Video games as a rehabilitation strategy for children with cerebral palsy

by

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Abstract

Video games have recently emerged as a potential motivational tool in rehabilitation. Research suggests that video games can enhance motivation to exercise and increase adherence to physical practice. Active video games (AVGs), also known as "exergames" require body movement beyond the conventional hand controller-based video games. AVGs have been used for rehabilitation purposes in population with neuromotor dysfunction such as stroke and Parkinson's disease. There is emerging interest in using AVGs to augment rehabilitation with children with cerebral palsy. However, it is unclear whether AVGs are effective for improving rehabilitation outcomes for this group of children. This thesis comprised two parts; Part one is a systematic review and meta-analysis for the effectiveness of video games in the rehabilitation of children with Cerebral Palsy (CP) (Chapter 2). The systematic review is a summary of the evidence of effectiveness for AVGs used as a rehabilitation tool for improving outcomes including balance, executive functioning, reaction time, upper limb function, visual perceptual skills, and gross motor function. In total, 19 studies were included based on the eligibility criteria and were divided into three categories based on the comparisons in the study: 1) video games compared to no therapy, 2) video games compared to regular therapy, 3) video games and regular therapy compared to regular therapy. The evidence to support the effectiveness of AVGs for improving rehabilitation outcomes was weak and inconclusive due to issues in the quality of the included studies. The second part of this thesis is a description of a detailed process involved in the design, development, and preliminary evaluation of an AVG for lower limb strength training in children with CP. The reflection includes challenges and lessons learned through the process. A preliminary evaluation of the AVG provides an understanding of the feasibility and usability of the gaming system with respect to enjoyment, motivation, game engagement, and system usability.

Preface

This thesis is original work by Shivangi Bajpai. The research project, of which this thesis is a part, received ethics approval from the University of Alberta Research Ethics Board as "Evaluation of a video game to augment conventional lower limb strength training with children with cerebral palsy," No. Pro00087186, July 3, 2019. No part of this thesis has been previously published.

Dedication

To my father, Mr. Upendra Nath Bajpai. Despite struggling with Parkinson's at a young age, he worked hard to provide me and my brother the best education possible and inspired me to contribute to research in rehabilitation. I would not be the person I am today if it was not for him.
To my mother, Mrs. Pushpa Bajpai, for staying strong for my family and keeping my education above everything else.
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Chapter 1

Introduction

Cerebral Palsy

Cerebral palsy (CP) is "a group of disorders of the development of movement and posture, causing activity limitation, that is attributed to non-progressive disturbances that occurred in the developing foetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder." (1) Cerebral palsy is one of the most frequently occurring neurodevelopmental disorders of childhood affecting approximately 2.1 of 1000 live births (2). CP is a heterogeneous condition; gross motor abilities vary and range from difficulty in coordination during more complex movements (such as walking, running, or jumping) to exclusive use of a wheelchair for locomotion. Motor difficulties associated with CP can also cause challenges with daily living skills, including feeding, and self-care activities related to personal hygiene. Associated sensory processing impairments can be caused by a primary disturbance of the brain or secondary consequences of activity limitation that restrict learning and perceptual developmental experiences (3).

Gross Motor Function Classification

Gross motor classification for CP is based on a description of motor performance using the Gross Motor Function Classification System (GMFCS) (4). The GMFCS classifies performance related to gross motor functioning, including walking, running, jumping, and sitting. Performance is classified using a five-level scale with criteria for five age strata: 0-2 years, 2-4 years, 4-6 years, 6-12 years, and 12-18 years. Children classified as GMFCS Level I walk without restrictions and experience limitations in more advanced gross motor skills. Children classified as Level II walk without restrictions with limitations walking outdoors. Children classified at Level III walk with assistive mobility devices while children at Level IV experience limited movement and use wheelchairs as their primary method of locomotion. Children classified at Level V have limited movement, even with the use of assistive (4). The GMFCS promotes a common understanding and enhances communication about level of gross motor functioning between various health professionals. The GMFCS has been used in both observational and experimental research to describe study samples and to explore the role of gross motor function level as a predictor of outcomes such as gait characteristics, physical activity, and walking abilities (5).

In addition to GMFCS levels, CP is described by the presence of at least one muscle tone abnormality, including spasticity, ataxia, and dyskinesia (dystonia and athetosis). **Spasticity** is defined as "velocity-dependent resistance of a muscle to stretch" that occurs when resistance to externally imposed movement increases with increased stretching velocity. Spasticity varies with the direction of joint movement, and resistance to externally imposed movement rises rapidly above a threshold speed or joint angle (6). Approximately 75% of children with CP have spasticity. **Dyskinesia** is characterized by involuntary muscle tone fluctuation and is further divided into 1) dystonia and 2) choreoathetosis. Dystonia is defined as involuntary sustained or intermittent muscle contractions that cause twisting and repetitive movements, abnormal postures, or both (6). Choreoathetosis is characterized by hyperkinesia (increased activity) and hypotonia (decreased tone) (7,8). Many children with choreoathetosis experience difficulty with holding objects and using their hands. **Ataxia** is characterized by an abnormal pattern of posture or movement and challenges with muscle coordination so that movements are performed with abnormal force, rhythm, and accuracy (8). Approximately 4% of children with CP present with ataxia (8).

In addition to the type of muscle tone abnormalities, CP is described as unilateral or bilateral. Traditional classification systems remain in use and are based on the topographic distribution of limb involvement: 1) monoplegia - single limb involvement, 2) diplegia - primarily involvement of both legs, 3) hemiplegia - one side of the body is affected, and 4) quadriplegia- involvement of both arms and legs (9). In northern Alberta, approximately 87% of children with CP have spasticity, including 20.9% with diplegia, 6.8% with triplegia, 22.2% with quadriplegia, and 50% with hemiplegia/monoplegia (10).

In addition to the GMFCS, classification systems are used to describe fine motor and communication abilities. The **Manual Ability Classification System (MACS)** classifies how children use their hands while handling objects in daily activities and is based on the self-initiated manual ability of the child. Similar to the GMFCS, fine motor performance is divided into five levels. Classification system rating forms are available at www.macs.nu. The Communication Function Classification System (11) is used to classify communication performance.

Physical Therapy Interventions for Children with CP

Physical therapy interventions primarily aim to improve the functional motor abilities of children with CP and include passive stretching, static weight-bearing exercises, muscle strengthening, aerobic and anaerobic exercise, task-specific exercises, treadmill training, and electrical stimulation (12). Muscle strengthening is performed by increasing a muscle's ability to generate force, consequently increasing generating power in weak muscles. Strengthening is important with children with CP because they often present with muscle weakness, and resulting asymmetry can result in difficulty coordinating movement. In addition, muscle weakness can affect balance if there are inadequate force and power production of muscles needed to maintain balance during movement (13). Walking ability is related to muscle weakness, indicating that muscle strength plays a major role in gross motor function (14). Several studies have demonstrated an association between muscle weakness and walking efficiency, velocity, gait, spasticity, and gross motor function (14,15).

Resistance Training

Progressive, resistance training is frequently used as a physical therapy intervention to increase the muscle strength of children and youth with CP (16). Resistance training is used to enhance motor abilities, including walking speed, balance, and coordination, endurance, and functional motor tasks (17). General principles of resistance training encourage consideration of the following factors that will influence the design of the training program (17):

1. Muscle actions: Muscle actions include concentric, eccentric, and isometric. Eccentric contractions permit the muscle to elongate in response to the greater opposite force, require less energy per level of force yet cause delayed muscle soreness. Concentric contractions permit muscles to shorten, thereby generating force. Most programs include repetitions of concentric and eccentric contractions. However, some advanced programs may include different forms of isometric training (e.g., functional isometrics) to maximize gains in strength and hypertrophy.
2. Targeted muscles/muscle groups: Resistance training can target major muscle groups that traverse one joint, known as single joint exercise or muscles that cross more than one joint. Single joint exercises are often used in the case of injury to minimize risk to the injured structures, while multiple joint training is used to gain muscular strength and power for large muscle mass involvement.
3. Exercise order and work out structure: There are three basic workout structures: 1) total-body workouts, 2) upper/lower body split workouts, and 3) muscle group split routines.

Total-body workouts involve all key muscle groups, while split routines target specific muscle groups.

4. Loading: Loading is the amount of weight lifted or the resistance used. Loading depends on other considerations such as exercise order, volume, frequency, muscle action, repetition speed, and rest interval length.
5. Volume: Training volume is altered by changing the number of repetitions performed per set, or the number of sets performed per session.
6. Rest interval: Different goals need different rest intervals. For example, goals related to hypertrophy and endurance require short rest intervals, while longer intervals are required to gain strength.
7. Velocity: Velocity plays an important role in building muscle strength. It is recommended that slow to moderate velocities be used by individuals who are new to strength training. Recommendations for advanced training includes the use of slow, moderate, and fast repetition velocities depending on the load, repetition number, and goals of the particular exercise (17).
8. Frequency: The number of training sessions performed in a given period of time may differ based on goals, medical condition, ability, volume, and type of exercise.

Progressive Resistance Training

All eight factors are manipulated to achieve a higher level of muscular fitness, a process called progressive resistance training. The basic principles of progressive resistance training include progression overload, specificity, and variation. **Progression overload** is a gradual increase in stress placed upon the body during exercise. As muscles are known to be highly adaptive, the tolerance level of muscles increases and they adapt as the physiological demand increases. **Specificity** is an important consideration for transferring strength gains to functional skills as it refers to the alignment of the exercise with actions required for particular tasks (17). Finally**, variation of intensity and volume** over a period increases muscle adaptation. Once a muscle adapts to increased demands, variation is required to further develop muscle strength. Hence, it is important to change one or more variables with time to gain better results (18).

Strengthening with children who are typically developing

Research suggests that prepubescent children achieve strength gain in response to progressive resistance training without associated muscle hypertrophy (19). In pre-pubescent children, the low androgen concentration obstructs the increase in muscle size; however, the neurological adaptation during training induces a change in motor unit activation (activation of more motor neurons and muscle fibers) resulting in increased muscle strength (19). Training induces changes in strength unaffected by male or female sex (20). Traditionally, strengthening was avoided due to misconceptions about the risk of growth plate injury, but more contemporary perspectives do not rule out resistance training with children. The American Academy of Pediatrics' guidelines for progressive resistance training in children and adolescents suggests that the risk of adverse effects related to linear growth or cardiovascular health is very low and recommends a well-designed strength training program for children following the recommended loads, sets, reps, volume and rest periods (21).

Progressive resistance training in children and youth with CP

Many studies have been conducted over the last two decades to evaluate the effectiveness of strength training in adults and children with CP (22,23)**.** Dodd et al. (2002) conducted a systematic review to summarize the effects of strength training with children with CP and suggested that there is evidence to support the effectiveness of strength training on muscle strength and motor functions in people with CP (16). Andersson et al. (2003) observed significant improvements in isometric strength (hip extensors and hip abductors) and isokinetic concentric muscle action after strength training with adults with CP (24). Similarly, MacPhail and Kramer (1995) reported a significant gain in knee extensor and flexor strength in adolescents with CP with an increase ranging from 12% to 28% after eight weeks of an isokinetic strength training program (25). Damiano et al. (1995) found a consistent increase in muscle strength in children with spastic CP (26) with no adverse effects on spasticity.

While there is a general consensus that resistance training should be considered as an intervention strategy for children with CP, Scianni et al. (2009) suggested that existing evidence does not support the effectiveness of strengthening; an impetus for increased research in this area (27). More recently, investigations of the effectiveness of power training, a form of strength training to develop muscle group's ability to contract at maximum force in minimal time ability velocity, have demonstrated promising results (28–30). Functional power training also appears to be an effective intervention to improve walking capacity and muscle strength in young children with CP (31). Power training is considered to be more effective than traditional strength training for improving the velocity of movement, muscle power, and walking performance as it helps to increase fascicle length and cross-sectional area while traditional strength training increases muscle size only (32). Moreau et al. (2012) suggest that power training should be incorporated into everyday clinical practice for children with CP (32).

Verschuren et al. (2016) (33) provided recommendations for traditional lower limb strength training of individuals with CP: 2–3 times per week on nonconsecutive days, and 1–4 sets of 6–15 repetitions with rest periods of at least 1 minute for a period of 12-16 weeks (33). For power training, Moreau et al. (2015) recommended a frequency of 2-3 times per week for at least eight weeks, rest periods of at least 1 minute, a volume of ≥3 sets of ≤6 repetitions ranging in intensity from 30% to 80% of 1RM (repetition maximum) with progression toward the higher end of the range (34). It is also important to ensure that training is eventually translated into functional activities.

Motor Learning

The production of movement required for strength can be challenging for children with CP since they experience co-contraction of agonists and antagonists and challenges with selective motor control required for isolated joint movement. Hence, it is important to consider motor learning for the acquisition of capabilities to perform any specific movement. One goal of rehabilitation interventions for children with CP is to enhance purposeful motor skills required to perform daily life activities (35). The process of attainment of the motor skills through practice resulting in permanent changes in the ability to perform a task is called "motor learning." Motor learning integrates the principles of psychology, neurology, rehabilitation, and physical education (35). Neuroplasticity, the ability of neurons and neuron circuits to change in form and function in response to alterations in their environment, enables humans to exhibit the capacity to learn by acquiring useful information about the environment through experience (36). The activity-dependent plasticity is a type of neuroplasticity that arises from the use of cognitive functions and personal experiences (37). Children with CP have greater potential for plasticity, as compared to adults, as younger brains are more amenable to neurite outgrowth and more capable of axonal projections. The developing brain is more plastic compared to a mature brain, suggesting that rehabilitation interventions could take advantage of developmentally regulated mechanisms for plasticity before maturation. (38). Several factors are considered in optimizing motor learning processes, such as how verbal instructions are provided, characteristics and variability of training sessions, the extent individuals, actively participate and are motivated, learning through trial and error, postural control, memory, and feedback (39). Motor learning strategies are observable therapeutic actions used to reinforce the principles of motor learning. Levac et al. (2009) emphasized the following three motor learning strategies (40):

- Use of verbal instructions with relevant task information or to direct the learner's attention to specific aspects of the task.
- Organization of structure, schedule, and amount of physical practice to optimize learning.
- Provision of frequent or infrequent verbal feedback about task performance or outcome.

Research has supported the value of motor learning-based interventions for children with CP (41,42). Toner et al. (1998) studied ankle strength training using a computer-assisted system based on principles of motor learning and found significant improvement in gross motor function and mechanical efficiency (43). Levac et al. (2009) also suggested that motor learning strategies are very useful for interventions that aim to improve motor abilities for children with neuromotor disorders (40). Abswoude et al. (2015) studied the effects of errors during practice on motor skill learning in young individuals with CP and suggested that intervention protocols should be designed with a reduced amount of errors to enhance the amount of learning and motor performance (44). Similarly, too much feedback may interfere with learning tasks with individuals with CP (45). Hence, while designing any new intervention to improve the motor skills of children with CP, it is important to consider motor learning strategies to maximize therapeutic impact.

Active Video Gaming and Rehabilitation

Video games have recently emerged as a potential motivational tool in rehabilitation. Research suggests that video games can enhance motivation to exercise and increase adherence to physical practice (46,47). Active video games (AVGs), also known as "exergames" require body movement beyond the conventional hand controller-based video games. Commercially available exergame systems such as Nintendo Wii, Microsoft Kinect, Sony PlayStation have been used for rehabilitation of individuals with neuromotor dysfunction (48–50). While the number of studies is limited and outcomes are varied, the literature generally supports the use of AVGs for improving motor function (51). Penko et al. (2010) reported that Wii based games lead to significantly higher physiologic measures of intensity (heart rate and VO_2) in children compared to treadmill walking. These findings suggest that active video games can be a viable motivational tool to promote change in physical activity behavior (52). In another study, children with CP demonstrated similar energy expenditure and responses as typically developing children, suggesting that active video games should be considered as a strategy to increase physical activity and motor control of children with CP (49).

The Nintendo Wii may be an effective strategy for improving balance with children with CP (53). Since the installation and use of computer gaming devices and software are convenient, the interventions can also be used by children with CP at home (53). In addition, there is some evidence that video game use is sustainable for individuals with CP. Chung et al. (2015) used a low-cost Microsoft KINECT®-based game to study the effects of active video games on adults with CP at a community center. The majority of the participants (95%) strongly agreed to continue using the video game as a therapeutic intervention (54).

Use of Video Games to Enhance Rehabilitation

Exergames focused on balance, muscle strengthening, and motivation have previously been designed for rehabilitation (55–57). To ensure the high motivation, the authors designed the game "Life is a Village" by identifying the following six requirements (56): **(1)** integrating music to induce positive mood states and reduce the feeling of discomfort, **(2)** facilitating leadership to novice players by providing guidance (e.g., directions) to the player within the game, **(3)** providing achievable short and long-term goals, **(4)** hiding players' fitness level to avoid perceived incompetence while playing with opponents who are more fit, **(5)** avoiding systemic barriers to grouping like peer pressure, and **(6)** actively assisting players in forming groups. Since these requirements may contradict each other or interfere with the design of an enjoyable game, the authors emphasized the importance of a balanced approach, which sometimes involves prioritizing requirements to achieve a successful game therapy program (56). Hernandez et al. (2013) designed various action games to understand challenges, design aspects, and requirements for children with CP and other motor disorders (58). They recommended the following measures for designers to create the game playable for children with CP (58):

- reducing the need for carefully timed actions to navigate the game
- ensuring that errors due to difficulties completing time-sensitive actions do not impair fun,
- reducing the number of decisions players need to make while using a simple control scheme,
- removing the need for precise positioning and aiming, reducing the demands on manual ability and visual-motor integration,
- making the game state visible by reducing the need for attention to gameplay, and
- compensating for differences in players' gross motor skills.

All these considerations are important for game design with children with CP as they accommodate motor challenges that may affect the ability to be successful with mainstream games.

Statement of the Problem

Strengthening exercises and motor learning involve intensive, long-term repetitive routines (59), which in turn require motivation and dedication (60). Additionally, younger children, in particular, may find it challenging to follow direct instructions required for the therapy. Studies suggest motivation as one of the most influential personal characteristics that determine motor and functional outcomes in children with CP (61,62). New strategies/tools with therapy are needed to create motivating therapy programs, and increase clarity of the exercises would likely facilitate increased engagement in therapy and improved rehabilitation outcomes. The use of AVG is one of the potential tools that has recently emerged to promote engagement and motivation behaviour towards health outcomes such as physical activity (46,63,64). The researchers have been trying to use the fun & enjoyment elements of the game for other therapeutic gains as well, such as improvement in balance, motor skills, walking abilities in children with CP (65–67). For future advances in this area, it would be helpful to examine existing evidence for the effectiveness of videogames in the rehabilitation of children with CP. Addressing the gaps in the evidence could highlight the areas of improvement for future researchers and help researchers to come up with improved interventions in the future. As the commercial gaming systems do not entirely adhere to the due to therapy guidelines due to their generic nature, and the gaming systems are not flexible to accommodate an individual's abilities and needs. Hence, new games or gaming systems are needed to be designed that could follow the therapy guideline for children with CP. We understand that designing a video game for therapy of children with CP can be challenging due to a wide range of variations in motor and cognitive abilities and restrictions with therapeutic principles. Studies that address the design aspects of the gaming system and possible challenges and their solutions may help promote innovation and development in the area of gaming rehabilitation for children with CP.

Research Objectives

The two specific objectives of this thesis were to:

1. Investigate the effectiveness of video-game interventions with children with CP based on existing evidence.
2. Design and develop and pilot test evaluation of a sensor-based video game to augment lower limb strength training for children with CP.

This thesis consists of four parts: 1) background and introduction, 2) a systematic review and meta-analysis of the effectiveness of video games for improving rehabilitation outcomes, 3) experience and learnings from the design, development, and evaluation of a sensor-based video game designed for to augment lower limb strength training in children with CP, and 4) summary of the work and future implications.

Chapter 2

Effectiveness of video games for improving rehabilitation outcomes of children with cerebral palsy: A Systematic review to be submitted as:

Bajpai, S. & Pritchard-Wiart, L. Effectiveness of video games for improving rehabilitation outcomes of children with cerebral palsy: A systematic review and meta-analysis

Introduction

Cerebral palsy (CP) is a heterogenous motor disorder resulting from damage to the infant brain that affects function and is often accompanied by other impairments that affect vision, hearing, and cognition (1). Physical and occupational therapists provide rehabilitation interventions that are focused on motor skills and functional mobility (68) and include stretching, goal-oriented therapy, muscle strengthening, aerobic and anaerobic exercise, treadmill training, and electrical stimulation (12). The use of video games to augment rehabilitation interventions has recently garnered attention in the literature (69). The games, specifically targeting rehabilitation, require body-movements to control targets on the screen. These games, known as active video games (AVG) or motion-controlled games, (70) help promote physical activity and fitness by providing an immersive and engaging environment. Many researchers have shown interest in using widely available commercial games such as Sony eye toy for PlayStation® (71), Nintendo Wii® (72) (73), and virtual reality (VR) games (74) (48), while some have tried to design new video games to augment conventional training by incorporating therapeutic principles and needs (75,76).

AVGs have created opportunities for the incorporation of video games for individuals with neurological disorders, including stroke, Parkinson's disease, and cerebral palsy (48,77–81). For children with disabilities, video games have demonstrated some effectiveness for improving motor performance, motivation, physical activity, and engagement in the therapy (66,81–83). Studies have suggested positive effects of video games-based interventions on upper extremity function (51,83,84) with individuals with CP. Two systematic reviews (66,82) reported the effectiveness of AVG to use various rehabilitation outcomes in non-typically developing children. Page et al. (2017) reported strong evidence that AVGs are effective in improving balance (66). The study did not investigate the gross motor skills in detail specifically for children with CP; however, indicated some evidence in favor of AVG (66). A review Bonnechère et al. (2014) synthesized evidence on the methods of incorporating video games with conventional methods for treatment in children with CP and suggests that video games use in rehabilitation are helpful in increasing motivation among children with CP (85). Lopes et al. (2018) (83) conducted a systematic review and reported some evidence for the efficacy of the video game on motor functions and physical activity and suggested that games may promote engagement in therapy resulting in therapeutic gains (83). Similarly, the other systematic review and meta-analysis (84) reported a significant difference between the motion-controlled games and conventional upper limb training. However, both of the reviews studied population with CP with no age limitation. The current systematic review and meta-analysis are different from the ones mentioned above because this systematic review determined the effectiveness of AVGs on a variety of rehabilitation outcomes, specifically in children with CP. Additionally, we included only randomized controlled trials for a more robust quality of the evidence.

Objectives

To determine the effectiveness of video game interventions for improving rehabilitation outcomes of children with cerebral palsy.

Research Questions

The three specific research questions for this systematic review are:

1. How effective are video game interventions for children with CP compared to no therapy?
2. How effective are video game interventions for children with CP compared to regular therapy?
3. How effective are video game interventions and regular therapy combined compared to regular therapy for children with CP?

Methods

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (86) was used to guide the reporting of this systematic review. We submitted the protocol for this systematic review on PROSPERO, an international database of prospectively registered systematic reviews (www.crd.york.ac.uk/prospero/) before initiation of data extraction.

Inclusion Criteria

Study design: We included only randomized controlled trials (RCTs). Studies using other research designs, reviews, newspaper articles, conference proceedings, were excluded.

Participants: Studies that included children with a diagnosis of cerebral palsy (any motor type and severity) aged 0 years to 20 years were eligible for inclusion.

Experimental/comparator interventions: We included studies that used video games only or in combination with conventional rehabilitation. Video games were defined as any type of electronic/computer-based game including but not limited to, Kinect® based games, virtual reality, computer games, screen games, internet games, Nintendo Wii®, console games, etc. As a comparator, we included studies that had no treatment or conventional rehabilitation (i.e., physical therapy, occupational therapy, psychology) in the control group.

Outcomes of Interest: We focused on outcomes relevant to pediatric occupational and physical therapy such as balance, functional motor abilities, walking ability, and upper limb function.

Search Strategy

A bibliographic search of the following six electronic databases was performed. The database search included MEDLINE (1841-2019), CINAHL(1937-2019), Scopus (2004-2019), EMBASE OVID (1974-2019), PsycINFO (1887-2019), SPORTDiscus (1841-2019) until June 5, 2019. We identified keywords using PICO (Population, Intervention, Comparator, and outcomes) with the assistance of a librarian specialized in health sciences. The main keywords used were ("cerebral palsy" OR preschool OR Adolescdolesc* OR pediat* OR paediat*) AND ("video games" OR "Virtual reality" OR "augmented reality" OR "computer gaming" OR PlayStation OR Xbox OR "Nintendo Wii" OR "Kinect*" OR "Immersive game.") No restrictions were made regarding the language of the publication. The search strategy for each database is provided in Appendix A.

Data Screening

Two reviewers (SB and LP) independently conducted the first phase of screening based on the article title and, if available, study abstract. Subsequently, independent reviews of full-text were performed by the same two reviewers based on pre-defined inclusion-exclusion criteria reported above and in Covidence (87). Conflicts were resolved via discussion between the two reviewers.

Data Extraction

Data extraction was carried out independently by the two reviewers and entered into Microsoft Excel sheet and Microsoft Word documents. Extracted data included study characteristics, type of intervention and comparator, duration and frequency of treatment, types of outcomes and outcome measures, and findings. For the studies that did not report between-group differences, we extracted all pre and post-treatment scores or mean change and standard deviations.

Risk of Bias Assessment

We used the Cochrane Risk of Bias, version 2nd (RoB-2) (88), a revised Cochrane risk of bias assessment tool for assessing the risk of bias and study quality. The five domains of the ROB-2 assessment are 1) randomization process, 2) deviation from intended intervention, 3) missing outcome data, 4) measurement of the outcome and 5) selection of the reported results. The assessment was performed by two independent reviewers (SB and LP), and any discrepancies were resolved by discussion. Trials were classified as high, unclear, or low risk of bias using the guidelines proposed by the Cochrane collaboration ROB-2 tool (88).

Data Analysis and Synthesis

Articles were categorized into three subgroups based on the three research questions: 1) Video game intervention compared to no treatment, 2) Video game intervention compared to regular therapy, and 3) Video game intervention and regular therapy compared to regular therapy. Meta-analyses were conducted on outcomes for which the same outcome measure was used in two or more studies using Review Manager (RevMan) software (89). We calculated the effect size and significance for each outcome using RevMan software (89) for the studies which did not report between-group differences. The results were reported using mean difference (MD) or standardized mean difference (SMD) and 95% confidence intervals, overall effect size (Z), and significance (p-value). If there were an adequate number of studies amenable to meta-analysis, i.e., if two or more studies evaluated the outcome using the same outcome measure, then their study designs were assessed for homogeneity, and the results were pooled. Ordinal data or measurement scales were analyzed as continuous data. Heterogeneity was evaluated statistically using the I^2 statistic.

Overall quality of the evidence using GRADE

The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) (90) were used to evaluate the quality of the evidence for outcomes (91). Outcomes were classified according to the International Classification of Functioning, Disability, and Health (ICF) (92,93). The ICF is a widely used classification system aiming to provide a unified and standard language for describing health and health-related state to improve communication between different users, such as health care workers, researchers, policymakers, and the public (92). The most common application of ICF among researchers and clinicians is using the system for rehabilitation and measurement of outcomes. The reason for categorizing the rehabilitation outcomes in the systematic review is because ICF includes all aspects of health and some health-relevant components of well-being. ICF categorizes the health information into functioning and disability and contextual factors. Functioning and disability are further classified into a) Body functions and structures, b) Activity, and participation (93). As cerebral palsy can affect all domains of the ICF (i.e., a) ***Body Structure and Functions***, b) ***Activity,*** *and* c) ***Participation*** (93), we used the ICF system for reporting the outcomes.

Once the outcomes were grouped together based on ICF, the quality of the evidence was classified as high, moderate, low, and very low using the five GRADE criteria (94). As all of the studies in our review were RCTs, any studies without significant limitations were considered as high-quality evidence. The overall quality of the evidence could be downgraded due to 1) the study design, 2) risk of bias, 3) inconsistency of results, 4) indirectness (not generalizable), 5) imprecision (insufficient data), other factors (e.g., reporting bias). The overall quality of the evidence could be upgraded for special considerations such as the large magnitude of effect sizes. We used the GRADE PRO tool (95) to assess and report the findings.

Results

The initial search of the literature resulted in 616 selected studies that were imported to Covidence (87) for the title and abstract screening. Out of 616 studies, 287 duplicate articles were identified and removed. An additional 305 studies were excluded in the title and abstract screening due to lack of relevance or not meeting inclusion criteria. We excluded an additional five articles during full-text screening as they did not meet the study design criteria; they were not RCTs (n=3), full study reports (i.e., one was a study protocol), or they were inconsistent with eligibility criteria. In total, 19 articles were included for data extraction; 578 participants were involved aged range 5 to 19 years old. Only seven studies included GMFCS level IV or V, while the rest of the studies included GMFCS level I, II and/or III. Nintendo Wii® was the most popular gaming system used by nine studies, Kinect by four studies, EyeToy with PlayStation® by two studies, and the other studies used specially designed or customized games such as Move-it-to-improve-it (Mitii™) (96), TYROMOTION (97) and computer-assisted arm rehabilitation games (98). The gaming systems mentioned above are further explained whenever appropriate. A flowchart of article selection is presented in Figure 1. Descriptive summaries of included studies are included in Table 1.

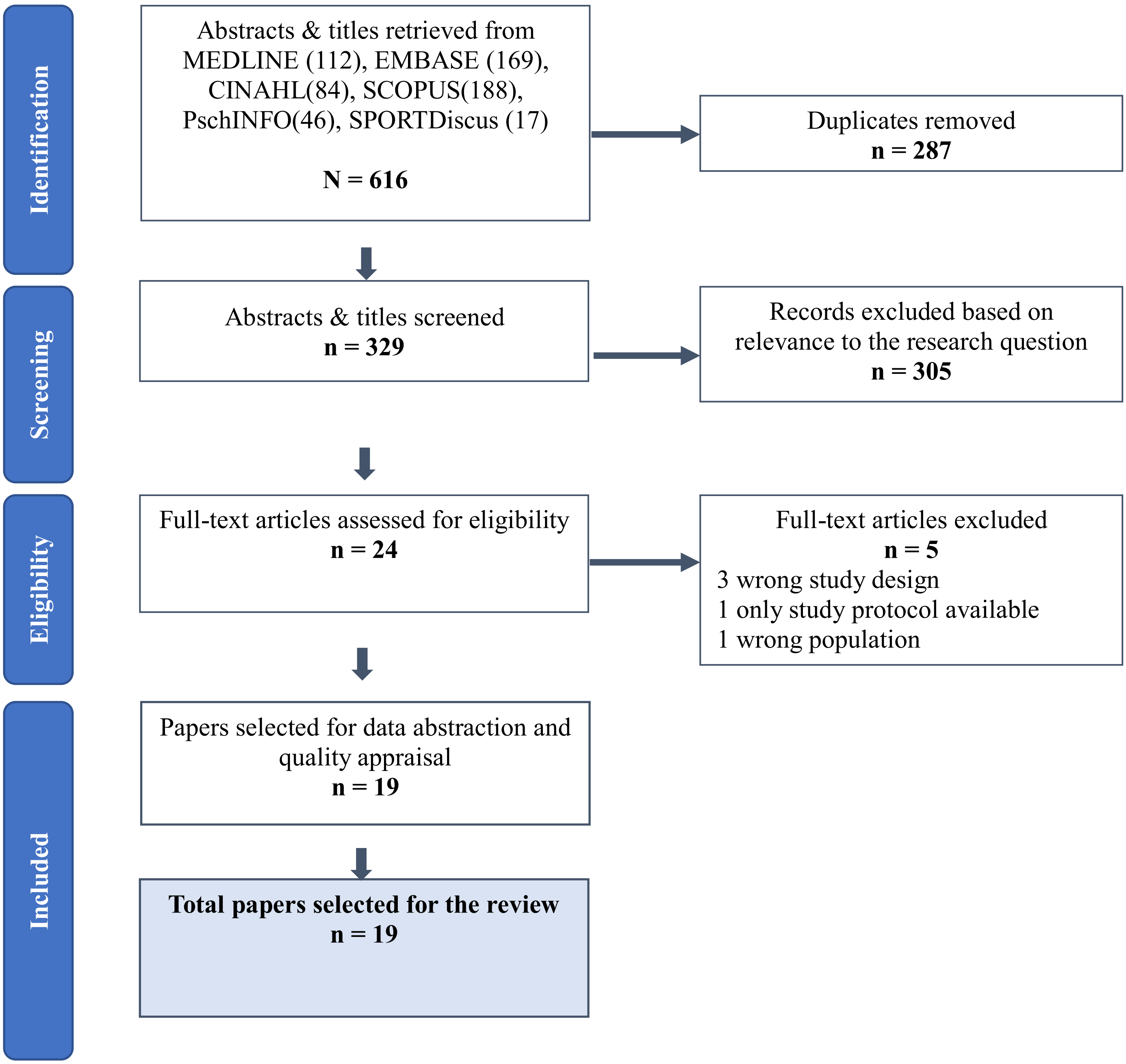


Figure 1: PRISMA Flow Diagram

Table 1: Summary of included articles

Author (year)/country/	Study Design	Participants	Description of intervention	Outcome (outcome measures)	ICF	Results
Alsaif et al. (2015)/Saudi Arabia	2 group RCT	**GMFCS** III **(n=40), age range:** 6-10 yr	**E:** Nintendo Wii-fit games (NW), 12 weeks, 20 minutes/day, Home **C:** No treatment	Motor Performance (mABC-2) Upper Body Coordination (BOTMP) Walking speed (One-minute walk)	A A A	**Total mABC-2 score#** **BOTMP#** **1-mWT #**
Arnoni et al. (2019) /Brazil	2 group RCT	**GMFCS** I & II **(n=15);** $\bar{x}$ **age (SD):** 10.0 (3.0)**, age range-** 5-15 yr	**E:** Virtual reality (VR-Kinect Xbox 360) +Neurodevelopmental therapy (NT), 8 weeks, 2 sessions/week Clinic **C**: Conventional Neurodevelopmental Therapy, 8 weeks, 2 sessions/week; Clinic	Balance (CoP sway area, displacement and velocity) Gross motor function (GMFM-66 – Dimension D and E)	BSF A	**Sway velocity-#** **GMFM-66#**
Uysal et al. (2016)/Turkey	2 group RCT	**GMFCS** I & II **(n=24); age range-** 6-14 yr	**E-**Nintendo Wii (NW)games along with physiotherapy program; 12 weeks, 2 days/week, 30 min/session; Clinic **C-** Physiotherapy program;12 weeks, 2 days/week, 45 mins/session; Clinic	Balance/Pediatric Balance Scale (PBS) Performance (COPM) Functional Mobility (PEDI)	BSF BSF A A	**PBS** – 0.95 ± 1.16; Z= -2.995; p=0.003* **COPM-** MD=0.64± 2.49; Z=-0.931; p= 0.352 **PEDI-** MD=4.5± 4.27; Z= -1.26; p= 0.207
Bedair et al. (2016) /Egypt	2 group RCT	**Modified Ashworth Scale score of 1**+ or 2 **(n=40);** $\bar{x}$ **age (SD):** 7.25 (0.96)**, age range-** 5-10 yr	**E-**VR by X-box system along with upper extremity therapeutic program; 24 weeks, 3 sessions/week, 30 mins/session; Clinic **C-**Upper extremity therapeutic program; 24 weeks, 3 sessions/week, 60 mins/session; Clinic	Upper limb Function (ABILHANDS-kids) Upper limb function (PDMS-2)	A A A	**ABILHAND-Kids Test** [a] - MD=0.90 [0.27,1.52]; Z=2.81; p=0.005* **Visual motor skills** [a] -MD=18.70[8.67, 28.73]; Z=3.66; p=0.0003* **Object manipulation** [a] - MD= 4.95[0.61,9.29]; Z=2.23; p= 0.03*
Chiu et al. (2014)/ Australia	2 group RCT	**GMFCS** I, II, III & IV **(n=62);** $\bar{x}$ **age (SD):** 9.4 (1.9)**, age range-** 6-13 yr	**E-** Nintendo Wii sports resort along with usual therapy; 6 weeks, 3 sessions/week, 40 mins/session; Home **C**- usual upper limb training; Clinic **Follow up** – 12 weeks	Coordination (Tracking task) Strength (Power Track II) Hand function (JTHFT)	BSF BSF A	**Coordination elbow** [a] -MD= 0.04 [-0.02, 0.10]; Z=1.21; p= 0.23 **Coordination fingers** [a] - MD= -0.01 [-0.25, 0.23]; Z=0.08; p= 0.95 **Strength(grip)** [a] - MD= 4.00 [-0.58, 8.58]; Z=1.71; p= 0.09 **JTHFT score** [a] - MD= 0.00 [-0.03, 0.03]; Z=0.00; p= 1.00 **Carer's perception** [a] **-** MD= 4.50 [-0.51, 9.51]; Z=1.76; p= 0.08
Gatica-Rojas et al.(2017)/Chile	2 group RCT	**GMFCS II (n=32); Age range-** 7-14 yr	**E-** Wii Therapy – Nintendo Wii Balance board; 6 weeks, 3 session/week; Rehabilitation centre **C-**Standard Physiotherapy; Rehabilitation centre **Follow up** – 8 and 10 weeks	Balance (CoP sway velocity)	BSF	**Sway velocity (open-eyes)** [a]- MD= -0.08 [-0.38, 0.22]; Z=0.53; P= 0.60) **Sway velocity (open-eyes)** [a] **-** MD= -0.18 [-0.50, 0.14]; Z=1.1; P= 0.27
Jannink et al. (2008)/ Netherlands	2 group RCT	**GMFCS** I, II, III & IV **(n=10); Age range-** 7-16 yr	**E-**Eye toy system in addition to the regular physical therapy, 6 weeks, 2 session/week, 30 mins/session; Clinic **C-**Regular physiotherapy	Upper limb function (Melbourne Assessment Scale)	BSF	**Melbourne Assessment Score #**
Piovesana et al. (2016)/Australi a	2 group RCT	**GMFCS** I, & II **(n=102); Age range-** 8-18 yr	**E-**Mitii (Move-it-to-improve-it) – Web-based multimodal Therapy program; 20 weeks, 6 days/week, 20-30 mins/session; Home	Attentional control (DBS); Cognitive flexibility (D-KEFS inhibition and number letter sequencing);	BSF BSF	**Attention control** –MD= 0.73[-0.40,1.87]; p=0.20 **Cognitive flexibility** - Inhibition; MD= 0.69[-0.73, 2.11]; p=0.34; number letter sequencing; MD=1.19[-0.55, 0.24]; p= 0.17

			C-Regular OT /PT; 20 weeks	Problem solving (D-KEFs Tower Test); Information processing (WISC-IV Symbol Search and Coding) Executive performance (BRIEF)	BSF BSF BSF A	**Problem solving** - MD= 0.73[-0.61, 2.09]; p=0.28 **Information processing -** Symbol; p=0.08; MD= 1.29[-0.16, 2.75]; p=0.08; Coding; MD=1.20[-0.12, 2.52]; p=0.07; **Executive performance** - MD= -4.32[-10.04, 1.38] p=0.13
Okmen et al. **(**2013)/ Turkey	2 group RCT	**GMFCS** I, II, III & IV **(n=41); Age range-** 5-15	**E-**EyeToy play system with Sony Play Station 2; 4 weeks, 3 sessions per week, Clinic **C**-Neurophysiological and conventional therapies (PT & OT), 4 weeks, 5 sessions per week; Clinic	Psychological adaptation (HPAS)	BSF	**HPAS total [a] -** MD= 7.07 [3.11, 11.03,]; Z=3.50; p= 0.0005*
Pin et al. **(**2019)/Iran	2 group RCT	**GMFCS** III or IV **(n=18); Age range-** 6-14 yr	**E-** Tyromotion; 6 weeks, 4 sessions per week, 20 min each session; School **C**-Usual physiotherapy program **Follow up** – 12 weeks	Gross motor function (GMFM-66) Balance (PRT) Walking endurance (2-mWT))	BSF A A	**GMFM-66 [a]** - MD= 0.29 [-6.38, 6.96]; Z=0.09; p= 0.93 **PRT forward [a]** -MD= 0.45 [-5.27, 6.17]; Z=0.15; p=0.88 **PRT right [a] -** MD= -0.33 [-5.04, 4.38]; Z=0.14; p=0.89 **PRT left [a] -** MD= 0.50 [-5.23, 6.23]; Z=0.17; p=0.86 **2-mWT [a]** - MD= -5.92 [-36.86, 25.02]; Z=0.09; p= 0.93
Pourazar et al. **(**2017)/Iran	2 group RCT	**GMFCS** I, II, & III **(n=30); Age range-** 7-12 yr	**E-**Xbox 360 Kinect on RT-888; 4 weeks, 3 sessions per week, 25 mins each session; School **C**-Common therapy program	Reaction time (SRT) Reaction time (DRT)	BSF BSF	**SRT [a]** - MD= 0.23 [0.15, 0.31]; Z= 5.59; p<0.00001* **DRT [a]** - MD= 0.30 [0.15, 0.45]; Z= 3.97; p<0.00001*
Preston et al. **(**2015)/UK	2 group RCT	**MACS** II, III & IV **(n=15); Age range-** 5-12 yr	**E-**Computer assisted gaming technology in addition to Botulinum and usual rehabilitation; 6 weeks, 30 mins/day, Home **C**- Botulinum and usual rehabilitation **Follow up** – 12 weeks	Upper limb function (ABILHAND-kids) Self-perception of performance (COPM)	A A	**ABILHAND-Kids**-MD= -0.51; p=0.919 **COPM**-MD= 0.9; p=0.221
Ramstrand et al. **(**2012)/Sweden	Cross-Over RCT	**GMFCS** I, & II **(n=18); range-** 8-17 yr	**E-**Nintendo Wii fit games; 6 weeks, 30 mins/day, Home **C**- no treatment	Balance (Sway velocity)	BSF	**Sway velocity** - p<0.05
Sajan et al. (2017)/ India	2 group RCT	**GMFCS** I, II, III & IV **(n=20); range-** 5-20 yr	**E-**Wii based interactive video games in addition to conventional therapy (OT, PT,ST); 18 sessions of 45 mins; 3 weeks Home **C**-goal directed, comprehensive rehabilitation program (PT, OT, ST)), 36 hours per week, 3 weeks, Home	Balance (PBS) Balance (Sway velocity) Upper limb function (QUEST) Visual perception (TVPS) Walking speed (1mWT) Walking endurance (distance covered)	BSF BSF A BSF A A	**PBS [a]** - MD= -1.56 [-4.26, 1.14]; Z=1.13; p=0.26 **Sway velocity eyes open [a]** - MD= 44.87 [-55.31, 145.05]; Z= 0.88; p=0.38 **Sway velocity eyes closed [a]** -MD=60.96 [8.47, 113.45]; Z=2.28; p=0.02) **QUEST tota [a] l** -MD= 2.36 [-0.29, 5.01]; Z=1.74; p=0.08 **QUEST Dissociated [a]** -MD= 2.11 [-1.85, 6.07] Z=1.04; p=0.30 **QUEST Grasp [a]** -MD=1.62 [-2.61, 5.85] Z=0.75; p=0.45) **TVPS [a]** - MD= -1.16 [-5.89, 3.57]; Z=0.48; p=0.63 **1mWT [a]** -MD=1.25 [-7.10, 9.60]; Z=0.29; p=0.77 **Distance covered [a]** –MD= -48.40 [-228.26, 131.46]; Z=0.53; p=0.60
Sharan et al. (2012)/ India	Cross-over RCT	**GMFCS** NS **(n=16); E $\bar{x}$ age (SD):** 8.88(3.23)**, C $\bar{x}$ age (SD):** 10.38(4.41)	**E-**Virtual reality-based training (Nintendo Wii sports and Wii Fit) along with Conventional Rehabilitation**;** 3 weeks, 3 days/week; Clinic **C**- Conventional Rehabilitation, **Follow up** – 12 weeks	Balance (PBS); Manual performance (MACS)	BSF A	**PBS [a]** - MD=-0.24 [-12.80, 12.32]; Z=0.04; p=0.97 **MACS [a]** - MD=0.19 [-0.73, 1.11]; Z=0.40; p=0.69

Tarakci et al. **(**2016)/ Turkey	2 group RCT	**GMFCS** I, II & III **(n=30); Age range-** 5-18 yr**)**	**E-**Nintendo Wii-Fit games; 12 weeks, 2 sessions/week; Clinic **C-**Conventional balance training; 12 weeks	Balance (FRT) Functional independence (Wee-FIM) Functional motor abilities (TUG) Functional motor abilities (10mWT) Functional motor abilities (STS) Function motor abilities (10SCT)	BSF A A A A A	**FRT Forward** [a] - MD=3.07 [-2.27, 8.41]; Z=0.1.13; p=0.26 **FRT Right** [a] - MD=2.66 [-1.14, 6.46]; Z=1.37; p=0.17 **FRT Left** [a] - MD=2.53 [-1.32, 6.38]; Z=1.29; p=0.20 **Wee-FIM** [a] - MD=0.19 [-0.73, 1.11]; Z=0.40; p=0.69 **TUG** [a] -MD=1.24 [-1.65, 4.13]; Z=0.84; p=0.40 **10mWT** [a] - MD=1.40 [0.32, 2.48]; Z=2.55; p=0.01* **STS** [a] - MD=2.07 [0.84, 3.30]; Z=3.31; p=0.0009* **10SCT** [a] -MD=0.99 [-1.99, 3.97]; Z=0.65; p=0.52 **Wee-FIM total** [a] - MD=3.43 [-3.75, 10.61]; Z=0.94; p=0.35
Wade et al. **(**2012)/Turkey	Cross-over RCT	**GMFCS IV or V (n=13); Age range-** 5-16 yr	**E-**Computer games using a sensor based sitting platform; 12 weeks, 3-5 sessions/week; School **C-**No treatment	Sitting ability (SACND) Sitting ability- Chailey Levels of box sitting Ability	A A	**Chailey Levels of box sitting Ability** 1. Shoulder girdle position - p=0.047* 2. Spinal profile - p=0.031* **SACND** – Overall score for rest and reach - p<0.05*
Zoccolillo et al. (2015)/Italy	Cross-over RCT	**GMFCS** I, II & III **(n=22); $\bar{x}$ age (SD):** 6.89(1.9)**, range-** 4-14 yr	**E-** Pre-video game (Kinect-box), post conventional Therapy); 8 weeks, 2 days/week, 30 minutes each session; Clinic **C-** pre-conventional, post videogame therapy	Upper limb function (QUEST) Upper limb function (ABILHAND-kids Test)	BSF A	**QUEST** – # **ABILHAND-kids**- #
Acar et al. (2016)	2 group RCT	**GMFCS** I, & II **(n=30); age range-** 6-14 yr	**E-**Nintendo Wii-Fit games in addition to NDT; 6 weeks, 2 days/week; 15 min/day,Clinic **C-** NDT; 6 weeks, 2 days/week; 45 min/day, Clinic	Upper limb function (QUEST) Hand function (JTHFT) Upper limb function (ABILHAND-kids Test) Functional independence (Wee-FIM)	BSF A A A	**QUEST Dissociated** [a] –MD=0.50 [-2.85, 3.85]; Z=0.29; p=0.77 **QUEST Grasp** [a] –MD=2.20 [-0.77, 5.17]; Z=1.45; p=0.15 **QUEST Weight bearing** [a] –MD=1.70 [-2.96, 6.36]; Z=0.72; p=0.47 **QUEST Protective extension** [a] – MD=1.10 [-3.06, 5.26]; Z=0.52; p=0.60 **JTHFT** [a] - MD=-0.33 [-1.79, 1.13]; Z=0.44; p=0.66 **ABILHANDS** [a] - MD= 0.13 [-0.53, 0.79]; Z=0.38; p=0.70 **Wee-FIM** [a] - MD=6.00 [3.37, 8.63];Z=4.48; p<0.00001*

BSF- Body structures and functions; A- Activity; # - Not enough information; *-Significant; [a] – Calculated on RevMan by reviewers; MD- Mean differenceRCT – Randomized controlled trial; NS- Not specified; NW- Nintendo Wii; $\bar{x}$-Mean; VR – Virtual reality; E – Experimental group; C- Control group; GMFCS- Gross Motor function Classification System; mABC-2 - Movement Assessment Battery for Children-2; BOTMP - Bruininks-Oseretsky Test of Motor Proficiency; PBS - Pediatric Berg's balance scale; GMFM - Gross Motor Function Measure; COPM -Canadian Occupational Performance Measure; PEDI -Pediatric Evaluation of Disability Inventory; PDMS-2 - Peabody Developmental scale-2; JTHFT -Jebsen Taylor Hand Function Test; CoP-Center of Pressure; DSB- Digit Span Backwards, WISC-IV- Wechsler Intelligence Scale for Children; BRIEF-The Behavior Rating Inventory of Executive Function; D-KEFS- Delis-Kaplan Executive Function System; HPAS - Hacettepe Psychological Adaptation Scale; SRT- Simple Reaction Time; DRT- Discriminative Reaction Time; MACS -Manual Ability Classification System; QUEST - Quality of Upper Extremity Skills Test; TVPS -Test for Visual-Perceptual Skills; FRT- Functional Reach Test; TUG- Timed Up and Go; STS- Sit-To-Stand; SACND- Sitting assessment for children with neuromotor dysfunction; NDT – Neurodevelopmental treatment; min – minute.

Methodological Quality Assessment

In total, 45 outcomes measures were evaluated across 19 studies. Overall judgment about each risk of bias item is presented as a percentage across outcome measures from each included study, and the risk of bias judgment on outcomes measured in each included study is illustrated in Figure 2. There were wide variations in the risk of bias of the studies across six domains. The overall risk of bias assessment resulted in only two studies (99,100) with low risk of bias, six studies (96,97,101–105) with a moderate risk of bias, and the remaining 11 studies with a high risk of bias. The risk of bias assessment for each domain of the ROB-2 is expanded upon below.

Randomization process: Of all included studies, nine had a low risk of bias, seven studies had some concerns, and three studies were assessed as a high risk of bias in the randomization process. Seven studies (97,104–109) did not provide any information about their randomization processes and concealment of group allocation. Several studies did not explain their sample adequately, making it challenging to assess randomization. Three studies (98,108,110) did not provide a list of baseline characteristics.

Deviation from intended intervention: As the intervention included video games, it was not possible for researchers to blind participants or carers to group assignment. We observed issues in estimating the effects of the intervention on the outcomes; many studies (n=7) only reported within-group (pre-post) differences or performed between-group analysis separately for pre-test score and post-test scores rather than comparing the difference in mean change in each group. Deviations from intended interventions arose for studies that involved home-based interventions due to no measure of fidelity (107)**.** With easily accessible commercial games like Nintendo Wii® and Kinect®, the control groups of five studies may have had access to Nintendo Wii® games at home (101–103,111,112), which may have led to lack of valid controls.

Measurement of the outcomes: Only five studies included masked assessors (96,100,101,108,111), the knowledge of assigned intervention could have influenced the use of outcomes like the Peabody Developmental Motor Scales (103), the Pediatric Balance Scale (100), the ABILHANDS-kids Test (103,112). One study (108) used the Manual Ability Classification System as an outcome measure for upper body function, the authors of this tool recommend the application of the tool in the classification of manual ability rather than using it for an outcome evaluation (113).

Selection of reported results: We observed some concerns in the selection of reported results as the majority of the studies did not provide any information about the masking of the statistician. Therefore, we could not verify that the analysis was performed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis and that the groups remained unknown to the statistician throughout the analysis. Only four studies (96,97,99,100) reported masked statisticians. A summary of each risk of bias item for each outcome assessed in all included studies is provided in Figure 2.

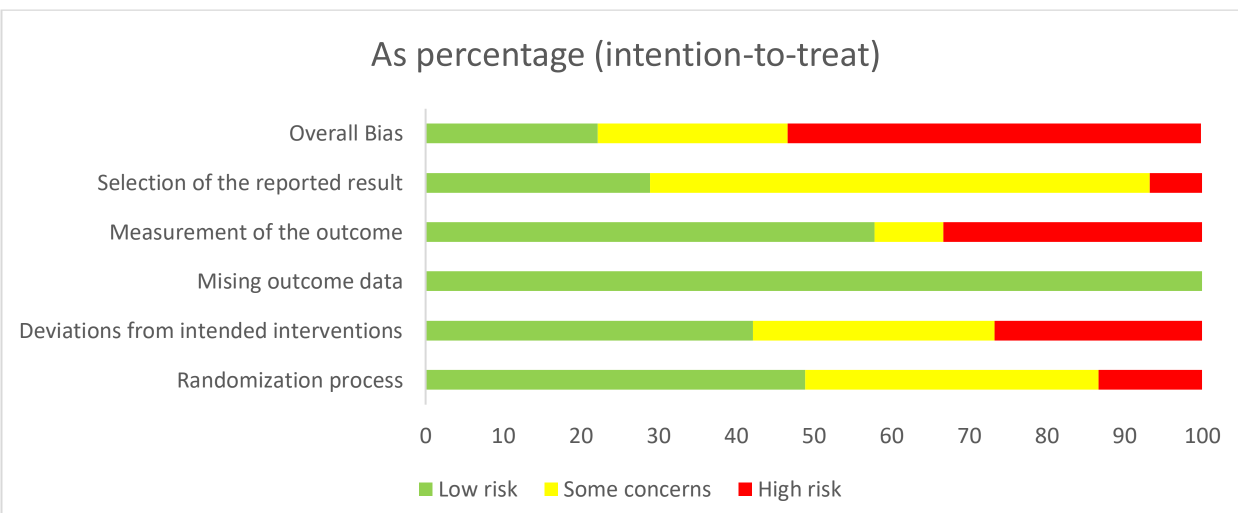


Figure 2: Risk of bias level of the 19 studies (%).

Experimental	Comparator	Outcome	Study ID	Randomization process	Deviation from intended interver	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall ROB			
NW	No Th.	mABC-2	Alsaif	?	−	+	−	?	−		+	Low risk
NW	No Th.	BOTMP	Alsaif	?	−	+	−	?	−		?	Some concerns
NW	No Th	1-mWT	Alsaif	?	−	+	−	?	−		−	High risk
AVG + NDT	NDT	CoP sway	Arnoni	+	+	+	+	?	?			
AVG + NDT	NDT	GMFM-88	Arnoni	+	+	+	+	?	?			
NW + PT	PT	PBS	Atasavan	+	+	+	+	+	+			
NW + PT	PT	PEDI	Atasavan	+	+	+	+	+	+			
NW + PT	PT	COPM	Atasavan	+	+	+	+	+	+			
VR + ULT	ULT	ABILHANDS	Bedair	+	?	+	+	?	?			
VR + ULT	ULT	PDMS-2	Bedair	+	?	+	−	?	−			
NW + RT	RT	Coordination	Chiu	+	?	+	+	?	?			
NW + RT	RT	Strength	Chiu	+	?	+	+	?	?			
NW+RT	RT	JTHFT	Chiu	+	?	+	+	?	?			
NW	RT	CoP sway	Gatica	−	−	+	+	?	−			
ET+PT	PT	MAS	Jannink	−	−	+	−	?	−			
Mitii	OT/PT	EF	Piovesana	+	+	+	+	+	+			
ET	NP+PT+OT	Psyc. Adaptatior	Okmen	?	+	+	−	−	−			
ET	PT	GMFM-66	Pin	?	?	+	+	+	?			
ET	PT	PRT	Pin	?	?	+	+	+	?			
ET	PT	2-mWT	Pin	?	?	+	+	+	?			
ET	PT	Reaction time	Pourazar	?	?	+	+	?	?			
CG+Bot.+ RT	Bot. + RT	ABILHANDS	Preston	+	−	+	+	?	−			
CG+Bot.+RT	Botu.+RT	COPM	Preston	+	−	+	+	?	−			
NW	No Th.	CoP sway	Ramstrand	?	+	+	+	?	?			
NW	RT	PBS	Sajan	+	+	+	+	+	+			
NW	RT	Sway velocity	Sajan	+	+	+	+	+	+			
NW	RT	QUEST	Sajan	+	+	+	+	+	+			
NW	RT	TVPS	Sajan	+	+	+	+	+	+			
NW	RT	1-mWT	Sajan	+	+	+	+	+	+			
NW	RT	1-mWT	Sajan	+	+	+	+	+	+			
NW+RT	RT	PBS	Sharan	+	−	+	−	?	−			
NW+RT	RT	MACS	Sharan	?	?	+	−	?	−			
NW	RT	FRT	Taracki	?	+	+	−	?	−			
NW	BT	Wee-FIM	Taracki	?	+	+	−	?	−			
NW	BT	TUG	Taracki	?	+	+	−	?	−			
NW	BT	10mWT	Taracki	?	+	+	−	?	−			
NW	BT	STST	Taracki	?	+	+	−	?	−			
CG on SP	No th.	SACND	Wade	+	?	+	−	−	−			
CG on SP	No th.	CLBSA	Wade	+	?	+	−	−	−			
VG	RT	QUEST	Zoccolillo	?	?	+	+	?	−			
VG	RT	ABILHANDS	Zoccolillo	?	?	+	+	?	−			
NW+NDT	NDT	QUEST	Acar	−	−	+	?	?	−			
NW+NDT	NDT	JTHFT	Acar	−	−	+	?	?	−			
NW+NDT	NDT	ABILHANDS-Kids	Acar	−	−	+	?	?	−			
NW+NDT	NDT	Wee-FIM	Acar	−	−	+	?	?	−			

Figure 3: Risk of bias summary of each outcome in included studies AVG - *; NW -Nintendo Wii; RT – Regular Therapy; NDT- Neurodevelopmental training; RT- regular therapy; PT- Physical therapy; OT- occupational therapy; No Th. – No therapy; ULT - Upper line Training; ET - Eye toy; CG- Computer-assisted game; Chailey level of box sitting ability CLBSA; STS- sit to stand; Psyc.- Psychological; VR –

Virtual reality; E – Experimental group; C- Control group; GMFCS- Gross Motor function Classification System; mABC-2 - Movement Assessment Battery for Children-2; BOTMP - Bruininks-Oseretsky Test of Motor Proficiency; PBS - Pediatric Berg's balance scale; GMFM - Gross Motor Function Measure; COPM -Canadian Occupational Performance Measure; PEDI -Pediatric Evaluation of Disability Inventory; PDMS-2 - Peabody Developmental scale-2; JTHFT-Jebsen Taylor Hand Function Test; CoP-Center of Pressure; HPAS -Hacettepe Psychological Adaptation Scale; SRT- Simple Reaction Time; DRT- Discriminative Reaction Time; MACS -Manual Ability Classification System; QUEST - Quality of Upper Extremity Skills Test; TVPS -Test for Visual-Perceptual Skills; FRT- Functional Reach Test; TUG- Timed Up and Go; STS- Sit-To-Stand; SACND- Sitting assessment for children with neuromotor dysfunction; min – minute.

Quality of the evidence (GRADE)

We evaluated three comparisons: 1) video games compared to no therapy, 2) video games compared to regular therapy, and 3) video games and regular therapy compared to only regular therapy. The summary of findings is presented in Table 2, Table 3, and Table 4, respectively, using the GRADE framework. Overall, the evidence is of low-to-moderate quality, and the number of studies that assessed each outcome was limited. The most apparent reason for low quality is due to the studies with a high risk of bias and heterogeneity. The reasons for high risk of bias are described above, and high heterogeneity was assessed through between-group analysis on RevMan by including all the studies that evaluated and reported appropriate data for the same outcome. The quality of evidence for each outcome is described below.

Table 2: Grade Summary (video games compared to no therapy control)

Certainty assessment							№ of patients		Effect		Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	video game	no therapy	Relative (95% CI)	Absolute (95% CI)	
Balance (assessed with: Body sway)											
1	randomised trials	very serious [a]	not serious	not serious	not serious	none	8	8	-	-	⊕⊕◯◯ LOW
Gross Motor Function (assessed with: mABC-2)											
1	randomised trials	very serious [b]	serious [c]	not serious	not serious	none	-	-	-	-	⊕◯◯◯ VERY LOW
Functional motor abilities (assessed with: Sitting ability)											
1	randomised trials	very serious [d]	not serious	not serious	not serious	none	12	14	-	-	⊕⊕◯◯ LOW
Maximum walking speed (assessed with: 1-mWT)											
1	randomised trials	very serious [b]	not serious	not serious	not serious	none	-	-	-	-	⊕⊕◯◯ LOW
Upper limb function (assessed with: BOTMP)											
1	randomised trials	very serious [b]	not serious	not serious	not serious	none	-	-	-	-	⊕⊕◯◯ LOW

CI: Confidence interval; **SMD:** Standardized mean difference

a. Some concerns with randomization process
b. High risk of bias due to deviation from intended intervention and measurement of the outcome. Some concerns in randomization process and selection of the reported outcome. Only post score was compared (107)
c. mABC-2 tool was not developed for children with CP (107)
d. High risk of bias due to deviation from intended intervention and measurement of the outcome

Table 3: GRADE Summary (effects of video games compared to regular therapy control)

Certainty assessment							№ of patients		Effect		Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	video game	regular therapy	Relative (95% CI)	Absolute (95% CI)	
Balance (assessed with: Body sway/PBS/PRT/Wii balance)											
3	randomised trials	very serious [a]	not serious	not serious	not serious	none	50	50	-	SMD **0.15 SD higher** (0.25 lower to 0.54 higher)	⊕⊕◯◯ LOW
Psychological adaptation (assessed with: HPAS)											
1	randomised trials	very serious [b]	not serious	not serious	not serious	none	21	20	-	MD **7.07 higher** (3.11 higher to 11.03 higher)	⊕⊕◯◯ LOW
Executive functioning (assessed with: DBS/D-KEFS/WISC-IV)											
1	randomised trials	very serious [c]	not serious	not serious	not serious	none	51	50	-	MD **0.73 higher** (0.4 lower to 1.87 higher)	⊕⊕◯◯ LOW
Reaction time (assessed with: SRT/DRT)											
1	randomised trials	serious [d]	not serious	not serious	not serious	none	15	15	-	MD **0.23 higher** (0.15 higher to 0.31 higher)	⊕⊕⊕◯ MODERATE
Gross motor function (assessed with: GMFM-66)											
1	randomised trials	serious [e]	not serious	not serious	not serious	none	9	9	-	MD **0.29 higher** (6.38 lower to 6.96 higher)	⊕⊕⊕◯ MODERATE
Functional motor abilities (assessed with: TUG/STS/Wee-FIM/10-mWT)											
1	randomised trials	serious [f]	not serious	not serious	not serious	none	15	15	-	MD **3.43 higher** (3.75 lower to 3.61 higher)	⊕⊕⊕◯ MODERATE

CI: Confidence interval; **SMD:** Standardized mean difference; **MD:** Mean difference

Explanations

a High risk of bias in 2 studies (111,114), some concerns in one study (97)
b. High risk of bias due to randomization process, deviation to intended intervention and selection of reported outcomes
c. Some concerns in selection of reported outcomes
d. Some concerns in 3 domains of risk of bias, overall high risk of bias
e. Some concerns in 2 domains of risk of bias.
f. Some concerns in randomization process and high risk of bias in the measurement of the outcome

Table 4: GRADE Summary (effects of video games plus regular therapy compared to regular therapy control)

Certainty assessment							№ of patients		Effect		Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	video game and regular therapy	regular therapy	Relative (95% CI)	Absolute (95% CI)	
Balance (assessed with: Body sway/PBS)											
4	randomised trials	very serious [a]	not serious	not serious	not serious	none	20	20	-	**1.41 higher** (0.25 higher to 2.56 higher)	⊕⊕◯◯ LOW
Gross motor function (assessed with: GMFM-88)											
1	randomised trials	very serious [b]	not serious	not serious	not serious	none	7	8	-	-	⊕⊕◯◯ LOW
Functional motor abilities (assessed with: PEDI/COPM)											
2	randomised trials	very serious [b]	serious [c]	not serious	not serious	none	27	27	-	SMD **3.39 SD higher** (1.57 lower to 8.34 higher)	⊕◯◯◯ VERY LOW
Upper limb function (assessed with: MACS/Tracking task/Power track II/ABILHANDS/Nine Hole Peg Test/PDMS/JTHFT/MAS/QUEST/Wee-FIM)											
8	randomised trials	very serious [d]	serious [e]	not serious	not serious	none	75	74	-	**0.35 higher** (0.25 lower to 0.95 higher)	⊕◯◯◯ VERY LOW
Visual perception (assessed with: TVPS)											
1	randomised trials	not serious	not serious	not serious	serious [f]	none	10	10	-	MD **1.6 lower** (5.89 lower to 3.57 higher)	⊕⊕⊕◯ MODERATE
Maximum walking speed/endurance (assessed with: 1-mWT)											
1	randomised trials	not serious	not serious	not serious	not serious	none	24	24	-	SMD **0.13 higher** (-0.17 lower to 1 higher)	⊕⊕⊕⊕ HIGH
Upper limb function (assessed with: QUEST)											

Certainty assessment							№ of patients		Effect		Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	video game and regular therapy	regular therapy	Relative (95% CI)	Absolute (95% CI)	
2	randomised trials	serious [g]	serious [h]	not serious	not serious	none	10	10	-	MD **0.17 higher** (-1.39 lower to 3.73 higher)	⨁⨁◯◯ LOW

CI: Confidence interval; **SMD:** Standardized mean difference; **MD:** Mean difference

Explanations

a. 2 studies with high risk of bias (101,106)
b. One study with high risk of bias (104)
c. 89% heterogeneity due to variability in types of outcome measures
d. Six studies with high risk of bias Low precision estimate (99)
e. 87% heterogeneity due to variability in the types of outcome measures
f. Low precision estimate
g. One study with low risk of bias (99) and the other study with high risk of bias (99)
h. 50% heterogeneity in pooled analysis.

Effects of Intervention

In total, 15 studies contributed to the data on the between-group differences. Between-group differences were not demonstrated in four studies (101,107,110) (109). One study (107) did not report the number of participants assigned in each group. One study (110) did not report pre-post scores or mean change and standard deviation in each group; therefore, we could not perform between-group analysis. Two studies (101,109) only reported the percentage change in each group; we could not calculate the difference between the groups. Two randomized cross-over studies (98,105) did not report individual scores for each group; hence, we could not evaluate the mean difference between the groups. Between-group mean differences, 95% confidence interval, and significance for each outcome in each study are presented in Table 1. Below we have provided summaries of evidence outcomes and meta-analysis results organized based on ICF.

Body Functions and Structures

Balance

Eight studies evaluated the effects of the intervention on balance using a variety of outcome measures. Four studies (99,101,107,111) assessed balance by sway velocity, three studies (99,100,108) used the Pediatric Balance Scale (115), and two studies (97,114) used the Functional Reach Test (116) or the Pediatric reach Test (117).

Video games vs. no therapy: Only one study (107) evaluated the effects of video games on balance using a cross-over RCT design. The study used a suite of computer games operated by leaning in one of four directions (i.e., left, right, forward and backward) with a platform that detected movement of the center of pressure placed on the seat surface. The change in velocity of the center of pressure (CoP) was insignificant between the groups ($p>0.05$). Similarly, the results of reactive balance and rhythmic weight shift did not result in a statistically significant difference between the two groups. We determined there was a high risk of bias in deviation from the intended intervention and measurement of the outcome, which contributed to the low quality of the evidence for balance in comparison to no treatment control (Table 2). We were unable to estimate the effect size for this study (107) due to missing information about the number of participants assigned in each group. The between-group analysis was also not possible because the mean score and standard deviation in the video game group were not reported.

Video games vs. regular therapy: Three studies compared the effects of video games and regular therapy and evaluated the effects on balance. Two studies used Nintendo Wii as video game intervention (97,114), and one study (111) used an EyeToy system. EyeToy is a color webcam used with the games that use gesture recognition or computer vision to process images taken by EyeToy, allowing players to play games using motions. One study (111) evaluated sway area and velocities using a force platform, and one study (114) reported Wii balance as an outcome measure for balance. Two studies (97,114) used the Functional Reach Test (116) or the Pediatric Reach Test (117), a modified version of the Functional Reach Test, both of them measured the maximum distance an individual can reach while standing in a fixed position. Two studies (111,114) were assessed as a high overall risk of bias, and some concerns were identified with the other (97), which contributed to the low certainty of the evidence (Table 3) for balance.

Pooled analysis was performed for the studies (97,114) that used the Functional Reach Test and the Pediatric Reach Test (116,117). The Forest plot of the Functional Reach Test shows no significant difference between video game intervention and regular therapy ($p>0.05$). The mean differences are 0.27[-0.30, 0.84]; P=0.35 (forward), 0.28[-0.29,0.85]; P=0.34 (right), and 0.31[-0.26,0.88]; P= 0.28 (left) (Figures 4, 5, 6).

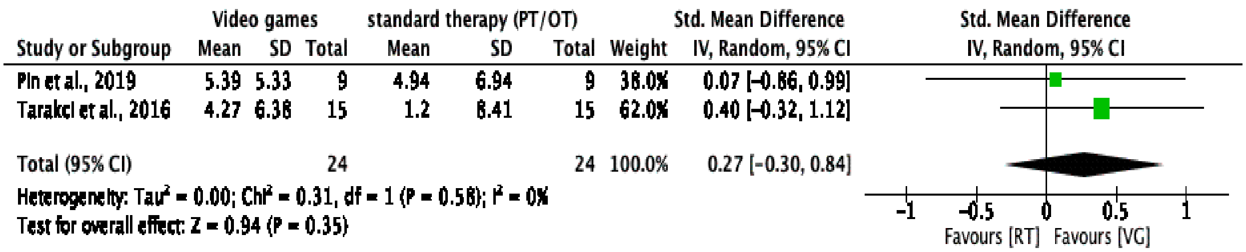


Figure 4. Forest plot of comparison: 1 Video games versus regular therapy, outcome: React Test* (Forward); VG- video games; RT – Regular therapy.

*Includes both Functional React Test and Pediatric React Test

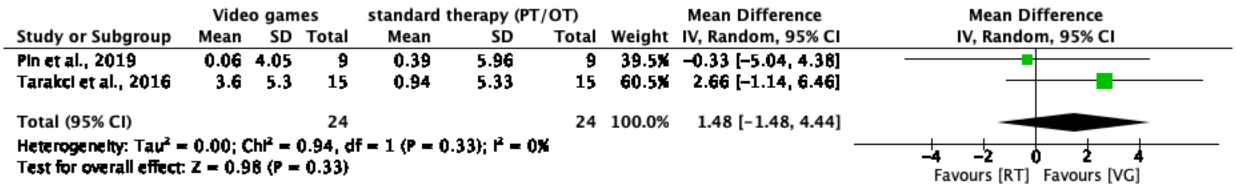


Figure 5. Forest plot of comparison: 1 Video games versus regular therapy, outcome: React Test* (Right); VG- video games; RT – Regular therapy.

*Includes both Functional React Test and Pediatric React Test

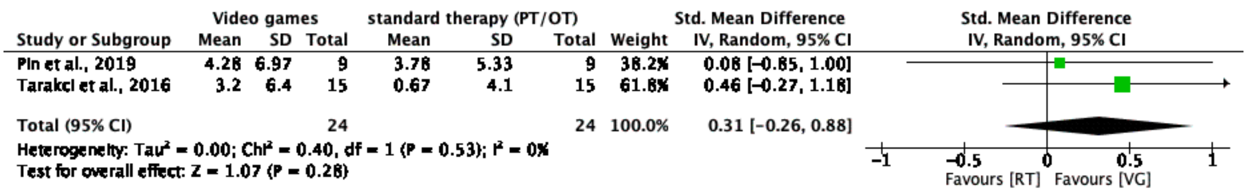


Figure 6. Forest plot of comparison: 1 Video games versus regular therapy, outcome: React Test* (Left); VG- video games; RT – Regular therapy.

*Includes both Functional React Test and Pediatric React Test

Video games and regular therapy vs. regular therapy: Four studies (99–101,108) reported the effects of video games plus regular therapy on balance. Two studies assessed sway velocity (99,101), but we could not pool the data for meta-analysis as one of the studies did not report pre- and post-test scores or mean change in each group. Three studies (99,100,108) used the Pediatric Balance Scale to assess balance. The mean difference and effect size is reported in Table 1.

The pooled analysis of three studies (99,100,108) (a total of 40 participants, 20 per group) revealed no significant difference between the groups on the Pediatric Balance Scale score (MD 0.26, 95% CI -2.12 to 2.65, with 50% heterogeneity; Figure 7). Although one of the studies had a low risk of bias in all the domains, we observed a high risk of bias in two of the studies (101,108) and some concerns in one study (100). We assessed the certainty of the evidence to be moderate (Table 4).

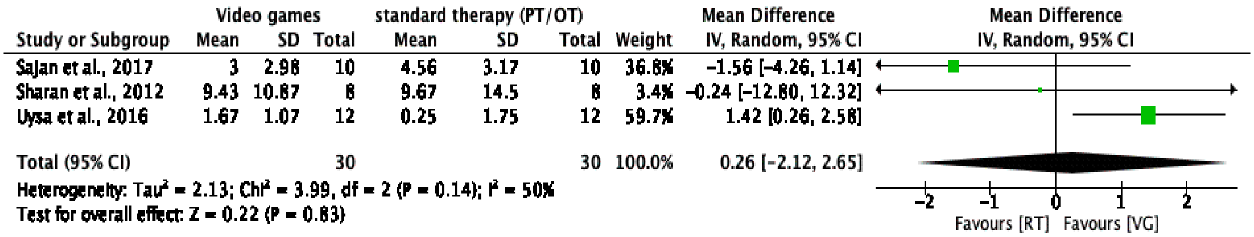


Figure 7. Forest plot of comparison: 1 Video games and regular therapy versus regular therapy, outcome: PBS; VG- video games; RT- Regular therapy

Psychological adaptation

One study (118) evaluated children with CP to assess the improvement in psychological adaptation levels using a tool called Hacettepe Psychological Adaptation Scale (118). Psychological adaptation is a functional, cognitive, and behavioral trait that helps an individual interact with the environment (119). The study compared the effects of a commercial EyeToy (webcam used with Playstation® that facilitates gesture or motion-based games) play virtual reality system connect with a TV and Sony Playstation-2 on psychological adaptation compared to regular therapy. The risk of bias assessment revealed some concerns in the randomization process; there was no information about the randomization process and randomization concealment. In addition, there were some concerns about the measurement of the outcome reporting of separate scores for introversion and extroversion level did not appear consistent with the original description of the tool. Consequently, the quality of evidence was assessed as low (Table 3).

Executive functioning

One large RCT (n=102) (96) evaluated executive functioning. The study used Move-it-to-improve-it (Mitii™), a web-based multimodal training intervention. There was no significant difference between groups in attention control, cognitive flexibility, number-letter sequencing, problem-solving, information processing, and executive performance. We assessed some concerns in the overall risk of bias in this study; hence, the quality of evidence for executive functioning remained moderate. The overall risk of bias in the study was assessed as low; therefore, the quality of the evidence remained high (Table 3).

Reaction time

One study (104) evaluated reaction time assessed by simple reaction time (SRT) and discriminative reaction time (DRT) and reported significant improvement in the intervention group (eye toy) for both outcomes post-treatment. We calculated between-group differences in RevMan and are presented in Table 3. The overall risk of bias has some concerns due to the lack of enough information on randomization and allocation concealment; hence, the quality of the evidence for reaction time was assessed as moderate (Table 3).

Visual perception

One study (99) assessed visual-perceptual skills and reported combined scores of all seven domains of the Test of Visual-Perceptual Skills (120,121). No significant improvement was reported between the two groups (Nintendo Wii vs. regular therapy). The overall risk of bias was low, but we observed a low precision estimate in the results. Therefore, the quality of evidence was assessed to be moderate (Table 4).

Activity

Functional motor abilities

Functional motor abilities were evaluated in four studies (98,100,106,114). These studies used a variety of tools such as the Chailey Level of Box Sitting Ability (122), the Sitting Assessment for Children with Neuromotor Dysfunction (123), the Timed Up and Go test (124), the Sit to Stand test (125), the 10 step climbing test (126), the Wee-FIM (127), the Pediatric Evaluation of Disability Inventory (PEDI) (128), and the Canadian Occupational Performance Measure (COPM) (129).

Video games vs. no therapy: One study (98) used a cross-over RCT design to evaluate sitting ability with the modified game compared to no therapy group using the Chailey Level of the Box Sitting Ability and the Sitting Assessment for Children with Neuromotor Dysfunction. An analysis of carry-over effects led to some concerns about the deviation from the intended intervention and high risk of bias in the measurement of the outcome domain. The study seemed to report multiple eligible outcome measurements within the sitting ability outcome causing a high risk of bias in the selection of the reported outcomes domain. Since the study reported a variety of subscores on the Chailey Level of Box Sitting Ability and the Sitting Assessment for Children with Neuromotor Dysfunction, only significant results are presented in Table 1. The quality of the evidence for functional motor ability was low due to a very serious risk of bias (Table 2).

Video games vs. regular therapy: One of the studies (114) assessed functional motor abilities using the Wee-FIM (127), the 10-Steps Climb Test for functional strength, balance, and agility (126), the Timed Up and Go test (130) to assess functional strength, balance, fall risk, and walking ability and the Sit To Stand test (125) for functional lower extremity strength. The results in each test are presented in Table 1. We observed baseline differences between the groups (children in the control group were more involved as more used assistive mobility devices as compared to the intervention group), which suggested issues with randomization processes. We also noted some concerns about the measurement of the outcome and the selection of reported outcomes leading to the high overall risk of bias. We assessed the quality of evidence to be moderate (Table 3).

Video games and regular therapy vs. regular therapy: Three studies (100,106,112) compared video games and regular therapy to regular therapy alone. One study (100) used the Pediatric Evaluation of Disability Inventory (PEDI)(128,131) to measure functional skills and independence and reported the results based on PEDI subscales (Self-care, Mobility, Social) and the total score (Table 1). Both of the studies (100,106) evaluated video games with regular therapy on self-perception of activity performance using the Canadian Occupational Performance Measure (COPM) (129). The studies (100,106) did not find the difference between the groups statistically significant. Pooled analysis was not possible due to heterogeneity in outcome measurement. One study reported the mean change in scores (100) while the other reported only the median range (106). One study assessed functional independence using the Wee-FIM score and reported no significant difference between the groups. One of the studies (100) indicated a low risk of bias. However, two studies (106,112) showed a high risk of bias due to baseline differences between the group (106) and the lack of enough information on the randomization process (112). Consequently, the quality of the evidence for functional motor abilities was assessed as low (Table 4).

Gross motor function

Only three studies (97,101,107) evaluated the effects of video games on gross motor function.

Video games vs. no therapy: One study assessed gross motor function using the Movement Assessment Battery for Children-2 (mABC-2) to assess motor performance. Due to missing information about the number of participants in each group, we were unable to perform between-group analysis (107). We assessed the quality of evidence as low due to a high risk of bias in the study.

Video games vs. regular therapy: One study (97) evaluated the GMFM-66 item set (132). The study only reported within-group analysis results; the video game group showed significant improvements in the GMFM dimensions D (standing) (p=0.021) and E (walking, running, and jumping) (p=0.008) while the regular therapy group did not show any changes. The GMFM-66 item D and E results are reported in terms of percentage; hence it was not possible to analyse between-group differences. We assessed some concerns in deviation from the intended intervention domain due to missing information on the comparison of mean change scores. The overall risk of bias had some concerns; therefore, the quality of the evidence was assessed as moderate.

Video game and regular therapy vs. regular therapy: The study (101) used GMFM-88 (lying, sitting, four-point kneeling, high kneeling and standing) as a measurement tool to evaluate the effectiveness of video games and regular therapy compared to only regular therapy. The study reported no significant improvement in GMFM-66 item set score. The overall risk of bias assessment revealed some concerns in randomization process and allocation concealment. Therefore, the quality of evidence was assessed to be moderate.

Upper limb function

Nine studies focused on the effectiveness of video games on upper limb function. A variety of outcome measures were assessed by these studies; the ABILHANDS-kids test, the Quality of Upper Extremity Training, and the Jebsen Tylor Hand Function Test were most commonly used. Other outcome measures include the Bruininks-Oseretsky Test of Motor Proficiency, the Box and Block test, the Nine Hole Peg Test, the Peabody Developmental Motor Scales, the Melbourne Assessment of Unilateral Upper Limb Scale, the Wee-FIM, the carer's perception of hand function. The Manual Ability Classification System is a tool developed for the classification of children with CP based on how they use their hands to handle objects in their daily activities. One of the studies (108) used the tool as an outcome measure, which is not recommended by the authors (113).

Video game vs. no therapy: One study (107) assessed upper limb coordination using a 1-item subtest (touching a swinging ball) from the Bruininks-Oseretsky Test of Motor Proficiency. The authors report significant improvements in scores within the Nintendo Wii group post-intervention; however, the p-value was not reported in the article. Furthermore, the study did not report the number of participants assigned in each group and did not perform the comparison between the groups. Hence, we were unable to assess the difference between the two groups. The quality of evidence for the effect of video games on upper limb function was low as a high risk of bias was revealed through the assessment (Table 2).

Video game vs. regular therapy: One study (110) assessed upper limb function to evaluate the effect of video games compared to regular therapy using the Quality of Upper Extremity Training (133) and the ABILHANDS-Kids test (134). However, the study did not reveal a significant difference between the groups. The methodological assessment revealed high risk of bias; hence, low quality of evidence.

Video game and regular therapy vs. regular therapy: The effect of video games with regular therapy on the upper limb function was assessed by seven studies (99,102,103,106,108,109,112). One study (103) used Kinect® X-box, and the other (112) used Nintendo Wii® and regular therapy as an intervention compared to only regular therapy. Two studies (103,112) used the ABILHANDS-Kids test (134) to evaluate upper body limb function. One study (103) reported a significant difference between the groups ($p=0.008$), while no significant difference ($p=0.70$) between the groups was revealed in the other study (112). The

Pooled analysis of two studies (103,112) for ABILHANDS-Kids outcome measure revealed no statistically significant difference between the two groups (SMD 0.62, 95% CI -0.27 to 1.51, with high heterogeneity (80%); Figure 8).

In addition to the ABILHANDS-kids test, the study (112) also used the Jebsen Taylor Hand Function Test (135), and the study reported significant change between pre-post scores of both the groups. There was no statistically significant difference between the groups (p=0.66) as per our calculations in RevMan. One other study (102) assessed hand function by the Jebsen Taylor Hand Function as an outcome measure to evaluate the effectiveness of video games with regular therapy compared to the regular therapy, and the results showed no improvement in any group. The pooled analysis of Jebsen Taylor Hand Function outcome measure revealed no statistically significant difference between the groups (standard mean difference -0.05; 95% CI -0.46 to 0.36; p=0.81, 0% heterogeneity; Figure 9).

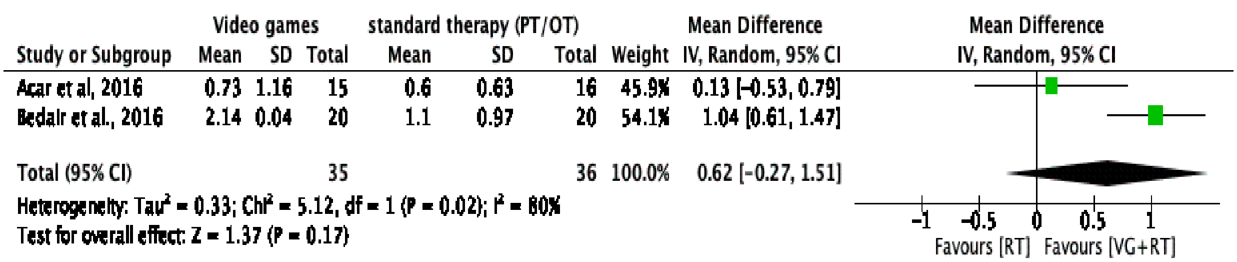


Figure 8: Forest plot of comparison: 1 Video games and regular therapy versus regular therapy, outcome: ABILHANDS-Kids test; VG- video games, RT – Regular therapy.

In addition to the ABILHANDS-kids test, the study (112) also used the Jebsen's Taylor Hand Function Test (135), and the study reported significant change between pre-post scores of both the groups. There was no statistically significant difference between the groups (p=0.66) as per our calculations in RevMan. One other study (102) assessed hand function by the Jebsen Taylor Hand Function as an outcome measure to evaluate the effectiveness of video games with regular therapy compared to the regular therapy, and the results showed no improvement in any group.

The pooled analysis of Jebsen Taylor Hand Function outcome measure revealed no statistically significant difference between the groups (standard mean difference -0.05; 95% CI -0.46 to 0.36; p=0.81, 0% heterogeneity; Figure 9).

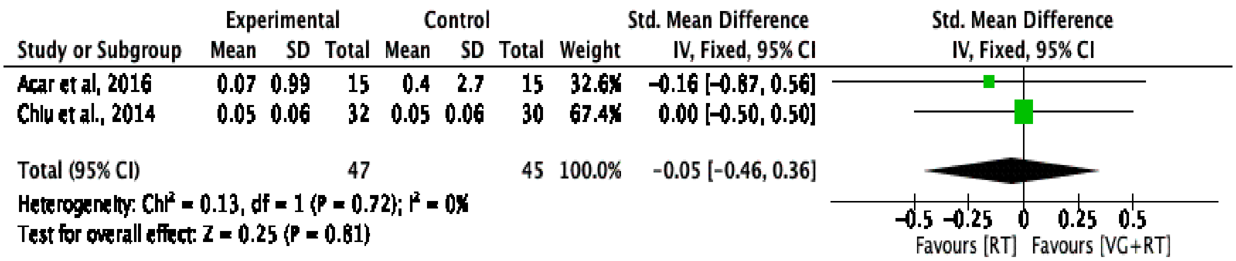


Figure 9: Forest plot of comparison: 1 Video games and regular therapy versus regular therapy, outcome: Jebsen Taylor Hand Function; VG- video games, RT – Regular therapy.

We performed a pooled analysis of two studies (99,112) for the Quality of Upper Extremity Training (133) in dissociated movement and grasp domains. While both of the studies indicated a trend toward the video game and regular therapy group, the meta-analysis results reveal no significant difference in dissociated movement domain (MD 1.17, 95% CI -1.39 to 3.73, with no heterogeneity; Figure 10) or grasp domain (MD 2.01, 95% CI -0.42 to 4.44, with no heterogeneity; Figure 11)

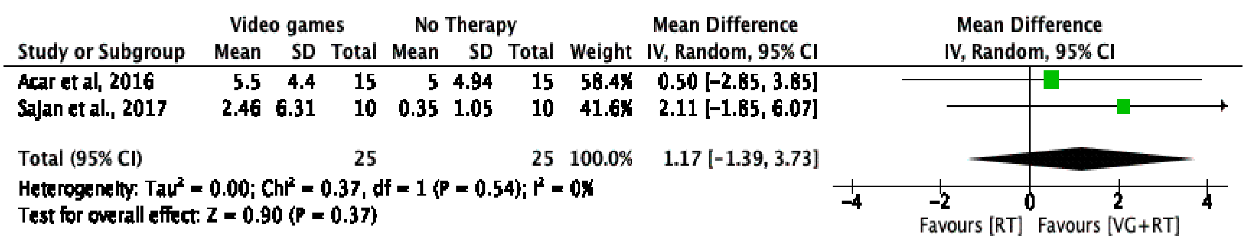


Figure 10: Forest plot of comparison: 1 Video games and regular therapy versus regular therapy, outcome: QUEST dissociated movement; VG- video games, RT – Regular therapy.

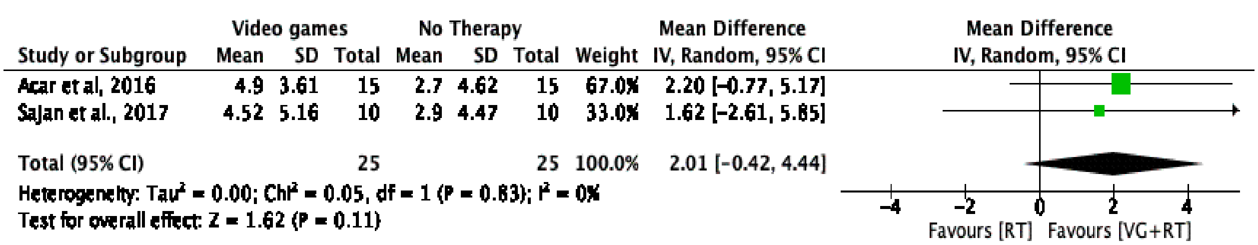


Figure 11: Forest plot of comparison: 1 Video games and regular therapy versus regular therapy, outcome: QUEST grasp; VG- video games, RT – Regular therapy.

The majority of the studies (106,108,109,112) indicated a high risk of bias except for one study (99) had a low risk of bias in all the domains. Very low quality of the evidence (Table 4) indicated that the effects of video games and regular therapy were insignificant.

Maximum walking speed/endurance

Four studies (99,107,114) evaluated the effects of video games on maximum walking speed, and two studies (97,99) assessed the effects on walking endurance. Only one study (107) evaluated the video games compared to no therapy using the 1-minute Walk Test. The between-group analysis was not possible due to missing information about the number of participants assigned to each group. In video games vs. regular therapy comparison, one study (114) compared maximum walking speed using the 10-meter Walk test. The other study (97) evaluated walking endurance (maximum walking distance) using the 2-minute Walk Test. The study revealed a high risk of bias, and low quality of evidence indicated an insignificant effect of video games on maximum walking speed and endurance (Table 3). Similarly, only one study compared video games and regular therapy compared to regular therapy (99) on walking speed and endurance. With a low risk of bias in all the domains, high quality of evidence revealed an insignificant effect on walking speed and endurance (Table 4).

Discussion

This systematic review examined the effectiveness of video games for improving rehabilitation outcomes in cerebral palsy. Overall, the body of evidence was weak due to the limited number of studies with a high risk of bias, small sample sizes, and variability in assessment tools, which made it difficult to compare the studies. Factors influencing the results of this systematic review include poor reporting of methodology and results in the majority of the randomized control trials, insufficient duration of the intervention for changes to become apparent, and inappropriate outcome measures given the game activity. For example, using a tennis game while seated is most likely not an effective way to improve walking ability, one of the outcomes measured in the study (99). Furthermore, the majority of the included articles failed to follow the recommended guidelines on reporting parallel group randomized trials (136) and randomized cross-over trials (137) particularly, the reporting of randomization processes and allocation concealment. Some studies only reported within-group differences (97,104,107), or between-group difference at baseline and post-treatment separately (104,108,114,118). Some studies reported results in terms of percentages instead of actual scores (101,109) or did not report baseline and post-treatment scores for each group (98,105,107,110). These issues obstructed the estimation of the overall effect of video games on an outcome and affected the methodological quality of evidence. Overall, the evidence to support the effectiveness of video games for improving body structure and function impairments such as balance and activity level outcomes such as functional motor abilities, upper limb function, functional independence, and walking is weak and inconclusive.

Only three studies included in the review (96,99,100) demonstrated a low risk of bias. The results of two low risk of bias studies showed an insignificant effect of video games on executive functions (96), upper limb function (99), activities of daily living (100), activity performance (100). Of all studies with low risk of bias, Sajan et al. (2016) (99) reported insignificant effects of video games on functional balance, by contrast, Atasavun and Baltaci (2016) (100) indicated a significant effect of video games on functional balance. The possible reason for contradicting results could be the difference in the duration and intensity of the video game sessions. The majority of the studies conducted the trial for a limited duration (2 to 6 weeks), which may be an insufficient duration to achieve change in the outcomes evaluated. Bedair et al. (2016) (103) included a 24-week intervention for video games along with upper extremity training and upper extremity training groups, indicating a significant between-group difference in upper limb function, object manipulation, and visual-motor skills. Similarly, Atasavun and Baltaci (2016) (100) provided 12-weeks of video games along with physiotherapy and only physiotherapy groups. The study reported a significant difference in functional balance in favor of the use of the Nintendo Wii® (100). These results suggest that interventions with longer duration and/or intensity may be needed to affect rehabilitation outcomes.

Longer duration interventions have been reported for other rehabilitation interventions. Program duration of 12-16 weeks is recommended for strength training to maximize the likelihood of a training effect in people with CP (33). The same study prescribed optimal cardiorespiratory endurance training for a minimum of 2-3 times a week, a minimum of 20 minutes per session, for at least eight consecutive weeks, when training three times a week, or 16 consecutive weeks when training two times a week (33). Uzun (2013) evaluated the effects of a long-term training program on balance in children with CP, and the results demonstrate improvements in the handgrip, strength, and range of motion after 28 weeks (122). A 16-week physical activity program with balance training had facilitated general motor functions; however, functional limitations remained the same, following the 12-week training (122). Evaluation of optimal program duration and intensity of such programs for children with CP will help make an informed decision on the effectiveness of video games on various outcomes such as balance, walking abilities, and gross motor functions.

The included studies used two different approaches to the use of video games in rehabilitation for children with cerebral palsy. Some studies evaluated video games as alternatives to traditional rehabilitation (compared video games to no therapy), while others viewed games as strategies to augment conventional therapy (compared video games alone of plus therapy to regular therapy). Nintendo Wii was the most common gaming system (n=8) (99,100,102,105,107,108,111,114). It offers a variety of games such as boxing, tennis, bowling, frisbee, and basketball, requiring specific body movements. An advantage of using a commercial system is that the games can be used in both the sitting and standing position. Therefore, it can potentially be used by children who have minimal ability to walk or stand. However, the studies with Nintendo Wii® focused on a variety of outcomes and a variety of outcome measures for the same outcome, such as Wii balance, sway velocities, the Pediatric Balance Test, the Functional Reach Test for assessing balance. The outcome measures in the included studies make it difficult to compare results across the studies.

For an effective video game as an intervention, it is crucial to select video games that match functional movements to the intended outcomes. In a comparison of video games with regular therapy, one study (96) used Move-it-to-improve-it (Mitii™)- a web-based therapy program with high quality of evidence indicating no significant improvement with video games. However, there is a chance that unfavorable results were due to the design of the web-based therapy program as only 3 out of 14 modules focused on the cognitive component. The study suggested that there is a possibility that the game might not have been sufficiently challenging to drive change in executive functions (96). Similarly, Sajan et al. (2016) (99) reported a variety of outcomes such as upper limb function, balance, and walking ability. The nature of the games (boxing and tennis) in the study aimed more at upper limb movement than lower limb movements, and some of the participants played Wii games in sitting posture (99). This misalignment between game demands and outcomes measured may have contributed to the insignificant findings. Two studies (109,118) evaluated the eye toy system with Sony Play Station, which involves interaction with the virtual object by touching the screen. Since the games required hand movement to touch the screen, the upper limb function's evaluation seems appropriate (109). However, the lack of sufficient information about the nature of the game made it difficult to understand its role in improving psychological adaptation (118). Only three studies used customized or specially designed systems for therapy in children with CP. Wade and Porter (2012) (98) assessed sitting ability using a specially designed sitting platform with a computer game controller that detects movement of the center of gravity for improvement. Pin and Butler (2019) used TYROMOTION, a commercial force plate gaming system specially designed for postural control rehabilitation (97) and evaluated balance, gross motor function, and maximum walking endurance. The third study (106) used a customized computer-assisted arm rehabilitation games as an add on to the therapy.

Poor reporting of methodology and results affected the quality of the studies, decreases confidence in the results, and limits the inferences that can be made. Stronger reporting such as that outlined in the CONSORT guidelines (136,137) is recommended to strengthen this body of evidence. For future studies, thorough descriptions of games and concurrent rehabilitation interventions would facilitate comparison across studies. In addition to the specific functions in the game, and information about fidelity, it would be helpful if researchers included measures of motivation and engagement which can be driving forces behind improved health outcomes (138). The use of less enjoyable, engaging, and challenging games may lead to low participation, hence, low improvement in the outcomes. Feasibility studies and single case studies that would allow a more exploratory approach with children with cerebral palsy might help understand the level of engagement, and the outcomes targeted by the specific game.

The significant improvements in intervention group post-treatment indicated that engaging commercial video games like Nintendo Wii, Microsoft Kinect®, Sony PlayStation® could be beneficial in promoting body movements and activities, which could lead to improved outcomes. At the same time, we understand that these commercial games are not designed based on therapeutic guidelines, which could contribute to the insignificant between-group differences. We believe that fun commercial games can be utilized as add on to the regular therapy program for increased enjoyment and participation. To replace the therapy with video games, researchers should consider customizing existing commercial games or specially designing the game aligned with therapeutic principles for children with cerebral palsy.

Strengths and Limitations

In this review, we analyzed the effects of video games on a broad range of outcomes for children with cerebral palsy, which has not been done in any of the previous systematic reviews. In addition, we evaluated two different approaches for implementing video games as an intervention and compared their results separately to understand the feasibility of each method. This systematic review includes a rigorous process using established methodologies, including PRISMA, RoB-2 tool, and GRADE. This review could be one of the first systematic reviews that has used RoB-2 Cochrane risk of bias tool for assessing methodological quality. RoB-2 (88) is a revised version Cochrane risk of bias tool consisting of a more elaborated and rigorous process of assessing the risk of bias; hence, a better understanding of the role of risk of bias in influencing study results. We could only perform a meta-analysis on two outcomes: 1) balance (Functional Reach Test and Pediatric Balance Scale), and 2) upper limb function (ABILHANDS-Kids Test, Quality of Upper Extremity Skills Test, and JebsenTylor Hand Function Test). Additionally, we could not report the results of four studies due to the unavailability of enough data. This systematic review included randomized trials only; hence, we might have missed other important studies that did not use this study design.

Conclusion

There is limited research examining video-based intervention for improving rehabilitation outcomes in children with cerebral palsy. The majority of studies showed a high risk of bias, and the quality of the evidence for reported results varied from very low to moderate. Significant issues in quality of evidence occurred due to observed in methodology and outcomes by the studies and heterogeneity due to variability in outcome measures. Weak evidence suggests no effect of video games on the majority of the outcomes; however, limited studies, small sample sizes, shorter trials, and inappropriate or unmatched games for the specific outcome might have been responsible for such results. Post-treatment significant changes were observed for many outcomes such as balance, reaction time, and upper limb function, which suggests that video games have some potential to improve rehabilitation outcomes. More work is needed in this area to use or create more engaging games aligned with therapeutic concepts for children with cerebral palsy. Further, more extensive trials with high-quality research are required to determine the effectiveness of video game-based interventions.

Chapter 3

Reflections on design, development, and evaluation of a video game to augment strength training in children with cerebral palsy

Introduction

Cerebral palsy (CP) is one of the most common neurodevelopmental disorders of childhood affecting approximately 2.1 of 1000 live births (2). CP is “a group of disorders of the development of movement and posture, causing activity limitation, that is attributed to non-progressive disturbances that occurred in the developing foetal or infant brain. Motor difficulties associated with CP can cause challenges with functional abilities such as mobility and daily living skills, including feeding and self-care” (1). CP is a heterogeneous condition; gross motor abilities vary and range from difficulty with coordination during more complex movements (such as walking, running, or jumping) to exclusive use of a wheelchair for locomotion.

Muscle weakness and resulting asymmetry can contribute to difficulty with coordinating and initiating movement. In addition, muscle weakness can affect balance if there are inadequate power production and force needed to maintain balance during movement (13). Muscle strengthening, also known as resistance training, is a common intervention used by physical therapists (16) and is performed by increasing a muscle’s ability to generate force, consequently increasing generating power in weak muscles (17). Several studies have demonstrated an association between muscle weakness and decreased walking efficiency, increased spasticity, and gross motor function limitations (14,15). General principles of resistance training encourage consideration of muscle actions, targeted muscle groups, workout structure, loading(weight lifted or resistance used), volume (changing repetitions performed per set or number of sets performed per session), rest interval, repetitive velocity, and frequency, which influence the design of the training program (17). These factors are manipulated to gradually increase demands and increase muscle strength, a process called progressive resistance training. The basic principle of progressive resistance training includes progressive overload, a gradual increase in stress placed upon the body during exercise, specificity**,** alignment of the exercise with actions required for particular tasks (17), and variation of intensity and volume over a period of time increases muscle adaptation. Once a muscle adapts to increased demands, variation is required to develop muscle strength further. Hence, it is essential to change one or more variables with time to optimize strength gains (18).

While there continues to be some debate about effectiveness (27), many studies have been conducted over the last two decades to evaluate the effectiveness of strength training in adults and children with CP (22,23). Evidence supports the effectiveness of strength training and resistance training in increasing muscle strength and motor function in people with CP (16). Studies have demonstrated an increase in walking speed and step rate (24), improvements in isometric strength (24), gain in knee extensor, and flexor strength (25) in participants with CP.

More recently, investigations of the effectiveness of power training, a form of strength training to develop muscle group's ability to contract at maximum force in minimal time, have demonstrated promising results (28–30). Functional power training also appears to be an effective intervention to improve walking capacity and muscle strength in young children with CP (31). Power training is considered to be more effective than traditional strength training for enhancing the velocity of movement, muscle power, and walking performance as it helps to increase fascicle length and cross-sectional area. In contrast, traditional strength training increases muscle size only (32). Moreau et al. (2012) suggest that power training should be incorporated into everyday clinical practice for children with CP (32).

The production of movement required for strength can be challenging for children with CP since they experience co-contraction of agonists and antagonists and challenges with selective motor control necessary for isolated joint movement. Hence, it is important to consider motor learning for the acquisition of capabilities to perform any specific movement. The process of attainment of the motor skills through practice resulting in permanent changes in the ability to perform a task is called “motor learning” (40). Several factors are considered in optimizing motor learning processes, such as how verbal instructions are provided, characteristics and variability of training sessions, the extent to which individuals actively participate and are motivated, learning through trial and error, postural control, memory, and feedback (39). Research has supported the value of motor learning-based interventions for children with CP (41,42). Levac et al. (2009) recommended motor learning strategies beneficial for functionally based interventions for children with neuromotor disorders (40).

Strengthening exercises and motor learning involve intensive, long-term repetitive routines (59), which in turn require motivation and dedication (60). Additionally, children find it difficult (or may not be willing) to follow direct instructions needed for the therapy. Studies suggest motivation as one of the most influential personal characteristics that determine motor and functional outcomes in children with CP (61,62). New strategies/tools with therapy to create motivating therapy programs for improved health outcomes are needed.

Video games have recently emerged as a potential motivational tool in rehabilitation. Research suggests that video games can enhance motivation to exercise and increase adherence to physical practice (46,47). Active video games (AVGs), also known as “exergames” require body movement beyond the conventional hand controller-based video games. Commercially available exergame systems such as Nintendo Wii®, Microsoft Kinect®, Sony PlayStation® have been used for the rehabilitation of individuals with neuromotor dysfunction (69,139). While the number of studies is limited and outcomes are varied, the literature generally supports the use of AVGs for improving motor function (51). Findings suggest that active video games can be a viable motivational tool to promote change in physical activity behavior (52). Children with CP demonstrated similar energy expenditure and responses as typically developing children, suggesting that active video games should be considered as an augmentative strategy to increase physical activity and motor control of children with CP (49).

Although various activity-based video games like dancing, boxing, bowling, and tennis encourage motor learning to some extent, strategic design and selection of active video games to target a specific muscle or muscle group or motor function could help facilitate therapeutic interventions (64) and enhance motivation to participate in rehabilitation. Games can also assist in progress monitoring, which is often challenging for clinicians (140). The need for specially designed and commercially available games for children with CP has been identified (140). However, the development of games for children with CP requires consideration of how the exercise fits with functional tasks. Specific body movements, speed, frequency, and intensity of training, feedback, and amount of time based on the type of therapy to be delivered are all important considerations. Ni et al. (2014) successfully designed and evaluated a virtual reality-based game and reported that the intervention was highly engaging for children (76). In addition, the convenience of easily adjusting difficulty levels was appreciated by therapists (76). Additional considerations have been recommended for increasing motivation to use AVGs, such as integrating music for positive mood and comfort, providing directions to the novice players within the game, setting achievable short- and long-term goals, avoiding barriers like peer pressure, and actively assisting players in forming groups (56). Since these requirements may contradict each other or interfere with the design of an enjoyable game, the authors emphasized the importance of a balanced approach, which sometimes involves prioritizing requirements to achieve a successful game therapy program (56). Hernandez et al. (2013) designed and evaluated various action games to understand specific requirements for children with CP and other motor disorders, including appropriate challenges and design aspects (58). The recommendations include the following measures for designers to create a playable game for children with CP (58): 1) reducing the need for carefully timed actions to navigate the game, 2) ensuring that difficulties completing time-sensitive actions do not impair the fun, 3) reducing the number of decisions players need to make and enabling a simple control scheme, 4) removing the need for precise positioning and aiming, 5) reducing the demands on manual ability and visual-motor integration, 6) making the game state visible by reducing the need for attention to gameplay, and 7) compensating for differences in players' gross motor skills. All of these considerations are important for game design with children with CP as they accommodate motor challenges that may affect the ability to be successful with mainstream games.

The goal of this project was to design and develop an affordable, therapeutic video game to supplement conventional lower limb strength training using a shuttle system (see Appendix B) and to assess feasibility in training children with cerebral palsy.

Design and Development

To optimize the benefits of AVGs, it is crucial that game design is based on the users (therapist, children, and parent) preference. We used principles of user-centric design, an approach based on the needs, beliefs, values, and preferences of the user (141), in this study users include physical therapists, children with CP and their parents. The design process involved consultation and numerous trials by the physical therapists at the Glenrose Rehabilitation Hospital (GRH), which helped inform the further iterations to the sensor system and the game to accommodate therapists' preferences and convenience to use the system. This iterative process resulted in gaining a better understanding of design considerations and the areas for improvement to make it more appropriate and convenient for therapists and children with CP. The steps and rationale of this process are outlined below.

The incorporation of motor learning principles is important for optimizing rehabilitation outcomes. We used the principles outlined in Levac's Motor Learning Strategies rating instrument to include the principles of motor learning into game design (142). The principles used were as follows:

1. **Practice characteristics and variability:** Practice characteristics include amount and structure. Amount refers to the ***amount*** of time spent practicing the task or the number of repetitions of the task. ***Structure*** refers to the composition of the practice trial, which includes practicing the task in its entirety (whole practice) vs. practicing parts of the task (part practice). In addition, the variable practice involves "rehearsal of many variations of the same movement class and, by contrast, in constant practice, the task does not vary. ***The schedule*** refers to the order in which tasks are practiced during a session, for example, in blocked practice, the first task is practiced, and then the second, etc. In random practice, task order is intermixed (143). These parameters are modified as the training progresses to make the task challenging, thus enabling the patient to perform the same task in different settings. Training sessions should also include appropriate rest periods to facilitate effective learning and less mental and physical exhaustion (39).

2. **Verbal instructions**: Extrinsic feedback is information provided to the learner to augment the naturally occurring intrinsic feedback (144). Verbal feedback is a form of extrinsic

feedback that includes form and frequency. The form includes encouraging instructions like “very good,” or “you can do better,” or information related to movements or tasks and the frequency refers to the frequency of feedback provided to the learner (40). (19)

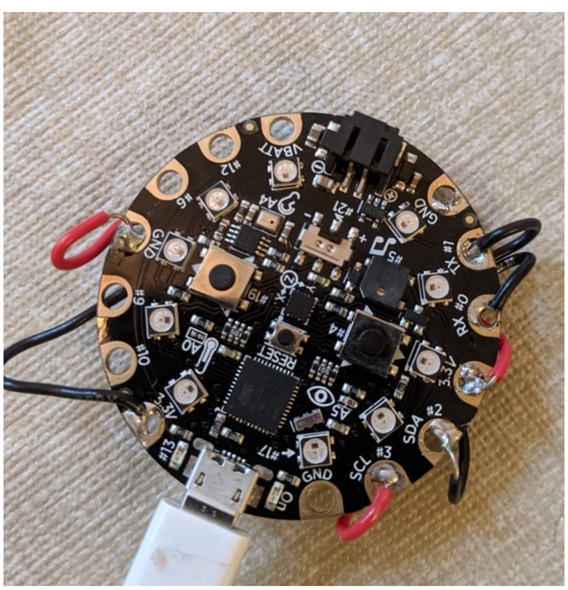
3. **Active participation and motivation**: Active participation and motivation play an important role in completing the task and resolving issues. Allowing individuals to make mistakes, encouraging them to propose their solutions to the problem, or providing them with options that enhance the learning efficiency (39) encourages active participation.

4. **Feedback**: Feedback aims to encourage the individual to achieve objectives, provide information about the result of movement/activity, and performance of the action. (39) Qualitative feedback refers to positive or negative feedback, e.g., “very good” or “you can do better” (positive reinforcement results in better learning experience than negative) to encourage the patient during the activity. Quantitative feedback is information about the recorded quantities of the performance (information about the movement) or the result (40).

Considering the principles mentioned above, the AVG was designed to augment knee extension exercises to strengthen quadriceps muscles on a shuttle machine under two conditions: traditional strength training and power training. The shuttle was selected because it is commonly used for intensive strengthening programs, and the equipment provides some consistency in how the exercises are completed, an important consideration for game design. The AVG system consists of a sensor and an Arduino board connected with a computer which has the 2D runner game that was designed on the Unity game development platform. The computer was also connected to a TV to display the game on a bigger screen for a good game experience. The sensor system includes a distance sensor and an Arduino board, which was programmed to measure and calculate movement aspects (distance and velocities) of the exercise and communicate with the computer a specific key on the keyboard (keypress function). The game playing in the computer picks up the keypress function and performs an appropriate action/feedback in the game. The feedback in the game includes visual cues, auditory cues, and rewards system, which is further discussed in detail below. Similarly, the sensor system and the 2D game are described below, with details of the design and therapeutic aspects integrated into the AVG system.

Development of the game controller

I developed a sensor system (figures 1 and 2) composed of an Adafruit Circuit Playground® and Adafruit® VL53L0X Micro-Lidar Distance Sensor. Adafruit Circuit Playground® is an electronic circuit board compatible with Arduino IDE software for programming, and the VL53L0X Micro-Lidar Distance Sensor detects the distance from a surface using an invisible laser source that is reflected off the surface. The Micro-Lidar sensor was placed on the shuttle right below the footplate, and a white cardboard surface was placed on the moving slider to reflect the laser. The sensor can measure approximately 50mm to 1200 mm, which was appropriate for the distance between the mounted sensor and the cardboard surface on the moving slider (moving surface), as demonstrated in Figure 3.



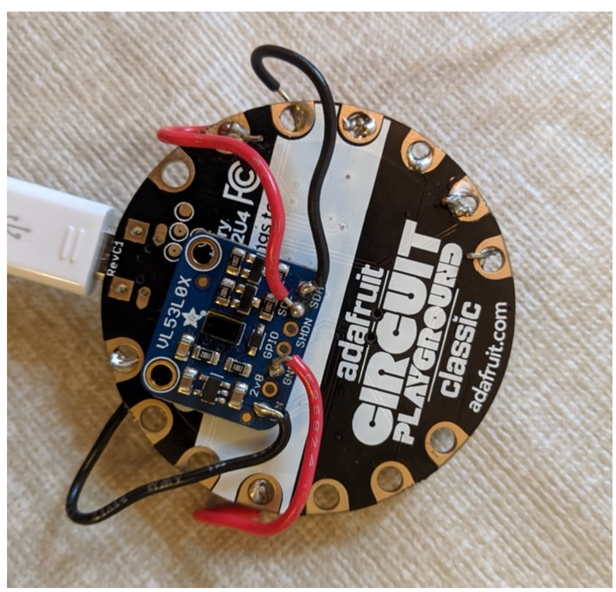


Figure 1: Adafruit Playground Circuit® **Figure 2: VL53L0X Micro-Lidar Distance Sensor**

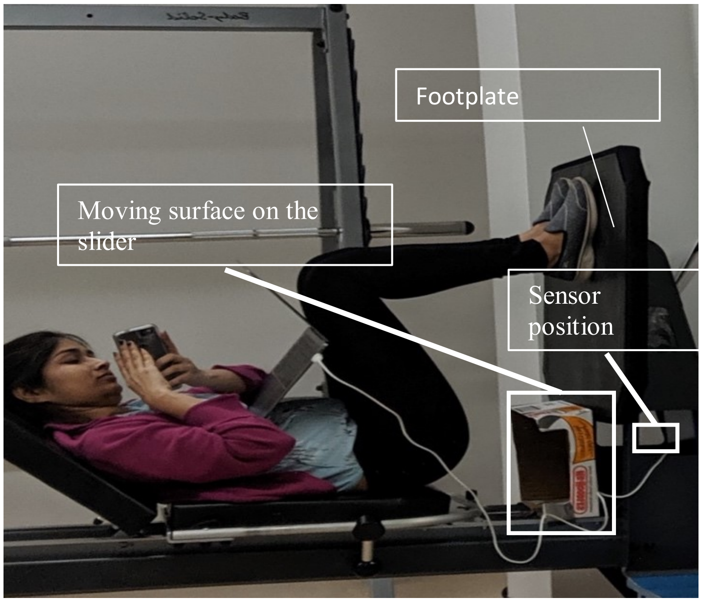


Figure 3: The position of the sensor and the white reflecting surface on the moving slider

The sensor system (Circuit Playground® and distance sensor) measures the distance of the moving surface from the sensor for concentric and eccentric movements during leg press movements. The sensor system detects an eccentric movement when the moving surface reaches the minimum distance from the sensor, i.e., 277 mm. The sensor system detects a concentric movement when the surface moves away from the sensor and reaches a certain distance, i.e., the maximum distance an individual could reach in a concentric leg press movement. Since the maximum distance depends on the height of the individual, the threshold for maximum distance was set in the presence of the individual and the therapist through a test run program. During the test run, the child was asked to perform one concentric movement, and the sensor system measured and reported the maximum distance of the moving surface from the sensor. The maximum distance was then entered into the main Arduino program before starting the game trial.

The main Arduino program includes measurement of the distance of the moving surface from the sensor, calculation of the velocities separately for concentric, and eccentric movement and calibration of the velocities. To consider individuals' limitations and variations in velocity, we embedded calibration by requiring the therapist to instruct the participant to move five times with the correct concentric and eccentric velocities aligned with tradition or power-based strengthening. The calibration part of the program calculates the average of the velocities for concentric and eccentric movement using the data (change in distance (mm) per milliseconds) from the first five consecutive movements. The program then uses the average velocities (concentric and eccentric) obtained from the calibration and sets a velocity range (calibrated average velocity+0.1 mm/milliseconds to calibrated velocity-0.1 mm/milliseconds) for each type of movement. If the movement occurs within the concentric velocity range and the individual reaches the maximum possible distance, the main Arduino program presses the space key on the keyboard, which triggers a jump in the game, and the player scores one point. Similarly, the up and down arrow keys on the keyboard were assigned for the cases of higher and lower velocities, respectively. The keypress function gets identified the game (same as a regular computer game that runs through keyboard buttons), and appropriate action is performed in the game. For example, the up arrow key makes the game character jump over the star while the down arrow key (makes the character jump below the star. During an eccentric movement, if the velocity falls above the eccentric velocity range and the individual reaches the minimum distance, the left arrow key gets pressed automatically by the Arduino program. The game detects Left arrow keypress and provides audio feedback to slow down during eccentric movement. Similarly, if the eccentric velocity falls within the eccentric velocity range and the individual reaches to the minimum distance, the right arrow key gets pressed automatically, and the game identifies the keypress. However, the game was programmed in such a way that it only provides audio feedback such as "good job" or "excellent" when a correct concentric movement and a correct eccentric movement have occurred consecutively. The schematic diagram provided in Figure 4 describes the program logic and scheme used for the sensor system and its communication with the game.

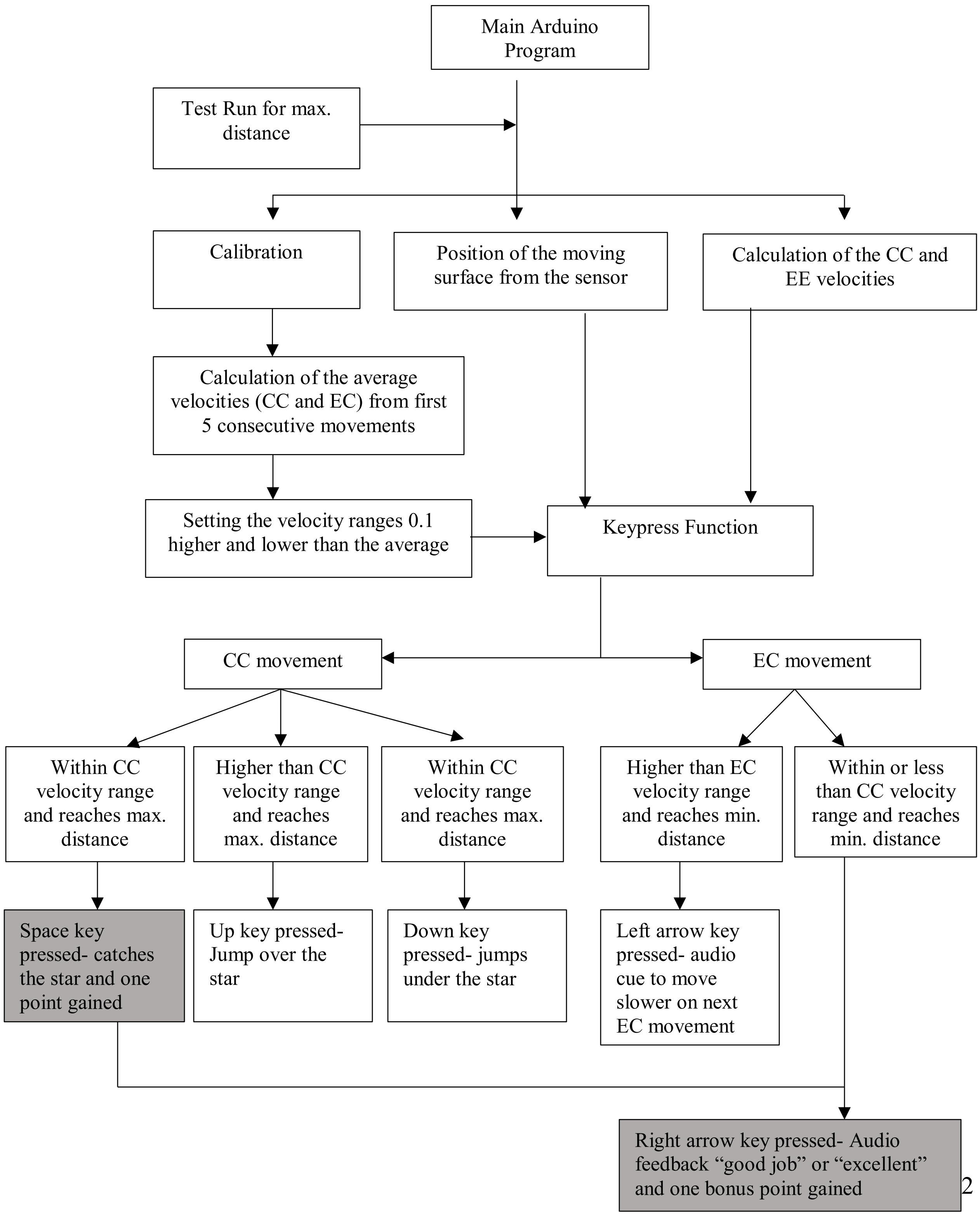


Figure 4: Schematic diagram of the sensor program and communication with the game.

Max Distance: Maximum distance needed for the individual for concentric movements; CC: Concentric movement; EC: Eccentric movement

Sensor design considerations

1. We aimed to develop an affordable, lightweight sensor that can conveniently be placed and removed when needed. A portable, lightweight sensor was necessary as the system was used by many people unaware of the study; we did not want to leave the sensor on the machine to avoid any damage to it. In addition, this feature will help explore the future applications of this sensor for other exercise machines. The selected sensor system cost $35 CDN and weighed approximately 10 g.

2. The sensor was positioned on the machine near the footplate, and the moving slider on the shuttle is a thin metal plate placed perpendicular to the sensor; hence it was not possible for the sensor to track the movement of the slider. Therefore, I had to attach a white cardboard surface to the moving slider of the shuttle to track the movement. The distance sensor measures the distance by the reflection of the laser from the moving surface; thus, a white surface worked better for this sensor.

3. During the sensor development process, we conducted numerous trials on the shuttle to determine all possible velocity variations, time of response, consistency and, distance from the sensor to accommodate individuals of any height (maximum distance covered on concentric movement). Children with CP have variations in their motor abilities and velocity of movement; hence our aim is to develop a game that could accommodate as much variation as possible.

Therapeutic considerations

1. Movement velocity plays a crucial role in strength training. Traditional or power-based training can be performed in different conditions: a) fast concentric and slow eccentric movement (power training), and b) slow concentric and slow eccentric movement (traditional strengthening). Therefore, I programmed the sensor to measure and respond to eccentric (towards the sensor) and concentric movements (away from the sensor) separately.

2. Movement velocity varies between individuals due to differences in spasticity and selective motor control. To consider individuals' limitations and variations in velocity, the calibration feature allows therapists to consider the individual's ability and decide the eccentric and concentric velocities aligned with traditional or power-based strengthening. The sensor records the velocities during the initial five sets of movements (instructed by the therapist) and calculates the averages of the velocities for concentric and eccentric movement separately. The sensor system then uses the average to set the velocity thresholds for both concentric and eccentric movements (see Appendix C for therapeutic aspects integrated with the sensor).

Game design and development

The aim of integrating a video game in therapy was to maximize engagement and enjoyment to increase motivation to participate in therapy. Hence, we created an appealing game designed for children, leading and directing the player's experience and considering reducing timed-based actions. The game design aspects involved primary focus, anticipation (time to inform the player that something is about to happen), and the announcement of the changes in the game using sounds or notifications (145). Specifics about game design are included below. We hired a game designer and a game developer for this project. The game developer developed the game on Unity, a popular game development engine used for developing 2D or 3D games. The game development was conducted in collaboration with the Glenrose Rehabilitation Research, Innovation, and Technology group. The final game was installed for use at the Glenrose Rehabilitation Hospital (see Appendix C for therapeutic aspects integrated with the game).

Game mechanics

Prior to starting the game, therapists program the number of sets and rest time (Figure 5) and repetitions (Figure 6) into the gaming system based on the therapeutic plan. The game then prompts therapists to establish the desired velocity by instructing the children to perform the initial five leg press movements with correct velocity as described above (Figure 7). As described above, the sensor system uses these movements to automatically establish a velocity range.

Figure 5: Game screen for the therapist to input the number of sets and rest interval

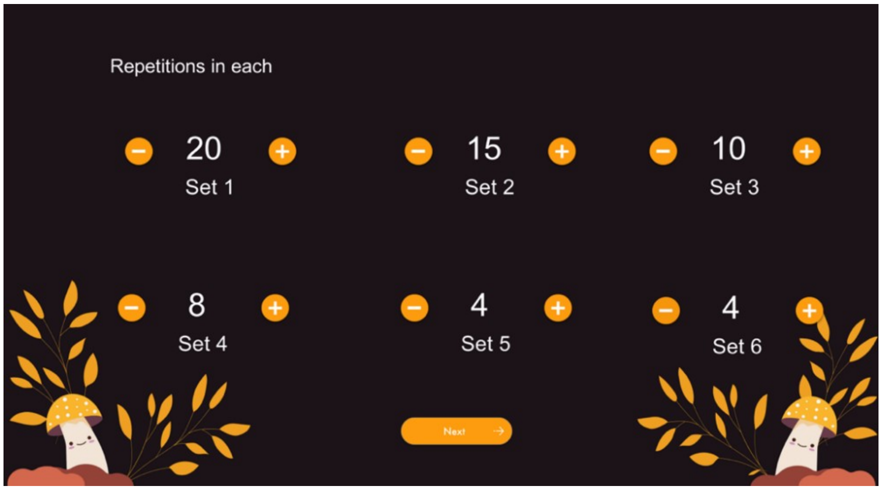


Figure 6: Game screen for the therapist to input the number of repetitions in each set

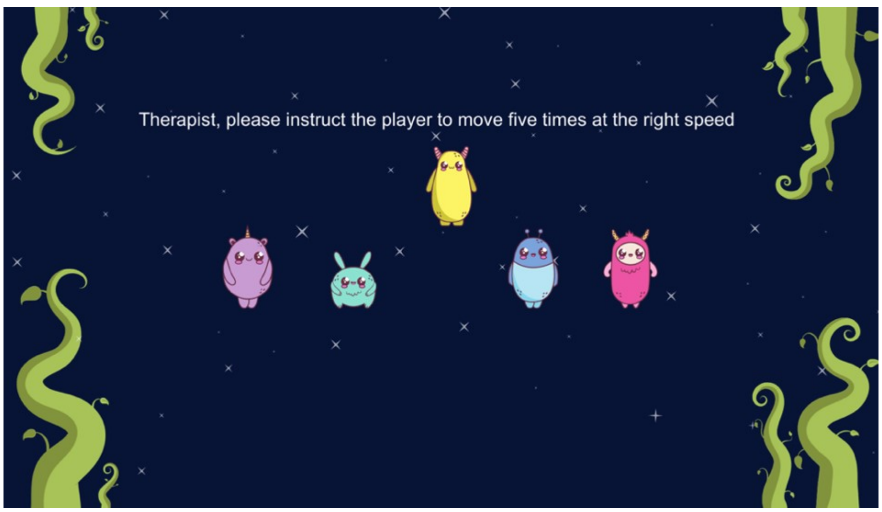


Figure 7: Calibration screen for five consecutive jumps, jumps occur on concentric movement (away from the sensor)

The game consists of a game character running from left to right who discovers numerous stars (depends on the number of repetitions entered by the therapist) as rewards as the character runs through an animated forest (Figure 8). The objective is to achieve the rewards which contribute to a total score. To earn rewards, the player has to jump in the game. Jumping can be performed by concentric leg press movement, moving one's feet to apply force on the platform at the correct velocity (the one calibrated before), which is detected by the sensor attached to the shuttle machine. The jump is triggered as soon as the sensor detects the platform of the shuttle moving away at a specific maximum distance that was set for the individual after the test run. The game has two game scenes (Figures 8 and 9), which alternate depending upon the number of sets (levels) decided by the therapist.

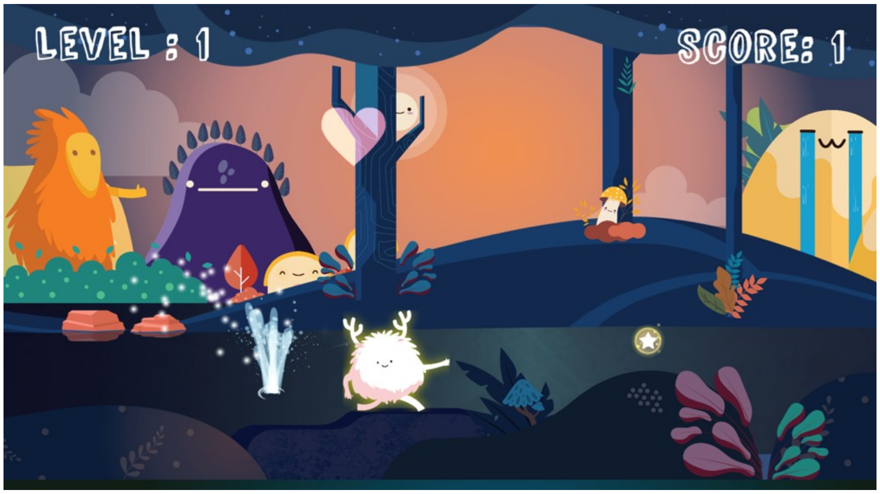


Figure 8: Level 1 screen; character jumped with correct velocity; gained the star

Once the game starts, the individual has to continue moving the character forward and jumping using consistent velocities for concentric movement to catch the stars and achieve an as high score as possible. In concentric movement, when the child produces slower concentric movement than required, the character fails to reach the star (either jumping over (Figure 9) or moving under the star (Figure 10)). If the child moves with the correct concentric velocity, the character catches the star and gains one point for that movement. In keeping with the feedback principle of motor learning, we recorded one of the therapists' voice and used the recordings in the game as auditory feedback for the eccentric movement only. When the child produces faster eccentric movement than required, the player receives as audio feedback, "*Try to lower more slowly next time.*" Additionally, if the player successfully performs a correct concentric and eccentric movement consecutively, positive feedback is provided by the game, such as "*Good Job*" or "*Excellent*," and gets one bonus point. Of note, if the player performs correct eccentric movement but the concentric movement right before that is incorrect, the player does not receive any visual or auditory feedback or a reward. Such a decision was taken in consultation with a therapist who suggested that controlled the concentric movements are comparatively more important than eccentric movements. Furthermore, it is suggested that too much feedback may interfere with learning tasks with individuals with CP (45); hence we decided to add encouraging feedback ("good job"/"excellent") only for a consecutive correct concentric and eccentric movement and corrective feedback ("try to lower more slowly next time") for the incorrect eccentric movement.

Figure 9: Level 2 screen, character jumped with higher velocity than required; missed the star

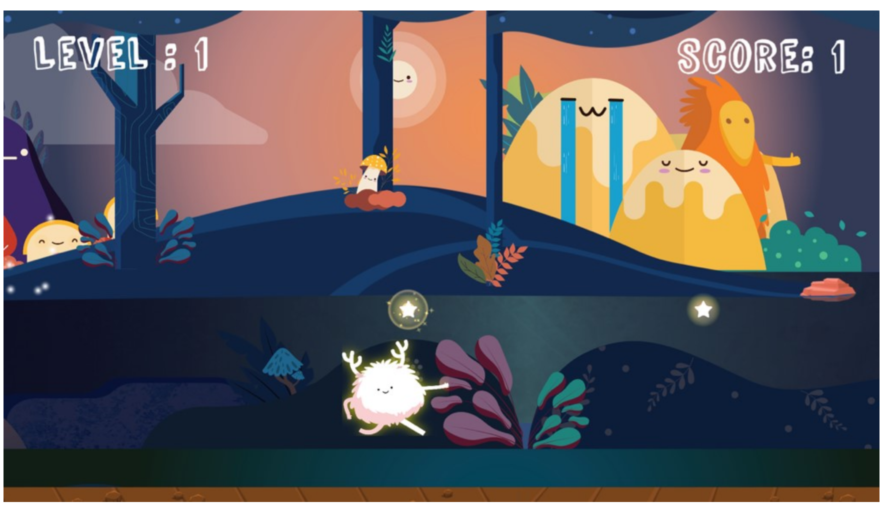


Figure 10: Level 1 screen; character jumped with slow velocity; missed the star

The scoring system (top right side of Figure 9, and 10) works as positive reinforcement, encouraging self-competition and enhancing performance to obtain a higher score. The scoring feature and visual and auditory cues in the AVG are aimed at improved exercise adherence. The level stays the same until the required number of repetitions (jumping in the game) has been performed. At the end of each level (set), the player receives encouraging audio feedback "*You did such a great job*" with their score and a timer (displaying rest interval) for their next level if applicable. At a final screen, the player will get to see the total score achieved in the game (Figure 11) (see Appendix C for therapeutic aspects integrated into the game).

Figure 11: Final screen with the game score

Game design considerations

1. Aesthetics: We collaborated with the game designer to create the theme of the game, overall function, and appearance to create an attractive design appropriate for children aged 5-10 years. We aimed to make the experience fun, engaging, and easy to understand for children and to guide and encourage correct exercise techniques.

2. Time of feedback: Setting up the timing of feedback was a challenging task since we needed to accommodate all velocity conditions and individuals with different heights. Children with shorter heights may take only a few seconds to perform both concentric and eccentric movement, which does not leave a lot of time for delivery of two types of feedback (concentric and eccentric). Additionally, receiving similar feedback for

both movements within seconds could be confusing. Hence, we used a different set of cues to manage this. For example, successful jumping indicated that they performed concentric movement velocity: catching stars was a visual cue that the velocity was within the correct range. Auditory cues include the sound of coins clicking was an additional auditory cue that a point had been received. To differentiate between concentric and eccentric movement, we used the therapist's voice for auditory feedback.

3. Ease of use: We aimed to ensure that the system was user-friendly and easy to learn in order to decrease the burden on therapists. Therapists were part of the design process from the beginning through the feasibility evaluation stage. We developed the system to be convenient for therapists to input, and control, exercise parameters, and ensure the ability to focus on the children.

Therapeutic Considerations

The main principles of motor learning were integrated into the AVG in the following ways:

1. **Practice characteristics and variability**

We integrated "*practice characteristics and variability*" in the form of the number of levels in the game, which represent "number of sets," and the number of jumps representing the "number of repetitions (reps)" in each set. The participant has a break after finishing one level, representing the "rest time" required between the sets. The training volume (number of sets, reps, rest period) were entered manually by the physical therapist before starting the game. The velocity cut-offs in the game were set up based on the average velocity of the first five exercise movements instructed by the therapist and was used to provide velocity specific feedback to the participant through the game. The manual entry and setting up the velocity range before every session helped to facilitate *practice characteristics and variability*, one of the components of Motor Learning Strategies Rating Instrument (142).

2. **Verbal instructions**

To maintain attention and correct movement velocity, as needed, we integrated verbal instructions into the system. For example, for concentric movements, slower or faster movement than required resulted in missing the stars, thus guiding the player to move faster or slower for the next moves. Similarly, game score and creative audio comments in the game encouraged them and delivered the information about their performance.

3. **Active participation and motivation**

This game provides instructions or cues only when it is necessary. It allows individuals to make mistakes, learn, and figure out on their own how to enhance their performance. To integrate this feature, we proposed a points system to reward them for active participation.

5. **Feedback**

To integrate this principle, various creative visual and audio *feedback* included in the game informed the participants about their performance and encouraged them to perform better.

Evaluation

The two aims of this evaluation were to 1) conduct a preliminary evaluation of an outcome measurement protocol to determine effectiveness for increasing enjoyment, exercise adherence, and motivation, and 2) evaluate user engagement and usability of the AVG.

Ethical consideration: This study (ID: Pro00087186) was approved by the University of Alberta, Health Research Ethics Board. Information letters and consent forms are provided in Appendices F, G, H, J.

Study Design: We used a single case (ABAB) design for this preliminary evaluation (146). The single-subject design is useful for evaluating the effects of a single intervention with a small group of participants. The ABAB design provides an opportunity to demonstrate the effects of the manipulation of the independent variable (video game), and re-implementation of the intervention in a second "B" phase with the benefit of an additional demonstration of experimental control (second AB) (146). The child started the therapy with the baseline (A phase; baseline, no video game). The conditions were then alternated and repeated with the intervention condition (i.e., with the AVG). In addition, at least three sets were performed to obtain three data points in each phase. The type of training, i.e., traditional strength training or power training on the shuttle, was selected by the therapist irrespective of the phase.

Participants: The original plan was to recruit five children with CP; however, participant recruitment and data collection were stopped due to COVID-19 restrictions. Hence, a preliminary evaluation of the game was conducted with only one child with CP. The criteria include children (aged 5 to 10 years) with CP with GMFCS Level I - III with the ability to view a computer screen from a distance of 6 to 12 feet. We excluded children if they or their parents were unable to speak and read English to ensure their ability to complete the questionnaires and understand the feedback provided from the game. A planned sample size of five was selected as five is an acceptable number for single-case designs (146).

Participant Recruitment: Children with cerebral palsy who attended the Glenrose Rehabilitation Hospital strengthening program were invited by their physical therapists to participate. Interested participants contacted the researchers directly or signed an Alberta Health Services release of information form (see Appendix E). They subsequently were contacted by the researchers. Prior to data collection, the parent and the therapist received an information letter (Appendices F & G) and completed a consent form (Appendices H and I). Child participants provided an informed assent (Appendix I).

Data collection and analysis

Enjoyment and exercise adherence were evaluated using a single subject (ABAB) design, and the motivation was also assessed after each trial. The results of motivation could not be assessed using single-subject design as we obtained only one data point in each phase, a minimum of three data points are needed to qualify for a single subject research design (146). In addition, information about overall user experience (system usability) and engagement with the game (conducted at the final session only) was collected during informal interviews at the end of the final session. The child participated in two sessions of strength training (i.e., traditional strength or power training, the therapist decided the type of training based on the child's training needs) on the shuttle without the game and two sessions of the same exercise with the AVG. Sessions were videotaped and subsequently coded for enjoyment and exercise adherence (see below). In addition, the child completed the Intrinsic Motivational Inventory (Appendix K) to measure motivation (objective 1). Finally, we collected parent and therapist feedback through interviews at the end of the final therapy session to learn about their perspectives about engagement, usability, other overall impressions of the game, and use of the game to augment strength training (Objective 2).

Data collection included 1) videos of the child completing exercises with and without the AVG (all four sessions) were used for behavioural coding for enjoyment and exercise adherence, 2) Measurement of motivation using the Intrinsic Motivation Inventory (147) (after all four sessions), 3) The Game Engagement Questionnaire (GEQ) (148) to evaluate the child's perceived engagement offered by the AVG (after final session only). 4) System usability score –therapist's perception of the implementation and usability of the designed game for the therapeutic purpose (after final session only). 5) Informal interviews with the parent and the therapist about their perspectives. The participant received a $25 gift card as a gesture of appreciation for his contributions to the evaluation.

The time duration of the sessions was consistent with the typical intervention session length (approximately half an hour). I set up the sensor and the game before each session and performed a test run to calculate the maximum distance the child could reach based on his height. On starting the game, the treating therapist programmed the exercise routine by entering the rest time, the number of sets, and the number of repetitions required by the participant.

Behavioral coding

Enjoyment and exercise adherence were evaluated from video recordings using behavioral coding techniques for each outcome. The original plan was to have two independent observers code the videos. However, due to lack of sufficient participant recruitment in the evaluation, I alone performed the behavioral coding. To avoid behaviour change due to the camera, I started the video recording before starting the therapy session (during the previous exercise) to allow desensitization to the camera. At least three sets were conducted in each session. The duration for each set may have varied due to differences in exercise parameters. The behavioural coding was conducted from the beginning to the end of each set, which gave us three data points in each phase to establish dependent measure stability.

We used the interval recording method to code the target behaviors throughout the session. The session was divided into short intervals of 5-seconds each, and the target behavior was scored as having occurred or not occurred at each interval. If the behavior was ongoing with an unclear beginning or ending or occurred for an extended period of time, it was scored during each interval in which it had occurred. Specific information about operational definitions and coding for each outcome (i.e., enjoyment and adherence) to exercise is described below.

1. ***Enjoyment*:** The working definition of enjoyment is "an optimal psychological state (i.e., flow) that leads to performing an activity primarily for its own sake and is associated with positive feeling states" (149). The more that individuals are in situations in which enjoyment may be experienced, the greater the possibility that perceptions of competence and feelings of self-determination contributing to increased intrinsic motivation (60). Fun and enjoyment are commonly stated reasons for video gaming (150). Items on the observer checklists are described below with score sheets for enjoyment behavior:

- Smile- The Cambridge Dictionary (151) describes a smile as an expression on the face in which the ends of the mouth curve up slightly, often with the lips moving apart so that the teeth can be seen, expressing happiness, pleasure, amusement, or a friendly feeling. In this evaluation, we included any facial expression that includes lips tugged upwards, and the curve of the mouth need not be equal on both sides of the face.
- Laughter- According to the Cambridge Dictionary (152), laughter can be described as an act of smiling while making sounds with voice. For this evaluation, a smile with an open mouth, creating sounds that indicate pleasure or fun, was included as laughter.
- Cheering- Cheering is an act of giving loud sound (through voice or hitting something) as approval, excitement, encouragement, or achievement. Any positive body language with sound or comments like yay, yes, clap, hitting on something that shows their excitement

towards the activity. Cheering also included any positive comments by the child about the activity.

A sample for the rating for enjoyment indicators is provided in Appendix D.

2. ***Exercise adherence*****:** The main goal of using the AVG was to augment exercise and facilitate exercise adherence, and therefore it was important to evaluate if the functions in the game fulfill the strength training exercise requirements such as the number of sets, reps, rest time, and speed. Adherence is defined by WHO as the 'extent to which a person's behavior corresponds with agreed recommendations from a healthcare provider. In the preliminary evaluation, exercise adherence means the degree to which a person's behavior corresponds with recommendations from guidelines for lower limb strength training/ power training. The physical therapist was told that she could provide comments or instructions during the sessions whenever needed irrespective of the conditions (with or without AVG). As a proxy for adherence, we coded the frequency of corrective comments required by the therapist in each session. For example, if the therapist encouraged the child to go faster or slower or encouraged the child to continue if he stopped prior to finishing a set. We used the interval recording method to measure the target behaviors throughout the session. Each session was divided into short intervals of 5 seconds each, and the target behavior was scored as having occurred or not occurred at each interval. If the behavior is ongoing with an unclear beginning or ending or occur for a long period of time, it was scored during each interval in which it had occurred. A sample for the rating for exercise adherence is provided in Appendix D.

   Items on the observer checklists are described below with score sheets for exercise adherence:

- Therapist instructions to move faster or slower- We instructed the physical therapist to provide a comment whenever needed. Any comment that included an instruction to move faster or slowdown was marked down on the score sheet.
- To start moving or stop- In case the child stops in the middle of the set or starts at the wrong time, the therapist instructed the child to stop or start the movement. Any instructions that indicated child to start movement were included, such as "push up," "push down," or "move up" were considered as corrective feedback to start.

After behavioural coding, the graphs of individual behavioural data for each outcome (enjoyment and exercise adherence) were presented. The data were graphically displayed over the course of the baseline and intervention phases. Visual inspection was conducted by judging the changes in means, and the percentage of non-overlapping data (PND). For enjoyment, the desired behaviour was expected to increase; hence, the PND was calculated by dividing the total number of data points in the intervention phase that exceeded the highest data point in the baseline by the total number of data points in the intervention phases and multiplied by 100. The mean difference in scores was discussed descriptively, and the video recordings were observed to identify the possible reasons for specific behaviour or change in levels.

Motivation

Self-determination theory (SDT) focuses on human's ability to acquire the motivation for initiating a health-related behaviour change and maintaining them over time. Motivation can be defined as a current sensational state that modulates the (cognitive or behavioural) effort an organism is willing to invest to achieve internal or external goals (63). SDT suggests two types of motivation regulating one's behaviour – *Intrinsic motivation* and *extrinsic motivation*. *Intrinsic motivation* is defined as performing an activity because of its inherited satisfactions, such as feelings of enjoyment, personal accomplishment, and excitement. *Extrinsic* motivation refers to doing an activity for instrumental reasons or when behaviour and outcome are separable such as to gain tangible outcomes such as social recognition or seeking power or influence (153). Video games can be intrinsically motivating because of their inherently enjoyable nature created by offering rewards in the form of wins or game scores (63).

We used the Intrinsic Motivational Inventory (22-item scale in Appendix K) (147) as a tool to rate the child's motivation during the therapy session. The instrument assesses participants' interest/enjoyment, perceived competence, felt pressure and tension, and perceived choice while performing a given activity within six subscales. The tool is flexible, hence different versions of the scale have been used depending upon the study question (154). It has four subscales: interest/enjoyment, perceived choice, perceived competence, and pressure/tension. The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation; perceived choice and perceived competence are theorized to be positive predictors of both self-report and behavioural measures of intrinsic motivation. Pressure tension is theorized to be a negative predictor of intrinsic motivation. The participant completed the questionnaire after each session, and the total scores for each subscale were calculated for all four phases. The data were presented graphically for each subscale over the course of baseline and intervention phases for the participant.

Post-therapy measures

The second objective was to assess the usability of the developed game and overall impression, for which we used the Game Engagement Questionnaire (GEQ) to assess user engagement with the game system, and the System Usability Scale to evaluate the usability of the AVG as a therapeutic tool for lower limb strength training with children with CP. We conducted informal interviews with the parent and the therapist to collect their feedback about various aspects of the game and its application to therapy. The tools are described in more detail below.

User engagement: To measure user engagement, it is necessary to understand and identify core attributes that develop engaging behaviour. Brockmyer et al. (2009) developed a theory-based measure of engagement in playing video games that can be useful in assessing the potential impact of playing video games (148). This includes identification and defining core attributes such as immersion, presence, flow, psychological absorption, and dissociation. The Game Engagement Questionnaire (GEQ) (Appendix - L) is a 19-item scale that assesses several aspects related to gameplay engagement. These include presence, flow, immersion, and absorption (148). It includes statements such as "I lose track of time," to which participants responded "no," "sort of," or "yes." I selected the GEQ because it specifically measures participant engagement in digital games and because the items in this instrument have been tested for validity and reliability. (148). The child was asked to fill the GEQ (Appendix L) only after the completion of each session with the AVG. To create a composite score, scores of yes were assigned 3, sort of as 2, and no as 1, were tallied to create a total score. We used the GEQ scores to compare the level of engagement of the child between the two sessions with the AVG.

Usability of the therapeutic gaming system: Usability of a system is defined as "an extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use." (155). User-focussed designs help in making the product as usable as possible. User testing during the product development phase can help make improvements that can benefit the end user (156). The "System Usability Scale" (SUS)

(157) (Appendix K) is a rating scale that we employed to measure the usability of the therapeutic game developed for children with cerebral palsy. The SUS (Appendix-K) contains ten questions based on the Likert five-point scale; the scoring rule is as follows: (1) based on the level, each problem has a base score that ranges from 1–5, which corresponds to the range from "strongly disagree" to "strongly agree"; (2) the scores for questions 1, 3, 5, 7, and 9 are equal to the base score minus 1; the scores for questions 2, 4, 6, 8, and 10 are equal to five minus the base score; (3) the scores of the ten questions are added to obtain the total score of the questionnaire; and the questionnaire SUS score is the total score times 2.5.

Table 1: Criteria for deciding the system usability.

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

This questionnaire was completed at the final therapy session by the parent and therapist. The results provided information about the usability of the gaming system for lower limb therapy in children with CP.

Interviewing: After completing all the sessions, we conducted an informal interview with the parent and therapist (Appendices L and M). The interviews were recorded, and notes were taken regarding their views on the game features, its application as a therapeutic intervention, and issues faced by the participant or the therapist, suggestions on desired changes in the system. The therapist had an additional question regarding the alignment of game features with the exercise program, and ease of use of the system. The interview questions for the therapist and the parent are provided in Appendices N and O.

Findings

A nine year old child classified as GMFCS level II participated in this study. The following are the results obtained from the single-subject design, questionnaires, and interviews:

Enjoyment: The graph in Figure 11 demonstrates the enjoyment expressed as the mean responses (left side) observed in each set in each session per minute and enjoyment expressed as the percentage of the 5-second interval during which the child expressed enjoyment. The visual analysis of the graph and percentage of PND suggest that the use of the AVG to augment lower limb strength training was effective in increasing the enjoyment level of this child. The percentage of interval mean at baseline (session1 without the AVG) was 5.9%, which increased to 10.8% when the conditions were altered from the control to intervention. No enjoyment indicators were observed when the conditions were reversed. Again, when the conditions were altered from the control to the intervention phase, the mean increased to 38.9. The changes in the mean across phases suggest that the use of video game raised the enjoyment level experienced by the child during the therapy. In addition, the difference in mean response between the two intervention phases (session 2 and session 4) indicates that the enjoyment level may also depend on the development of improved skills and understanding in the game. The instability and drop-in enjoyment responses during set 3 in each intervention phase might be attributed to the scoring system of the game. It took some time for the child to adjust to the game and start scoring well, which compromised the total score in the game. The child seemed disappointed with the score by the end of the session, which is one of the issues that may need to be addressed on further development and research. Five out of six (83.33%) data points in the intervention phase exceeded the highest data point in the control condition, which means the AVG was effective in raising the enjoyment level in the child. However, it is noted that in addition to the feedback from the game, the child received encouragement from the therapist on achieving the target. Video recording observations indicated that the 2-3 smiles in the session might have occurred due to external encouragement. The video recordings also revealed that the enjoyment indicators in the control condition occurred due to lack of focus in the therapy and moving the slider fast back and forth, while in the intervention condition, the responses occurred on performing the task correctly. In addition, after finishing each session, the child was asked if he wants to continue the exercise. He seemed excited during session 2 and completed three more sets in session 2, which indicates that the use of the AVG might help increase participation and adherence to the therapy.

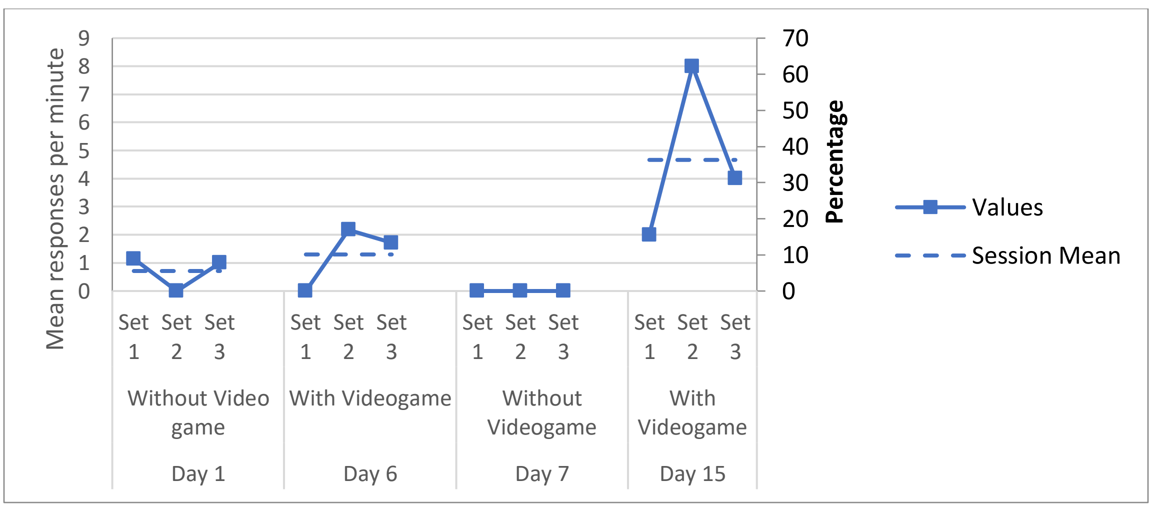


Figure 12: Enjoyment ratings

PND= (5/ 3+3) *100= 83.33%

Data are expressed as the mean enjoyment responses occurred per minute (left) and the percentage of 5-second intervals (right) during which the child expressed enjoyment within a set (time varied from 45 to 95 seconds), each session. The highest point in each A phase was used to calculate PND because an increase in enjoyment indicators was desired with the treatment.

Exercise adherence: Figure 12 demonstrates exercise adherence expressed as the mean of the number of therapist's corrective comments provided to the child per minute. Figure 12 displays exercise adherence expressed as the percentage of the 5-second interval when the child received corrective feedback by the therapist. On visual inspection, the desirable change in level was indicated by the reduction in the mean the percentage of interval for the therapist's correct feedback. The mean percentage of the interval was 64.9% at the baseline, which dropped to 45.2% when the condition was altered from control to intervention for the first time. Although the change in corrective feedback occurred in the anticipated direction, the less magnitude of change could possibly be attributed to the first-time introduction of the game, which needs some time to understand the functions well. The observations from the video recordings showed that during session 2, the child had difficulty understanding how far he has to go to get the point, and it took him some time to figure out how the game worked. When the conditions were altered from the intervention to the control phase, the mean increased to 52%. However, on further alternation of the condition from the control to the intervention the change, the mean lowered to 9.2%, which means the therapist did not need to provide much feedback on the movement and velocities as compared to the control phase. The PND result suggests that only 66.66% of data points in the intervention phase were less than the lowest data point in the control group. As the PND results are below 70%, the effectiveness of the AVG on exercise adherence is inconclusive.

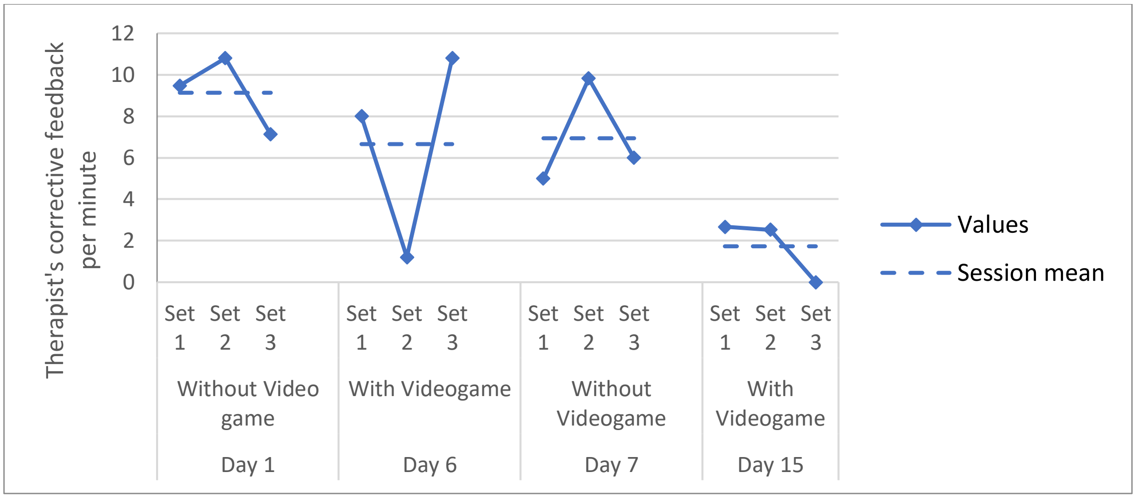


Figure 13: Therapist corrective feedback (frequency per minute)

PND= (4/3+3) *100=66.66%
Data are expressed as the mean of corrective feedback given by the therapist within a set (time varied from 45 to 95 seconds), each session. The lowest point in each A phase was used to calculate PND because a decrease in corrective feedback was desired with the treatment.

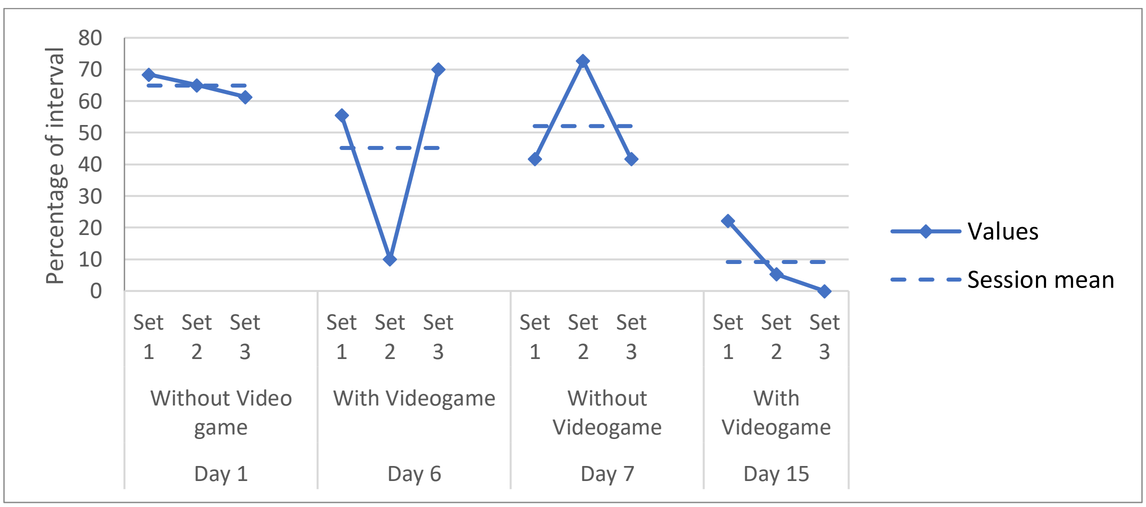


Figure 14: Therapist's corrective feedback (percentage of intervals)

PND= (4/3+3) *100=66.66%
Data are expressed as the percentage of 5-second intervals during which the child received corrective feedback within a set (time varied from 45 to 95 seconds), each session. The lowest point in each A phase was used to calculate PND because a decrease in corrective feedback was desired with the treatment.

Motivation: Figure 12 demonstrates the scores for subscales Intrinsic Motivation Scale in each session. Although the change is small, the child seemed to enjoy video game therapy sessions more than regular therapy. On observation of the video recordings, the child was observed to be more focused on the game screen and seemed motivated to control the movements based on the feedback by the game. In sessions without the AVG, the child seemed distracted by the other people (therapists and patients) and things in the room; he had difficulty following his therapist's instructions due to the distractions. During sessions with the AVG, he stopped looking around the room and focused on his task.

Based on the total score of perceived competence subscale, a slight increase was observed in perceived competence scores in sessions 2 and 4. The child perceived himself as more skilled and confident about his performance in the task when exposed to the therapy with the AVG compared to regular therapy. The scores of pressure/tension subscale across the phases remained constant except during the first session (without the AVG). His pressure/tension level seemed to reduce after Session 1 as it was the first time when the child was using the shuttle. Hence, the results indicate that exercising with the AVG did not put the child into any pressure on the child to perform. The scores in perceived choice remained constant when the phases were altered from the control to the intervention phase, when the phases were reversed, the scores increased by 42.86% and remained constant when the phases were further altered from the control to the intervention.

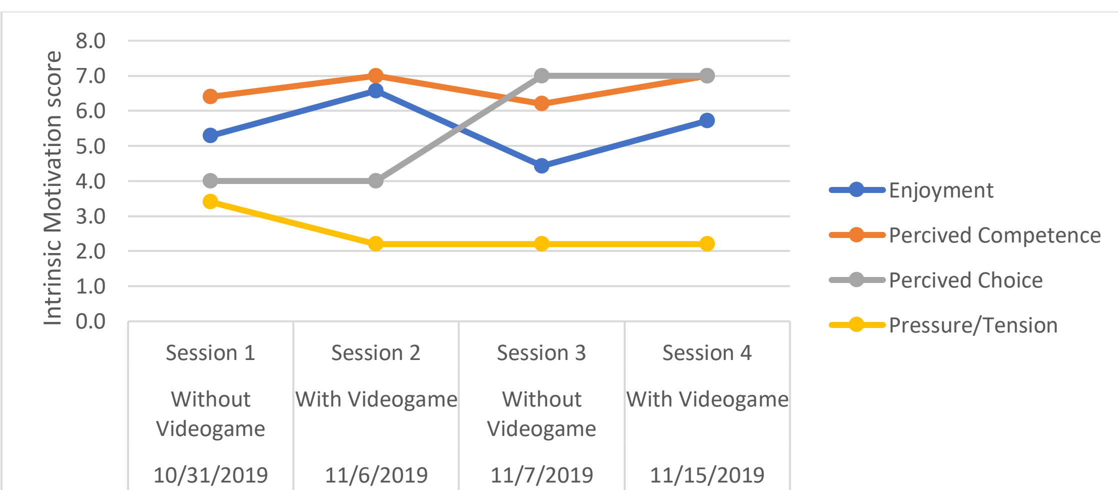


Figure 15: Intrinsic motivation subscores in each session

Game Engagement- The total GEQ score obtained after session 2 (with the AVG) was 38, while the total GEQ score for session 4 (with the AVG) was 48. The observation of the video recordings of both of the sessions supports the results obtained by the GEQ. During session 2, the child complained about the game and called it "boring" on a further discussion, he said that "the game was boring because it was too difficult for him." However, during session 4, he completed the task well and scored more than in session 2, and the video recording did not reveal frustration or negative comments about the game. Hence, the difference in the engagement level might be attributed to the exposure to a new game rather than the nature of the game. The GEQ subscale scores seemed to improve in session 4 compared to session 2 as follows: 1) absorption increased by 66.6%, 2) flow increased by 23.1%, 3) Pressure scores remained the same, and 4) immersion increased by 50%. The mean score from both sessions was 43.

System usability: The total score of the system usability scale was 72.5/100 (grade B level), which means the therapist considered the system suitable for use. The results suggest that the therapist considered the system quick to learn and convenient to use and agreed that the game and the exercise were well integrated. The therapist did not find any inconsistencies in the game. In addition, the therapist agreed that she did not have to put a lot of effort to learn and understand the system before using it.

Interviews - Interview answers with the therapist favour the use of the video game AVG for lower limb training on the shuttle. The therapist considered the game system easy to set up and easy for the child to follow. The therapist perceived that the child paid more attention to the AVG compared to therapy without the AVG, in which he kept getting distracted by other things happening in the room. Although the game helped the child to pay more attention to the exercise, the therapist recommended adding visual cues for eccentric movements as well. She noticed that the child switched quickly from eccentric to concentric movement, and sometimes did not even complete the eccentric movement due to the excitement of catching the next star. Observing the video recording confirmed that the stars as a visual cue for concentric movement guided the child on how far he needed to extend his legs and how fast or slow he needed to go. While for eccentric movement, the game has only audio instruction, which did not appear to attract enough attention for the child to complete the movement. Overall, the therapist feedback suggests that the game was useful in maintaining attention, controlling the movements, and positive reinforcement, and challenges both motor and cognitive abilities. The therapist suggested the addition of a feature that would enable saving an individual's profile in the game, which will not only help therapist in programing the exercise routine (increasing or decreasing the velocity, changing weights, sets or repetitions), but the feature might also make individuals compete with their score and improve performance. Other suggestions include changing the music as the level gets harder, and convenience to change the velocity and/or weight if the child is able to catch all the stars easily.

Although the child's grandmother was only present in two of the sessions (session 1 and session 4), I interviewed her to gain insight into her opinions about the use of the game. She suggested that the child likes the game, and the smiling faces and hearts on catching the stars kept him engaged throughout. She also indicated that his performance was better in the session with the AVG. She observed changes in his behavior; during session 1(without video game) where he moved too quickly and did not take the exercise seriously, while during session 4 (with the AVG), she observed him going slow to gain rewards in the game. She added that the child had a long day at school and was tired during the session with the AVG as compared to the without the AVG, which was conducted in the morning. Overall, the feedback from her confirmed that the game had some valuable contribution towards the engagement and attention throughout the therapy session.

Challenges

Through evaluation, I discovered new issues and aspects of the game, which were not realized during the prototyping stage. For example, there was no visual cue for the eccentric movement. It was much easier for the child to remember and control the speed for concentric movement as compared to the eccentric movement. I noticed that the absence of any visual cues or visual targets while moving toward the sensor made it difficult for the child to learn and control the speed during the eccentric movement. Although integrated audio instructions recorded by one of the therapists at the GRH were helpful to an extent, we think that additional visual cues can make the game more effective for the therapy.

In addition, the child had a negative response towards the scoring system in the game. In the game, the child could see the score at the end of each level. Although the child seemed excited throughout the session, he showed frustration when the game ended. The score was cumulative, and consisted of the scores obtained at each level so, if he performed better at the last level, the overall score did not reflect his expectation for points and therefore he was disappointed with his score. The game requires trial with other children to determine if there is a personal factor involved or an issue with the scoring system. If the scoring system is not optimal, we will need to develop a creative way to show progress by the end of the therapy without creating disappointment with the game. A possible option could be to replace the numbers with different achievement levels depending on their performance, for example, using bronze, silver, and gold tier to provide a sense of achievement.

Participant recruitment was one of the major challenges that we faced during this evaluation. It was already challenging to recruit children with cerebral palsy, and the age requirement of 5 to 12 years old made it more challenging to recruit participants for this evaluation. Additionally, since we needed physical therapist's feedback who are explicitly using the shuttle for lower limb strengthening, we decided to recruit the participants who are already involved in this program. The decision to recruit through the hospital delayed the trial as we had no control over the recruitment.

Discussion

The current paper described the process of designing and developing an AVG to augment lower-limb strength training in children with CP and discussed the challenges throughout the process. In addition, the feasibility evaluation of the AVG provided a preliminary understanding of the feasibility and usability of the game by assessing the level of enjoyment, motivation, game engagement, and system usability. Interviews with the therapist and the parent highlighted the aspects of the game that couldn't be evaluated through the observation and the questionnaires. The results indicated that the AVG was successful in increasing the enjoyment during the therapy compared to the therapy without the AVG. However, after keen observations through the video recordings of the sessions and feedback from the therapist, issues with the scoring system and lack of sufficient feedback led to some confusion and frustration while playing. The results from behavioral coding of corrective feedback by the therapist support the observation on lack of adequate feedback. The feedback from the therapist highlighted the problem with a lack of guidance in eccentric movement as compared to concentric. Other positive aspects of the AVG observed by the therapist and the parents are controlling the movement and directing the child's attention to the exercise. The therapist's ideas new features and game modifications, such as saving individual profiles and progress and the need for a visual target for eccentric movement, are some of the possibilities for future improvement in the game.

For effective game design, Lyons (2015) (158) described various mechanism of feedback, challenges, and rewards could be used in improving the enjoyment of exergames. However, motor and cognitive limitations, and specificity of the therapeutic exercise limit the application of some of the mechanisms. We followed Harnandez et al. (2013) (58) recommendations for designing exergames for children with cerebral palsy such as avoiding the need of carefully timed actions, enabling a simple control (jump and land) and reducing visual-spatial reasoning or precise positioning by providing a fixed target that depends on specific leg movement and balancing the differences in gross motor abilities. The present study demonstrates that despite challenges and restrictions with therapy guidelines, it is possible to create exergames by including therapists and children with CP in their design process itself.

The following are some of the important lessons learned throughout the AVG development and feasibility evaluation.

Balancing physical therapy goals and game design

We had a wide range of conditions and variations in strength and power training. A compromise was needed between fun elements in the game design and restrictions with therapeutic needs and concepts. For example, popular 2D runner games like Super Mario® includes the occurrence of exciting events and actions, for example, unexpected enemies or rewards on the way, gaining and losing power, which was not possible in this game as the therapeutic guidelines required the same movement occurring in a specific time. In addition, we had to avoid negative reinforcement, which narrowed our options to create a more interactive environment in the game. On the other hand, some of the therapy-related issues were also compromised, such as keeping the knees together while pushing the weight back and forth due to the inability of the current sensor to track knee movement. With the help and suggestions by therapists, the designer, and the game developer, I was able to add therapeutic features like feedback for eccentric movement, verbal feedback, etc., in later stages of the development.

Importance of involving therapists and children in design and development

The involvement of therapists who have worked with children with CP guided me in the overall design and development process. For example, the position of the sensor on the machine was decided with a therapist to avoid any interruption or discomfort in using the machine and damage to the sensor as well. Similarly, a therapist played the game on different exercise conditions to ensure the correct time of response and feedback through the game. Regular meetings with the therapist at the Glenrose Rehabilitation Hospital led to the identification of major concerns with the game. For example, initially, the game was designed to focus on concentric velocity only. Still, on one of the game trials, the therapist suggested including feedback for eccentric movement as well as children tend to extend their legs too quickly. The game developer and I modified the scoring system to add one more point as a reward for correct concentric and eccentric movement consecutively. In addition, therapist commands were recorded and added to provide feedback correct eccentric movement. In addition to the therapist's feedback, I believe trials and feedback by children with CP and their parents could help to make significant improvements in the game to accommodate variations in the level of sensitivity, height, and all possible velocities.

Possibility of increasing the level of fun and enjoyment in the therapy

The game was successful in maintaining a consistent velocity and controlling the movements for the participant during the evaluation. However, the events in the game were simple and may not be exciting enough for every child; in addition, longer duration therapy will need more advanced design and a storyline to maintain the excitement among the children. For longer therapy sessions, the introduction of a variety of game choices, levels, and features might help in keeping them interested in the activity for a more extended period of time. Designing a common theme that is exciting for the age group 5 to 18 years old with adjustable difficulty level based on the individual's age, motor, and cognitive abilities might be more impactful, and more people could benefit from it.

For future development of AVG games for children with CP, we suggest interdisciplinary teams of therapists, engineers, designers, and behavioral researchers as it helps in maintaining a balance of game design and therapeutic principles. Although commercial systems are popular in gaming rehabilitation, a few researchers have developed innovative sensor-based gaming controllers for exergaming (159–161). The sensor-based system facilitates the measurement of a variety of exercise-related parameters using a combination of sensors at an affordable cost. More development in sensor-based gaming technology is needed to realize its potential in the field of rehabilitation.

Limitations

The findings in this evaluation are based on the evaluation by one participant. More work is needed on the game design to ensure it is interactive and interesting. Since only one participant participated in this evaluation, the rating for enjoyment and exercise adherence was not performed by an independent observer. This may have led to some bias in observation from the video recordings. Although the items in the GEQ are validated and reliable, the authors did not continue further research on this tool, and they do not provide specific instructions on the method of calculating the total score. In addition, the use of subscales of the GEQ has not been validated yet.

Conclusion

In conclusion, a sensor-based video game was developed in collaboration with therapists, engineers, and a game designer for lower limb strength training on the shuttle in children with CP. The game integrated principles of strength training (18) and Levac's Motor Learning Strategies (142) for therapeutic gains. The design process involved prototyping and re-iterations based on the feedback and trials by therapists. The game was evaluated by a child in a single-subject research design, and the results demonstrate that the video game was feasible, and the tools were useful in increasing the level of enjoyment, controlling the movement, and directing the attention to the exercise. Although the corrective feedback by the therapist reduced in intervention phases, the percentage of non-overlapping data was only 66.66%, which cannot be considered as clinically meaningful. Such a result could be the consequence of insufficient feedback for eccentric movements. The therapist suggested a few changes for improving the AVG, including the need for visual cues for eccentric movements and saving individual profiles and progress.

Chapter 4

General discussion and conclusions

Main Findings

This thesis included two parts: the first part of the thesis was a systematic review and meta-analysis aimed to examine the effectiveness of video game interventions on rehabilitation outcomes in children with cerebral palsy (CP). The studies included in the systematic review (n=19) were parallel randomized controlled trials and randomized cross-over trials, which compared video games with no therapy, video games with regular therapy, or video games and regular therapy with regular therapy alone. The Cochrane Risk of Bias, version 2nd (RoB-2) (88) was used to assess the risk of bias and study quality and the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) (90) was used to evaluate the quality of the evidence for outcomes (91). The body of evidence in the systematic review was weak due to the limited number of studies with a high risk of bias, small sample sizes, and variability in assessment tools. Factors influencing the results of this systematic review include poor reporting of interventions, poor reporting methods and outcomes in the majority of the randomized control trials, insufficient duration of the intervention for changes to become apparent, and the use of inappropriate or unmatched games for the specific outcomes they were trying to achieve. Overall, we assessed the evidence related to outcomes such as balance, gross motor function, walking abilities, and upper limb function is weak and inconclusive.

The studies included in this systematic used two different approaches to the use of video games in rehabilitation for children with cerebral palsy. Some studies evaluated video games as alternatives to traditional rehabilitation (compared video games to no therapy), while others viewed games as strategies to augment conventional therapy (compared video games alone of plus therapy to regular therapy). The majority of the studies (n=15) used commercial games by Nintendo Wii®, Eye toy system, and Microsoft Kinect®, and only four studies used the video games that were customized or specially designed for therapy in children with CP. For an effective video game intervention, consideration should be made related to the specificity of the therapy and variations in the needs and abilities of children with CP. Hence, there is a chance that the children with CP could benefit more from customized or specially designed games based on the therapy. While some of the commercial games are engaging and popular among children, researchers developing specially designed video games for children with CP need to focus on creating highly interactive and immersive games that are engaging and in alignment with the therapeutic tasks required. That is, games can be specifically designed using therapeutic principles, including principles of motor learning, to maximize therapeutic benefit.

We addressed this gap by specially designing an immersive video game with a sensor controller to augment lower limb strength training in children with CP with the assistance of a designer, engineers, and pediatric physical therapists. The second part of the thesis contains a description of the design and development and preliminary evaluation of a video game for lower limb strength training on the Shuttle for its feasibility and usability and therapeutic intervention. The elaborated process of design and development of the game controller and the sensor demonstrates the considerations that should be made to design a video game for children with CP. The considerations include the specificity, amount and structure of the exercise/therapy, other therapeutic strategies involved in the therapy, variations in needs, preferences, and capabilities of individuals with CP, and behavioral changes in enjoyment, motivation, and engagement that play a crucial role in improved outcomes (63,162). In addition to the therapeutic and behavioral aspects of designing, studies recommended some design considerations on game mechanics, story, challenges and feedback mechanics, incentives/rewards (158,163). A lot of general considerations of game design may not be applicable for children with CP. Therefore, Harnandez et al. (2013) (58) design recommendations such as avoiding the need of carefully timed actions, enabling simple a control (jump and land) and reducing visual-spatial reasoning, precise positioning, and balancing the differences in gross motor abilities can be helpful for future researchers and designers. In addition, the involvement of therapists and children with CP at the initial stages of development is useful for better design and improved outcomes (164).

The results from behavioural evaluation of one participant indicated that the AVG was successful in increasing the enjoyment during the therapy compared to the therapy without the AVG. After keen observations through the video recordings of the sessions and feedback from the therapist, I found some issues with the scoring system and lack of sufficient feedback led to some confusion and frustration while playing. The results from behavioral coding of corrective feedback by the therapist support the observation on lack of sufficient feedback. The feedback from the therapist highlighted the problem with lack of guidance in eccentric movement as compared to concentric. Other positive aspects of the AVG observed by the therapist and the parents are controlling the movement and directing the child's attention to the exercise. The therapist's ideas, new features, and game modifications, such as saving individual profiles and progress and the need for a visual target for eccentric movement, are some of the possibilities for future improvement in the game. Evaluation with more participants will help in developing more understanding of the feasibility of the game for lower limb strength training in children with CP.

Future Research Directions

Better quality of studies is needed to build a strong quality of evidence for the effectiveness of the video game on various rehabilitation outcomes in children with CP. Stronger reporting of randomized trials such as those outlined in the CONSORT guidelines (136,137) is recommended to strengthen this body of evidence. Prior to evaluating effectiveness through randomized trials, and single-case research design studies with children with cerebral palsy might be helpful in understanding the level of engagement, and efficiency of the game on the outcomes targeted by the specific game.

I understand that commercial games are not designed based on therapeutic guidelines, which could contribute to the insignificant between-group differences. Although the commercial games can be utilized as a tool augment to the regular therapy program for increased enjoyment and participation, customizing existing commercial games or specially designing the game for children with cerebral palsy should be considered to target specific therapy needs. In addition to the game design principles, researchers should consider game development recommendations that were especially proposed for game designing for children with CP (58). Also, multidisciplinary teams for game design and development and involvement of therapists and children with CP during the prototyping and iteration stage is useful in developing an efficient game therapy system.

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Appendix A

Database search strategy for the systematic review

Databases	Population	Diagnosis	Video games	Number of articles
Medline EBSCOhost (1841-2019)	(MH "Child, Preschool") or (MH "Adolescent") or (MH "Child+") or preschool* or pre-school* or kindergarten* or kindergarden* or elementary school* or nursery school* or schoolchild* or toddler* or boy or boys or girl* or middle school* or pubescen* or juvenile* or teen* or youth* or high school* or adolesc* or pre-pubesc* or prepubesc* or child* or adolesc* or pediat* or paediat*)	(MH "Cerebral Palsy") or (MH "Hemiplegia") or "cerebral palsy" or hemiplegia or diplegia or monoplegia or quadriplegia	((MH "Video Games") or "screen game*" "virtual reality game*" or "virtual reality gaming" or "augmented reality game*" or "augmented reality gaming" or "electronic game*" or "electronic gaming*" or "computer gaming" or "computer game*" or playstation or xbox or "Nintendo Wii" or "kinect game*" or "kinect based game*" or "kinect based gaming*" or "kinect based gaming*" or "kinect gaming*" or "multiplayer video game*" or "multiplayer video gaming" or "console game*" or "console gaming" or "serious gaming" or "serious game*" or "immersive game*" or "immersive gaming*")	112
CINAHL EBSCOhost (1937-2019)	(MH "Child, Preschool") or (MH "Adolescent") or (MH "Child+") or preschool* or pre-school* or kindergarten* or kindergarden* or elementary school* or nursery school* or schoolchild* or toddler* or boy or boys or girl* or middle school* or pubescen* or juvenile* or teen* or youth* or high school* or adolesc* or pre-pubesc* or prepubesc* or child* or adolesc* or pediat* or paediat*)	(MH "Cerebral Palsy") or (MH "Hemiplegia") or "cerebral palsy" or hemiplegia or diplegia or monoplegia or quadriplegia	((MH "Video Games") or "screen game*" "virtual reality game*" or "virtual reality gaming" or "augmented reality game*" or "augmented reality gaming" or "electronic game*" or "electronic gaming*" or "computer gaming" or "computer game*" or playstation or xbox or "Nintendo Wii" or "kinect game*" or "kinect based game*" or "kinect based gaming*" or "kinect based gaming*" or "kinect gaming*" or "multiplayer video game*" or "multiplayer video gaming" or "console game*" or "console gaming" or "serious gaming" or "serious game*" or "immersive game*" or "immersive gaming*")	84
SCOPUS (2004-2019)	(child* OR adolescen* OR preschool OR "pre-school" OR teen* OR youth OR pediat* OR paediat*)	"cerebral palsy" OR hemiplegia OR quadriplegia OR diplegia	"video game*" OR "Video gaming" OR "virtual reality game*" OR "Kinect game*" OR "Kinect based game*" OR "Console game*" OR "Computer game*" OR "X-box" OR "serious game*" OR "playstation" OR " Augmented reality game*" OR "Nintendo Wii" OR " screen game*"	188
	***(** TITLE-ABS-KEY (* child* *OR* adolescen* *OR* preschool *OR* "pre-school" *OR* teen* *OR* youth *OR* pediat* *OR* paediat* *) AND TITLE-ABS-KEY (* "cerebral palsy" *OR* hemiplegia *OR* quadriplegia *OR* diplegia *) AND TITLE-ABS-KEY (* "video game*" *OR* "Video gaming" *OR* "virtual reality			

	game*" *OR* "Kinect game*" *OR* "Kinect based game*" *OR* "Console game*" *OR* "Computer game*" *OR* "X-box" *OR* "serious game*" *OR* "PlayStation" *OR* " Augmented reality game*" *OR* "Nintendo Wii" *)*			
EMBASE OVID (1974-2019)	exp child/ or exp infant/ or adolescent/ or exp pediatrics/ or pediatric*.mp. or paediatric*.mp. or child*.mp. or newborn*.mp. or congenital*.mp. or infan*.mp. or baby.mp. or babies.mp. or neonat*.mp. or pre-term.mp. or preterm*.mp. or premature birth*.mp. or NICU.mp. or preschool*.mp. or pre-school*.mp. or kindergarten*.mp. or kindergarden*.mp. or elementary school*.mp. or nursery school*.mp. or schoolchild*.mp. or toddler*.mp. or boy.mp. or boys.mp. or girl*.mp. or middle school*.mp. or pubescen*.mp. or juvenile*.mp. or teen*.mp. or youth*.mp. or high school*.mp. or adolesc*.mp. or pre-pubesc*.mp. or prepubesc*.mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	exp Hemiplegia/ or exp Cerebral Palsy/ or "Cerebral palsy".mp. or hemiplegia.mp. or diplegia.mp. or monoplegia.mp. or quadriplegia.mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	exp Video Games/ or "video game*".mp. or "Screen game*".mp. or "virtual reality game*".mp. or "virtual reality gaming".mp. or "Augmented reality gaming".mp. or "Augmented reality game*".mp. or "electronic gaming".mp. or "electronic game*".mp. or "computer gaming".mp. or "computer game*".mp. or playstation.mp. or "X-Box".mp. or "Nintendo Wii".mp. or "Kinect based game*".mp. or "Kinect gaming".mp. or "Kinect game*".mp. or "Multiplayer video gaming".mp. or "Multiplayer video game*".mp. or "multimedia video gaming".mp. or "multimedia video game*".mp. or "console gaming".mp. or "console game*".mp. or "Neo geo*".mp. or "Serious game*".mp. or "Serious gaming*".mp. or "interactive gaming".mp. or "interactive game*".mp. or "imersive game*".mp. or "imersive gaming*".mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	169
PsycInfo (1887- 2019)	Child* OR Children OR Preschool OR "Elementary school" OR "Nursery school" OR toddler* OR boy* OR girl OR "Middle school*" OR Pubescen* OR Juvenile* OR teen* OR youth* OR adolscen* OR prepubesc* OR child* OR adolesc* OR pediat* OR paediat*	"Cerebral Palsy" OR "Hemiplegia" OR diplegia OR monoplegia OR quadriplegia	"Video Games" OR "screen game*" OR "virtual reality game*" OR "virtual reality gaming" OR "augmented reality game*" OR "augmented reality gaming" OR "electronic game*" OR "electronic gaming*" OR "computer gaming" OR "computer game*" OR playstation OR xbox OR "Nintendo Wii" OR "kinect game*" OR "kinect based game*" OR "kinect based gaming*" OR "kinect based gaming*" OR "kinect gaming*" OR "multiplayer video game*" OR "multiplayer video gaming" OR "console game*" OR	46

			"console gaming" OR "serious gaming" OR "serious game*" OR "immersive game*" OR "immersive gaming"	
SPORTdiscus (1841-2019)	(MH "Child, Preschool") or (MH "Adolescent") or (MH "Child+") or preschool* or pre-school* or kindergarten* or kindergarden* or elementary school* or nursery school* or schoolchild* or toddler* or boy or boys or girl* or middle school* or pubescen* or juvenile* or teen* or youth* or high school* or adolesc* or pre-pubesc* or prepubesc* or child* or adolesc* or pediat* or paediat*)	(MH "Cerebral Palsy") or (MH "Hemiplegia") or "cerebral palsy" or hemiplegia or diplegia or monoplegia or quadriplegia	((MH "Video Games") or "screen game*" "virtual reality game*" or "virtual reality gaming" or "augmented reality game*" or "augmented reality gaming" or "electronic game*" or "electronic gaming*" or "computer gaming" or "computer game*" or playstation or xbox or "Nintendo Wii" or "kinect game*" or "kinect based game*" or "kinect based gaming*" or "kinect based gaming*" or "kinect gaming*" or "multiplayer video game*" or "multiplayer video gaming" or "console game*" or "console gaming" or "serious gaming" or "serious game*" or "immersive game*" or "immersive gaming*")	17

Appendix B

Shuttle TNT

Appendix C

Integration of therapy principles with the sensor and the game functions

Therapeutic aspects/requirement	**Sensor functions**
Concentric movement	Moving away from the sensor
Eccentric movement	Moving towards the sensor
Maximum quadricep muscle contraction concentrically	The threshold range (distance) the child should reach while moving away from the sensor i.e. Pushing up
Maximum quadricep muscle contraction eccentrically	The threshold range (distance) the child should reach while moving away from the sensor i.e. Moving down
Need for different velocities for eccentric and concentric movements	The sensor tracks the velocity separately for both the movements
Variations in motor abilities and Individual therapy program/work out structure	The sensor tracks initial 5 movements and uses average velocity to set threshold range
Therapeutic aspects/requirements	**Game functions**
Concentric movement with correct velocity and sufficient muscle contraction	The character jumps and catches the star (1 point)
Concentric movement with slower velocity and sufficient muscle contraction	The character jumps below the star (no points)
Concentric movement with faster velocity than required velocity and sufficient muscle contraction	The character jumps over the star (no points)
Eccentric movement with faster velocity and sufficient muscle contraction	Audio feedback "try to move more slowly next time"
Consecutive correct (velocity and extend of muscle contraction) concentric and eccentric movement	Audio feedback "good job" or "excellent" (1 point)
Number of sets	Number of levels
Number of repetitions	Number of stars in one level

Rest interval	Time between the two levels
Therapist decides structure of the exercise	Calibration scene asks therapist to instruct the child to move 5 times with correct velocities
Recommended guidelines for game designing for Children with CP	**Integration into the game**
Reducing the need for carefully timed actions to navigate the game	The jump in the game occurs after the movement is completed, the timed actions are not required to navigate in the game.
ensuring that difficulties completing time-sensitive actions do not impair the fun	No time-sensitive action is required in the game, the the navigation depends on number of jumps, which are not time sensitive
removing the need for precise positioning and aiming,	The star appears at a fixed height from the ground, and catching the star depends of velocity of the legs movement rather than position of the star
reducing the demands on manual ability and visual-motor integration,	The game is designed to challenge motor abilities, the game has simple controlled that does not need any decision making by the player. Challenges reasonable amount of visual-motor integration
making the game state visible by reducing the need for attention to gameplay	The game state remains visible allowing the player to gain control back quickly in case of distraction
compensating for differences in players' gross motor skills.	Calibration feature in the game allows therapist to set the task and challenge level based on the players gross motor skills and therapy requirements
Motor Learning Strategies	**Game functions**
Practice characteristics and variability (amount, structure and schedule)	Flexibility to program number of sets, repetitions in each set and rest intervals

Verbal instructions	Positive reinforcement using audio comments such as “excellent”, “good job” and “try to move slowly next time” for eccentric movement.
Active participation and motivation	The game allows the child to make mistakes, learn, and figure out on their own on how to enhance their performance. Combination of visual and auditory cues wherever necessary and reward system motivates the child to perform better on the next move
Feedback	A combination of visual (stars) and auditory cues (therapist’s voice recordings) as feedback to inform the child about his performance

Appendix D

Rating table for enjoyment indicators (set 2 session 4, Duration:90 seconds)

	Time interval (secs)											
Indicators	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60
Smile											*	*
Laughter												
Cheering												
	Time interval (secs)											
Indicators	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	115-120
Smile	*	*	*	*	*	*						
Laughter												
Cheering												

Rating table for adherence indicators (set 1 session 2, Duration: 55 seconds)

Indicators	Time interval (secs)											
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60
Move Faster												
Slow down		1		1				1				
Start moving	1		1	1	1	1						
Stop												

Appendix E

Study title: Evaluation of a video game to augment conventional lower limb strength training with children with cerebral palsy.

Principal Investigators: Lesley Wiart, PT PhD and Shivangi Bajpai, B.Tech

Ethics ID#:

Permission to Release Information

The Health Information Act requires us to obtain your permission to provide your contact information to researchers. You have indicated that you are interested in learning more about the study called 'Evaluation of the specially designed video game by children with cerebral palsy during lower limb traditional strength and power training'. Please read the statements below and sign if you understand and agree.

I authorize ___________________________ to give my name and telephone number to the
(health care provider)
research assistant of this study.

I understand that the research assistant will contact me to tell me more about the study.

My name and phone number are required for the researchers to contact me. Alternatively, I can contact the researchers directly.

My consent may be revoked at any time by contacting the health care provided indicated on this form by calling _________________________ .

_________________________ _________________________ _________________________
Print name Signature Date

Appendix F

Information Letter - Parents

Title of Project: Evaluation of a video game to augment conventional lower limb strength training with children with cerebral palsy.

Ethics ID#: Pro00087186

Principal Investigators: Lesley Wiart PT, PhD
Shivangi Bajpai B. Tech

Purpose: The purpose of this study is to evaluate a video game used during lower limb strength exercises by children aged 5-10 with cerebral palsy.

Background: We have developed a video game to use with leg muscle strength training for children with cerebral palsy. We want to know if video games can be used to motivate children to do their exercises and if the game makes the exercise more fun. We also want to know what you think about the game. Feedback collected from you and your child will also help us improve the game.

Procedures: You have been invited by your child's physical therapist to participate in the study. Children who participate will be asked to fill out a questionnaire after four sessions- two with and two without playing a video game during the strengthening exercises. After your child completes these four sessions, you will be asked to fill another questionnaire regarding the game. We will also be video record the four therapy sessions and we will observe the videos for signs of motivation and engagement. We will also conduct an informal interview with you about games features, like/dislikes, and suggestions for improving the game.

Honoraria: You will receive four parking passes and your child will receive a 25$ gift card for Chapters.

Risks and Benefits: There are no known risks to participating. Your child may benefit from using the video game during the strengthening exercises.

Confidentiality: All information will be confidential (not revealed to anyone). The information you provide will be kept for at least five years after the study is done. The information will be kept in a locked cabinet. Your name and your child's name or any identifying information will not be kept with the information you give. Your name and your child's name will never be used in any presentations or reports of the study results. The information from this study may be looked at in the future to help us answer other questions. If so, the ethics board will first review the study to ensure the information is used properly. If your child is ineligible for the study, any information that was collected in the screening assessment will not be used in the study but will be kept with the study data. By signing this consent form, you are saying it is okay for the study team to collect, use and disclose information about you from your personal health records as described above.

Freedom to withdraw: You can decide not to participate. You can withdraw from the study at any time. There are no consequences for withdrawing from the study.

Additional Contact Information: Please contact the University of Alberta Research Ethics Office at (780) 492-2615 if you have any questions regarding your rights as a research participant. If you have any concerns about the conduct of this study, you can contact the Health Research Ethics Board office at (780) 492-0

Appendix G

Information Letter- Physical Therapists

Title of Project: Evaluation of a video game to augment conventional lower limb strength training with children with cerebral palsy.

Principal Investigator: Lesley Wiart, PT, PhD
Graduate Student Researcher: Shivangi Bajpai, B.Tech.

Ethics ID#: Pro00087186

Purpose: The purpose of this study is to evaluate a video game to augment lower limb strength exercises by children aged 5-10 with cerebral palsy.

Background: - We have developed a video game to augment conventional lower limb strength training for children with cerebral palsy. We want to know if the video game is motivating and increases participation and performance in lower limb strength exercises. We want to collect your feedback about usability of the system.

Risks and Benefits: There are no known risks to participating in this study. You will contribute to knowledge about the effectiveness of video games for enhancing motivation and engagement in therapy. Your feedback will also help to improve the game that we developed for this project.

Confidentiality: All information will be confidential (not revealed to anyone). The information you provide will be kept for at least five years after the study is done. The information will be kept in a locked cabinet department of Physical Therapy at the University of Alberta. Your name or any identifying information will not be kept with the information you give. Your name will never be used in any presentations or reports of the study results. The information from this study may be looked at in the future to help us answer other questions. If so, the ethics board will first review the study to ensure the information is used properly.

Freedom to withdraw: You can decide not to participate. You can withdraw from the study at any time. There are no consequences for withdrawing from the study.

Additional Contact Information: Please contact the University of Alberta Research Ethics Office at (780) 492-2615 if you have any questions regarding your rights as a research participant. If you have any concerns about the conduct of this study, you can contact the Health Research Ethics Board office at (780) 492-0302.

Appendix H

CONSENT FORM

Title of Project: Evaluation of a video game to augment conventional lower limb strength training with children with cerebral palsy.

Principal Investigator: Lesley Wiart, PT, PhD
Graduate Student Researcher: Shivangi Bajpai, B.Tech.

Ethics ID#: Pro00087186

	YES	NO
Do you understand that you and your child have been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you and/or your child are free to refuse to participate or withdraw from the study at any time, without any reason and without affecting future care or services?	☐	☐
Has the issue of confidentiality been explained to you?	☐	☐
I understand that the video recordings will be used for research purposes only.	☐	☐
Do you agree to be contacted by the researchers about future studies?	☐	☐
Do you agree to allow the researchers to use video for research presentation purposes?	☐	☐

Signatures

Who explained this study to you? ______________________________
I agree to participate in this study: YES: ☐ NO: ☐
I agree to my child's participation in the study: YES: ☐ NO: ☐

Signature of Research Participant: ______________________________

Printed Name: ____________________ Date: ________________

Witness (if available): ____________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.
Signature of Investigator or Designee: ____________________ Date: ______________

*THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT

Please contact the University of Alberta Research Ethics Office at (780) 492-2615 if you have any questions regarding your rights as a research participant. If you have any concerns about the conduct of this study you can contact the Health Research Ethics Board office at (780) 492-0302.

Appendix I

Child Participant Information Letter and Assent

Title of Project: Evaluation of a video game to augment conventional lower limb strength training with children with cerebral palsy.

Principal Investigator: Lesley Wiart, PT, PhD
Graduate Student Researcher: Shivangi Bajpai, B.Tech.

Ethics ID#: Pro00087186

What is this study about?
We want to know what you think about a video game that we have made to help with your therapy exercises. We have developed a video game to help you with your exercises. We want to know if the video game can help you enjoy the exercises more and perform better. We also want to know about what you think about therapy with and without the video game. What you tell us will help improve the video game.

What do I need to do?
You will do two therapy sessions with and two sessions without the video game. At the end of your therapy, we will ask you some questions about the video game. We will take a video of you doing the exercises. We will look at this video later to compare how you do your exercise with and without the video game.

Will anyone know that I did this study?
We will not share anything you said or did with anyone who is not part of this study unless we talk to you and your Mom or Dad first.

What are the good and bad things about doing this?
We think that there are no bad things about being in the study. You may like to help to make the video game better for other children.

Do I have to do this?
If you do not want to answer the questions, that's OK. It's also OK if you don't want to do the study. You can tell your parents or me that you do not want to be in this study. If you say yes now, you can change your mind later. You can still say no. That is OK too! None of this will affect the care that you get at the Glenrose.

What if I am not sure?
Your parents know about this study. Ask them questions if you do not understand what this is about. You can also talk to us about the study before you decide if you want to be involved. Thank you for thinking about helping us with this project.

I agree to take part in the study.

______________________________	________________
Your signature (research participant)	Date
______________________________	________________
Signature of witness	Date
______________________________	________________
Signature of Investigator	Date

You or your parent can contact the University of Alberta Research Ethics Office at (780) 492-2615 if you have any questions regarding your rights as a research participant. If you have any concerns about the conduct of this study, you or your parent can contact the Health Research Ethics Board office at (780) 492-0302

Appendix J

CONSENT FORM- Physical Therapists

Title of Project: Evaluation of a video game to augment conventional lower limb strength training with children with cerebral palsy.

Principal Investigator: Lesley Wiart, PT, PhD
Graduate Student Researcher: Shivangi Bajpai, B.Tech.

Ethics ID#: Pro00087186

	YES	NO
Do you understand that you have been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to refuse to participate or withdraw from the study at any time, without any reason?	☐	☐
Has the issue of confidentiality been explained to you?	☐	☐
Do you understand that the video recordings will be used for research purposes only?	☐	☐

Signatures

Who explained this study to you? ______________________________________

I agree to participate in this study: YES: ☐ NO: ☐

Signature of physical Therapist: ______________________________________

Printed Name: ___________________________ Date: ______________________

Witness (if available): ____________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.
Signature of Investigator or Designee: _________________________ Date: _________________

*THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT

Please contact the University of Alberta Research Ethics Office at (780) 492-2615 if you have any questions regarding your rights as a research participant. If you have any concerns about the conduct of this study, you can contact the Health Research Ethics Board office at (780) 492-0302.

Appendix K

Intrinsic Motivation Inventory

TASK EVALUATION QUESTIONNAIRE
For each of the following statements, please indicate how true it is for you, using the following scale:

1	2	3	4	5	6	7
not at all true			***somewhat true***			***very true***

1. While I was working exercising, I was thinking about how much I enjoyed it.
2. I did not feel at all nervous about doing the exercise.
3. I felt that it was my choice to do the exercise.
4. I think I am pretty good at this exercise.
5. I found the exercise very interesting.
6. I felt tense while doing the exercise.
7. I think I did pretty well at this exercise, compared to other students.
8. Doing the task was fun.
9. I felt relaxed while doing the exercise.
10. I enjoyed doing the exercise very much.
11. I didn't really have a choice about doing the exercise.
12. I am satisfied with my performance at this exercise.
13. I was anxious while doing the exercise.
14. I thought the exercise was very boring.
15. I felt like I was doing what I wanted to do while I was working on the exercise.
16. I felt pretty skilled at this exercise.
17. I thought the exercise was very interesting.
18. I felt pressured while doing the exercise.
19. I felt like I had to do the exercise.
20. I would describe the exercise as very enjoyable.
21. I did the task because I had no choice.
22. After working at this exercise for a while, I felt pretty competent.

Appendix L

Game Engagement Questionnaire

Please indicate how you felt while playing the game for each of the items, on the following scale:
Yes Sort of No

1.	I lose track of time	Yes	Sort of	No
2.	Things seem to happen automatically	Yes	Sort of	No
3.	I feel different	Yes	Sort of	No
4.	I feel scared	Yes	Sort of	No
5.	The game feels real	Yes	Sort of	No
6.	If someone talks to me, I don’t hear them	Yes	Sort of	No
7.	I get wound up	Yes	Sort of	No
8.	Time seems to kind of standstill or stop	Yes	Sort of	No
9.	I feel spaced out	Yes	Sort of	No
10.	I don’t answer when someone talks to me	Yes	Sort of	No
11.	I can’t tell that I’m getting tired	Yes	Sort of	No
12.	Playing seems automatic	Yes	Sort of	No
13.	My thoughts go fast	Yes	Sort of	No
14.	I lose track of where I am	Yes	Sort of	No
15.	I play without thinking about how to play	Yes	Sort of	No
16.	Playing makes me feel calm	Yes	Sort of	No
17.	I play longer than I meant to	Yes	Sort of	No
18.	I really get into the game	Yes	Sort of	No
19.	I feel like I just can’t stop playing	Yes	Sort of	No

Appendix M

System Usability Scale (SUS)

Thank you for participating in this evaluation. Your answers, based on sessions with and without the video game, will help us to improve the game.

Instructions- *Please indicate the degree to which you disagree/agree with the following statements.*

1. I think that I would like to use this system frequently.

   ○ ○ ○ ○ ○

   Strongly Disagree **Disagree** **Neutral** **Agree** **Strongly Agree**

2. I found this system unnecessarily complex.

   ○ ○ ○ ○ ○

   Strongly Disagree **Disagree** **Neutral** **Agree** **Strongly Agree**

3. I thought this system was easy to use.

   ○ ○ ○ ○ ○

   Strongly Disagree **Disagree** **Neutral** **Agree** **Strongly Agree**

4. I think that I would need assistance to be able to use this system.

   ○ ○ ○ ○ ○

   Strongly Disagree **Disagree** **Neutral** **Agree** **Strongly Agree**

5. I found the various functions in this system were well integrated.

   ○ ○ ○ ○ ○

   Strongly Disagree **Disagree** **Neutral** **Agree** **Strongly Agree**

6. I thought there was too much inconsistency in this website.

   ○ ○ ○ ○ ○

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. I would imagine that most people would learn to use this system very quickly.

○	○	○	○	○
Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

8. I found this system very cumbersome/awkward to use.

○	○	○	○	○
Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

9. I felt very confident using this system.

○	○	○	○	○
Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

10. I needed to learn a lot of things before I could get going with this system.

○	○	○	○	○
Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

Appendix N

Informal Interview with therapist

Your answers to these questions are important for understanding your views on the newly designed game for the therapy. Your feedback will help us in developing an improved therapeutic game.

1. What was your experience with the video game? Did it affect how you provided therapy? If yes, how? If no why not?

2. Do you have any concerns regarding the use of the game with strengthening exercises?

3. Did the use of the game contribute to a more positive or negative therapy experience? Please explain.

4. What changes in the system would make the game more effective for increasing engagement, motivation and enjoyment?

5. Was the game easy to use? Why or why not? How can we make the system easier to use?

6. What changes would you like to see in an improved version of this game?

7. Does the game need to be more interesting? If yes, how can we make the game more interesting for therapy?

8. What age of child do you think the game is best suited for?

Appendix O

Informal Interview therapists

Your answers to these questions are important for understanding your views on the newly designed game for the therapy. Your feedback will help us in developing an improved therapeutic game.

1. Which sessions do you think your child preferred (with or without the video game)?
2. Which specific features in the game do you think kept your child engaged (or not) in the activity?
3. What changes would you like to see in an improved version of the game?
4. Do you have any concerns related to the use of this game with therapy?
5. How can we make the game more interesting for your child?