2 (W2) is an 8 -year old male with spastic hemiplegic CP centred in his right upper and lower extremities. He is left-hand dominant, and his parent - reported MACS and GMFCS level is 2 for both.

W2 completed the 6 weeks of training, the post-test and the 4-week follow-up, on schedule. In total, W2 completed 24 daily exercise log entries, out of a prescribed 30, which represents a study compliance rate of 24/30 x100 = 80%. In terms of the Nintendo Wii intervention dosage, W2 completed 955 minutes of exercise, out of a prescribed 1200 minutes, which represents a treatment compliance rate of 955/1200 x100 = 79.6%.

W2 responded to the three daily log intervention questions displayed in Table 34 23 times each. For question 1, which was "how much did you use your affected arm today?" his responses ranged from 2 (" a few times") to 5 ("all the time"), with a weighted mean response of 4.26 (SD±0.81). For question 2, which was "how hard did you exercise today?", his responses ranged from 0 ("not at all") to 5 ("all the time"), with a weighted mean response of 4.22 (SD±1.24). Finally, for question 3, which was "did you have fun exercising today?", his response was 5 ("I had a lot of fun") for all responses (5.00,SD±0).

Figure 14 displays W2's frequency of play for each of the prescribed Nintendo Wii Sports Resort games. Overall, tennis was W2 most preferred game, while archery was his least preferred game. Please see Appendix 14 for the complete daily intervention logs for this participant.

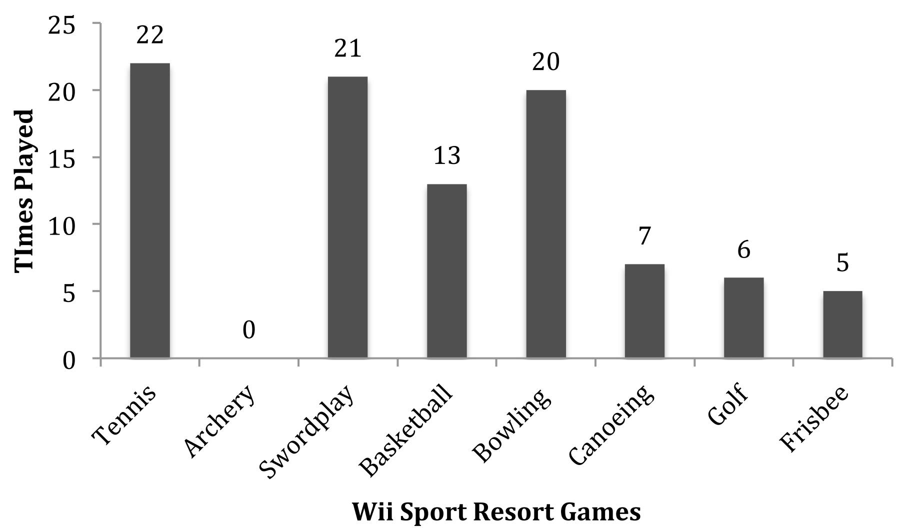

Figure 14. Frequency of play for prescribed Wii Sports Resort games, for Wii Participant-2

W2's parent responded to all 4 of the parent feedback form rate response questions displayed in Table 34. For question 1, which was "overall, how much fun do you think your child had during the exercise program?", the response was 5 ("a lot of fun"). For question 2, which was "how easy was it to motivate your child to do the exercise program?", the response was 4 ("not difficult"). For question 3 which was "was your exercise program difficult to do five days a week with your child's schedule?" the response was 4 ("not hard"), and for question 4, which was "how easy were the instructions for your exercise program to follow for your child?", the response was 5 ("easy"). Table 37 depicts the verbatim answers of W2's parent to the four written response questions on the parent feedback form.

Table 37. Parent feedback form written responses for Wii Participamt-2

1. Do you feel that your child benefited from this exercise program?	2. Was there anything that got in the way of your child doing the exercise program on a daily basis? (i.e. daily chores, appointments, etc). If so, what was it?	3. What would you change about the exercise program, or the study, to make it more beneficial for your child, or easier to do at home?	4. Do you have any further comments, or suggestions as to how to improve home-based therapy programs for children with cerebral palsy?
"I feel as though [W2] has benefited from using this program. He enjoyed playing the games and challenging himself"	"Nothing got in the way. [W2] had a few days that he wasn't feeling well, so he couldn't use it. We tried our best o use it as much as we could"	"I wouldn't change anything"	"I think its great that programs like this can be offered. Its helpful to have a chance to see how beneficial that using the Wii has been for [W2].Thank you for this great opportunity. We have enjoyed having it at our house."

Wii Participant-3

Wii Participant-3 (W3) is a 12- year old male with spastic hemiplegic CP centred in his left upper and lower extremities. He is right-hand dominant, and his parent-reported MACS and GMFCS level is 2 for both.

W3 completed the 6 weeks of training, the post-test and the 4-week follow-up, on schedule. In total, W3 completed 25 daily exercise log entries, out of a prescribed 30, which represents a study compliance rate of 25/30 x100 = 83.3%. In terms of the Nintendo Wii intervention dosage, W1 completed 2340 minutes of exercise, out of a prescribed 1200, which represents a treatment compliance rate of 2340/1200 x 100 = 195%. In other words, W3 played almost twice as much as was prescribed in this study.

W3 responded to the three daily log intervention questions displayed in Table 34, 25 times each. For question 1, which was "how much did you use your affected arm to exercise today?", his response was 5 ("all the time"), for all responses (5.00, ±SD). For question 2, which was "how hard did you exercise today?", his responses ranged from 3 ("medium hard"), to 5 ("very hard"), with a weighted mean response of 4.92(±0.40). for question 3, which was "did you have fun exercising today?", his response was 5 ("I had a lot of fun"), for all responses (5.00, SD ±0).

Figure 15 displays W3 s frequency of play for each of the prescribed Nintendo Wii Sports Resort games. Overall, tennis was W3's most preferred game, while golf and Frisbee were his least preferred game. Please see Appendix 14 for the complete daily intervention logs for this participant.

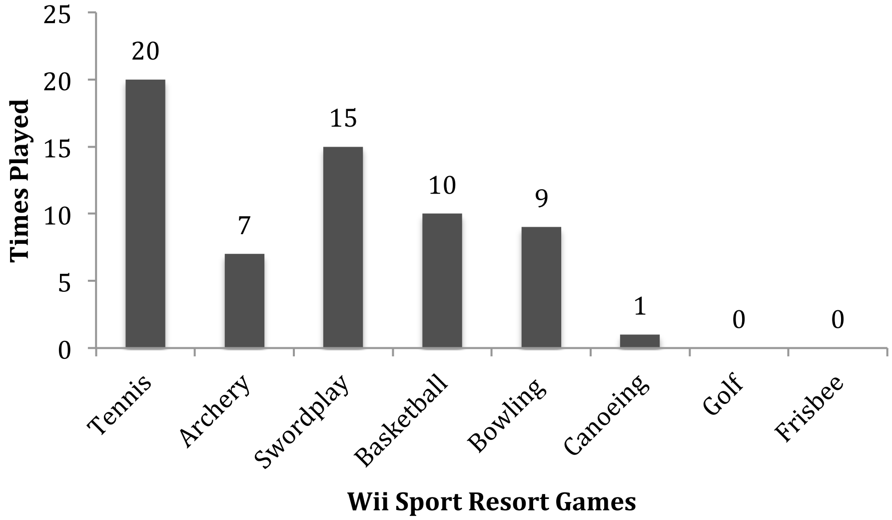

Figure 15. Frequency of play for prescribed Wii Sports Resort games, for Wii Participant-3

W3's parent responded to all 4 of the parent feedback form rate response questions displayed in Table 34. For question 1, which was "overall, how much fun do you think your child had during the exercise program?", the response was 5 ("A lot of fun"). For question 2, which was "how easy was it to motivate your child to do the exercise program?", the response was 4 ("not difficult"). For question 3 which was "was your exercise program difficult to do five days a week with your child's schedule?" the response was 3 ("neutral"), and for question 4, which was "how easy were the instructions for your exercise program to follow for your child?", the response was 5 ("easy"). Table 38 depicts the verbatim answers of W3's parent to the four written response questions on the parent feedback form.

Table 38. Parent feedback form written responses for Wii Participant-3

1. Do you feel that your child benefited from this exercise program?	2. Was there anything that got in the way of your child doing the exercise program on a daily basis? (i.e. daily chores, appointments, etc). If so, what was it?	3. What would you change about the exercise program, or the study, to make it more beneficial for your child, or easier to do at home?	4. Do you have any further comments, or suggestions as to how to improve home-based therapy programs for children with cerebral palsy?
"He had fun, used his arm and hand without any complaints"	"normal stuff, a school trip to Quebec for skiing, physio therapy and homework"	"I would probably put it in another room"	"n/a"

Non-Equivalent Control Group – Resistance Training

Resistance Participant-1

Resistance Participant-1 (R1) is a 10-year old male with spastic hemiplegic CP centred in his right upper and lower extremities. He is left hand-dominant, and his parent-reported MACS and GMFCS level is 1 for both.. R1 received a TheraBand Soft Gel hand-held ball weight of 1.5 kilograms, and a Light tension Elite resistance band.

R1 completed the 6 weeks of training, the post-test and the 4-week follow-up on schedule. In total, R1 completed 2 daily exercise log entries, out of a prescribed 30, which represents a compliance rate of 2/30 x 100 = 6.67%. In terms of the resistance training intervention dosage, R1 completed 216 exercises, out of a prescribed 4320, which represents a treatment compliance rate of 216/4320 x 100= 5.00%.

R1 responded to the three daily log intervention questions displayed in Table 34, 2 times each. For question 1, which was "how much did you use your affected arm today?" his response was 4 ("most of the time"), for all responses (4.00, SD±0). For question 2, which was "how hard did you exercise today?", his response was 4 ("most of the time"), for all responses (4.00, SD±0). Finally for question 3, which was, "did you have fun exercising today?", his response was 4 ("most of the time"), for all responses (4.00, SD±0). Please see Appendix 14 for the complete daily intervention logs for this participant.

R1's parent responded to all 4 of the parent feedback form rate response questions displayed in Table 34. For question 1, which was "overall, how much fun do you think your child had during the exercise program?", the response was 1 ("a little"). For question 2, which was "how easy was it to motivate your child to do the exercise program?", the response was 0 ("very difficult"). For question 3 which was "was your exercise program difficult to do five days a week with your child's schedule?" the response was 1 (" hard"), and for question 4, which was "how easy were the instructions for your exercise program to follow for your child?", the response was 4 ("not difficult"). Table 39 depicts the verbatim answers of R1's parent to the four written response questions on the parent feedback form.

Table 39. Parent feedback form written responses for Resistance Participant-1

1. Do you feel that your child benefited from this exercise program?	2. Was there anything that got in the way of your child doing the exercise program on a daily basis? (i.e. daily chores, appointments, etc). If so, what was it?	3. What would you change about the exercise program, or the study, to make it more beneficial for your child, or easier to do at home?	4. Do you have any further comments, or suggestions as to how to improve home-based therapy programs for children with cerebral palsy?
"I think he would of ,if it had interested him a little more"	"No, I really think it was the lost of interest"	"Maybe make the exercises more adaptable to the child's activity level? Like for [R1] a little more challenging because he is high functioning"	"I think this is a very good way for families to have access to physio/OT for children, and that you should pursue this idea. Also, maybe look outside the Durham Region, like Sickkids Hosp., Wesley/Bayview Rehab (for children), Peterborough"

Resistance Participant-2

Resistance Participant-2 (R2) is a 7-year old male, with spastic hemiplegic CP centred in his right upper and lower extremities. He is left-hand dominant, and his parent-reported MACs and GMFCS level is 2, and 1, respectively.. R2 received a TheraBand Soft Gel hand-held ball weight of 0.5 kilograms, and a Light tension Elite resistance band.

R2 completed the 6 weeks of training, over a period of 10 weeks, due to illness, and completed the 4-week follow-up on schedule. In total, R2 completed 9 daily exercise log entries, out of a prescribed 30, which represents a compliance rate of 9/30 x 100 = 30.0%. In terms of the resistance training intervention dosage, R2 completed 1296 exercises out of a prescribed 4320,which represents a treatmentcompliance rate of 1296/4320 x 100= 30.0%.

R2 responded to the three daily log intervention questions displayed in Table 34, 3 times each. For question 1, which was "how much did you use your affected arm to exercise today?", his responses ranged from 4 ("most of the time") to 5 ("all the time"), with a weighted mean response of 4.67 (SD± 0.58). For question 2, which was" how hard did you exercise today?", his responses ranged from 4("hard") to 5 ("very hard"), with a weighted mean response of 4.33 (SD± 0.58). Finally, for question 3, which was "did you have fun exercising today?", his response was 4, for all responses (4.00, SD±0). Please see Appendix 14 for the complete daily intervention logs for this participant.

R2's parent responded to all 4 of the parent feedback form rate response questions displayed in Table 34. For question 1, which was "overall, how much fun do you think your child had during the exercise program?", the response was 1 ("a little"). For question 2, which was "how easy was it to motivate your child to do the exercise program?", the response was 0 (" very difficult"). For question 3 which was "was your exercise program difficult to do five days a week with your child's schedule?" the response was 0 ("very hard"), and for question 4, which was "how easy were the instructions for your exercise program to follow for your child?", the response was 5 ("easy"). Table 40 depicts the verbatim answers of R2's parent to the written response questions on the parent feedback form.

Table 40. Parent feedback form written responses for Resistance Participant-2

1. Do you feel that your child benefited from this exercise program?	2. Was there anything that got in the way of your child doing the exercise program on a daily basis? (i.e. daily chores, appointments, etc). If so, what was it?	3. What would you change about the exercise program, or the study, to make it more beneficial for your child, or easier to do at home?	4. Do you have any further comments, or suggestions as to how to improve home-based therapy programs for children with cerebral palsy?
" Yes, but difficult for us to stay on track"	" School, and work and his temperament"	"The exercises more child-friendly"	"n/a"

Resistance Participant-3

Resistance Participant-3 (R3) is a 12-year old male, with spastic hemiplegic CP centred in his right upper and lower extremities. He is left-hand dominant, and his parent-reported MACS and GMFCS level is 2 for both. In addition to spastic hemiplegic CP, R3 had a notable, co-ccuring intellectual disability. R3 received a TheraBand Soft Gel hand-held ball weight of 0.5 kilograms, and a Light tension Elite resistance band.

R3 completed the 6 weeks of training over a period of 9 weeks, due to illness, and completed the follow-up 3 weeks after the post-test, due to scheduling conflicts. In total, R3 completed 10 daily exercise log entries, out of a prescribed 30, which represents a compliance rate of 10/30 x 100 = 33.3%. In terms of the resistance training intervention dosage, R3 completed 648 exercises, out of a prescribed 4320, which represents a treatment compliance rate of 648/4320 x 100 = 15%.

R3 responded to the three daily log intervention questions displayed in Table 34, 10 times each. For question 1, which was “how much did you use your affected arm to exercise today?”, his responses ranged from 3 (“half the time”) to 5 (“all the time”), with a weighted mean response of 4.50 (SD± 0.71). For question 2, which was“ how hard did you exercise today?”, his responses ranged from 2 (“some”) to 5 (“very hard”), with a weighted mean response of 3.30 (SD± 1.06). Finally, for question 3, which was “did you have fun exercising today?”, his responses ranged from 3 (“it was okay”) to 5 (“I had a lot of fun”), with a weighted mean response of 4.50 (SD±0.71). Please see Appendix # for the complete daily intervention logs for this participant.

R3’s parent responded to all 4 of the parent feedback form rate response questions displayed in Table 34. For question 1, which was “overall, how much fun do you think your child had during the exercise program?”, the response was 4 (“fun”). For question 2, which was “how easy was it to motivate your child to do the exercise program?”, the response was 2 (“somewhat difficult”). For question 3 which was “was your exercise program difficult to do five days a week with your child’s schedule?” the response was 1 (“hard”), and for question 4, which was “how easy were the instructions for your exercise program to follow for your child?”, the response was 5 (“easy”). Table 41 depicts the verbatim answers of R3’s parent to the written response questions on the parent feedback form.

Table 41. Parent feedback form written responses for Resistance Participant-3

1. Do you feel that your child benefited from this exercise program?	2. Was there anything that got in the way of your child doing the exercise program on a daily basis? (i.e. daily chores, appointments, etc). If so, what was it?	3. What would you change about the exercise program, or the study, to make it more beneficial for your child, or easier to do at home?	4. Do you have any further comments, or suggestions as to how to improve home-based therapy programs for children with cerebral palsy?
" Although [R3] didn't do well with the whole program, I feel that what he did do, I noticed the exercises were getting easier for him to do. He did have fun during the exercises, but it was difficult to get him motivated. He enjoyed the ball exercises, and found the arm curls and resistance band difficult. But when motivated, he tried hard to do them"	"fitting it in to daily schedule; tired from busy day at school; he was quite sick during the time of the study"	"maybe aim for 3 times a week; make visuals that are colourful and pics of other children doing the exercise"	"n/a"

Part 2: Group Analyses, by Assessment

<u>Compliance</u>

Figure 16 compares the intervention treatment compliance rate (that is, the total number of minutes completed for the Nintendo Wii group out of 1200, and the total number of exercises completed for the resistance training group out of 4320 exercises) between the Nintendo Wii experimental group and the resistance training non-equivalent control group. Overall, all participants in the Nintendo group had a higher compliance rate than the most compliant resistance training participant.

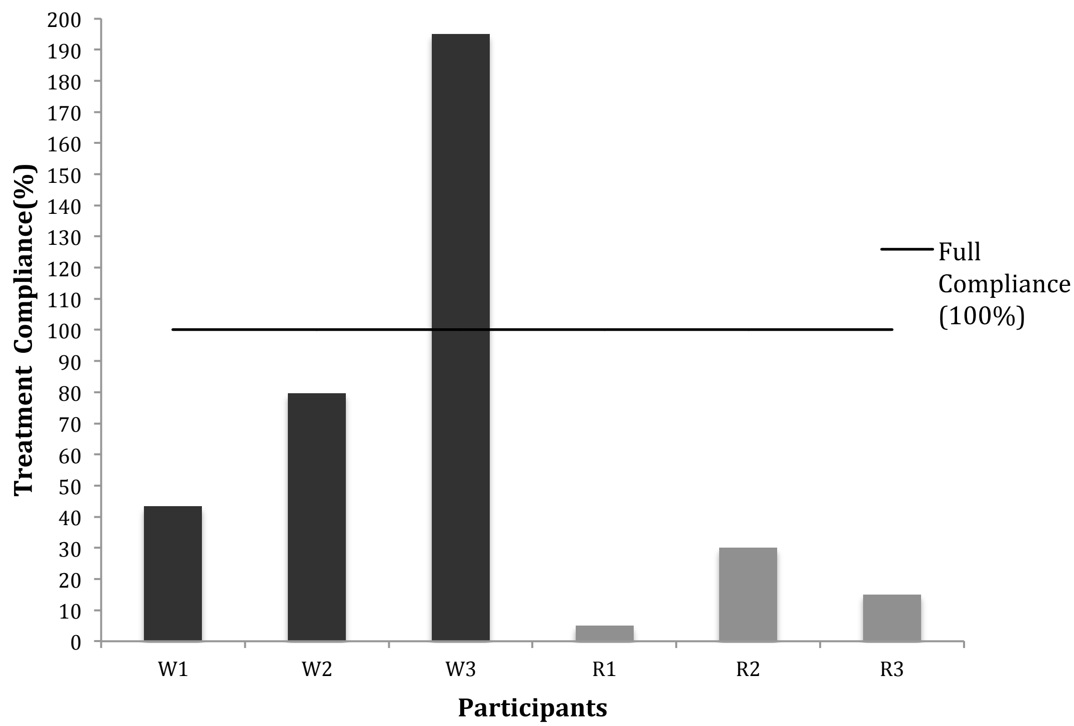

Figure 16. *Intervention dosage percent compliance rate by group for each participant*

<u>Daily Intervention Log Questions</u>

Table 42 depicts the mean, standard deviation and response rate (maximum 30 days x 3 participants =90 responses per group) for the daily intervention log questions in Table 34, for the Nintendo Wii and resistance training groups. Overall, the resistance training group had a higher mean response for all questions, but the Nintendo Wii group had a higher response rate, for all questions. Figures 17 to 22 display each participant's individual responses to these questions graphically, by group.

Table 42. Daily intervention log question weighted means and response rates by group

	"How much did you use your affected arm today?"			"How hard did you exercise today?"			"Did you have fun exercising today?		
	Mean (SD)	Number of Responses (max 90)	Response Rate%	Mean (SD)	Number of Responses (max 90)	Response Rate%	Mean (SD)	Number of Responses (max 90)	Response Rate%
Nintendo Wii	3.96(±1.22)	66	73.3	3.81(±1.37)	66	73.3	4.15(±1.48)	66	73.3
Resistance	4.39(±0.35)	15	16.7	3.88(±0.53)	15	16.7	4.17(±0.28)	15	16.7

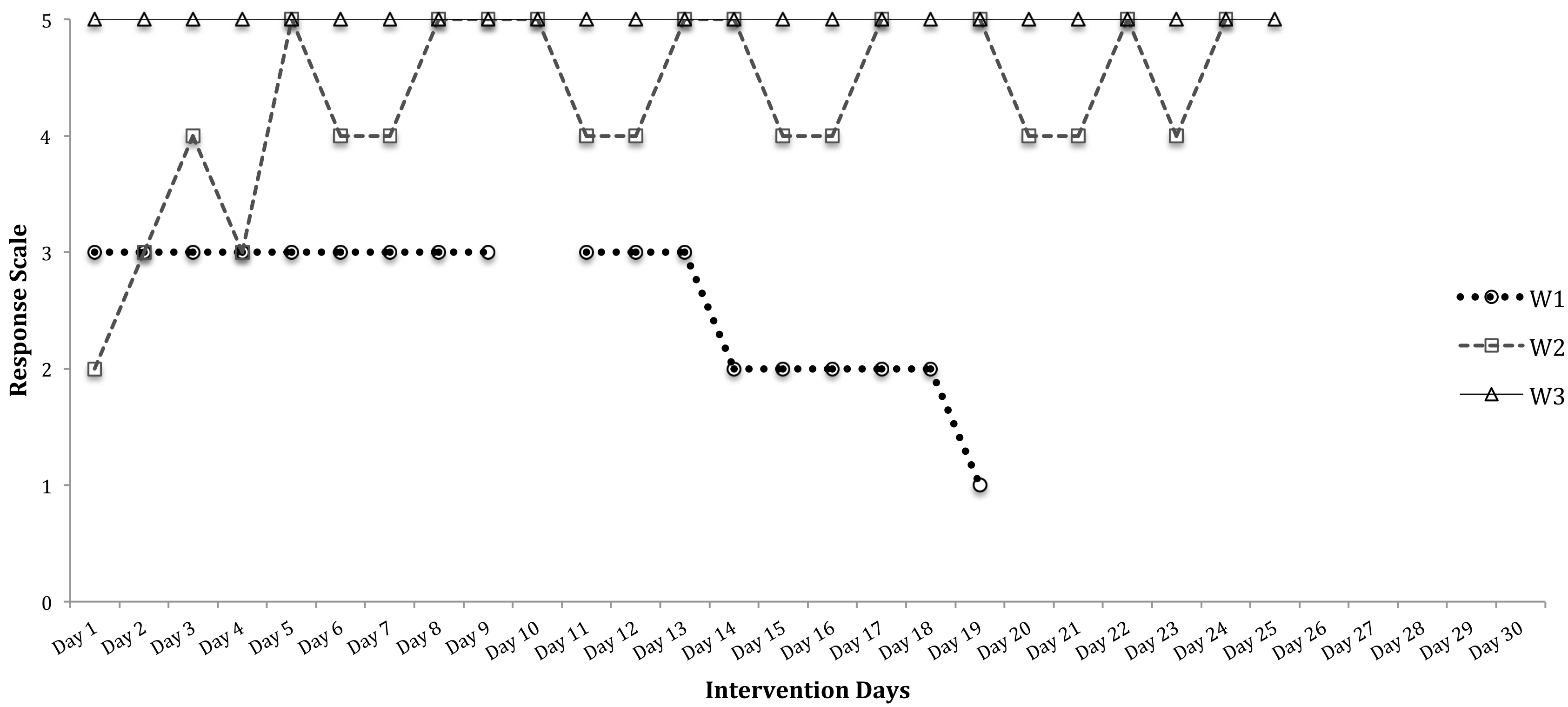

Figure 17. *Nintendo Wii group's responses to the daily log intervention question, "how much did you use your affected arm to exercise today?"*

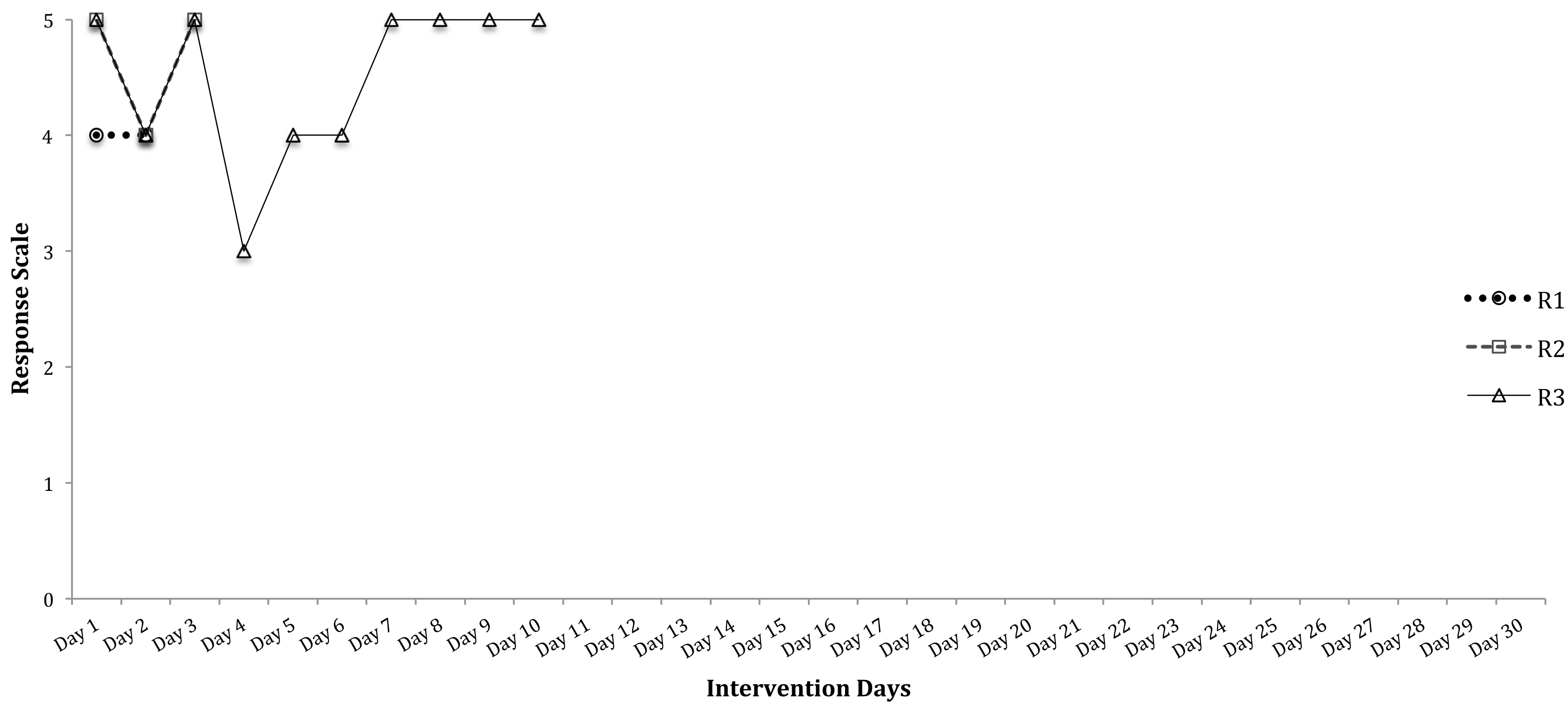

Figure 18. *Resistance group's responses to the daily log question, "how much did you use your affected arm to exercise today?"*

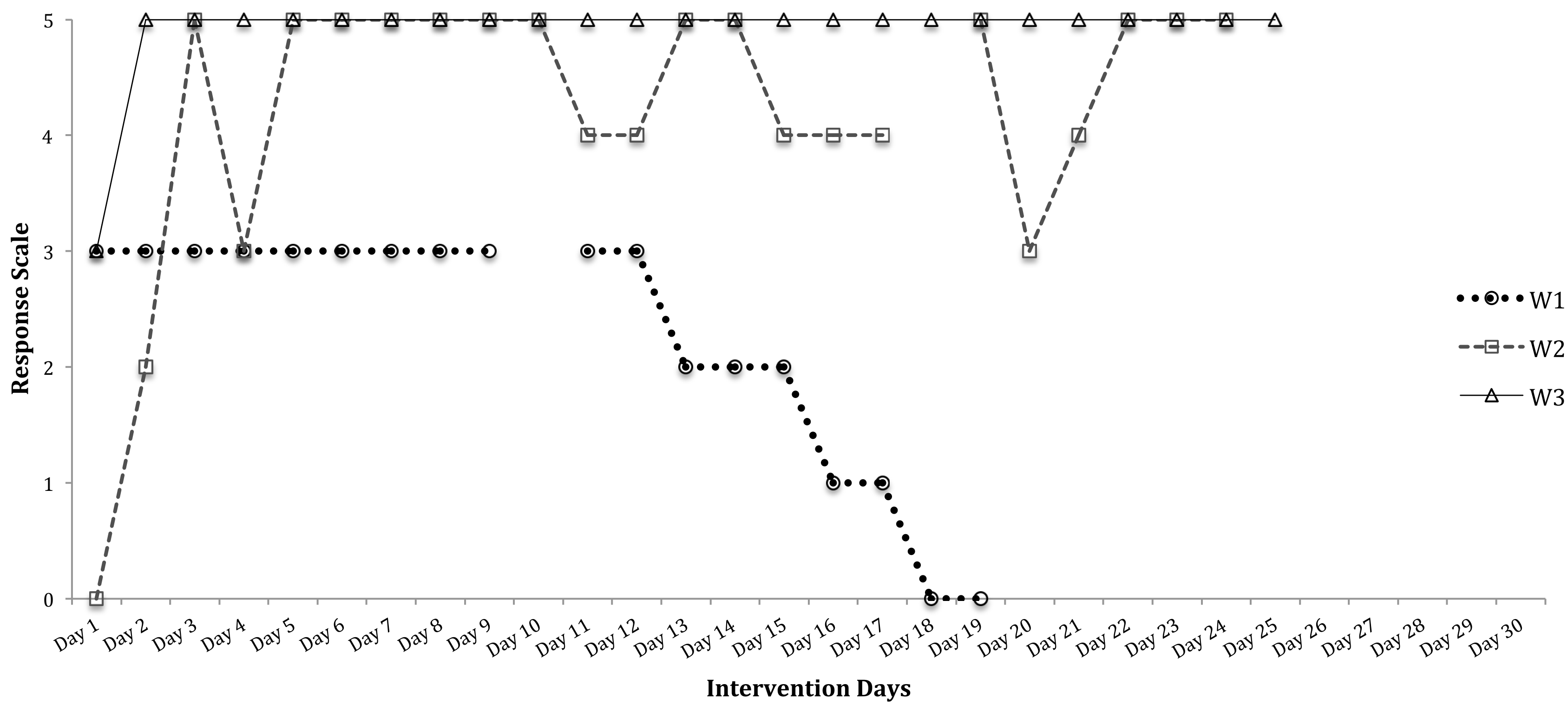

Figure 19. *Nintendo Wii's group responses to the daily log intervention questions," how hard did you exercise today?"*

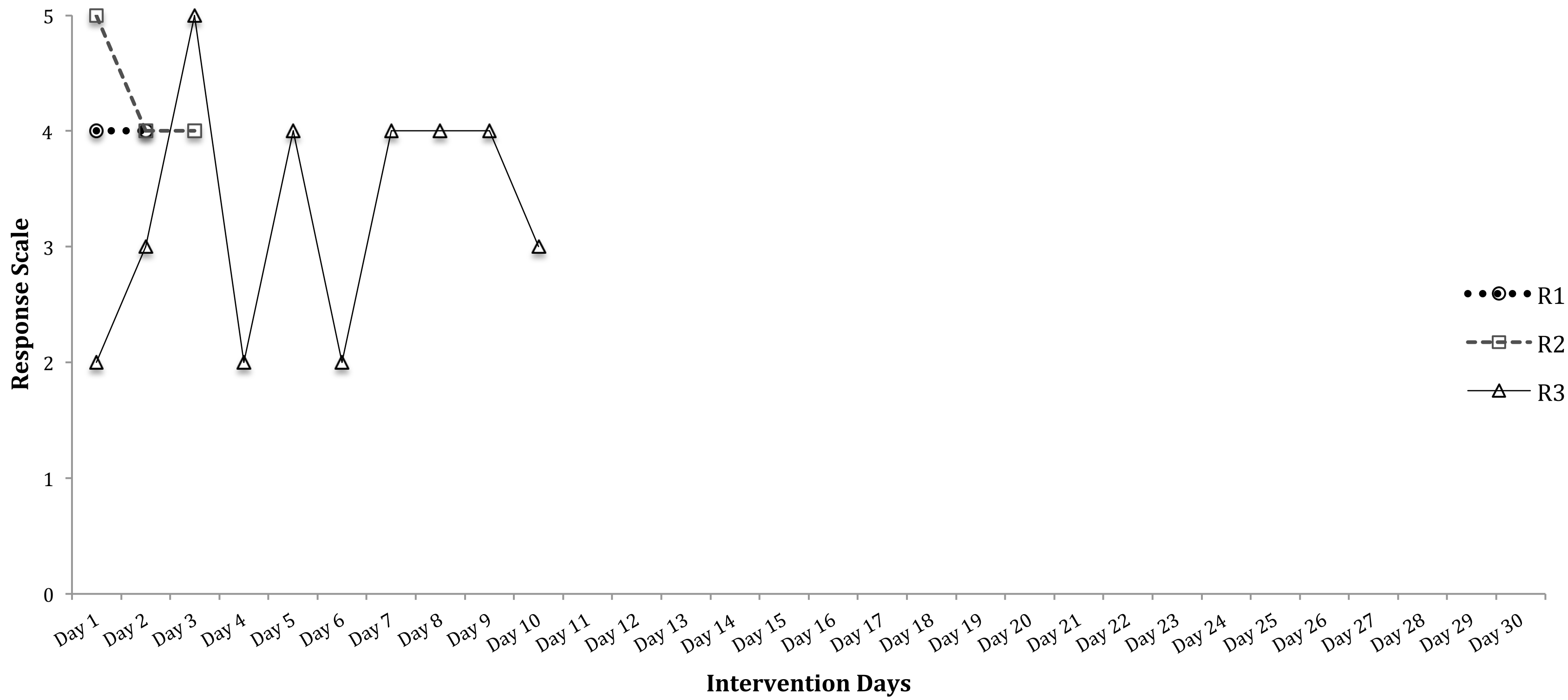

Figure 20. *Resistance group's responses to the daily log intervention question, "how hard did you exercise today?"*

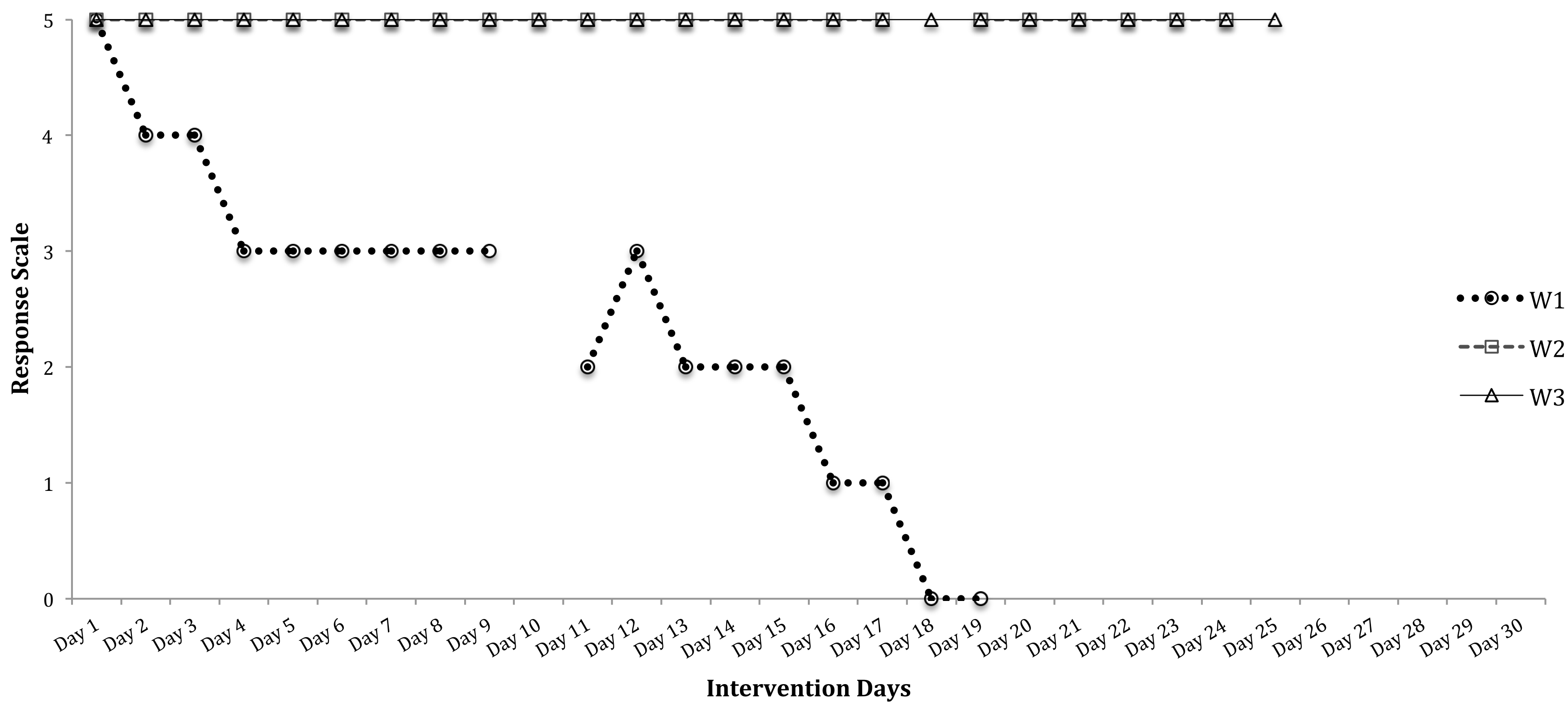

Figure 21. Nintendo Wii group's responses to the daily log question, "did you have fun exercising today?"

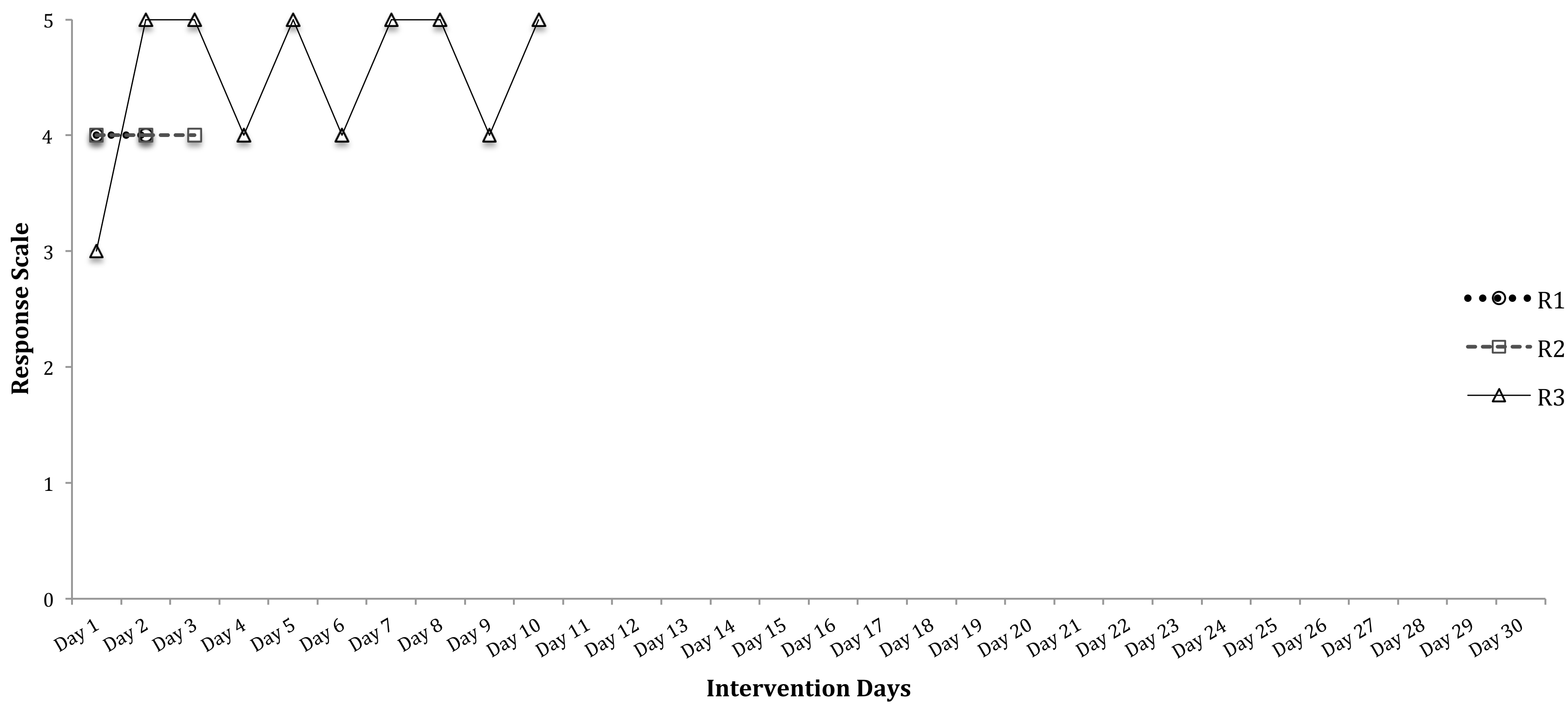

Figure 22. *Resistance training group's responses to the daily log intervention question, "did you have fun exercising today?"*

Parent Feedback Form Rate Response Questions

Table 43 displays the means and standard deviations for the rate-response questions in the parent-feedback form from Table 34, for the Nintendo Wii and resistance training group. Overall, the Nintendo Wii's group responses were higher than the resistance training group's responses, for all questions.

Table 43. Parent rate response questions means and standard deviations, by group

Intervention Group	Question 1,"Overall, how much fun do you think your child had during the exercise program?" Mean (±SD)	Question 2, " How easy was it to motivate your child to do the exercise program?" Mean (±SD)	Question 3, "Was your exercise program hard to do five days a week with your child's schedule?" Mean (±SD)	Question 4, "How easy were the instructions for your exercise program to follow for your child?" Mean (±SD)
Nintendo Wii	4.00 (±1.73)	3.00(±1.73)	2.33(±2.08)	5.00(±0.00)
Resistance	2.00(±1.73)	0.67 (±1.15)	0.67(±0.58)	4.67(±0.58)

Discussion

The purpose of this pilot study was to explore differences in compliance rates, and parent and participant perceptions of enjoyment, exertion and overall feasibility of a Nintendo Wii and resistance training intervention for children ages 7 to 12 with spastic hemiplegic CP, with respect to a Nintendo Wii and single -joint resistance training intervention to improve upper limb function. The resistance training program used in this study was designed to mimic the intensity and duration of 40 minutes of Wii play, and was designed to be easy for children and their parents to do at home, without the supervision of a therapist.

Compliance

The Nintendo Wii group was found to have a higher compliance rate than the resistance training group, as measured by the intervention dosage percent completion rate, where every participant in the Wii group had a higher compliance rate that the resistance participant with the highest compliance rate (Figure 16). This is an encouraging finding, as patient non-compliance with prescribed treatments is one the greatest barriers in effective rehabilitation (DiMatteo & DiNicola, 1982; Sluijs, Kok, & van der Zee, 1993), and it is in line with the findings of other studies that have conducted Nintendo Wii interventions for children with CP. Chiu, Ada, and Lee (2014) had a compliance rate of 96%, for their home-based Nintendo Wii intervention, while Gordon, Roopchand-Martin, and Gregg (2012) reported 100% attendance and compliance for their Nintendo Wii intervention study in a rehabilitation centre, to improve gross motor function in children with CP. Also, Sandlund, Lindh Waterworth, and Häger (2011), who found high compliance rates for their home-based VR study with children with CP, using the Sony EyeToy.

Moreover, in the present study, one participant in the Wii group, W3, exceeded the intervention dosage by more than 95%, exercising 1,140 minutes more than prescribed for the study. While it is not known whether extreme exercise rates such as this are typical for VR interventions for children with disabilities, it is an interesting finding, and one that warrants further investigation. It is possible that it can be explained by this participant's particular preference for the Wii and the games used in the study. However, it is also possible that it is due to specific personal, or familial characteristics that were not controlled for in this study. For example, one potential factor that may have contributed to this finding, is the presence of a similar aged sibling, with whom W3 may have played the Wii. Each household was only provided with one Wii Remote in this study, and participants were not instructed to play the Wii with others; however, siblings may have played together regardless, and the camaraderie and/or competitiveness of siblings exergaming together could have caused the participant to enjoy the games more, be more motivated to advance through the game levels, and therefore play for longer periods of time. Interestingly, W3 also experienced the greatest pre-test to follow-up improvements on the Melbourne Assessment-2 total score, out of all participants in the study (Manuscript 1), which underscores the relationship between compliance and functional outcomes. Moreover, this is supported the findings of O'Donovan et al. (2012), who reported that adult players expended more energy when playing the Xbox Kinect and the Nintendo Wii in multiplayer mode than in single player mode; and by Paw et al. (2008), who found that children were more motivated to play a VR dance game, in multiplayer mode, rather than alone. According to the self-determination theory, relatedness is one of five factors that enhance intrinisic motivation in VR gaming, and is experienced when a person feels connected to others who are doing the same activity (Przybylski, Rigby, & Ryan, 2010; Ryan, Rigby, & Przybylski, 2006). It is therefore possible that multiplayer gaming can enhance the rehabilitative potential of the Nintendo Wii for children with CP, and warrants further study.

Overall, these results provide further evidence for the ability of Nintendo Wii and VR rehabilitation in general, to promote higher compliance rates in children with CP, than conventional therapeutic approaches, which is important, since higher compliance rates with prescribed treatments lead to greater functional outcomes in participants (Maclean & Pound, 2000; Sluijs, Kok, & van der Zee, 1993).

Enjoyment

Participant enjoyment levels were captured by the daily log intervention question 3 in Table 34, which was "did you have fun exercising today?" Although participants in the Nintendo Wii and resistance groups had a similar mean response to this question, the Nintendo Wii group had a much higher mean response rate (Table 42). This indicates that the response rate of the resistance training group only captures participant motivation levels at the beginning of the study, and does not yield any information as to the motivation levels of participants throughout the entire duration of the study. By contrast, the line graph analysis for the Nintendo Wii group in Figure 21 reveals that the Nintendo Wii's group's experience of fun was constant for most of the intervention, especially for W2 and W3. This is in line with the findings of Winkels et al. (2013), who reported sustained levels of enjoyment in 15 children with CP who underwent a 6 week Nintendo Wii intervention to improve upper limb function.

Sustained enjoyment levels play an important role in higher compliance rates, and ultimately lead to improved functional outcomes (Maclean & Pound, 2000). Furthermore, 6 weeks is generally considered to be the minimum time needed to elicit a measureable treatment effect from an exercise intervention, in clinical populations (Chiu, Ada, & Lee, 2014; Dodd, Taylor, & Graham, 2003; Sandlund, Lindh Waterworth, & Häger, 2011). Therefore, the constant response of W2 and W3 of 5 ("I had a lot of fun") for this question, for a period close to 6 weeks suggest that the Nintendo Wii is able sustain enjoyment levels for a period long enough to influence functional outcomes in this population.

This conclusion is further reinforced by the overall higher average ratings of the parents of Wii participants to the parent feedback form rate response questions 1 and 2, which were "overall, how much fun do you think your child had in this exercise program?", and how easy was it to motivate your child to do the exercise program?", respectively. This suggests that parents in the Nintendo Wii group perceived that their children had more fun in the program, and that it was easier to motivate them to do program, than parents of children in the resistance-training group. This finding is supported by Sandlund, Dock, Häger, and Waterworth (2012), in their study on the perceptions of home-based rehabilitation using the Sony EyeToy for children with CP. Sandlund and colleagues reported that parents found it easier to motivate children to exercise on their own when using the VR system, without the constant need to cheer them on, or tell them what to do. By contrast, parents in the resistance-training group had low average responses to questions 1 and 2, and also commented in the written response question section, that “loss of interest” (R1, Table 7, question 2), made it difficult to comply with the study’s protocols, and that it was often “difficult to get [R3] motivated” to do the exercises (R3, Table 9, question 1).

It is important to note that there were outliers in this general trend of greater enjoyment and motivation in the Nintendo Wii group, and lower enjoyment and motivation in the resistance -training group. W1,’s enjoyment levels as measured by daily intervention log question 3, displayed a decreasing trend throughout the study, which eventually dropped to 0 at Day 18 and 19, his last days of participation in the study. According to his parent’s comments from the written response questions in the parent feedback form (Table 4), W1 “got bored of the games” (question 1), and suggested that “more games would of kept his interest” (question 3). Sandlund and colleagues also reported that some participants began to loose interest in VR training in the final weeks of their study (Sandlund, Dock, Häger, & Waterworth, 2012). According to SDT, intrinsic motivation related to the mastery of tasks requires, among other things, a choice of activities that represent a person’s interest, and a sense of volition (autonomy), and an experience of optimal challenge in order to acquire new skills and abilities (competence) (Przybylski, Rigby, & Ryan, 2010; Ryan & Deci, 2000; Ryan, Rigby, & Przybylski, 2006). Therefore, it is likely that W1 required a wider variety of choices in game selection, that offered him a sense of novelty and challenge. This speculation is reinforced by the fact that W1 was the only Wii participant to play all of the recommended games more than once (Figure 3), which suggests he exhausted his choices with respect to Wii Sports Resort. Furthermore, as he was classified as MACS level I, with relatively high scores on several functional assessments at baseline (Manuscript 1), the games of Wii Sports Resort were likely too easy for W1 to be optimally challenged, and therefore motivated to play. W1 was the only participant at MAC level I in the Nintendo Wii group, while the W2 and W3 were both classified at MAC level II.

Another outlier in the general trend of greater enjoyment and motivation in the Wii group, as compared to the resistance training group was R3. Although R3's parent expressed the view that it was difficult to motivate him to do the exercises (Table 41 question 1), his parent responded with 4 ("fun") to the rate response question "overall, how much fun do you think your child had during the exercise program?" (Table 34). Furthermore, in written response section of the parent feedback form, R3's parent commented that, "although [R3] didn't do well with the whole program…he did have fun during the exercises" (Table 41, question 1). One potential explanation for this discrepency is a higher degree of parent involvement in R3's exercise sessions, as compared to the other participants in the resistance group. R3 was the only participant with a notable co-occuring intellectual disability alongside his diagnosis of CP, which caused him to require more assistance in completing the exercises. Due to the expressed difficulty in motivating him to do the exercises, it is possible that his parent was highly involved in his training, using verbal encouragements, positive reinforcements, or even other motivational techniques such as music or television, in order to get R3 to comply, These techniques may have changed his enjoyment levels in the study. However, it should be noted that even though R3 experienced more fun in the resistance training intervention than the other resistance participants, and his overall compliance rate was still below 50% (Figure 16)

Overall, when taken together, the results from this study suggest that the Nintendo Wii has the potential to solicit greater, and more sustained enjoyment levels in children with CP, when compared to more conventional approaches at rehabilitation such as resistance training. This suggests that Wii training is a viable way to increase participant motivation in therapy, which will lead to greater compliance rates, and greater functional outcomes.

Participant Perceived Exertion and Use of the Affected Arm

Participant perceived exertion and use of their affected arm in the study was captured by the daily log intervention questions 1 and 2 in Table 34, which were, “how much did you use your affected arm to exercise today?, and “how hard did you exercise today”, respectively. The resistance group had a higher mean response to both of these questions, but the Wii group had a higher response rate, which indicates that these questions only capture the resistance group’s use of their affected limb and exertion, at the beginning of the study, while the Wii group’s responses are more indicative of sustained use of the affected limb, and exertion. Therefore, it is not known how the resistance group would have responded to these questions in the middle or end of the intervention, although it is possible that since the resistance exercises were all designed to be bimanual, resistance participants would have continued to give high responses to these questions.

By contrast, the Nintendo Wii varies with respect to unimanual and bimanual activities depending on the game, and although Wii participants were asked to use their affected hand when playing unimanual games, this was not enforced in the study design (i.e. with constraints on their affected limb). Generally speaking, the line graph analyses for daily log questions 1 and 2 in Figures 17, and 19 demonstrate the same overall trend as the participant enjoyment line graphs on Figure 21. The Wii participants with higher enjoyment levels(W2 and W3), tended to use their affected arm more, and experienced greater exertion while exercising, while W1 remained an outlier. It likely that use of the affected arm and perceived exertion when exercising are related, since children with spastic hemiplegic CP generally favour the use of their non-affected limb (Thompson, Chow, Vey, & Lloyd, 2015), and may therefore find it more tiring to use their affected limb when playing the Wii. Furthermore, it is also likely that the type of game favoured by participants influenced the use of the affected limb and perceived exertion as well. For instance, Howcroft et al. (2012) conducted a study to evaluate the potential of the Nintendo Wii to promote physical activity and energy expenditure in children with CP, and found that, while participants attained moderate levels of exertion while playing, this was dependant on the type of game, where those that engaged all four limbs during play lead to more energy expenditure than games that only engaged the upper or lower limbs, respectively. Similar findings were also reported in studies that used the Nintendo Wii Fit for lower limb rehabilitation and exercise intensity in children with CP (Ballaz, Robert, Lemay, & Prince, 2011; Robert, Ballaz, Hart, & Lemay, 2013),where different results were found, depending on the Wii game used. Therefore, it is likely that they types of games played by participants in this study affected their perceived level of exertion.

Overall, while it is not possible to make definitive comparisons between the Nintendo Wii and resistance groups in terms of which intervention solicits greater affected limb use and exertion in children with spastic hemiplegic CP, the results of this study suggest that further exploration into this, in terms of which games lead to more exertion, or the effects of constraint induced therapy on the upper limb in a Wii intervention, are warranted. It should be noted, however, that the Wii participants that responded that they used their affected arm more, had greater functional improvements upper limb outcome measures, which are discussed in Manuscript 1.

Feasibility

Feasibility of the Nintendo Wii and resistance training interventions was captured by questions 3 and 4 of the rate response questions in the parent feedback form, which were "was your exercise program hard to do five days a week, with your child's schedule?", and "how easy were the instructions for your exercise program to follow for your child?", respectively. Overall, the Nintendo Wii group had higher mean responses to both these questions, with a very similar response for both groups for question 4. This suggests that the Nintendo Wii intervention is easier to accommodate in a busy schedule, and that it is easier for children to understand and remember one direction ("play the Wii for 40 minutes") as opposed to several ("do these 6 exercises, 12 times each, twice a day"). This is important, as the ability of a home intervention to promote independent training in children is likely to reduce the parental effort needed to facilitate the exercise program, and increase positive functional outcomes.

With respect to question 3, there was a greater difference between the average responses of the Wii and resistance group, and the average response to question 3 for the Wii group, was only a 2.33 (Table 11), which represents a response between "somewhat hard" and "neutral" (Table 3). This reveals that despite group assignment, it is still difficult for the families of children with CP in general, to comply with prescribed therapy of this intensity and duration, as they often have multiple responsibilities and demands on their time. Furthermore, children often experience changes in mood, behaviour, and motivation levels from day-to-day, all of which can interfere with therapy, and constrain the schedules of their parents. These sentiments were expressed by parents in the written response section of the parent feedback form, where it was stated that "school, work and [the child's] temperament" interfered with study compliance (R2, Table 8, question 2), that there "just didn't seem to be enough time to work [the exercise program] into a schedule" (W1, Table 4, question 2), and perhaps it would be best to "aim for 3 times a week" (R3, Table 9, question 3) to exercise, rather than 5 days a week. Similar attitudes were also found by Sandlund, Dock, Häger, and Waterworth (2012), where parents expressed the view that an obligation to exercise every day could, in the long run, lead to less motivation.

Nevertheless, overall the results of this study suggest that the Nintendo Wii is more feasible than the specific resistance training program used in this study, in the homes of families of children with CP, even though the resistance program was designed to be of a comparable intensity level to 40 minutes of Wii play. Possible reasons for this include greater motivation and enjoyment levels for participants, which makes independent training for children more likely, and the ease with which children can understand and navigate the Nintendo Wii console.

Strengths and Limitations

The findings of this pilot study have both strengths and limitations. One strength of this study is that it is, to the best of our knowledge, the first study to compare Nintendo Wii training to resistance training for the upper limbs, in children with spastic hemiplegic CP. Therefore, this study fills a gap in the published literature, adding to the research on both Nintendo Wii interventions and resistance training interventions for the upper limbs in this populations. A second strength of this study is that it attempts to validate home-based therapeutic approach, which can be a useful adjunct to conventional physiotherapy for children with CP. Additionally, a third strength of this study is that it is community-based, and was run with minimal funding. Therefore, this study could be replicated with relative ease by other researchers and clinicians, who are interested in affirming or expanding upon its findings.

The primary limitation with this study its small sample size, which reduces our statistical power to detect true changes between groups. Other limitations include the lack of a representative sample of children with spastic hemiplegic CP – in this study, all participants were male, which is not reflective of the1.5 to 1, male to female distribution of CP (Christensen et al., 2014). Also, we were unable to compare both groups to true control, that received standard treatment centre based physiotherapy, and no home intervention. It was also not possible for us to control for the effects of boNT-A, cognitive and/or co-occuring disabilities, the use of other active video gaming consoles by participants, or their participation in other exercise programs during the course of the study. Another limitation is the inability of the daily intervention logs to capture the details of daily exercise, i.e. such as what individual exercises were done in the resistance group, or the level and difficulty settings of each game played in the Nintendo Wii intervention. As there are very few valid and reliable clinical assessment tools to measure participant motivation exercise exertion, or overall feasibility for home-based VR interventions for children with disabilities (Tatla et al., 2013), it was not possible for us to use them in this study. Finally, researchers in this study were not blind to group randomization, which may have introduced bias into the findings. However, despite these limitations, the results of this study were able to clearly demonstrate differences in compliance rates between these two interventions, and explore in some detail both individual and group differences with respect to enjoyment, use of the affected limb, exertion and overall feasibility of the interventions.

Future Research

Future research should expand upon these findings by the increasing sample size, and its male to female distribution. It would also improve the validity of the group comparisons if participants were matched in each group by age, ability, and MACS level, and a randomized control trial, with blinded assessors was conducted. Also, the use of more detailed daily exercise logs should be used in a format that does not increase participant burden, along with clinically validated scales for determining participant enjoyment and motivation levels, feasibility and exercise exertion in the context of VR, if they are available. The effects of different intervention intensities and dosage on the variables measured in this study are also warranted, along with an exploration of the effects of different Wii games, other AVG gaming consoles such as the Sony EyeToy or the Microsoft Kinect, and resistanece training programs of different intensities and . durations. Finally, a longer follow-up period would allow researchers to more clearly ascertain the effects of these interventions on this population with more certainty.

Conclusions

The purpose of this pilot study was to explore differences in compliance rates, and parent and participant perceptions of enjoyment, exertion and overall feasibility of a Nintendo Wii and a single joint resistance training intervention for children ages 7 to 12 with spastic hemiplegic CP, with respect to a Nintendo Wii and similar-intensity resistance training intervention to improve upper limb function. Overall, the Nintendo Wii group was found to have a higher compliance rate with the study's protocols, where every participant in the Wii group had a higher compliance rate than the resistance group participant with the highest compliance rate. The Nintendo Wii group also demonstrated sustained enjoyment levels, exertion, and use of a their affected limb, and parent perceptions of participant motivation levels throughout the study were, on average higher for the Wii group, than the resistance group. Finally, on average, parent's rated the Nintendo Wii intervention as more feasible to accommodate in their schedules, and easier for children to follow, as compared to the resistance training group.

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SECTION 5: THESIS CONCLUSIONS

Overview

Cerebral palsy (CP) is the most common cause of physical disability in children, with a prevalence rate of 2.0 to 2.5 per 1000 live births in Western countries (Hirtz et al., 2007; Koman, Smith, & Shilt, 2004). Of these children, approximately 23% of children with the spastic subtype of CP have spastic hemiplegic CP (Christensen et al., 2014). Spastic hemiplegic CP involves spasticity in one side of the body, usually with the arms more affected than the legs (Hoon & Tolley, 2013). Children with spastic hemiplegic CP experience a variety of motor impairments, including range of motion and coordination deficits (Arner, Eliasson, Nicklasson, Sommerstein, & Hägglund, 2008; Koman et al., 2008), sensory impairments (Cooper, Majnemer, Rosenblatt, & Birnbaum, 1995) and muscle weakness (Damiano, Dodd, & Taylor, 2002). These impairments can severely compromise a child's ability to perform upper limb functions such as reaching, grasping and manipulating objects, as well as performing daily activities that require the use of the upper limbs. Therefore, it is necessary to intervene in this area and use innovative and effective rehabilitation strategies, so as to enable children with spastic hemiplegic CP to participate fully in adult life. Specifically, it is important to validate new approaches to upper limb rehabilitation that are motivating for children, and easy to integrate into the home lives of families of children with CP and their families. Also, it is important to contrast novel rehabilitation strategies to more established therapeutic approaches, so as to promote greater knowledge and understanding of the functional and therapeutic gains of these interventions. One novel rehabilitation strategy that can address the need for effective and motivating therapy is the Nintendo Wii, which is an active video game (AVG) console, which requires physical activity beyond that of conventional hand-held controller games. However, there are only a few studies in the published literature that have examined the effects of a Wii intervention to improve upper limb function in children with CP (Chiu, Ada, & Lee, 2014; Howcroft et al., 2012; Winkels, Kottink, Temmink, Nijlant, & Buurke, 2013). By contrast, resistance training is conventional and a well –established approach to the rehabilitation of children with spastic CP (Damiano, 2009; Damiano, Dodd, & Taylor, 2002; Dodd, Taylor, & Damiano, 2002; Mockford & Caulton, 2008).

The primary purpose of this pilot study was to determine whether there are benefits to children between the ages of 7 to 12 with spastic hemiplegic CP, in terms of improvements in upper limb quality of movement (i.e. range of motion, accuracy, fluency and dexterity), grip strength and the performance of daily activities requiring the use of the upper limbs, after a Nintendo Wii U intervention using Wii Sports Resort, to improve upper limb function. A secondary objective was to determine the comparative effectiveness of a Nintendo Wii intervention, when compared to a single-joint resistance training program of a similar intensity and duration for the upper upper limbs , with respect to these outcomes. Finally, a tertiary objective of this study was to explore differences in compliance rates, and parent and participant perceptions of enjoyment, exertion and overall feasibility of a Nintendo Wii and resistance training intervention for this population.

Our findings indicate that there are benefits to Nintendo Wii training for children with spastic hemiplegic CP, with respect to upper limb quality of movement, grip strength and the performance of daily activities. All participants in the Wii intervention group experienced positive changes in more than one assessment from pre-test to follow-up. Furthermore, although participants in the resistance training group also experienced positive improvements from pre –test to follow-up, participants in the Wii group made greater positive changes in more assessments than the resistance training group, in a wider range of motor function domains. Furthermore, the Nintendo Wii group was found to have a higher compliance rate with the study's protocols, where every participant in the Wii group had a higher compliance rate than the resistance group participant with the highest compliance rate. The Nintendo Wii group also demonstrated sustained enjoyment levels, exertion, and use of their affected limb, and parent perceptions of participant motivation levels throughout the study were, on average higher for the Wii group, than the resistance group. Finally, on average, parent's rated the Nintendo Wii intervention as more feasible to accommodate in their schedules, and easier for children to follow, as compared to the resistance training group.

Overall, this pilot study suggests that Nintendo Wii interventions for the upper limbs may be a more effective home-based rehabilitation strategy than the specific upper-limb, single-joint resistance training program used in this study, for children with spastic hemiplegic CP, ptimarlydue to greater participant motivation to comply with Wii training and greater feasibility of Wii training in the home; which will ultimately translate into greater functional gains for the Wii group. Although there are clearly established benefits to resistance training in this population (Damiano, 2009; Damiano, Dodd, & Taylor, 2002; Dodd, Taylor, & Damiano, 2002; Mockford & Caulton, 2008), if participants do not, or are unable to comply with the training regimen, the functional benefits of resistance training will not be experienced by this population. Therefore, when designing therapeutic interventions for children with CP for use at home, it is essential to consider both the functional benefits of the therapy, participant motivation levels, and feasibility of use, in order to achieve higher compliance rates, and greater treatment outcomes.

Other findings of interest are related to the efficacy of the Nintendo Wii for certain subsets of children with CP, and the domains of motor function targeted. Specifically, it may be that Nintendo Wii training is appropriate for children with greater functional impairments, or lower MACS levels as opposed to those that are already fairly high functioning, with higher MACS levels. It appears that those at MACs level I do not experience Nintendo Wii training with the Wii Sports Resorts game as challenging enough to facilitate functional improvements. However, children at MACS level II do experience the games as challenging, although this would also need to assessed as being true for children and MACS level III or IV as well. Also, participants in the Nintendo Wii group experienced improvements in a variety of motor function domains , which suggests that the Nintendo Wii may be able to target a comprehensive range of parameters affecting upper limb functionality, such as movement fluency, dexterity, accuracy and range of motion. We hypothesize that throughout the course of its many games, the Nintendo Wii draws on a wider repertoire of integrated movements, while providing the player with visual, tactile and auditory feedback. However these hypothesis would need to be confirmed by more research.

Finally, the results of this study are supported by dynamics systems theory (Kamm, Thelen, & Jensen, 1990; Thelen, 1995, 2000), which postulates that movement is produced from the interaction of multiple sub-systems in within the person, the task and the environment, which self organize to produce energy efficient states of movement, known as attractor states. A slight change in one of the control parameters that organize a sub-system can cause the whole movement behaviour to shift, producing a new attractor state. In Nintendo Wii training, control parameter manipulation is achieved through the repeated practice and participation in a variety of games that simulate the motion used in sports, such as tennis, swordplay and archery. This experience using a virtual environment allows the child to gain the experience, strength, coordination and motivation to allow more skills to emerge. More research is needed to delineate which potential control parameters in children with spastic hemiplegic CP are targeted through active video games but we hypothesize that unimanual and bimanual coordination, range of motion, and muscular strength and endurance, along with fine motor functions such as dexterity. With respect to resistance training, control parameters of muscular strength and endurance are targeted (Fleck & Kraemer, 2014), and possibly also bimanual coordination, as the majority of exercises in this intervention involve simultaneous use of both hands. In addition, motivation can also acts as a psychological control parameter in participants. This leads to a permanent shift in the attractor states of children with CP , which causes their upper limb motor behaviours to shift from atypical movements to more efficient movement states.

Ultimately, the results of this pilot study indicate that the Nintendo Wii does demonstrate the potential to be a useful tool in upper limb therapeutic interventions for children with spastic hemiplegic CP, in the home environment. Therefore, future investigations into Nintendo Wii rehabilitation, along with resistance training for the upper limbs is warranted.

Recommendations

Future research should address some of this study's limitations, and expand upon its findings. The primary limitation with this study its small sample size, which reduces our statistical power to detect true changes between groups, and its lack of representation of children with spastic hemiplegic CP in terms of gender, since all participants were male, which is not reflective of the1.5 to 1, male to female distribution of CP (Christensen et al., 2014). Therefore, future research should increase sample size, and its male to female distribution. It would also improve the validity of the group comparisons if participants were matched in each group by age, ability, and MACS level, and a randomized control trial, with blinded assessors was conducted. Also, in order to decrease within- participant variability from one assessment period to another, multiple baseline assessments should be conducted, on all measures where possible. Furthermore a larger number of clinical assessment and techniques to quantify other dimensions of upper limb functionality should be used, in order to determine the functional outcomes of these interventions in more detail. Specifically, it would be useful to directly measure changes in both passive and active range of motion in the upper extremities, along with bimanual functionality, muscular strength of flexors and extensors and spasticity. Also a detailed kinematics analysis of different Wii games, in terms of the types of movements and motor functions solicited, would allow clinicians and researchers to determine the appropriate Wii game to use for this population, in order to target specific functional outcomes. This would assist game developers who are designing and/or modifying AVG consoles for pediatric rehabilitation in CP (Gregory, Howard, & Boonthum-Denecke, 2012; Hernandez, Ye, Graham, Fehlings, & Switzer, 2013). In addition to this, the effects of different intervention intensities and dosage on the variables measured in this study are also warranted, along with an exploration of the functional outcomes and differences with respect to MACS level, specific Wii games, and even other AVG consoles. Finally, a longer follow-up period would allow researchers to more clearly ascertain the effects of these interventions, on this population with more certainty.

Conclusions

In conclusion, this study is, to the best of our knowledge, the first to compare Nintendo Wii training to resistance training for the upper limbs, in children with spastic hemiplegic CP. Therefore, this study fills a gap in the published literature, adding to the research on both Nintendo Wii interventions and resistance training interventions for the upper limbs in this populations. Also, this study is an attempt to validate the Nintendo Wii, and VR interventions more generally, as a home-based therapeutic approach for the rehabilitation of children with CP, which can be a useful adjunct to conventional physiotherapy for children with CP. Finally, this study is community-based, and was run minimal funding, and the support of a local treatment centre for children with disabilities, This makes it relevant to the lives of children with disabilities and their families, allows it to be replicated with relative ease by other researchers and clinicians, who are interested in affirming or expanding upon its findings.

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SECTION 6: APPENDICES

Appendix 1: Letter of Approval from the University of Ontario Institute of Technology Research Ethics Board

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

RESEARCH ETHICS BOARD
OFFICE OF RESEARCH SERVICES

Date: August 18th, 2014

To: Caroline Kassee (Student PI) and Meghann Lloyd (Supervisor)

From: Bill Goodman, REB Chair

REB File #: 14-003 (Full Board Review)

Project Title: Conventional resistance training versus a Nintendo Wii intervention to improve upper limb functionality in children ages 7 to 12 with spastic cerebral palsy

DECISION: APPROVED

EXPIRY: August 18th, 2015

The University of Ontario, Institute of Technology Research Ethics Board (REB) has reviewed and approved the above research proposal. This application has been reviewed to ensure compliance with the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2) and the UOIT Research Ethics Policy and Procedures.

Please note that the (REB) requires that you adhere to the protocol as last reviewed and approved by the REB.

Always quote your REB file number on all future correspondence.

Please familiarize yourself with the following forms as they may become of use to you.

- **Change Request Form:** any changes or modifications (i.e. adding a Co-PI or a change in methodology) must be approved by the REB through the completion of a change request form before implemented.

- **Adverse or unexpected Events Form:** events must be reported to the REB within 72 hours after the event occurred with an indication of how these events affect (in the view of the Principal Investigator) the safety of the participants and the continuation of the protocol. (I.e. un-anticipated or un-mitigated physical, social or psychological harm to a participant).

- **Research Project Completion Form:** must be completed when the research study has completed.

- **Renewal Request Form:** any project that exceeds the original approval period must receive approval by the REB through the completion of a Renewal Request Form before the expiry date has passed.

University of Ontario, Institute of Technology
2000 Simcoe Street North, Oshawa ON, L1H 7K4
PHONE: (905) 721-8668, ext. 3693

Appendix 2: Letter of Approval from the Grandview Children's Centre Research Committee and Quality Leadership Council

GrandviewKids

July 7, 2014

UOIT Research Ethics Board
2000 Simcoe Street North
Oshawa, Ontario
L1H 7K4

Dear UOIT Research Ethics Board,

It is my pleasure to write a letter in support of the proposed "Conventional resistance training versus a Nintendo Wii intervention to improve upper limb functionality in children ages 7 to 12 with spastic cerebral palsy (CP)" being submitted to the University of Ontario Institute of Technology Research Ethics Board (REB) by Caroline Kassee who is a Graduate Student of Dr. Meghann Lloyd's. Dr. Lloyd is an assistant professor at the University of Ontario Institute of Technology (UOIT) and research associate at Grandview Children's Centre. This is Caroline's thesis project for her Master's.
This study is in line with our clinical and research objectives and we are aware that Caroline is asking for REB approval to use our client database for recruitment and we are supportive. We are aware that the study is voluntary and participation in this study will have no effect on any services at Grandview Children's Centre.
I fully support this endeavour and the efforts of Dr. Meghann Lloyd and Caroline Kassee as they seek ethics approval for this study and we look forward to working with UOIT. Any programs that can help children get active and improve their functional skills will benefit the whole child.

Sincerely,

LSMann

Lorraine Sunstrum-Mann ECEDH, RN, BA, MBA
Executive Director
600 Townline Road South
Oshawa , Ontario
L1H 7K6
905 728 1673 ext 2258
toll free 1-800-304 6180
lorraine.sunstrum-mann@grtc.ca

Appendix 3: Informed Consent form for Parents and Guardians of Study Participants

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

RESEARCH ETHICS BOARD
OFFICE OF RESEARCH SERVICES

Informed Consent:
Nintendo Wii intervention versus Resistance Training to improve upper limb functionality in children ages 7 to 12 with spastic cerebral palsy (CP)

Date: December 10th 2014

Investigators:

Caroline Kassee
Faculty of Health Sciences
University of Ontario Institute of Technology
905-721-8668, ext. 2953
caroline.kassee@uoit.ca

Meghann Lloyd, Ph.D
Faculty of Health Sciences
University of Ontario Institute of Technology
905-721-8668, ext. 5308
meghann.lloyd@uoit.ca

Dear Parents and/or Guardians,

I am a second year Masters student at the University of Ontario Institute of Technology in the Faculty of Health Sciences. My area of research involves investigating upper limb movement in children with spastic cerebral palsy (CP). I am requesting your permission for your child to participate in a voluntary study involving two therapeutic interventions for improving upper limb movement in children ages 7 to 12 with spastic CP. The two therapies under study are a Nintendo Wii intervention, and a resistance training intervention, which would both take place in your home. Your child will be randomly assigned to either the Wii group or the resistance training group, and will only take part in one intervention. The interventions will run for 6 weeks, where your child will train for 5 days a week, and follow a specific exercise program that will take approximately 30 to 40 minutes per day to complete. All equipment needed to complete the study will be provided for you. There will be three assessment periods: before the intervention begins, directly after the intervention, and four weeks after the study ends.

This research is being done in collaboration with Grandview Children's Centre in Oshawa, but if you choose not to participate, it will have no effect on the services or treatments you receive from Grandview, or your status as a client. Participation is completely voluntary, and you have the right to withdraw your child from this study at any point if you so choose. If you do choose to withdraw, this will also have no effect on your services, treatments or client status at Grandview.

Background and Rationale

The purpose of this study is to determine which intervention, resistance training or Nintendo Wii, will have more positive outcomes with respect to upper limb function for children with spastic CP, in order to figure out which intervention is better for use in the home alongside regular therapy. We will measure how your child uses their upper limbs, with a series of standardized assessments. We will also measure your child's motivation levels throughout the intervention, and how easy it was to implement the intervention in your home.

Why is this study important?

Upper limb challenges are common in children with spastic CP, and they often prevent a child from doing important activities in daily life, such as bathing, eating and dressing. Therefore, it is key that children with CP acquire as much upper limb function as possible, so they are able to be as independent as possible in daily life. There have been very few studies that look specifically at resistance training or Nintendo Wii interventions to improve upper limb function for children with CP, and therapeutic interventions that can be easily done in the homes of children with CP are also understudied. Home interventions are of particular interest, since they have the potential to be used in addition to therapy received in treatment centers, in order to promote even greater positive outcomes for these children.

Study Procedures

There will be 3 assessment periods for this study: right before the intervention begins, directly after the intervention, and four weeks after the study ends. Your child will be randomly assigned to either the resistance training or the Nintendo Wii group. During the first assessment, we will ask you a series of demographic and developmental history questions about your child, such as the age, gender, and current level of function of your child, whether they have underwent any surgeries in the upper limbs, or received botulinum toxin –A injections, among other questions. After this, we will conduct a series of standardized pretest measures will take place in your home. The assessments will take a maximum of 2 hours. These measures are:

1. Range of motion of the upper limbs, in order to determine the movement capabilities of your child

2. Grip Strength, to provide us with an estimate of your child's upper body strength

Resistance Training Group Exercises (approximately 30 minutes/day)

Exercises	Reps	Sets
1. Bicep curls with resistance bands	12	2 sets 5 days/week
2. Triceps extensions with hand-held weights	12	2 sets 5 days/week
3. Grip strength, with squeeze balls	12	2 sets 5 days/week
4. Shoulder Flexion, with hand-held weights	12	2 sets 5 days/week
5. Shoulder abduction, with resistance bands	12	2 sets 5 days/week
6. Shoulder extension, with resistance bands	12	2 sets 5 days/week

Permission to access client and patient information at Grandview Children's Centre

In order to ensure the scientific accuracy of this study, and to make sure our measurements are not confused by other factors that could influence this study, we ask for your permission to allow Dr. Carolyn Hunt, the Medical Director, and developmental pediatrician at Grandview Children's Centre to provide the researchers with some relevant information from your child's patient and developmental history files. Potential data of interest in the patient files include, but are not limited to, your child's level of lower limb function according to the Gross Motor Function Classification System (GMFCS), or the specific muscle groups in which your child received botulinum toxin-A injections.

Consent to release information from your child's client and patient files to us is completely voluntary, and choosing not to consent will not affect your child's participation in the other aspects of this study.

Video taping of the Melbourne Assessment-2

One of the data collection tools, the Melbourne Assessment of Unilateral Upper Limb Function- 2 (MA2), requires videotaping in order to be scored accurately. Videotaping your child's performance on this test is necessary, because it allows us to slow down the movements and break it into its components. Unfortunately, it is not possible to complete this study without this assessment, so refusal to consent to videotaping will constitute a withdrawal from this study.

If you do consent to allow your child to be videotaped, all videos will be encrypted, and password protected on a secure server in the Motor Development and Physical Activity

Lab at UOIT. Access will be limited to the research team, for viewing inside the research office only.

Data Storage and Protection

In addition to video files, all participant information contained on paper will be stored in a locked and secure filing cabinet in the Motor Development and Physical Activity Lab at UOIT. Electronic data, including videos, will be encrypted and stored on a secure server/drive on the UOIT network, where all files will be password protected. Each child will be assigned a unique numeric identifier for data analysis purposes in order to protect your child's confidentiality. Coded data will be entered into an electronic database, and a file containing the identification of the codes will be password protected and stored on a secure server on the UOIT network. Furthermore, any publications relying on this data will be completely anonymous and will contain no personal information that will identify your child.

Risks and Benefits of Participation

Your child's participation in this study does not pose any risks that would not typically be incurred during daily activities. All exercises used in this intervention have been carefully selected for this population, and are similar to standard physical activity interventions that are used in physiotherapy. As with any form of physical activity, there is a minimal risk if injury - for instance, children may fall, over-exert themselves or pull a muscle during either the Wii or resistance intervention. However, in order to minimize this risk, you will be encouraged to modify equipment for individual use if needed (e.g. using a tensor bandage to secure your child's grip on the Wii remote or weights), and will be given detailed instructions as to the proper and safe way to conduct the exercises in the interventions.

Your child will benefit from this study by receiving a cost-free, home-based intervention that has the potential to improve their upper limb function and performance of daily activities that require the use of the upper limbs. This may improve their independence, along with their self-perception. Finally, by participating in this study, you will be contributing to furthering scientific knowledge in designing and implementing therapeutic interventions in the home, and to the current scientific literature on resistance training and Nintendo Wii interventions for children with disabilities such as CP.

Responsibilities of the Participant

As a participant in this study, you and your child will be required to complete either the Nintendo Wii intervention, or the resistance training intervention, and comply with all of the study's protocols for their respective intervention to the best of your ability. This includes following the specified exercise program for the set length of time, diligently recording exercise time in the performance logs each day, and informing the researchers of any deviations from the study's procedures. At the end of the intervention period, you will be required to return all equipment to the researchers, and will be asked for your feedback about the study.

Right to Withdraw

You are free to withdraw your child at any point during the study and do not need to provide a reason for doing so. If you choose to withdraw, any data that has been collected from your child will be destroyed and will not be used in any analyses, publications or future research. Also, withdrawing from this study will have no affect on any of the services that you receive at Grandview Children's Centre.

Dissemination

If you wish, you can receive a copy of the results of this study following its completion. You will also receive a summary of your child's personal results once they have completed the final assessment session, in the form of a feedback letter. Also, if you would like to be contacted for any future studies that your child might be eligible for at the Motor Development and Physical Activity Lab at UOIT, you will be given the opportunity to provide your contact information to the researchers.

Questions about the study

If you have any questions about this study, please contact Caroline Kassee at 905-721-8668, ext. 2953, or Dr Meghann Lloyd at 905-721-8668, ext. 5308. This study has been reviewed, and is approved by the University of Ontario Institute of Technology Research Ethics Board (REB #14-003), which is a committee of the university that ensures the protection of the rights and welfare of people participating in research. The Research Ethics Board is not intended to replace a parent/guardian or child's judgments about what decisions are best for you.

If you have any questions about your child's rights as a research participant, you may contact the University of Ontario Institute of Technology Research Ethics Board at 2000 Simcoe St. N., Oshawa, ON, L1H 7K4, 905-721-8668, ext. 3693, or at compliance@uoit.ca

Informed Consent to Participate: Conventional resistance training versus a Nintendo Wii intervention to improve upper limb function for children ages 7 to 12 with spastic cerebral palsy

I have read and understood the attached information, or had the attached information sheets verbally explained to me, and have received a copy of this consent form. I have been fully informed of the details of the study and have had the opportunity to discuss my concerns. I understand that I am free to withdraw my child at any time or not answer questions, and by consenting to this form I do not waive any legal rights or recourse.

I,____,
(Your name)

the parent/guardian of ____:
(Your Child's name)

In order for your child to participate in this study, please consent to the following two conditions:

☐ **Give consent** for my child's participation in the above study

☐ **Give consent** for my child to be videotaped during assessments

Additionally, please indicate your consent to the following optional condition:

☐ I am willing to receive further information regarding future research studies that my child may be eligible for

Email:____

Phone:____

____
Name of Child

__________________________ __________________________________
Name of Parent/Guardian Contact Phone Number

__________________________ __________________________________
Signature of Parent/Guardian Date

Informed Consent to Allow Researchers to Access Client and Patient Information

In order to ensure the scientific accuracy of this study, and to make sure our measurements are not confused by any other factors, we ask for your permission to allow Dr. Carolyn Hunt, the Medical Director and a developmental pediatrician at Grandview Children's Centre, to provide us with information from your child's patient and client files at Grandview that is relevant to this study. If you consent to allow the researchers to access this information, please sign below:

I ___________________________________ (please print your name) give my permission for Dr. Carolyn Hunt to provide the researcher with supervised access to information from the client and patient files at Grandview for_______________________________ (please print name of the child), that are relevant to this study.

____________________________________ ________________

Signature of Parent/Guardian Date

Appendix 4: Child Assent Form for Study Participants

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

RESEARCH ETHICS BOARD
OFFICE OF RESEARCH SERVICES

Verbal Child Assent Form
Conventional resistance training versus a Nintendo Wii intervention to improve upper limb function in children ages 7 to 12 with cerebral palsy

Hi ____________________,(child's name) I'm here today because ______________________ (parent or guardian name), your ________________________ (relationship to child) has said that its okay for you to be a part of my research project. But first, I want to ask if it's okay with you. The reason we are doing this project is to help us understand what types of activities that you can do at home might help you to use your arms easier, for things like eating, putting a shirt on, or carrying things.

For the next 6 weeks, we will ask you to do some exercises almost every day, to work out both your arms, but especially the arm that you don't like using as much. We want you to try to use this arm more, because we think it might help it to get better at moving around after this project is over. We will also ask you, or [Mom or Dad or guardian], to write down what exercises you did that day, how long you did them, and how hard you worked out your arms.

You'll be seeing me and my friends [research assistants] 3 times over the next few weeks, and we'll do some tests together to see how your arms are moving. For one of the tests that we're going to do, we'll need to videotape you, if that's ok.

You don't have to participate if you don't want to, and the information we get won't be shared with anyone except you and your parents. You can also decide to stop being a part of the project at any time too.

Do you want to be part of my project? ______________yes_____________no
Is it okay if we videotape you?_________________yes___________no

Appendix 5: Letter of Invitation

2000 Simcoe Street North
Oshawa, Ontario L1H 7K4
T 905.721.3166
www.healthsciences.uoit.ca

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY
FACULTY OF HEALTH SCIENCES

Letter of Invitation

Conventional resistance training versus a Nintendo Wii intervention to improve upper limb functionality for children ages 7 to 12 with spastic cerebral palsy: a home study.

Date: November 10th 2014

Dear Parent and/or Guardian,

I am a second year Masters student at the University of Ontario Institute of Technology in the Faculty of Health Sciences. My area of research involves investigating upper limb movement in children with spastic cerebral palsy (CP). I am also affiliated with Grandview Children's Centre in Oshawa, Ontario, and was provided your contact information through their databases. I am writing to invite you and your child to participate in a voluntary study involving two therapeutic interventions for improving upper limb movement in children ages 7 to 12 with spastic CP. The two therapies under study are a Nintendo Wii intervention, and a resistance training intervention, that would take place in your home. The reason we are doing this study is to determine which interventions are the most effective in improving upper arm function in children with CP in the home environment.

If you are interested in participating, you will first be asked a series of screening questions in order to determine if your child meets the specific inclusion criteria for this study. Then, your child will be randomly placed in either the Wii group or the resistance group (but not both), and asked to follow a 6-week, 5 times a week training program for the upper arms. Your child will assessed at 3 time points during the intervention and 4 weeks after, using typical physiotherapy measures. Equipment required for the intervention will be provided to you. All assessments, information sessions, as well as the intervention itself, will take place in your home. Also, you will be asked to allow Dr Carolyn Hunt, the Medical Director, and a developmental pediatrician at Grandview Children's Centre, to provide us with some relevant information from your child's patient and developmental history files at Grandview (such as whether they received botox injections into the arms, etc.), in order to ensure the scientific accuracy of this study.

If you would like to participate, or have any questions about this study, please contact Caroline Kassee, or Dr Meghann Lloyd. We are happy to discuss any concerns you may have, either by phone, email, or in person if you prefer.

Sincerely,

Caroline Kassee
Faculty of Health Sciences
University of Ontario Institute of Technology
905-721-8668, ext. 2953
caroline.kassee@uoit.ca

Meghann Lloyd, Ph.D
Faculty of Health Sciences
University of Ontario Institute of Technology
905-721-8668, ext 5308
meghann.lloyd@uoit.ca

Appendix 6: Recruitment Poster

UOIT
CHALLENGE INNOVATE CONNECT

Do you, or someone you know, have a child with spastic Cerebral Palsy involving the upper limbs?

We are looking for children ages 7 to 12 with spastic CP involving the arms to participate in an intervention study led by a UOIT graduate student. Participants will be randomly placed into either a strength training or a Nintendo Wii intervention group, both aimed at improving upper limb function.

For more information, please contact Caroline or Meghann:

905-721-8668, ext. 2953

caroline.kassee@uoit.ca

meghann.lloyd@uoit.ca

REB #XX-XXX

905-721-8668, ext. 3693

compliance@uoit.ca

GRANDVIEW CHILDREN'S CENTRE

Caroline Kassee (2015)

Appendix 7: Verbal Recruitment Script

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

RESEARCH ETHICS BOARD
OFFICE OF RESEARCH SERVICES

Verbal Script for Recruitment by Phone Call

Hello, this is___________________________ . I am calling to invite you and your child to take part in a study we are running with the University of Ontario Institute of Technology.

The study aims to compare two therapies: a standard therapeutic exercise program involving resistance training, and a Nintendo Wii intervention, to see which one is more effective at home for improving upper arm function in kids with CP.

If you agree to participate, your child will be randomly placed in either the standard physiotherapy group, or the Nintendo Wii group, but not both. Then, we 'll ask your child to train for 6 weeks, 5 days a week (this is a total of 30 days) at home, in an exercise program that was designed to improve the function of their impaired (or spastic) arm. All assessments (there will be 3 assessment periods total) will be done at your home, so you won't be required to drive out to Grandview.

You should know that both intervention programs were designed to be beneficial for your child. So no matter what group they are placed in, there is likely to be some benefits for them.

Would you like to participate? Please note that your decision will not affect any services you receive at Grandview, in any way.

If yes: Thank you for your interest! With your permission, I will give your phone number to Caroline Kassee, the graduate student in charge of this study, and she will contact you as soon as possible. Is there a specific time that is best?

If you have any further questions in the meantime, please call her at 905-721-8668, ext 2953, at the Motor Behaviour and Physical Activity Lab at UOIT.

If no: Thank you for your time.

Appendix 8: Supplemental Data Form for Participant Demographic Information

2000 Simcoe Street North
Oshawa, Ontario L1H 7K4
T 905.721.3166
www.healthsciences.uoit.ca

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FACULTY OF HEALTH SCIENCES

Participant Demographic Information
Data Collection Sheet

1.Child's name

2. Age (and birthday)

3. Gender

4. Diagnosis

5. Location and Description of Spasticity

6. BoNT-A injections in the last 6 months

7. MACS level (Parents, and verified)

8. GMFCS level (parents, and verified)

Data collection 3

Appendix 9: Nintendo Wii Group Daily Log Sheet

2000 Simcoe Street North
Oshawa, Ontario L1H 7K4
T 905.721.3166
www.healthsciences.uoit.ca

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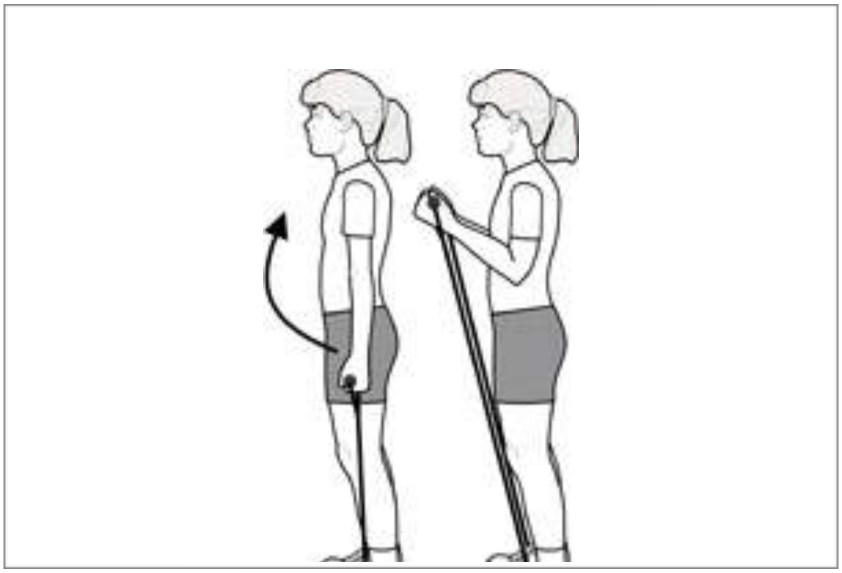
Nintendo Wii U
Daily Performance Log Sheet

1. Date						
2. Time and duration of exercise *(for a total of 40 minutes per day)*	**What time did you exercise?**			**How long did you exercise?**		
	e.g 4.30 pm *7.30 pm*			*20 minutes* *20 minutes*		
	1.					
	2.					
	3.					
	4.					
	5.					
	6.					
3. What games did you play today? (circle all that apply)	Tennis Archery Swordplay Basketball Bowling Canoeing Golf Frisbee					
4. How much did you use your affected arm to exercise today?	**0** Not at all	**1** Once or twice	**2** A few times	**3** Half the time	**4** Most of the time	**5** All the time
5. How hard did you exercise today?	**0** Not at all	**1** A little	**2** Some	**3** Medium Hard	**4** Hard	**5** Very Hard
6. Did you have fun exercising today?	**0** No	**1** A little	**2** Some	**3** It was okay	**4** I had fun	**5** I had a lot of fun

Parent/Guardian signature______________________________________

Appendix 10: Resistance Group Exercise Booklet

1. Arm Curls with Resistance Bands



a. Place feet in the middle of the resistance band, shoulder width apart

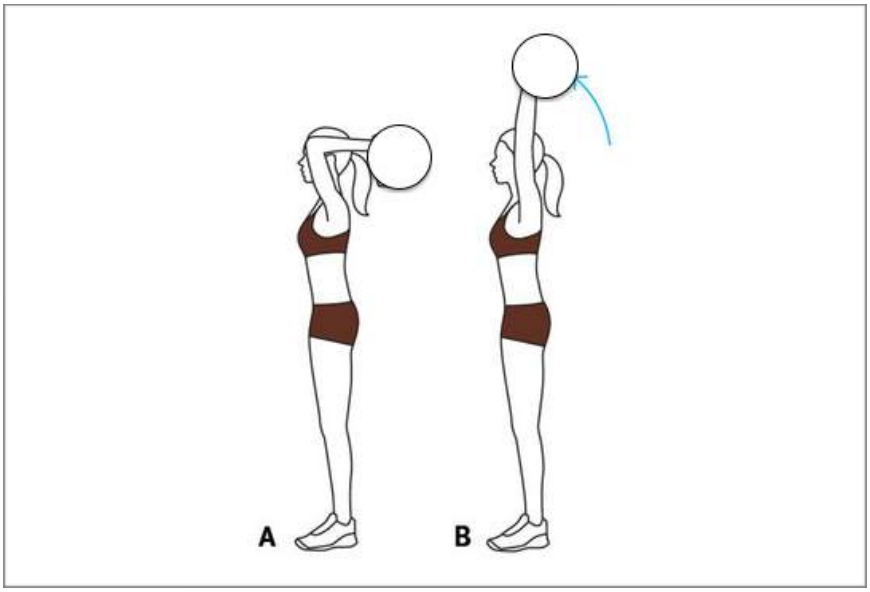
b. Grasp handles of the band and turn wrists to face the ceiling. Lock elbows.

c. Lift arms upwards, as high as possible, then down again. Try not to move shoulders

d. Go SLOWLY (2 Mississippi's up, 2 Mississippi's down, 1 Mississippi pause) d. After 12 repetitions, take a break

d. After 12 repetitions, take a break

2. Upper Arms with Ball Weights



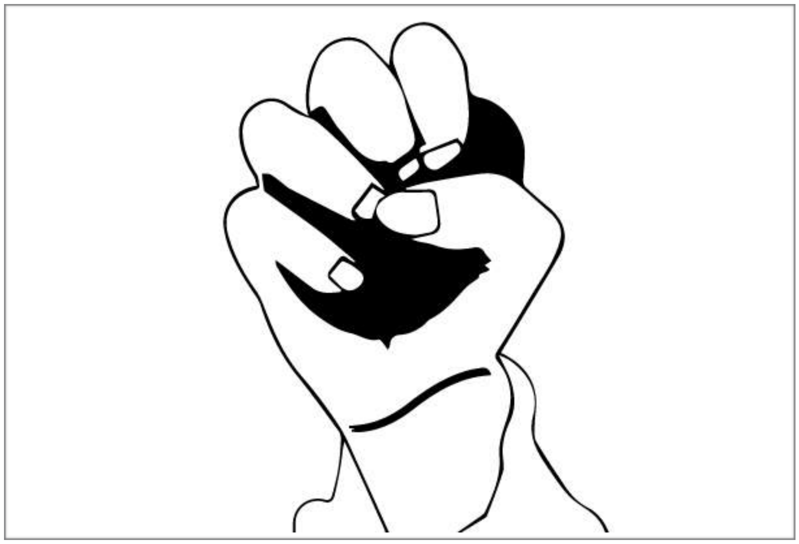
a. Hold the ball weight with both hands behind your neck, feet shoulder width apart, slightly bending your knees

b. Lift ball over your head by straightening your elbows, then bring the ball back behind your neck again. Try to keep elbows near your head

c.Go SLOWLY (2 Mississippi's up, 2 down, 1 pause)

d. After 12 repetitions, take a break

3. Grip, with Stress ball



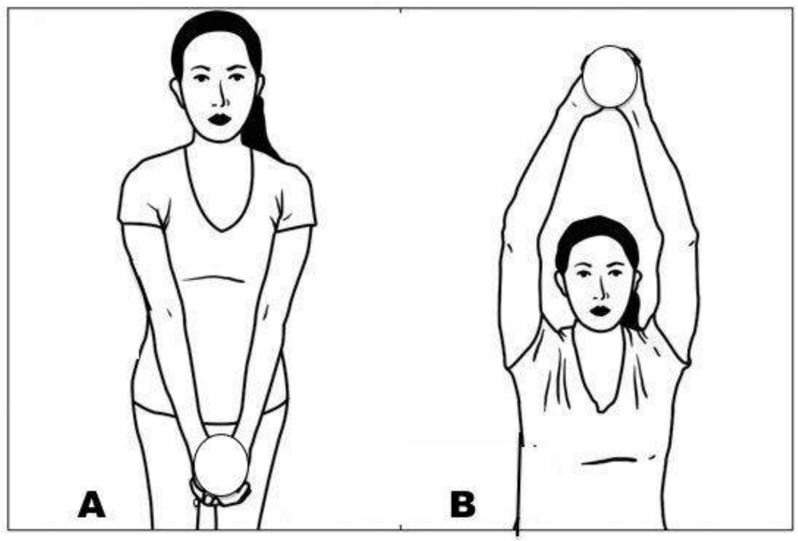
a.Hold the squeeze ball in one hand

b. Open palm, and then close it around the ball, and squeeze it as hard as you can

b. After you exercise one hand, do the <u>other hand</u>

b. After you exercise both hands, take a break

4. Shoulder raise, with ball weights



a. Hold ball weight in front of you with both hands, feet shoulder width apart

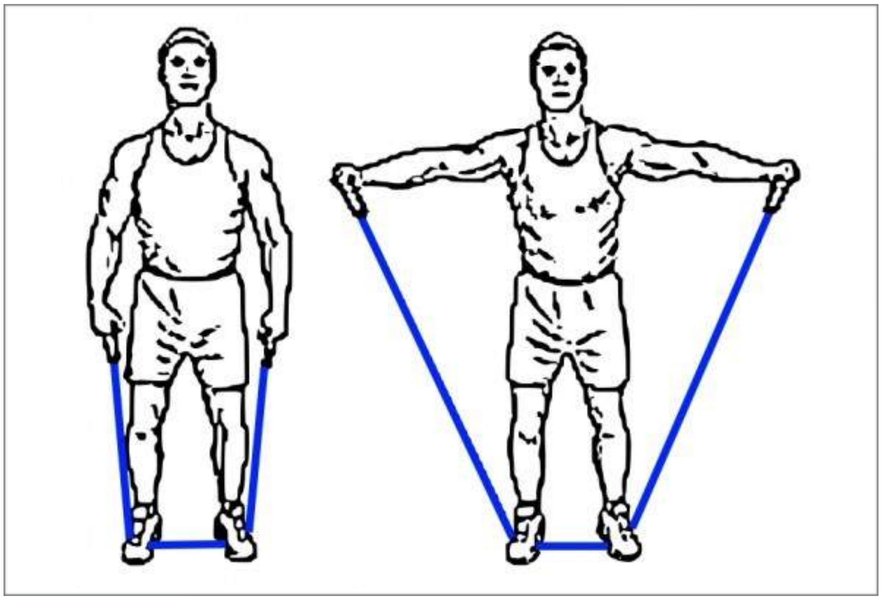
b. Slightly bending your elbows, lift the ball as high as you can, and back down.

c. Go SLOWLY (2 'Mississippi's up, 2 down, 1 pause)

b. After you do 12 repetitions, take a break

SHOULDER FLEXION

5. Shoulder raise, with resistance bands

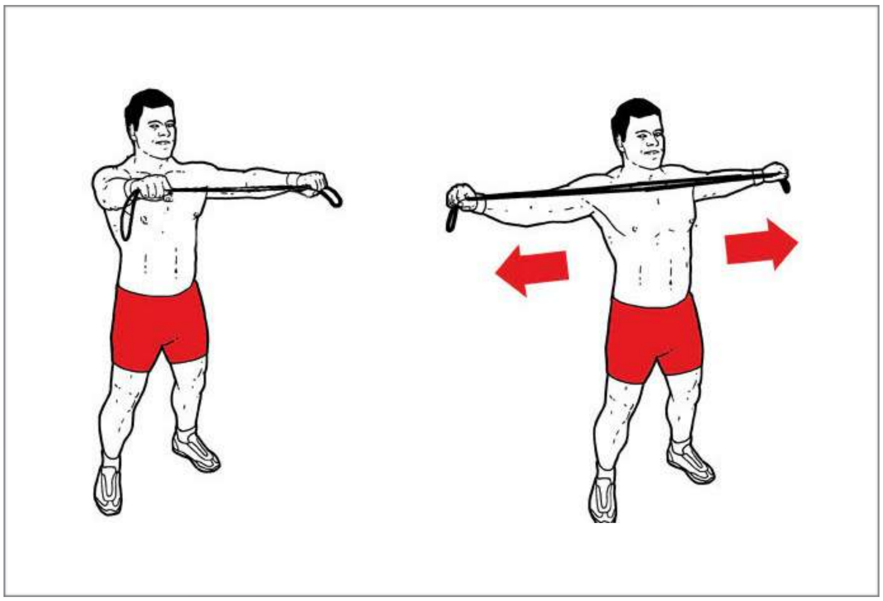


a. Stand in the middle of the resistance band, holding the handles, with feet shoulder width apart

b. Lift both arms out from your sides as high as you can, trying to make a "T" shape. Then bring your arms back to your sides

c. Go SLOWLY (2 'Mississippi's up, 2 down, 1 pause)

6. Pulling, with resistance bands



a. Hold resistance band out in front of you, with hands positioned close to the handles

b. Pull the band apart, as far outwards and backwards, as you can. Try to squeeze your shoulder blades

c. Go SLOWLY, (2 'Mississippi's apart, 2 inwards, 1 pause)

Appendix 11: Resistance Training Group Daily Log Sheet

2000 Simcoe Street North
Oshawa, Ontario L1H 7K4
T 905.721.3166
www.healthsciences.uoit.ca

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Resistance Intervention
Daily Performance Log Sheet

1. Date						
2. Time and duration of exercise sets *(1 set = all 6 exercises done 12 times each, for a total of 2 sets per day)*	**What time did you exercise?**		**How many sets did you do?**		**How long did you exercise?**	
	e.g 4.30 pm *7.30 pm*		*1 set* *1 set*		*15 minutes* *15 minutes*	
	1.					
	2.					
	3.					
	4.					
4. How much did you use your affected arm to exercise today?	**0** Not at all	**1** Once or twice	**2** A few times	**3** Half the time	**4** Most of the time	**5** All the time
5. How hard did you exercise today?	**0** Not at all	**1** A little	**2** Some	**3** Medium Hard	**4** Hard	**5** Very Hard
6. Did you have fun exercising today?	**0** No	**1** A little	**2** Some	**3** It was okay	**4** I had fun	**5** I had a lot of fun

Parent/Guardian Signature____

Appendix 12: Parent Feedback Form

2000 Simcoe Street North T 905.721.3166
Oshawa, Ontario L1H 7K4 www.healthsciences.uoit.ca

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY
FACULTY OF HEALTH SCIENCES

Intervention Follow-Up Questions for Parents/Guardians

Please rate your responses on a scale from 0 to 5:

1. **Overall, how much fun do you think your child had during the exercise program?**

0	1	2	3	4	5
None	A little	Some	Average	Fun	A lot of fun

2. **How easy was it to motivate your child to do the exercise program?**

0	1	2	3	4	5
Very Difficult	Difficult	Somewhat Difficult	Neutral	Not difficult	Easy

3. **Was your exercise program hard to do five days a week with your child's schedule?**

0	1	2	3	4	5
Very hard	Hard	Somewhat Hard	Neutral	Not Hard	Easy

4. **How easy were the instructions for your exercise program (i.e what exercises to do, what games to play, etc.) to follow for your child?**

0	1	2	3	4	5
Very Difficult	Difficult	Somewhat Difficult	Neutral	Not difficult	Easy

Please write your responses in the space below:

5. **Do you feel that your child benefited from this exercise program?**

2000 Simcoe Street North
Oshawa, Ontario L1H 7K4
T 905.721.3166
www.healthsciences.uoit.ca

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY
FACULTY OF HEALTH SCIENCES

6. **Was there anything that got in the way of your child doing the exercise program on a daily basis? (i.e. daily chores, appointments, etc). If so, what was it?**

7. **What would you change about the exercise program or the study, to make it more beneficial for your child, or easier to do at home?**

8. **Do you have any further comments, or suggestions as to how to improve home-based therapy programs for children with cerebral palsy?**

THANK YOU!

Appendix 13: Manuscript 1 Raw Data Tables

Experimental Group – Nintendo Wii Training

<u>*Wii Participant-1*</u>

Wii Participant-1 - Range of Motion Scores for the Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Range of Motion component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	3	3	n/d	0	n/d	n/d
Item 2: Reach sideways-elevated (3)	3	3	n/d	0	n/d	n/d
Item 5:Release of crayon (3)	2	2	n/d	0	n/d	n/d
Item 7: Release of pellet (3)	3	3	n/d	0	n/d	n/d
Item 10:Reach forehead- back neck (3)	3	3	n/d	0	n/d	n/d
Item 11: Palm to bottom (2)	2	2	n/d	0	n/d	n/d
Item 12: Pronation/supination (4)	4	4	n/d	0	n/d	n/d
Item 13:Reach to opposite shoulder (3)	3	3	n/d	0	n/d	n/d
Item 14: Hand to mouth and down (3)	3	3	n/d	0	n/d	n/d
Subscale raw total	26	26	n/d	0	n/d	n/d
Maximum score total	27	27	n/a	n/a	n/a	n/a
Percentage	96.30%	96.30%	n/d	0%	n/d	n/d
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable', n/d is 'no data'						

Wii Participant -1- Accuracy –Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with an Accuracy component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	3	3	n/d	0	n/d	n/d
Item 2: Reach sideways – elevated (3)	3	3	n/d	0	n/d	n/d
Item 5: Release of crayon (3)	3	3	n/d	0	n/d	n/d
Item 7:Release of pellet (3)	3	3	n/d	0	n/d	n/d
Item 9a: Pointing – green rectangle (4)	3	3	n/d	0	n/d	n/d
Item 9b: Pointing - blue rectangle (4)	3	4	n/d	1	n/d	n/d
Item 13: Reach to opposite shoulder (3)	3	2	n/d	-1	n/d	n/d
Item 14: Hand to mouth and down (2)	2	2	n/d	0	n/d	n/d
Subscale raw total	23	23	n/d	0	n/d	n/d
Maximum total score	25	25	n/a	n/a	n/a	n/a
Percentage	92.00%	92.00%	n/d	0%	n/d	n/d
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable', n/d is 'no data'						

Wii Participant-1 - Dexterity -Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Dexterity component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 3: Grasp of crayon (3)	3	3	n/d	0	n/d	n/d
*Item 4: Drawing grasp (3)	-	-	-	n/a	n/a	n/a
Item 5: Release of crayon (3)	2	3	n/d	1	n/d	n/d
Item 6: Grasp of pellet (4)	4	4	n/d	0	n/d	n/d
Item 7: Release of pellet (3)	3	3	n/d	0	n/d	n/d
Item 8: Manipulation (3)	2	2	n/d	0	n/d	n/d
Subscale raw total	14	15	n/d	1	n/d	n/d
Maximum total score	16	16	n/a	n/a	n/a	n/a
Percentage	87.50%	93.75%	n/d	6.25%	n/d	n/d
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable', n/d is 'no data ** Item 4 is not scored, as the assessed hand is the non-dominant hand*						

Wii Participant-1 – Fluency - .Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Fluency component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 1: Reach forwards (3)	3	3	n/d	0	n/d	n/d
Item 2: Reach sideways (3)	3	3	n/d	0	n/d	n/d
Item 8: Manipulation (3)	2	2	n/d	0	n/d	n/d
Item 10: Reach forehead – back neck (3)	3	3	n/d	0	n/d	n/d
Item 11: Palm to bottom (3)	3	3	n/d	0	n/d	n/d
Item 13: Reach to opposite shoulder (3)	3	3	n/d	0	n/d	n/d
Item 14: Hand to mouth and down (3)	3	3	n/d	0	n/d	n/d
Subscale raw total	20	20	n/d	0	n/d	n/d
Maximum total score	21	21	n/a	n/a	n/a	n/a
Percentage	95.24%	95.24%	n/d	0%	n/d	n/d
Notes: The number in brackets indicate the maximum score possible per item; n/a is ‘not applicable’, n/d is ‘no data						

Wii Participant-1 Maximal Grip Strength Raw Data				
	Left		Right	
	Trial 1	Trial 2	Trial 1	Trial 2
Pre-test (psi)	3.00	3.00	2.00	2.00
Post-test (psi)	4.00	5.00	4.00	4.50
Follow-up (psi)	n/d	n/d	n/d	n/d
Psi is pounds per square inch; n/d is no data				

Wii Participant-1ABILHAND-Kids Questionnaire Scores

Items (listed from easiest to perform, to hardest)	Pre-test (Impossible=0; Difficult = 1; Easy = 2)	Post-test (Impossible=0; Difficult = 1; Easy = 2)	Follow-Up (Impossible=0; Difficult = 1; Easy = 2)	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Switching on a bedside lamp	2	2	n/d	0	n/a	n/a
Unwrapping a chocolate bar	2	2	n/d	0	n/a	n/a
Taking a coin out of a pocket	2	2	n/d	0		
Putting on a hat	2	2	n/d	0	n/a	n/a
Taking off a T-shirt	2	2	n/d	0	n/a	n/a
Opening a bread box	*–	2	n/d	n/a	n/a	n/a
Filling a glass with water	2	2	n/d	0	n/a	n/a
Washing the upper-body	2	2	n/d	0	n/a	n/a
Opening the cap of a toothpaste tube	2	2	n/d	0	n/a	n/a
Opening a bag of chips	2	2	n/d	0	n/a	n/a
Unscrewing a bottle cap	1	2	n/d	1	n/a	n/a
Squeezing toothpaste onto a toothbrush	2	2	n/d	0	n/a	n/a
Fastening the snap of a jacket	2	2	n/d	0	n/a	n/a
Zipping up trousers	1	2	n/d	1	n/a	n/a
Putting on a backpack/schoolbag	2	2	n/d	0	n/a	n/a
Sharpening a pencil	2	2	n/d	0	n/a	n/a
Rolling up a sleeve of a sweater	2	2	n/d	0	n/a	n/a

Table 10. Continued						
Zipping up a jacket	2	2	n/d	0	n/a	n/a
Opening a jar of jam	1	2	n/d	1	n/a	n/a
Buttoning up a shirt/sweater	2	2	n/d	0	n/a	n/a
Buttoning up trousers	2	2	n/d	0	n/a	n/a
Raw Score (max 42)	37	42	n/d	5	n/a	n/a
Logits (Standard Error)	3.887(±0.666)	6.684(±1.685)	n/d	2.797	n/a	n/a
* *dash indicates that the category was not assessed; n/d is no data, n/a is not applicable*						

Wii Participant-2

Wii Participant-2 – Range of Motion Scores for the Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Range of Motion component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	2	2	2	0	0	0
Item 2: Reach sideways-elevated (3)	2	3	2	1	-1	0
Item 5:Release of crayon (3)	2	2	2	0	0	0
Item 7: Release of pellet (3)	2	2	2	0	0	0
Item 10:Reach forehead- back neck (3)	3	3	3	0	0	0
Item 11: Palm to bottom (2)	2	2	2	0	0	0
Item 12: Pronation/supination (4)	3	2	2	-1	0	-1
Item 13:Reach to opposite shoulder (3)	2	2	2	0	0	0
Item 14: Hand to mouth and down (3)	2	2	3	0	1	1
Subscale raw total	20	20	20	0	0	0
Maximum score total	27	27	27	n/a	n/a	n/a
Percentage	74.07%	74.07%	74.07%	0%	0%	0%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Wii Participant -2 - Accuracy Scores for the Melbourne Assessment of Unilateral Upper Limb Function						
Items with an Accuracy component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	2	3	2	1	-1	0
Item 2: Reach sideways – elevated (3)	2	3	2	1	-1	0
Item 5: Release of crayon (3)	2	3	3	1	0	1
Item 7:Release of pellet (3)	2	3	3	1	0	1
Item 9a: Pointing – green rectangle (4)	3	3	4	0	1	1
Item 9b: Pointing - blue rectangle (4)	4	4	4	0	0	0
Item 13: Reach to opposite shoulder (3)	3	3	3	0	0	0
Item 14: Hand to mouth and down (2)	1	2	2	1	0	1
Subscale raw total	19	24	23	5	-1	4
Maximum total score	25	25	25	n/a	n/a	n/a
Percentage	76.00%	96.00%	92.00%	20.00%	-4.00%	16.00%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Wii Participant-2 - Dexterity - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Dexterity component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 3: Grasp of crayon (3)	2	3	2	1	-1	0
*Item 4: Drawing grasp (3)	-	-	-	n/a	n/a	n/a
Item 5: Release of crayon (3)	1	2	2	1	0	1
Item 6: Grasp of pellet (4)	4	3	3	-1	0	-1
Item 7: Release of pellet (3)	2	2	2	0	0	0
Item 8: Manipulation (3)	1	1	1	0	0	0
Subscale raw total	10	11	10	1	-1	0
Maximum total score	16	16	16	n/a	n/a	n/a
Percentage	62.50%	68.75%	62.50%	6.25%	-6.25%	0%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable' ** Item 4 is not scored, as the assessed hand is the non-dominant hand*						

Wii Participant-2 - Fluency - .Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Fluency component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 1: Reach forwards (3)	1	2	2	1	0	1
Item 2: Reach sideways (3)	1	2	3	1	1	2
Item 8: Manipulation (3)	1	2	2	1	0	1
Item 10: Reach forehead – back neck (3)	2	2	2	0	0	0
Item 11: Palm to bottom (3)	2	2	2	0	0	0
Item 13: Reach to opposite shoulder (3)	2	2	2	0	0	0
Item 14: Hand to mouth and down (3)	1	2	3	1	1	2
Subscale raw total	10	14	16	4	2	6
Maximum total score	21	21	21	n/a	n/a	n/a
Percentage	47.62%	66.66%	76.19%	19.04%	9.53%	28.57%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable'						

Wii Participant-2 Maximal Grip Strength Raw Data				
	Left		Right	
	Trial 1	Trial 2	Trial 1	Trial 2
Pre-test (psi)	2.50	3.00	1.50	1.50
Post-test (psi)	3.50	3.00	2.00	2.50
Follow-up (psi)	3.00	2.50	1.50	1.50
Psi is pounds per square inch				

Wii Participant-2 ABILHAND-Kids Questionnaire Scores						
Items (listed from easiest to perform, to hardest)	Pre-test (Impossible=0; Difficult = 1; Easy = 2)	Post-test (Impossible=0; Difficult = 1; Easy = 2)	Follow-Up (Impossible=0; Difficult = 1; Easy = 2)	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Switching on a bedside lamp	1	1	1	0	0	0
Unwrapping a chocolate bar	2	1	1	-1	0	-1
Taking a coin out of a pocket	1	1	2	0	1	1
Putting on a hat	2	2	2	0	0	0
Taking off a T-shirt	1	2	1	1	-1	0
Opening a bread box	1	2	2	1	0	1
Filling a glass with water	1	2	2	1	0	1
Washing the upper-body	1	1	1	0	0	0
Opening the cap of a toothpaste tube	1	1	1	0	0	0
Opening a bag of chips	1	1	1	0	0	0
Unscrewing a bottle cap	1	0	1	-1	1	0
Squeezing toothpaste onto a toothbrush	1	1	1	0	0	0
Fastening the snap of a jacket	1	1	1	0	0	0
Zipping up trousers	0	1	1	1	0	1
Putting on a backpack/schoolbag	0	1	1	1	0	1
Sharpening a pencil	0	0	0	0	0	0
Rolling up a sleeve of a sweater	2	2	1	0	-1	-1

Table 10. Continued						
Zipping up a jacket	1	1	1	0	0	0
Opening a jar of jam	0	0	0	0	0	0
Buttoning up a shirt/sweater	1	1	1	0	0	0
Buttoning up trousers	0	1	0	1	-1	0
Raw Score (max 42)	19	23	22	4	-1	3
Logits (Standard Error)	−0.332(±0.412)	0.340(±0.412)	0.172(±0.411)	0.672	-0.168	0.504

Wii Participant-3

Wii Participant-3 - Range of Motion -Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Range of Motion component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	2	3	3	1	0	1
Item 2: Reach sideways-elevated (3)	2	3	3	1	0	1
Item 5:Release of crayon (3)	1	1	2	0	1	1
Item 7: Release of pellet (3)	1	3	2	2	-1	1
Item 10:Reach forehead- back neck (3)	3	3	3	0	0	0
Item 11: Palm to bottom (2)	2	2	2	0	0	0
Item 12: Pronation/supination (4)	3	4	4	1	0	1
Item 13:Reach to opposite shoulder (3)	3	3	3	0	0	0
Item 14: Hand to mouth and down (3)	3	3	3	0	0	0
Subscale raw total	20	25	25	5	0	5
Maximum score total	27	27	27	n/a	n/a	n/a
Percentage	74.07%	92.59%	92.59%	18.52%	0%	18.52%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Wii Participant-3 – Accuracy - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with an Accuracy component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	3	3	3	0	0	0
Item 2: Reach sideways – elevated (3)	3	3	3	0	0	0
Item 5: Release of crayon (3)	2	3	3	1	0	1
Item 7:Release of pellet (3)	3	3	3	0	0	0
Item 9a: Pointing – green rectangle (4)	4	4	4	0	0	0
Item 9b: Pointing - blue rectangle (4)	4	4	4	0	0	0
Item 13: Reach to opposite shoulder (3)	3	3	3	0	0	0
Item 14: Hand to mouth and down (2)	2	2	2	0	0	0
Subscale raw total	24	25	25	1	0	1
Maximum total score	25	25	25	n/a	n/a	n/a
Percentage	96.00%	100%	100%	4%	0%	4%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Wii Participant-3 – Dexterity - Melbourne Assessment of Unilateral Upper Limb Function-2 -						
Items with a Dexterity component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 3: Grasp of crayon (3)	2	2	2	0	0	0
*Item 4: Drawing grasp (3)	-	-	-	n/a	n/a	n/a
Item 5: Release of crayon (3)	2	3	2	1	-1	0
Item 6: Grasp of pellet (4)	1	4	3	3	-1	2
Item 7: Release of pellet (3)	2	3	3	1	0	1
Item 8: Manipulation (3)	1	1	2	0	1	1
Subscale raw total	8	13	12	5	-1	4
Maximum total score	16	16	16	n/a	n/a	n/a
Percentage	50.00%	81.25%	75.00%	31.25%	-6.25%	25.00%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable' * *Item 4 not scored, as the assessed hand is the non-dominant hand*						

Wii Participant-3 - Fluency - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Fluency component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 1: Reach forwards (3)	2	2	2	0	0	0
Item 2: Reach sideways (3)	2	2	2	0	0	0
Item 8: Manipulation (3)	1	2	1	1	-1	0
Item 10: Reach forehead – back neck (3)	2	3	3	1	0	1
Item 11: Palm to bottom (3)	2	2	2	0	0	0
Item 13: Reach to opposite shoulder (3)	3	3	3	0	0	0
Item 14: Hand to mouth and down (3)	3	3	3	0	0	0
Subscale raw total	15	17	16	2	-1	1
Maximum total score	21	21	21	n/a	n/a	n/a
Percentage	71.43%	80.95%	76.19%	9.52%	-4.76%	4.76%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable'						

Wii Participant-3 Maximal Grip Strength Raw Data				
	Left		Right	
	Trial 1	Trial 2	Trial 1	Trial 2
Pre-test (psi)	3.00	2.00	5.00	4.00
Post-test (psi)	3.00	2.50	5.00	5.50
Follow-up (psi)	4.00	3.00	5.50	5.00
Psi is pounds per square inch				

Wii Participant-3 ABILHAND-Kids Questionnaire Scores						
Items (listed from easiest to perform, to hardest)	Pre-test (Impossible=0; Difficult = 1; Easy = 2)	Post-test (Impossible=0; Difficult = 1; Easy = 2)	Follow-Up (Impossible=0; Difficult = 1; Easy = 2)	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Switching on a bedside lamp	2	1	1	-1	0	-1
Unwrapping a chocolate bar	2	2	2	0	0	0
Taking a coin out of a pocket	1	1	1	0	0	0
Putting on a hat	2	2	2	0	0	0
Taking off a T-shirt	2	2	2	0	0	0
Opening a bread box	2	2	2	0	0	0
Filling a glass with water	2	2	2	0	0	0
Washing the upper-body	2	1	2	-1	1	0
Opening the cap of a toothpaste tube	2	2	2	0	0	0
Opening a bag of chips	2	2	2	0	0	0
Unscrewing a bottle cap	1	2	2	1	0	1
Squeezing toothpaste onto a toothbrush	2	1	2	-1	1	0
Fastening the snap of a jacket	2	2	1	0	-1	-1
Zipping up trousers	1	2	1	1	-1	0
Putting on a backpack/schoolbag	2	2	2	0	0	0
Sharpening a pencil	2	1	1	-1	0	-1
Rolling up a sleeve of a sweater	1	0	0	-1	0	-1

Table 10. Continued						
Zipping up a jacket	1	1	1	0	0	0
Opening a jar of jam	1	2	1	1	-1	0
Buttoning up a shirt/sweater	0	0	0	0	0	0
Buttoning up trousers	0	1	1	1	0	1
Raw Score (max 42)	32	31	30	-1	-1	-2
Logits (Standard Error)	1.963(±0.456)	1.763(±0.456)	1.571(±0.438)	-0.200	-0.192	-0.392

Non-equivalent Control Group

Resistance Partcipant-1

Resistance Participant-1 - Range of Motion- Melbourne Assessment of Unilateral Upper Limb Function-2 -						
Items with a Range of Motion component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	3	3	3	0	0	0
Item 2: Reach sideways-elevated (3)	3	3	3	0	0	0
Item 5:Release of crayon (3)	2	2	2	0	0	0
Item 7: Release of pellet (3)	3	3	3	0	0	0
Item 10:Reach forehead- back neck (3)	3	3	3	0	0	0
Item 11: Palm to bottom (2)	2	2	2	0	0	0
Item 12: Pronation/supination (4)	4	4	4	0	0	0
Item 13:Reach to opposite shoulder (3)	3	3	3	0	0	0
Item 14: Hand to mouth and down (3)	3	3	3	0	0	0
Subscale raw total	26	26	26	0	0	0
Maximum score total	27	27	27	n/a	n/a	n/a
Percentage	96.30%	96.30%	96.30%	0%	0%	0%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Resistance Participant-1 – Accuracy - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with an Accuracy component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	3	3	3	0	0	0
Item 2: Reach sideways – elevated (3)	3	3	3	0	0	0
Item 5: Release of crayon (3)	3	3	3	0	0	0
Item 7:Release of pellet (3)	3	3	3	0	0	0
Item 9a: Pointing – green rectangle (4)	4	4	3	0	-1	-1
Item 9b: Pointing - blue rectangle (4)	4	4	4	0	0	0
Item 13: Reach to opposite shoulder (3)	3	3	3	0	0	0
Item 14: Hand to mouth and down (2)	2	2	2	0	0	0
Subscale raw total	25	25	24	0	-1	-1
Maximum total score	25	25	25	n/a	n/a	n/a
Percentage	100%	100%	96.00%	0%	-4%	-4%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Resistance Participant- 1 - Dexterity - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Dexterity component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 3: Grasp of crayon (3)	3	3	3	0	0	0
*Item 4: Drawing grasp (3)	-	-	-	n/a	n/a	n/a
Item 5: Release of crayon (3)	3	3	3	0	0	0
Item 6: Grasp of pellet (4)	4	4	4	0	0	0
Item 7: Release of pellet (3)	3	3	3	0	0	0
Item 8: Manipulation (3)	1	1	1	0	0	0
Subscale raw total	14	14	14	0	0	0
Maximum total score	16	16	16	n/a	n/a	n/a
Percentage	87.50%	87.50%	87.50%	0%	0%	0%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable' **Item 4 is not scored, as the assessed hand is the non-dominant hand*						

Resistance Participant-1 - Fluency - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Fluency component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 1: Reach forwards (3)	3	3	3	0	0	0
Item 2: Reach sideways (3)	3	3	3	0	0	0
Item 8: Manipulation (3)	2	2	3	0	1	1
Item 10: Reach forehead – back neck (3)	2	3	2	1	-1	0
Item 11: Palm to bottom (3)	3	3	2	0	-1	-1
Item 13: Reach to opposite shoulder (3)	3	3	3	0	0	0
Item 14: Hand to mouth and down (3)	3	3	3	0	0	0
Subscale raw total	19	20	19	1	-1	0
Maximum total score	21	21	21	n/a	n/a	n/a
Percentage	90.48%	95.24%	90.48%	4.76%	-4.76%	0%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable'						

Resistance Participant-1 Maximal Grip Strength Raw Data				
	Left		Right	
	Trial 1	Trial 2	Trial 1	Trial 2
Pre-test (psi)	7.00	6.50	5.00	3.50
Post-test (psi)	5.50	6.50	3.00	2.50
Follow-up (psi)	7.00	5.00	3.50	3.00
Psi is pounds per square inch				

Resistance Participant-1 ABILHAND-Kids Questionnaire Scores

Items (listed from easiest to perform, to hardest)	Pre-test (Impossible=0; Difficult = 1; Easy = 2)	Post-test (Impossible=0; Difficult = 1; Easy = 2)	Follow-Up (Impossible=0; Difficult = 1; Easy = 2)	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Switching on a bedside lamp	2	2	2	0	0	0
Unwrapping a chocolate bar	2	2	2	0	0	0
Taking a coin out of a pocket	2	2	2	0	0	0
Putting on a hat	2	2	2	0	0	0
Taking off a T-shirt	2	2	2	0	0	0
Opening a bread box	2	2	2	0	0	0
Filling a glass with water	2	2	2	0	0	0
Washing the upper-body	2	2	2	0	0	0
Opening the cap of a toothpaste tube	2	2	2	0	0	0
Opening a bag of chips	2	2	2	0	0	0
Unscrewing a bottle cap	1	1	2	0	1	1
Squeezing toothpaste onto a toothbrush	2	2	2	0	0	0
Fastening the snap of a jacket	2	2	2	0	0	0
Zipping up trousers	2	2	2	0	0	0
Putting on a backpack/schoolbag	2	2	2	0	0	0
Sharpening a pencil	2	2	2	0	0	0
Rolling up a sleeve of a sweater	2	1	1	-1	0	-1

Table 10. Continued						
Zipping up a jacket	2	2	2	0	0	0
Opening a jar of jam	1	1	1	0	0	0
Buttoning up a shirt/sweater	1	1	2	0	1	1
Buttoning up trousers	1	2	1	1	-1	0
Raw Score (max 42)	38	38	39	0	1	1
Logits (Standard Error)	3.512(±0.602)	3.512(±0.602)	3.900(±0.663)	0	0.088	0.088

Resistance Participant-2

Resistance Partcipant-2 - Range of Motion- Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Range of Motion component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	2	2	2	0	0	0
Item 2: Reach sideways-elevated (3)	2	2	2	0	0	0
Item 5:Release of crayon (3)	1	2	3	1	1	2
Item 7: Release of pellet (3)	2	3	3	1	0	1
Item 10:Reach forehead- back neck (3)	2	2	2	0	0	0
Item 11: Palm to bottom (2)	2	2	1	0	-1	-1
Item 12: Pronation/supination (4)	2	3	3	1	0	1
Item 13:Reach to opposite shoulder (3)	2	2	2	0	0	0
Item 14: Hand to mouth and down (3)	2	2	2	0	0	0
Subscale raw total	17	20	20	3	0	3
Maximum score total	27	27	27	n/a	n/a	n/a
Percentage	62.96%	74.07%	74.07%	11.11%	0%	11.11%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Resistance -2 – Accuracy - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with an Accuracy component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	2	3	3	1	0	1
Item 2: Reach sideways – elevated (3)	2	3	3	1	0	1
Item 5: Release of crayon (3)	2	3	3	1	0	1
Item 7:Release of pellet (3)	3	3	3	0	0	0
Item 9a: Pointing – green rectangle (4)	3	4	4	1	0	1
Item 9b: Pointing - blue rectangle (4)	3	4	4	1	0	1
Item 13: Reach to opposite shoulder (3)	3	2	3	-1	1	0
Item 14: Hand to mouth and down (2)	2	2	2	0	0	0
Subscale raw total	20	24	25	4	1	5
Maximum total score	25	25	25	n/a	n/a	n/a
Percentage	80.00%	96.00%	100%	16.00%	4.00%	20.00%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Resistance Participant- 2 - Dexterity - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Dexterity component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 3: Grasp of crayon (3)	2	2	2	0	0	0
*Item 4: Drawing grasp (3)	-	-	-	n/a	n/a	n/a
Item 5: Release of crayon (3)	3	2	2	-1	0	-1
Item 6: Grasp of pellet (4)	3	3	3	0	0	0
Item 7: Release of pellet (3)	2	2	2	0	0	0
Item 8: Manipulation (3)	1	1	1	0	0	0
Subscale raw total	11	10	10	-1	0	-1
Maximum total score	16	16	16	n/a	n/a	n/a
Percentage	68.75%%	62.50%	62.50%	-6.25%	0%	-6.25%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable' **Item 4 is not scored, as the assessed hand is the non-dominant hand*						

Resistance Participant -2 - Fluency- Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Fluency component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 1: Reach forwards (3)	2	2	2	0	0	0
Item 2: Reach sideways (3)	2	2	2	0	0	0
Item 8: Manipulation (3)	1	1	1	0	0	0
Item 10: Reach forehead – back neck (3)	1	2	2	1	0	1
Item 11: Palm to bottom (3)	2	2	2	0	0	0
Item 13: Reach to opposite shoulder (3)	2	2	2	0	0	0
Item 14: Hand to mouth and down (3)	2	2	2	0	0	0
Subscale raw total	12	13	13	1	0	1
Maximum total score	21	21	21	n/a	n/a	n/a
Percentage	57.14%	61.90%	61.90%	4.76%	0%	4.76%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable'						

Resistance Participant-2 Maximal Grip Strength Raw Data				
	Left		Right	
	Trial 1	Trial 2	Trial 1	Trial 2
Pre-test (psi)	6.00	6.00	1.50	2.00
Post-test (psi)	4.00	5.50	2.00	1.00
Follow-up (psi)	5.50	5.00	2.50	1.50
Psi is pounds per square inch				

Resistance Participant-2 ABILHAND-Kids Questionnaire Scores

Items (listed from easiest to perform, to hardest)	Pre-test (Impossible=0; Difficult = 1; Easy = 2)	Post-test (Impossible=0; Difficult = 1; Easy = 2)	Follow-Up (Impossible=0; Difficult = 1; Easy = 2)	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Switching on a bedside lamp	2	1	2	-1	1	0
Unwrapping a chocolate bar	1	1	1	0	0	0
Taking a coin out of a pocket	1	1	-	0	-	-
Putting on a hat	2	2	2	0	0	0
Taking off a T-shirt	2	1	2	-1	1	0
Opening a bread box	2	1	2	-1	1	0
Filling a glass with water	2	2	2	0	0	0
Washing the upper-body	1	1	2	0	1	1
Opening the cap of a toothpaste tube	1	1	1	0	0	
Opening a bag of chips	1	1	1	0	0	0
Unscrewing a bottle cap	1	1	1	0	0	0
Squeezing toothpaste onto a toothbrush	2	2	1	0	-1	-1
Fastening the snap of a jacket	0	1	0	1	-1	0
Zipping up trousers	0	0	0	0	0	0
Putting on a backpack/schoolbag	2	2	2	0	0	0
Sharpening a pencil	1	1	1	0	0	0
Rolling up a sleeve of a sweater	1	1	1	0	0	0

Table 10. Continued						
Zipping up a jacket	1	1	1	0	0	0
Opening a jar of jam	0	0	0	0	0	0
Buttoning up a shirt/sweater	0	0	0	0	0	
Buttoning up trousers	0	0	0	0	0	0
Raw Score (max 42)	23	21	22	-2	1	1-
Logits (Standard Error)	0.340(±0.412)	0.004(±0.411)	0.446(±0.422)	-0.336	0.442	0.106

Resistance Participant-3

Resistance Participant- 3 - Range of Motion - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Range of Motion component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	2	3	2	1	-1	0
Item 2: Reach sideways-elevated (3)	2	2	3	0	1	1
Item 5:Release of crayon (3)	1	1	2	0	1	1
Item 7: Release of pellet (3)	2	2	2	0	0	0
Item 10:Reach forehead- back neck (3)	2	3	2	1	-1	0
Item 11: Palm to bottom (2)	2	2	2	0	0	0
Item 12: Pronation/supination (4)	3	4	4	1	0	1
Item 13:Reach to opposite shoulder (3)	3	2	2	-1	0	-1
Item 14: Hand to mouth and down (3)	3	3	3	0	0	0
Subscale raw total	20	22	22	2	0	2
Maximum score total	27	27	27	n/a	n/a	n/a
Percentage	74.07%	81.48%	81.48%	7.41%	0%	7.41%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Resistance Participant- 3 - Accuracy - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with an Accuracy component	Pre-test	Post-test	Follow-up	Pre to Post Change	Post to Follow Up Change	Pre to Follow Up Change
Item 1: Reach forwards (3)	3	3	3	0	0	0
Item 2: Reach sideways – elevated (3)	3	3	3	0	0	0
Item 5: Release of crayon (3)	3	3	3	0	0	0
Item 7:Release of pellet (3)	3	3	3	0	0	0
Item 9a: Pointing – green rectangle (4)	4	4	3	0	-1	-1
Item 9b: Pointing - blue rectangle (4)	4	4	3	0	-1	-1
Item 13: Reach to opposite shoulder (3)	2	2	2	0	0	0
Item 14: Hand to mouth and down (2)	2	2	2	0	0	0
Subscale raw total	24	24	22	0	-2	-2
Maximum total score	25	25	25	n/a	n/a	n/a
Percentage	96.00%	96.00%	88.00%	0%	-8.00%	-8.00%
Notes: The number in brackets indicates the maximum score possible per item; n/a is 'not applicable'						

Resistance Participant-3 - Dexterity - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Dexterity component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 3: Grasp of crayon (3)	3	3	3	0	0	0
*Item 4: Drawing grasp (3)	-	-	-	n/a	n/a	n/a
Item 5: Release of crayon (3)	2	3	3	1	0	1
Item 6: Grasp of pellet (4)	4	4	4	0	0	0
Item 7: Release of pellet (3)	3	3	3	0	0	0
Item 8: Manipulation (3)	1	1	1	0	0	0
Subscale raw total	13	14	14	1	0	1
Maximum total score	16	16	16	n/a	n/a	n/a
Percentage	81.25%	87.50%	87.50%	6.25%	0%	6.25%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable' **Item 4 is not scored, as the assessed hand is the non-dominant hand*						

Resistance Participant -3 - Fluency - Melbourne Assessment of Unilateral Upper Limb Function-2						
Items with a Fluency component	Pre-test	Post-test	Follow-Up	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Item 1: Reach forwards (3)	3	2	3	-1	1	0
Item 2: Reach sideways (3)	3	3	3	0	0	0
Item 8: Manipulation (3)	2	2	2	0	0	0
Item 10: Reach forehead – back neck (3)	3	2	2	-1	0	-1
Item 11: Palm to bottom (3)	3	2	2	-1	0	-1
Item 13: Reach to opposite shoulder (3)	2	3	2	1	-1	0
Item 14: Hand to mouth and down (3)	2	3	2	1	-1	0
Subscale raw total	18	17	17	-1	0	-1
Maximum total score	21	21	21	n/a	n/a	n/a
Percentage	85.71%	80.95%	80.95%	-4.76%	0%	-4.76%
Notes: The number in brackets indicate the maximum score possible per item; n/a is 'not applicable'						

Resistance Participant-3 Maximal Grip Strength Raw Data				
	Left		Right	
	Trial 1	Trial 2	Trial 1	Trial 2
Pre-test (psi)	4.00	n/d	2.50	n/d
Post-test (psi)	5.50	n/d	3.50	n/d
Follow-up (psi)	4.00	n/d	5.00	n/d
Psi is pounds per square inch				

Resistance Participant-3 - ABILHAND-Kids Questionnaire Scores						
Items (listed from easiest to perform, to hardest)	Pre-test (Impossible=0; Difficult = 1; Easy = 2)	Post-test (Impossible=0; Difficult = 1; Easy = 2)	Follow-Up (Impossible=0; Difficult = 1; Easy = 2)	Pre to Post Change	Post to Follow-Up Change	Pre to Follow-Up Change
Switching on a bedside lamp	1	0	0	-1	0	-1
Unwrapping a chocolate bar	1	2	1	1	-1	0
Taking a coin out of a pocket	0	0	0	0	0	0
Putting on a hat	2	2	2	0	0	0
Taking off a T-shirt	2	2	2	0	0	0
Opening a bread box	1	2	1	1	-1	0
Filling a glass with water	1	1	1	0	0	0
Washing the upper-body	1	1	1	0	0	0
Opening the cap of a toothpaste tube	1	1	1	0	0	0
Opening a bag of chips	1	2	1	1	-1	0
Unscrewing a bottle cap	1	1	1	0	0	0
Squeezing toothpaste onto a toothbrush	1	1	1	0	0	0
Fastening the snap of a jacket	1	1	1	0	0	0
Zipping up trousers	0	0	1	0	1	1
Putting on a backpack/schoolbag	1	1	1	0	0	0
Sharpening a pencil	0	1	0	1	-1	0
Rolling up a sleeve of a sweater	1	1	1	0	0	0

Table 10. Continued						
Zipping up a jacket	1	1	1	0	0	0
Opening a jar of jam	0	0	1	0	1	1
Buttoning up a shirt/sweater	0	0	0	0	0	0
Buttoning up trousers	0	0	0	0	0	0
Raw Score (max 42)	16	20	18	4	-2	2
Logits (Standard Error)	0.653(±0.427)	0.614(±0.411)	0.501(±0.414)	-0.039	-0.113	-0.152

Appendix 14: Manuscript 2 Raw Data Tables

Experimental Group – Nintendo Wii Training

Wii Participant-1

Intervention Day	**Date**	**Time**	**Duration (minutes)**	**What games did you play today?** (t =Tennis, a =Archery, s=Swordplay, ba=Basketball, bo=Bowling, g=Canoeing, g =Golf, f=Frisbee)	**How much did you use your affected arm to exercise today?** (0= Not at all, 1= Once or twice, 2=A few times 3= Half of the time, 4=Most of the time, 5= All the time)	**How hard did you exercise today?** (0=Not at all, 1=A little' 2=Some, 3=Medium Hard, 4=Hard, 5=Very Hard)	**Did you have fun exercising today?** (0=No, 1= A little, 2=Some, 3=It was okay, 4=I had fun, 5 = I had a lot of fun)
1	24-Nov	5.30 pm	40	t,a,s,ba,bo,c,f	3	3	5
2	28-Nov	12.00 am	40	t,a, s,ba,bo,c,f	3	3	4
3	29-Nov	10.00 am	40	t,a,s,ba,bo,c,f	3	3	4
4	1-Dec	7.00 pm	20	n/d	3	3	3
5	2-Dec	6.30 pm	30	t,a,s,ba,bo,c,f	3	3	3
6	3-Dec	6.30 pm	30	t,a,s,ba,bo,c,f	3	3	3

7	4-Dec	7.00 pm	20	n/d	3	3	3
8	5-Dec	6.30 pm	30	t,a,s,ba,bo,c,f	3	3	3
9	7-Dec	10.00 am	40	t,a,s,ba,bo,c,f	3	3	3
10	8-Dec	7.00 pm	20	t,a,s,ba,bo,c,f	n/d	n/d	n/d
11	10-Dec	6.45 pm	20	t,a,s,ba,bo,c,f	3	3	2
12	11-Dec	6.45 pm	30	t,a,s,ba,bo,c,f	3	3	3
13	12-Dec	7.00 pm	30	t,a,s,ba,bo,c,f	3	2	2
14	13-Dec	12.00 pm, 1.00 pm	10, 15	t,a,s,ba,bo,c,f	2	2	2
15	14-Dec	1.00 pm, 3.00 pm, 6.00 pm	1015,10	t,a,s,ba,bo,c,g,f	2	2	2
16	15-Dec	7.00 pm	20	t,a,s,ba,bo,c,g,f	2	1	1
17	17-Dec	7.00 pm	15	t,a,s,ba,bo,c,g,f	2	1	1
18	18-Dec	7.00 pm	15	t,a,s,ba,bo,c,g,f	2	0	0
19	19-Dec	6.00 pm	20	t,a,s,ba,bo,c,g,f	1	0	0
20	n/d	n/d	n/d	n/d	n/d	n/d	n/d
21	n/d	n/d	n/d	n/d	n/d	n/d	n/d
22	n/d	n/d	n/d	n/d	n/d	n/d	n/d
23	n/d	n/d	n/d	n/d	n/d	n/d	n/d
24	n/d	n/d	n/d	n/d	n/d	n/d	n/d
25	n/d	n/d	n/d	n/d	n/d	n/d	n/d
26	n/d	n/d	n/d	n/d	n/d	n/d	n/d
27	n/d	n/d	n/d	n/d	n/d	n/d	n/d
28	n/d	n/d	n/d	n/d	n/d	n/d	n/d
29	n/d	n/d	n/d	n/d	n/d	n/d	n/d
30	n/d	n/d	n/d	n/d	n/d	n/d	n/d

Wii Participant-2

Intervention Day	**Date**	**Time**	**Duration (minutes)**	**What games did you play today?** (t =Tennis, a =Archery, s=Swordplay, ba=Basketball, bo=Bowling, g=Canoeing, g =Golf, f=Frisbee)	**How much did you use your affected arm to exercise today?** (0= Not at all, 1= Once or twice, 2=A few times 3= Half of the time, 4=Most of the time, 5= All the time)	**How hard did you exercise today?** (0=Not at all, 1=A little' 2=Some, 3=Medium Hard, 4=Hard, 5=Very Hard)	**Did you have fun exercising today?** (0=No, 1= A little, 2=Some, 3=It was okay, 4=I had fun, 5 = I had a lot of fun)
1	2-Feb	5.00pm	40	t, s,ba,bo, g, f	2	0	5
2	4-Feb	6.00 pm	40	t,s,f	3	2	5
3	5-Feb	6.00 pm	40	s	4	5	5
4	7-Feb	3.00 pm	40	t,s	3	3	5
5	8-Feb	2.00 pm	40	t, s, bo, g	5	5	5
6	9-Feb	4.40 pm	40	t, s, bo	4	5	5
7	10-Feb	7.00 pm	40	t, s, bo	4	5	5
8	12-Feb	7.00 pm	40	t, ba, bo	5	5	5
9	15-Feb	3.15 pm	40	t, s,ba,bo	5	5	5
10	17-Feb	3.10 pm	40	t,bo	5	5	5
11	18-Feb	4.50 pm	40	t,s,bo	4	4	5
12	21-Feb	2.00 pm	40	t, s, ba,bo	4	4	5

13	22-Feb	5.50 pm	40	t, s,bo	5	5	5
14	24-Feb	3.20 pm	40	t,s,bo	5	5	5
15	26-Feb	3.05 pm	40	t, s	4	4	5
16	27-Feb	3.10 pm	40	t,s,ba,bo,c,g,f	4	4	5
17	2-Mar	3.30 pm	40	t,ba,bo,g	5	4	5
18	3-Mar	5.30 pm	40	t,s, ba, bo, c	n/d	n/d	n/d
19	4-Mar	3.30 pm	40	t,s,ba.bo,c,g,f	5	5	5
20	5-Mar	3.35 pm	40	t, s,ba,bo,c,	4	3	5
21	7-Mar	12.10 pm	40	t, s, ba,bo, c,g	4	4	5
22	10-Mar	7.05 pm	40	t, s, ba,bo, c	5	5	5
23	13-Mar	3.40 pm	40	t, s,ba,bo,c	4	5	5
24	16-Mar	9.45 am	35	t, s, ba,bo,f	5	5	5
25	n/d	n/d	n/d	n/d	n/d	n/d	n/d
26	n/d	n/d	n/d	n/d	n/d	n/d	n/d
27	n/d	n/d	n/d	n/d	n/d	n/d	n/d
28	n/d	n/d	n/d	n/d	n/d	n/d	n/d
29	n/d	n/d	n/d	n/d	n/d	n/d	n/d
30	n/d	n/d	n/d	n/d	n/d	n/d	n/d

Wii Participant-3

Intervention Day	**Date**	**Time**	**Duration (minutes)**	**What games did you play today?** (t =Tennis, a =Archery, s=Swordplay, ba=Basketball, bo=Bowling, g=Canoeing, g =Golf, f=Frisbee)	**How much did you use your affected arm to exercise today?** (0= Not at all, 1= Once or twice, 2=A few times 3= Half of the time, 4=Most of the time, 5= All the time)	**How hard did you exercise today?** (0=Not at all, 1=A little' 2=Some, 3=Medium Hard, 4=Hard, 5=Very Hard)	**Did you have fun exercising today?** (0=No, 1= A little, 2=Some, 3=It was okay, 4=I had fun, 5 = I had a lot of fun)
1	12-Feb	7.30 pm	45	s	5	3	5
2	13-Feb	10.00 am	90	t,a,s,ba,bo	5	5	5
3	15-Feb	3.00 pm	60	s,ba	5	5	5
4	16-Feb	10.00 am, 3.00 pm	150,60	t,a,ba,bo,c,	5	5	5
5	19-Feb	4.00 pm	90	ba, bo	5	5	5
6	20-Feb	5.00 pm, 7.00 pm	90, 60	t, a,ba	5	5	5
7	21-Feb	10.00 am, 1.00 pm	60, 60	t,a,s.bo	5	5	5
8	26-Feb	4.30 pm	60	t,s,ba	5	5	5
9	27-Feb	6.00 pm	60	t,bo	5	5	5

10	28-Feb	9.00 am, 4.00 pm	120, 90	t,a,bo	5	5	5
11	1-Mar	8.00 pm	90	t,a,bo	5	5	5
12	2-Mar	4.15 pm	75	s,bo	5	5	5
13	5-Mar	4.30 pm	60	t,s	5	5	5
14	6-Mar	6.00 pm	60	t,s	5	5	5
15	7-Mar	8.00 am,10.00 am, 1.00 pm	60, 30, 60	t,a, ba	5	5	5
16	9-Mar	4.30 pm	60	s, ba	5	5	5
17	12-Mar	4.30 pm, 6.00 pm	60, 30	t,s,ba	5	5	5
18	13-Mar	8.00 am,11.00 am, 2.00 pm	60, 30,30	t,s, ba	5	5	5
19	16-Mar	9.00 am, 2.00 pm	60, 60	t,s	5	5	5
20	17-Mar	9.00 am, 2.00 pm	60, 60	t,s	5	5	5
21	19-Mar	9.00 am, 2.00 pm	60, 60	t,s,bo	5	5	5
22	23-Mar	9.00 am, 5.00pm	60, 30	t	5	5	5
23	24-Mar	5.00 pm	30	t,s	5	5	5
24	26-Mar	5.00 pm	30	t	5	5	5
25	27-Mar	4.15 pm	30	t	5	5	5
26	n/d	n/d	n/d	n/d	n/d	n/d	n/d
27	n/d	n/d	n/d	n/d	n/d	n/d	n/d
28	n/d	n/d	n/d	n/d	n/d	n/d	n/d
29	n/d	n/d	n/d	n/d	n/d	n/d	n/d
30	n/d	n/d	n/d	n/d	n/d	n/d	n/d

Non-Equivalent Control Group

Resistance Participant-1

Equipment Assignment: red (1.5 kg) weight, light (yellow) resistance band, squeeze balls							
Intervention Day	**Date**	**Time**	**Number of Sets**	**Duration** (minutes)	**How much did you use your affected arm to exercise today?** (0= Not at all, 1= Once or twice, 2=A few times 3= Half of the time, 4=Most of the time, 5= All the time)	**How hard did you exercise today?** (0=Not at all, 1=A little' 2=Some, 3=Medium Hard, 4=Hard, 5=Very Hard	**Did you have fun exercising today?** (0=No, 1= A little, 2=Some, 3=It was okay, 4=I had fun, 5 = I had a lot of fun)
1	16-Jan	4.30 pm	2	12	4	4	4
2	24-Jan	3.00 pm	1	13	4	4	4
3	n/d	n/d	n/d	n/d	n/d	n/d	n/d
4	n/d	n/d	n/d	n/d	n/d	n/d	n/d
5	n/d	n/d	n/d	n/d	n/d	n/d	n/d
6	n/d	n/d	n/d	n/d	n/d	n/d	n/d
7	n/d	n/d	n/d	n/d	n/d	n/d	n/d
8	n/d	n/d	n/d	n/d	n/d	n/d	n/d
9	n/d	n/d	n/d	n/d	n/d	n/d	n/d

10	n/d	n/d	n/d	n/d	n/d	n/d	n/d
11	n/d	n/d	n/d	n/d	n/d	n/d	n/d
12	n/d	n/d	n/d	n/d	n/d	n/d	n/d
13	n/d	n/d	n/d	n/d	n/d	n/d	n/d
14	n/d	n/d	n/d	n/d	n/d	n/d	n/d
15	n/d	n/d	n/d	n/d	n/d	n/d	n/d
16	n/d	n/d	n/d	n/d	n/d	n/d	n/d
17	n/d	n/d	n/d	n/d	n/d	n/d	n/d
18	n/d	n/d	n/d	n/d	n/d	n/d	n/d
19	n/d	n/d	n/d	n/d	n/d	n/d	n/d
20	n/d	n/d	n/d	n/d	n/d	n/d	n/d
21	n/d	n/d	n/d	n/d	n/d	n/d	n/d
22	n/d	n/d	n/d	n/d	n/d	n/d	n/d
23	n/d	n/d	n/d	n/d	n/d	n/d	n/d
24	n/d	n/d	n/d	n/d	n/d	n/d	n/d
25	n/d	n/d	n/d	n/d	n/d	n/d	n/d
26	n/d	n/d	n/d	n/d	n/d	n/d	n/d
27	n/d	n/d	n/d	n/d	n/d	n/d	n/d
28	n/d	n/d	n/d	n/d	n/d	n/d	n/d
29	n/d	n/d	n/d	n/d	n/d	n/d	n/d
30	n/d	n/d	n/d	n/d	n/d	n/d	n/d

Resistance Participant -2

Equipment Assignment: tan (0.5 kg) weight, light (yellow) resistance band, squeeze balls							
Intervention Day	**Date**	**Time**	**Number of Sets**	**Duration** (minutes)	**How much did you use your affected arm to exercise today?** (0= Not at all, 1= Once or twice, 2=A few times 3= Half of the time, 4=Most of the time, 5= All the time)	**How hard did you exercise today?** (0=Not at all, 1=A little' 2=Some, 3=Medium Hard, 4=Hard, 5=Very Hard	**Did you have fun exercising today?** (0=No, 1= A little, 2=Some, 3=It was okay, 4=I had fun, 5 = I had a lot of fun)
1	15-Jan	3.45 pm	2	15	5	5	4
2	16-Jan	5.00 pm	2	15	4	4	4
3	20-Jan	5.00 pm	2	20	5	4	4
4	23-Feb	n/d	"All sets"*	n/d	n/d	n/d	n/d
5	24-Feb	n/d	"All sets"	n/d	n/d	n/d	n/d
6	25-Feb	n/d	"All sets"	n/d	n/d	n/d	n/d
7	27-Feb	n/d	"All sets"	n/d	n/d	n/d	n/d
8	28-Feb	n/d	"All sets"	n/d	n/d	n/d	n/d
9	3-Mar	n/d	n/d	n/d	n/d	n/d	n/d
10	7-Mar	n/d	n/d	n/d	n/d	n/d	n/d
11	8-Mar	n/d	n/d	n/d	n/d	n/d	n/d

12	10-Mar	n/d	n/d	n/d	n/d	n/d	n/d
13	14-Mar	n/d	n/d	n/d	n/d	n/d	n/d
14	15-Mar	n/d	n/d	n/d	n/d	n/d	n/d
15	16-Mar	n/d	n/d	n/d	n/d	n/d	n/d
16	21-Mar	n/d	“All sets”	n/d	n/d	n/d	n/d
17	n/d	n/d	n/d	n/d	n/d	n/d	n/d
18	n/d	n/d	n/d	n/d	n/d	n/d	n/d
19	n/d	n/d	n/d	n/d	n/d	n/d	n/d
20	n/d	n/d	n/d	n/d	n/d	n/d	n/d
21	n/d	n/d	n/d	n/d	n/d	n/d	n/d
22	n/d	n/d	n/d	n/d	n/d	n/d	n/d
23	n/d	n/d	n/d	n/d	n/d	n/d	n/d
24	n/d	n/d	n/d	n/d	n/d	n/d	n/d
25	n/d	n/d	n/d	n/d	n/d	n/d	n/d
26	n/d	n/d	n/d	n/d	n/d	n/d	n/d
27	n/d	n/d	n/d	n/d	n/d	n/d	n/d
28	n/d	n/d	n/d	n/d	n/d	n/d	n/d
29	n/d	n/d	n/d	n/d	n/d	n/d	n/d
30	n/d	n/d	n/d	n/d	n/d	n/d	n/d

Resistance Participant-3

Equipment Assignment: tan (0.5 kg) weight, light (yellow) resistance band, squeeze balls							
Intervention Day	**Date**	**Time**	**Number of Sets**	**Duration** (minutes)	**How much did you use your affected arm to exercise today?** (0= Not at all, 1= Once or twice, 2=A few times 3= Half of the time, 4=Most of the time, 5= All the time)	**How hard did you exercise today?** (0=Not at all, 1=A little' 2=Some, 3=Medium Hard, 4=Hard, 5=Very Hard	**Did you have fun exercising today?** (0=No, 1= A little, 2=Some, 3=It was okay, 4=I had fun, 5 = I had a lot of fun)
1	29-Jan	4.30 pm	1	20	5	2	3
2	1-Feb	2.10 pm	n/d	20	4	3	5
3	3-Feb	7.00 pm	1	15	5	5	5
4	4-Feb	7.00 pm	1	25	3	2	4
5	8-Feb	6.00 pm	1	20	4	4	5
6	12-Feb	5.00 pm	1	20	4	2	4
7	23-Feb	6.20 pm	1	15	5	4	5
8	2-Mar	6.30 pm	1	20	5	4	5
9	3-Mar	6.00 pm	1	25	5	4	4
10	5-Mar	7.00 pm	1	20	5	3	5
11	n/d	n/d	n/d	n/d	n/d	n/d	n/d

12	n/d	n/d	n/d	n/d	n/d	n/d	n/d
13	n/d	n/d	n/d	n/d	n/d	n/d	n/d
14	n/d	n/d	n/d	n/d	n/d	n/d	n/d
15	n/d	n/d	n/d	n/d	n/d	n/d	n/d
16	n/d	n/d	n/d	n/d	n/d	n/d	n/d
17	n/d	n/d	n/d	n/d	n/d	n/d	n/d
18	n/d	n/d	n/d	n/d	n/d	n/d	n/d
19	n/d	n/d	n/d	n/d	n/d	n/d	n/d
20	n/d	n/d	n/d	n/d	n/d	n/d	n/d
21	n/d	n/d	n/d	n/d	n/d	n/d	n/d
22	n/d	n/d	n/d	n/d	n/d	n/d	n/d
23	n/d	n/d	n/d	n/d	n/d	n/d	n/d
24	n/d	n/d	n/d	n/d	n/d	n/d	n/d
25	n/d	n/d	n/d	n/d	n/d	n/d	n/d
26	n/d	n/d	n/d	n/d	n/d	n/d	n/d
27	n/d	n/d	n/d	n/d	n/d	n/d	n/d
28	n/d	n/d	n/d	n/d	n/d	n/d	n/d
29	n/d	n/d	n/d	n/d	n/d	n/d	n/d
30	n/d	n/d	n/d	n/d	n/d	n/d	n/d