A BIOMECHANICAL ASSESSMENT OF
ACTIVE VIDEO GAMING
IN CHILDREN WITH CEREBRAL PALSY
DETAILING
ENERGY EXPENDITURE, MUSCLE ACTIVATIONS, AND
UPPER LIMB KINEMATICS

By

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A thesis submitted in conformity with the requirements
for the degree of Masters of Health Sciences
Institute of Biomaterials and Biomedical Engineering
University of Toronto

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A biomechanical assessment of active video gaming in children with cerebral palsy detailing energy expenditure, muscle activations, and upper limb kinematics

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Abstract

This thesis evaluated energy levels, muscle activity, and upper limb kinematics during AVG play in children with cerebral palsy (CP). For context, a systematic review was conducted, which found that AVGs elicited light to moderate physical activity in typically developing children. In children with CP, moderate levels of physical activity were achieved for Dance Dance Revolution and Wii Boxing, while light levels of physical activity were achieved for Wii Bowling and Wii Tennis. Muscle activity was highest during Wii Boxing, but remained below the maximum voluntary effort for all games and muscles. Angular velocities and accelerations were significantly larger in the dominant limb compared to the hemiplegic limb. When children played against a real opponent, dominant arm activity increased, while hemiplegic arm activity decreased. The results of this thesis indicate that AVGs may be an enjoyable and relatively safe option for children with CP to attain moderate physical activity.
Dedication

To my supervisor, Dr. Elaine Biddiss, who has been a constant source of guidance, kindness, wisdom, and insights into the many complexities of a successful research project. She has inspired me to strive for excellence throughout this journey and in my future endeavours.

To my fiancé, family, and friends who have provided me with constant support and encouragement throughout my whole life. Their confidence in my ability to persevere and succeed, and their pride in my accomplishments have been a huge motivator throughout this journey.

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List of Abbreviations

AVG: Active video game
BMI: Body mass indices
CI: Confidence interval
CIMT: Constraint-induced movement therapy
CP: Cerebral palsy
DDR: Dance Dance Revolution
EE: Energy expenditure
FCR: Flexor carpi radialis
GMFCS: Gross Motor Function Classification System
GROUP: Group game play scenario (i.e. participant versus member of research team)
HR: Heart rate
IQR: Interquartile range
MACS: Manual Ability Classification System
MET: Metabolic equivalent for task
MVE: Maximum voluntary effort
OMNI: OMNI Scale of Perceived Exertion
PACES: Physical Activity Enjoyment Scale
PAR-Q: Physical Activity Readiness Questionnaire
RSI: Repetitive strain injury
SD: Standard deviation
sEMG: surface Electromyography
SOLO: Solo game play scenario (i.e. participant versus computer)
WEB: Wrist extensor bundle

VCO₂: Carbon dioxide exhalation

VO₂: Oxygen consumption
Chapter One: Introduction

1.1 Motivation

Cerebral palsy (CP) is used to define a group of disorders that affect the development of movement and posture and are attributable to non-progressive disturbances that occurred during fetal development or in the infant brain.\textsuperscript{1} CP occurs in 1.5 to 2.5 per 1000 live births.\textsuperscript{2} The varying levels of impairment affecting children with CP are commonly described using two scales. Firstly, the Gross Motor Classification System (GMFCS) is used to identify children with respect to their gross motor function into 1 of 5 distinct levels and has been found to have high interrater reliability ($\kappa=0.75$, $G=0.93$) and test-retest reliability ($G=0.79$) in children with CP.\textsuperscript{2-3} Secondly, the Manual Ability Classification System (MACS) is used to group children with CP into 1 of 5 levels with regards to their fine motor skills.\textsuperscript{4} It has been found to have high interrater reliability (ICC of 0.97 between therapists and of 0.96 between therapists and parents) and high reliability coefficients (ICC between 0.7 and 0.9) for children with CP.\textsuperscript{4,5} The complete scales for the GMFCS and MACS can be found in the Appendix. The research reported in this thesis will focus on higher functioning children with CP who are categorized as either Level I or II on the GMFCS and the MACS.

Children with CP have a higher incidence of obesity and physical inactivity compared to the general population.\textsuperscript{6-8} Physical inactivity is a risk factor for several chronic conditions including diabetes, cardiovascular disease, and cancer.\textsuperscript{9} It also puts children with CP at a greater risk for developing the following secondary conditions: mobility limitations, deconditioning, fatigue, pain, pressure sores, depression, and social isolation.\textsuperscript{10} Children with CP also tend to have lower endurance, muscular strength, and cardiorespiratory fitness compared to the general population.\textsuperscript{10}
In 2004, the World Health Organization established the “Global Strategy on Diet, Physical Activity, and Health Promotion”, which recognizes the key role that physical activity plays in disease prevention and promotion of lifelong health. Furthermore, due to the additional risks children with CP face, it has been suggested that achieving a high level of fitness and physical activity is more important for these individuals than the general population. Increased physical activity can increase muscular and cardiorespiratory fitness, which can have a positive effect on children with CP. Furthermore, increased activity can reduce the incidence of a variety of negative health outcomes including: Type 2 diabetes, heart disease, stroke, osteoporosis, and depression.

Children, particularly those with CP, face many barriers to physical activity. Some of the mainstream barriers to physical activity for children include: lack of interest, preference for indoor activities, low energy levels, time constraints, unsafe neighbourhoods, self-consciousness, lack of motivation, and insufficient social support from parents and peers. The effect of these barriers on children with CP specifically has not been investigated to date. However, children with CP face additional barriers to physical activity including: weakness, muscle spasticity, imbalance, poor accessibility, lack of transportation, equipment, and resources, parental restrictions, and learned helplessness.

Active video games (AVGs) may offer a different type of physical activity for children with CP that is less affected by environmental barriers, which limit accessibility. AVGs refer to systems such as the Nintendo Wii, which require some degree of physical activity (e.g. swinging arms, stepping, and dancing) beyond that of conventional, hand-controlled games that use inputs such as a keyboard or mouse. AVGs have the potential to provide low-cost (compared to physical therapy and recreational programs), home-based, all-season, self-directed, and
potentially enjoyable physical activity for children with CP. This technology is particularly promising as the typical child between 8 and 10 years of age spends approximately 65 minutes per day in video game play.\textsuperscript{16} In addition, 83\% of American youth have access to at least one video game console in their bedroom.\textsuperscript{17} Screen time activities, such as the television, internet, and video games, are highly valued by children with and without disabilities.\textsuperscript{18} Therefore, a potentially successful strategy to promote physical activity is to replace sedentary screen time with active screen time using AVGs. This approach may promote health by increasing participation in physical activity and reducing time spent in sedentary activities.\textsuperscript{19}

Behavioural theories also support the potential for AVGs to encourage physical activity in children.\textsuperscript{17,20} Self-initiation and choice are important motivating factors for children to engage in physical activity.\textsuperscript{21} Children allowed to freely choose activities experience a greater sense of control that can result in self-reward and motivation to continue to pursue the activity.\textsuperscript{17} Level of enjoyment is also a key factor in activity choice, and the most frequently reported reason for participation in physical activity by children is “fun”.\textsuperscript{17,22-23} AVGs may provide an enjoyable pastime that encourages physical activity, which is well in-line with recommendations of the American Academy of Pediatric’s mandate to provide structured and non-structured opportunities for physical activity and recreational play.\textsuperscript{9} Increases in non-programmed and lifestyle related physical activities appear to be important for sustaining weight loss and fitness levels.\textsuperscript{10,24}

Although the potential for AVGs to increase energy expenditure from sedentary levels in able-bodied children has been demonstrated and will be described in greater detail in Chapter 2, the potential risks of AVG play have not been sufficiently investigated. Five case studies have been published to date reporting on injuries occurring as a direct result of AVG play. The first
reported injury was acute tendonitis to the right infraspinatus in a 29 year old male resulting from Wii Tennis game play. An additional case was reported in which a 22 year old male acquired tendonitis in the shoulder and upper arm as a result of ‘aggressively’ playing “Brunswick Pro Bowling” on the Nintendo Wii system. An incidence of carpal tunnel syndrome in a 19 year old female has also been reported after extensive Wii Bowling game play. These injuries indicate that AVG play may cause repetitive strain injuries (RSIs). AVGs can also cause injuries that normally occurred during traditional athletic activities. A 16 year old boy acquired a transient patella dislocation while playing on the Nintendo Wii system (game not specified), which is an injury that typically occurs during participation in an athletic event. Furthermore, a 42 year old woman developed a partial tear in her left Achilles tendon while playing Wii Fit.

While no studies have been published to date reporting an injury in a disabled person as a result of AVG play, athletes with CP are known to be predisposed to upper and lower limb injuries as a result of spasticity. With increasing interest in and use of AVGs by both typically developing and disabled children, it is important to examine potential risks for injuries associated with this activity in order to gain a better understanding of AVG play and how/if it can be used safely by this population.

1.2 Research Approach

The research presented herein encompasses (1) an overview of the current knowledge base concerning AVG play in able-bodied children, and (2) an evaluation of AVG play in children with CP that focuses on energy expenditure, upper body muscle activation, and movement patterns. The goal of this evaluation was two-fold: to evaluate the potential benefits in terms of levels of physical activity (Chapter 3) and therapeutic potential (Chapter 5 and 6), and to evaluate the potential musculoskeletal risks (Chapter 4) of AVG play in children with CP.
1.3 Primary Research Questions

To date, physical activity levels have primarily been assessed in able-bodied populations with only one study evaluating AVG play in adults with CP.\textsuperscript{31} Furthermore, investigations concerning muscle activation and movement patterns in children are currently limited.\textsuperscript{32-33} Nevertheless, it is important to determine if AVGs are safe for disabled populations, which may be at a higher risk for injury compared to their able-bodied peers.\textsuperscript{30} As such, the goal of this thesis is to investigate all of these factors during AVG play in children with CP. The specific thesis objectives are as follows:

(1) To review the levels of metabolic expenditure and changes in activity patterns associated with AVG play in children and adolescents in the literature.

(2) To quantify energy expenditure associated with a range of AVGs in children with CP using a portable system for exercise testing.

(3) To determine the muscular involvement of the dominant arm and evaluate the potential for musculoskeletal risks (e.g. RSI, over-strain) during AVG play in children with CP through electromyography (EMG).

(4) To describe the upper body movement patterns associated with AVG play in children with CP through motion capture.

(5) To determine if solo play and group play elicit different levels of energy expenditure, muscle activation, and movement patterns in children with CP.

1.4 Layout of Thesis

The thesis is presented as a compilation of papers that taken as a whole provide a detailed assessment of AVG play in children with CP. The research is of interest to game designers,
researchers, and health care professionals involved in employing AVGs to promote physical activity, developing AVGs, and utilizing the therapeutic potential of AVGs. The following presents the layout and content of each chapter subsequent to this introduction:

Chapter 2 presents a systematic review of the literature pertaining to AVG play in children and adolescents with a focus on energy expenditure levels and changes in activity patterns. It provides recommendations for future research areas, AVG development, and implementation of AVG-based activity programs.

Chapter 3 evaluates the levels of energy expenditure elicited during AVG play in children with CP. These findings are presented with regards to accepted thresholds of physical activity. Factors that have the potential to affect energy expenditure during AVG play such as prior experience and gender are also explored.

Chapter 4 determines the level of muscle activation achieved during AVG play in the dominant arm of children with CP. The potential for musculoskeletal injury, specifically over/acute-strain injuries and RSIs, is also assessed.

Chapter 5 provides a description of the typical movements elicited during AVG play. Data pertaining to ranges of motion, angular velocities, and accelerations are provided. Differences in movement patterns between the dominant, non-affected arm and hemiplegic arm are investigated. Factors that had the potential to alter movement patterns were explored such as level of impairment and gender.

Chapter 6 describes the differences between solo and group AVG play in terms of levels of energy expenditure, muscle activation, and movement patterns. Implications of these findings in terms of activity levels and therapeutic benefits are discussed.
Chapter 7 will conclude the thesis with a summary of this research’s key contributions and directions for future work.

Of note, Chapters 2 through 6 have been written in a format suitable for submission as a journal publication. As such, there is some repetition in each of their introductory sections. References associated with each paper are provided at the end of each chapter. References associated with Chapters 1 (Introduction) and 7 (Conclusion) are located at the end of the thesis document.
Chapter Two: Literature Review

Active Video Games to Promote Physical Activity in Children and Youth: A Systematic Review

This chapter provides an overview of active video game (AVG) play in typically developing children and youth (≤21 years) since the introduction of the first AVG Dance Dance Revolution (DDR) in 1998 until 2010. The focus of this review is to: (1) evaluate levels of energy expenditure during AVG play in children and youth, (2) examine patterns of activity associated with AVG play, and (3) provide directions for future research and development of AVGs. This review is meant to present a current synthesis of AVG play in children and youth and provide a basis for comparison for the assessment of AVG play in children with cerebral palsy that will follow in Chapters 3 to 6. It also highlights the current paucity of literature pertaining to AVG play in disability populations.

This review paper has been published by The Archives of Pediatric and Adolescent Medicine. Biddiss E, Irwin J. Active Video Games to Promote Physical Activity in Children and Youth: A Systematic Review. Arch Pediatr Adolesc Med. 2010; 164(7): 664-672. Copyright © 2011 American Medical Association. All rights reserved. The link, presented below, provides access to published paper.

http://archpedi.amapassn.org/cgi/content/full/164/7/664?ijkey=OI94TVyBShafU&keytype=ref&siteid=amajnls
Chapter Three: Energy Expenditure during AVG Play

Energy expenditure of children with cerebral palsy during active video game play

While energy expenditure levels during active video game (AVG) play have been assessed in able-bodied children as presented in Chapter 2, no attempts have been made to date to quantify energy expenditure levels in children with CP. This chapter quantifies levels of energy expenditure elicited during AVG play in children with CP and determines the level of physical activity achieved (i.e. light, moderate, or vigorous). Levels of enjoyment of AVG play are also assessed. Exploratory assessments of factors that may affect energy expenditure levels such as gender and prior AVG experience are presented.
3.1 Abstract

**Aim.** Increased energy levels during active video game (AVG) play have been demonstrated in typically developing children. This study evaluates energy levels during AVG play in children with cerebral palsy. **Methods.** Thirteen children (9.6±1.82 years) with cerebral palsy (Gross Motor Function Classification System [GMFCS] Level I) played four AVGs (Wii Bowling, Wii Tennis, Wii Boxing, and DDR Disney Dance Grooves). Energy expenditure was monitored using the Cosmed K4b² cardio pulmonary testing unit. Qualitative measures of activity levels and activity enjoyment were obtained using the OMNI and PACES. **Results.** Mean Metabolic Equivalent for Task (MET) for DDR (3.20 ± 1.04) and Wii Boxing (3.36 ± 1.50) reached moderate levels of physical activity. MET levels for Wii Bowling (2.14 ± 0.68) and Wii Tennis (2.60 ± 0.78) indicated light levels of physical activity. All energy measures were significantly elevated during AVG play compared to rest (p≤0.002). The average PACES scores for AVG play were 4.5 ± 0.3 out of a maximum score of five, indicating a high level of enjoyment. **Conclusions.** In children with mild cerebral palsy (GMFCS Level I), AVG play may be an enjoyable opportunity for light to moderate physical activity. Future research exploring the use of AVGs in the home environment is needed to understand how AVGs affect the balance of sedentary and non-sedentary daily activities and whether AVG play increases daily levels of physical activity.
3.2 Introduction

Ambulatory children with cerebral palsy (CP) are more likely to be overweight and obese and less physically active than their typically developing peers.\textsuperscript{1-3} Lower activity levels increase the risk of developing chronic conditions including diabetes, cardiovascular disease, and cancer.\textsuperscript{4} Obesity puts children at an increased risk for high blood pressure, Type 2 diabetes, hyperlipidemia, asthma, obstructive sleep apnea, joint disease and musculoskeletal pain, gastrointestinal problems, liver and gallbladder problems, and early maturation.\textsuperscript{5} Obesity can also lead to poorer psychological and emotional health.\textsuperscript{5} Encouraging daily physical activity at an early age is a vital strategy in the battle against obesity, and for the promotion of lifelong health, fitness, and well-being for all children.\textsuperscript{6}

Children encounter many barriers to physical activity including: lack of interest, preference for indoor activities, low energy levels, time constraints, unsafe neighbourhoods, self-consciousness, lack of motivation, and insufficient social support from parents and peers.\textsuperscript{7} Children with CP face a number of additional barriers including: weakness, muscle spasticity, imbalance, poor accessibility, lack of appropriate transportation, equipment, and/or resources, parental restrictions, and learned helplessness.\textsuperscript{8-10} The degree that these barriers limit physical activity is likely dependent on the severity of the disability, particularly a child’s ability to ambulate independently.\textsuperscript{11}

For children with\textsuperscript{12} and without disabilities\textsuperscript{13-14}, excessive screen time has been identified as a causative factor of childhood obesity and physical inactivity. On average, a typical child between 8 and 10 years of age spends approximately 65 minutes per day in video game play.\textsuperscript{15} In addition, 83% of American youth have access to at least one video game console in their bedroom.\textsuperscript{16} Screen time activities, such as the television, internet, and video games, are highly
valued by children with and without disabilities.\textsuperscript{17} Therefore, a potentially successful strategy to promote physical activity is to replace sedentary screen time with active screen time using active video games (AVGs). AVGS or “Exergaming” refer to systems such as the Nintendo Wii, which require some degree of physical activity (e.g. swinging arms, stepping, and dancing) beyond that of conventional, hand-controlled games that use inputs such as a keyboard or mouse. This approach may promote health by increasing participation in physical activity and reducing time spent in sedentary activities.\textsuperscript{18} Furthermore, AVG may offer a different type of physical activity for children with CP that is less affected by motivational or environmental barriers (e.g. weather, transportation). AVGS have the potential to be a low-cost (compared to physical therapy and recreational programs), home-based, all-season, self-directed, and potentially enjoyable physical activity for children with CP.

The potential for AVGS to increase physical activity from sedentary levels in able-bodied children has been demonstrated. In children and adolescents, under 21 years of age, energy expenditure increased by 222\% (±100\%) during AVG play and heart rate increased by 64\% (±20\%) with reported Metabolic Equivalent for Task (MET) levels ranging from 2.0 (for XaviX Bowling) to 5.0 (for XaviX J-Mat and EyeToy Knockout).\textsuperscript{19} Energy expenditure tended to be higher for games that encouraged lower body and full body movements, as opposed to strictly upper body movements.\textsuperscript{19} There have been minimal studies that have explored AVG play in individuals with CP. One study of 8 adults with bilateral CP found that energy levels for Wii Boxing and Wii Tennis were both in the moderate range at 5.0±1.1 METs and 4.5±1.1 METs, respectively.\textsuperscript{20} No studies have evaluated energy expenditure levels in a child disability population, to the best of our knowledge. The objectives of this study are to (1) investigate the levels of energy expenditure elicited in children with CP during AVG play, (2) perform an
exploratory assessment of the effect of characteristics of children with CP (i.e. gender, experience with AVG, play style) on the level of physical activity they achieve during AVG play, and (3) determine whether children with CP enjoy playing AVGs.

3.3 Methods

3.3.1 Participants

Children between the ages of 7 and 13 years with CP and Gross Motor Function Classification System (GMFCS) Level I or II were recruited to participate in this study. The GMFCS classifies children with CP according to their ability to ambulate and ranges from Level I (able to perform gross motor skills with some limitation in balance, speed, and coordination) to Level V (all areas of motor function are affected and a wheelchair is required to ambulate). The interested reader is directed to Palisano et al. 1997 for information on the GMFCS and Wood et al. 2000 for additional information on validity and reliability. GMFCS Level I and II children were recruited for this study to provide an initial evaluation of AVG play before moving onto to children with more severe motor disabilities where risks for injury may be increased. Furthermore, limiting the study to Level I/II children eliminated the possibility of disparities in energy expenditure levels due to overall body position during AVG play (i.e. standing versus sitting). The level of fine motor function in the children, measured using the Manual Ability Classification System (MACS), was not restricted but was obtained when available. The interested reader is directed to Eliasson et al. 2006 and Morisson et al. 2006 for information on the MACS and its reliability. All children were recruited from Holland Bloorview Kids Rehabilitation Hospital and ErinoakKids Centre for Treatment and Development.
Children were screened using a modified Physical Activity Readiness Questionnaire (PAR-Q) to ensure that they were able to engage in physical activity.\textsuperscript{25-26} Children were screened for the following exclusion criteria:

- A heart condition or chest pains during exercise,
- Feeling faint or having spells of severe dizziness,
- High blood pressure,
- Broken bones in the last six months,
- Epilepsy,
- Chronic asthma,
- An injury or disability that would make moderate exercise unsafe,
- A visual, cognitive, or auditory disability that would interfere with game play,
- Receiving a botulinum toxin treatment in the last three months,
- Or receiving orthopaedic surgery in the last six months.

Approval for this study was granted by the local ethics committees. Informed assent and consent was obtained from the child and guardian, respectively.

3.3.2 Anthropometric Measurements

Body mass, in kilograms, and body height, in centimeters, were measured using an upright scale (Health o Meter Inc., Bedford Heights, OH). The children were measured with their shoes removed. Mass to the nearest 0.5 kg and body height to the nearest 0.5 cm were recorded.

3.3.3 Energy Measurements

The Cosmed K4b\textsuperscript{2} cardio pulmonary testing unit (Cosmed Inc., Chicago, IL) was used to obtain physiological measures of oxygen consumption (VO\textsubscript{2}), energy expenditure (EE), and
heart rate (HR). EE was determined based on measures of VO$_2$ and carbon dioxide exhalation (VCO$_2$) using the following equation: \[ EE = 3.781 \times VO_2 + 1.237 \times VCO_2. \] The heart rate monitor was a Polar heart rate monitor (Lake Success, NY). The Cosmed K4b$^2$ was calibrated prior to each session using manufacturer protocols. Specifically, calibration of the O$_2$ and CO$_2$ sensors was completed using a sample gas of known concentrations. Respiratory volume was calibrated using a 3-liter volume calibration syringe. A delay calibration was also performed to ensure adequate response time to a breathing cycle.

### 3.3.4 Active Video Games

Four active video games were investigated in this study. All were played on the Wii gaming platform with a Wii Remote and Nunchuck (Nintendo, Inc., Redmond, WA). Three of the games are part of the Wii Sports package: Wii Bowling, Wii Tennis, and Wii Boxing (Nintendo, Inc., Redmond, WA). The fourth game is Dance Dance Revolution (DDR) Disney Dance Grooves (Konami Digital Entertainment, Inc., El Segundo, CA). Wii Bowling and Wii Tennis require the use of the Wii Remote. Wii Boxing requires the use of the Wii Remote and Nunchuck. DDR Disney Dance Grooves requires the use of the Wii Remote, Nunchuck, and Dance Mat (Intec, Inc., Miami, FL).

### 3.3.5 Study Protocol

The study consisted of a single visit by each child to Holland Bloorview’s Gait Laboratory. Anthropometric measures were taken, and the child was familiarized with the equipment and test procedures before testing began. The child was fitted with the Cosmed K4b$^2$ cardio pulmonary testing unit. Of note, children were also wearing surface electromyography sensors and motion capture reflective markers. These are described in greater detail in Chapter 4.
and 5. A DVD was played for the child, who sat quietly for 20 minutes to achieve a baseline state that provided a close approximation of resting energy levels, as recommended in previous studies measuring resting energy expenditure in children.\textsuperscript{27-28} The first 10 minutes were used to establish a resting steady state with VO\textsubscript{2} data collected for the following 10 minutes to obtain the baseline level of energy expenditure. The child then played the four active video games in a randomized order. Randomization was achieved by having the child select their order of game play from an envelope containing all of the possible orders. Selections were made without replacement. The entire game play session was video recorded. The child was allowed to familiarize themselves with the games before playing for a maximum of five minutes. The child played each game for eight minutes with a rest period of five minutes between each game. Energy expenditure data were collected for the entire eight minutes of game play. The child ranked their level of perceived exertion, using the OMNI Scale of Perceived Exertion (OMNI) after playing each game.\textsuperscript{29} The OMNI has been found to have good validity in children irrespective of gender and race.\textsuperscript{29} Following game play, the child completed the Physical Activity Enjoyment Scale (PACES).\textsuperscript{30} The PACES consists of 18 statements (11 positive and 7 negative), and each statement was scored between 1 and 5. The score numbers equate to the following phrases: ‘1’=‘Disagree a lot’, ‘2’=‘Disagree’, ‘3’=‘Neither agree nor disagree’, ‘4’=‘Agree’, and ‘5’=‘Agree a lot’. The PACES scale has been found to have good internal consistency, item-total correlation, and validity for use with children.\textsuperscript{30}

3.3.6 Data Analysis

All data (except OMNI scores) are expressed as mean plus or minus the standard deviation (SD). The ordinal OMNI scores are expressed as median (interquartile range [IQR])). Standard error bars are displayed on all graphs. For energy measures, the first thirty seconds of
data associated with each new game was eliminated to allow the subject to acclimatize. The mean and standard deviation were then calculated for the remaining data. The Metabolic Equivalent for Task (MET) is calculated by normalizing the average rate of oxygen consumption during AVG play to the baseline oxygen consumption rate. The overall PACES score was determined by averaging the score for each individual item.\textsuperscript{30} Participants were divided into various subgroups to allow for exploratory determinations of differences in energy levels between: gender, MACS level, experience with the AVGs, and movement style (i.e. realistic or adapted movements). Realistic movements (i.e. movements similar to those that would be used during ‘real world’ boxing or tennis that involve more emphasis on proximal upper limb movements) and adapted movements (i.e. changes in movement patterns from those that would be used during ‘real world’ boxing or tennis that involve more emphasis on distal upper limb movements) were identified from the video recordings by two independent reviewers.

All statistical analyses were performed using SPSS v.17 with a significance level of \( p<0.05 \). A repeated ANOVA with a Bonferroni correction was utilized to determine if significant differences existed in the quantitative measures of energy expenditure between the four AVGs. A Friedman test was used to determine if significant difference existed between any of the OMNI scores. If significant, a Wilcoxon signed-rank test was performed. Inter-rater reliability of observations distinguishing between realistic and adapted movements was assessed with Cohen’s Kappa (\( \kappa \)). Independent t-tests were used to determine if significant differences existed between participant subgroups (i.e. gender and experience level) for specific games. Equality of variance was assessed with Levene’s Test for Equality of Variances for all independent t-tests. Pearson correlation coefficients were calculated to assess bivariate correlations between participant characteristics (i.e. BMI and age) and energy measures.
3.4 Results

3.4.1 Participants

Thirteen children (8 boys and 5 girls) with cerebral palsy, GMFCS Level I, participated in the study. Demographic and anthropometric information is presented in Table 1. Twelve of the 13 participants had hemiplegic CP and one had diplegic CP. MACS levels were known for 9 of the 13 participants. Of these 9, 5 were MACS Level 1 and 4 were MACS Level 2. The sample included a representative range of body mass indices (BMI) with an average percentile of 58.54±31.96% and a range of 10th percentile to the 95th percentile.

Table 1: Participant Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Females (n=5)</th>
<th>Males (n=8)</th>
<th>All Participants (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>9.60 ± 1.82</td>
<td>9.94 ± 2.08</td>
<td>9.81 ± 1.91</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>138.00 ± 10.25</td>
<td>143.75 ± 11.54</td>
<td>141.54 ± 11.00</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>35.66 ± 10.74</td>
<td>38.38 ± 11.29</td>
<td>37.33 ± 10.71</td>
</tr>
<tr>
<td><strong>BMI (kg/m²)</strong></td>
<td>18.46 ± 3.71</td>
<td>18.34 ± 3.21</td>
<td>18.38 ± 3.26</td>
</tr>
</tbody>
</table>

3.4.2 Energy Measures

Mean levels for the energy expenditure measures (e.g. VO₂, MET, EE, and HR) and the median scores for the OMNI are presented in Table 2. For all of the energy measures, levels during the baseline state were significantly lower than during AVG play (p ≤ 0.002). Furthermore, for all energy measures, levels were significantly higher for DDR (p ≤ 0.001) and Wii Boxing (p ≤ 0.039) compared to Wii Bowling. MET levels during Wii Tennis were also significantly higher than those during Wii Bowling (p = 0.041). MET levels are presented in Figure 1.

For Wii Boxing, six participants achieved moderate levels of physical activity and one participant achieved vigorous levels of activity (MET=6.69), representing 54% of all participants. For DDR, 62% of the participants (n=8) achieved moderate levels of physical...
activity. For Wii Tennis, only 23% of the participants (n=3) achieved moderate levels of physical activity. For Wii Bowling, only two participants (15%) achieved moderate levels of physical activity.

The median OMNI scored during AVG play ranged from 2 (‘Very easy’) for Wii Bowling to 4 (‘Just feeling a strain’) for DDR and Wii Boxing. The Friedman test indicated that significant differences did exist between the AVG play scenarios and rest (p<0.001) and between the AVGS themselves (p<0.023). The individual, Wilcoxon comparisons found perceived exertion during rest was significantly lower than during AVG play (p≤0.004). Perceived exertion for Wii Bowling was significantly lower when compared to Wii Tennis (p=0.031) and Wii Boxing (p=0.022). No significant differences were found between Wii Boxing, Tennis or DDR with regards to perceived exertion (p≥0.13).

Table 2: Energy measures at rest and during AVG play

<table>
<thead>
<tr>
<th></th>
<th>Baseline State</th>
<th>Wii Bowling</th>
<th>Wii Tennis</th>
<th>DDR Disney Dance Grooves</th>
<th>Wii Boxing</th>
</tr>
</thead>
<tbody>
<tr>
<td>( VO_2 ) (mL/min)</td>
<td>170.91 ± 36.13</td>
<td>351.88 ± 131.50</td>
<td>405.23 ± 144.15</td>
<td>535.88 ± 212.30</td>
<td>542.66 ± 193.10</td>
</tr>
<tr>
<td>( MET )</td>
<td>1.00 ± 0.00</td>
<td>2.14 ± 0.68</td>
<td>2.60 ± 0.78</td>
<td>3.20 ± 1.04</td>
<td>3.36 ± 1.50</td>
</tr>
<tr>
<td>Energy Expenditure (EE, kJ/min)</td>
<td>3.01 ± 0.62</td>
<td>6.40 ± 2.21</td>
<td>7.82 ± 2.25</td>
<td>9.71 ± 3.64</td>
<td>10.08 ± 3.74</td>
</tr>
<tr>
<td>% Increase in EE from rest</td>
<td>-</td>
<td>114 ± 69</td>
<td>163 ± 79</td>
<td>222 ± 107</td>
<td>243 ± 155</td>
</tr>
<tr>
<td>( Heart Rate ) (HR, bpm)</td>
<td>88.35 ± 10.37</td>
<td>112.54 ± 17.61</td>
<td>120.05 ± 17.75</td>
<td>127.47 ± 16.71</td>
<td>137.12 ± 19.11</td>
</tr>
<tr>
<td>% Increase in HR from rest</td>
<td>-</td>
<td>28 ± 16</td>
<td>24 ± 42</td>
<td>45 ± 20</td>
<td>57 ± 31</td>
</tr>
<tr>
<td>OMNI</td>
<td>1 (0)</td>
<td>2 (1)</td>
<td>3 (2.5)</td>
<td>4 (1.5)</td>
<td>4 (5)</td>
</tr>
</tbody>
</table>
3.4.3 Individual Factors Effecting Energy Levels

The $\kappa$ coefficient for inter-rater reliability of distinguishing between realistic and adapted movements was $0.731\pm0.103$ indicating good agreement. Of note, adapted movements were only identified for Wii Tennis and Wii Boxing.

The following describes exploratory assessments of differences in energy expenditure between various subgroups. While energy expenditure was consistently lower for experienced players (i.e. those who had played these AVGs prior to the study) compared to inexperienced players, no statistically significant differences were found between the subgroup of participants with Wii Sports (Bowling, Tennis, and Boxing) experience ($n=10$) and those without ($n=3$) and between participants with DDR experience ($n=2$) and those without ($n=11$) for any of the energy measures (Wii Sports: $p\geq0.31$, DDR: $p\geq0.50$). While increased energy expenditure was observed...
when Wii Tennis and Wii Boxing were played with realistic movements (n=7) compared to adapted movements (n=6), this tendency was not statistically significant (p≥0.42). A significant difference in energy expenditure was found between males (n=8) and females (n=5). Males had significantly higher METs (p = 0.025), VO$_2$ level (p = 0.015), and EE (p = 0.018) at 2.45±0.63, 417.53±101.72 mL/min, and 7.39±1.89 kJ/min, respectively, compared to females at 1.63±0.40, 246.83±106.66 mL/min, and 4.70±1.28 kJ/min, respectively, during Wii Bowling play. This pattern was also found for the other AVGs; however it did not reach the level of statistical significance (p ≥ 0.06).

Age and BMI were also examined to determine if a correlation existed between these characteristics and energy levels. A significant positive correlation was found between age and MET levels (r = 0.58, p = 0.039) and EE levels (r = 0.58, p = 0.037) during DDR play. A correlation was not found between age and the other tested AVGs (p≥0.17). A significant trend was not found between BMI and any of the energy measures for all tested AVGs (p≥0.18).

### 3.4.4 Enjoyment of AVG Play

The average PACES score for all the AVGs was 4.5±0.3 out of five, indicating a high level of enjoyment. The average scores for each item on the PACES are shown in Figure 2. The highest scoring (i.e. most positive) statement was ‘I enjoy it’ with an overall score of 4.8±0.4. The lowest scoring (i.e. most negative) statement, with reverse scoring taken into account, was ‘I feel as though I’d rather be doing something else’ with an overall score of 1.9±1.2 (equivalent to 3.1±1.2 when reversed).
Figure 2: Average scores for each item on the PACES. Error bars depict standard errors. Note: Scoring word anchors for the PACES are as follows: ‘1’: ‘Disagree a lot’; ‘2’: ‘Disagree’; ‘3’: ‘Neither Agree nor Disagree’; ‘4’: ‘Agree’; ‘5’: ‘Agree a lot’

3.5 Discussion

3.5.1 Key Findings

This study examined the energy levels of children with cerebral palsy while playing four different AVGs: Wii Bowling, Wii Tennis, Wii Boxing, and DDR Disney Dance Grooves. This study established that children with cerebral palsy (GMFCS Level I) significantly elevate their energy expenditure levels during AVG play compared to baseline. During games that require full body movements (i.e. Wii Boxing and DDR), moderate levels of physical activity were often achieved, although not by all participants. This is in-line with the levels of physical
activity achieved in able-bodied children as presented in Biddiss et al. 2010, which found that Boxing and DDR AVGs could elicit moderate levels of activity but that Bowling and Tennis AVGs consistently elicit light levels of physical activity. It is recommended that children achieve 60 minutes of moderate to vigorous activity on a daily basis with moderate physical activity defined as an activity with MET levels between 3.0 and 6.0 and vigorous physical activity defined as an activity with MET levels greater than 6.0. This suggests that AVGs could be used in this population to increase daily activity levels in children who spend considerable time in sedentary screen activities (comparable to our rest condition of quietly watching a DVD).

While the sample size was small, this study did perform an exploratory assessment of differences in energy expenditure between subgroups in order to guide future research directions. This assessment found that males used significantly more energy than females while playing Wii Bowling. This tendency was also found in the other AVGs, although it did not reach the level of statistical significance. It was also determined that energy expended during DDR play increased with age. A correlation between age and energy expenditure was not found for the other AVGs. DDR is the most demanding game tested in terms of hand-eye and foot-eye coordination. Therefore, the differences between the younger and older children may be due to the delayed development of hand-eye coordination in children with cerebral palsy. This reduced coordination may mean that the younger children were attempting fewer of the game prompts (i.e. to step or shake the remote) compared to the older children resulting in a difference in MET levels.

The PACES scores indicated that the tested AVGs are an enjoyable activity for children with CP. This is an encouraging result, in terms of successfully incorporating AVG play into the
home environment, as ‘fun’ is a major motivator for children’s choice of and participation in an activity. While use of the standardized PACES measure is a step forward in describing children’s enjoyment levels of AVG play, some aspects of the measurement session (e.g. measurement equipment, no choice in games) may have affected the results. While we expect that player enjoyment would likely increase in the absence of these constraints, future studies are needed to track player enjoyment in the home and over extended periods of time.

3.5.2 Limitations

Our results pertaining to subgroup comparisons are exploratory and require validation in studies with larger samples. In particular, the need for a larger study investigating the differences between realistic and adapted movements is strongly indicated. A trend of decreased energy expenditure was seen with adapted movements, but it did not reach statistical significance with the limited sample size. Furthermore, the results of this study are only applicable to children with CP GMFCS Level I. The majority of subjects were also hemiplegic, with only one diplegic participant, limiting the generalizability of the results.

All subjects started the AVGs at a beginner level. This was done in an attempt to ensure consistency amongst the subjects. However, the beginner level may have been too easy for some of the experienced players and may have reduced their energy levels from those they would achieve when playing at home (i.e. at their actual skill level). This is in-line with the study performed by Sell et al. 2008, which concluded that, for DDR, energy expenditure increased with increasing game difficulty. Finally, the equation used to calculate EE were based on data from adults. Inaccuracies are likely present in these calculations when applied to children with CP. However, this equation is currently used to determine EE in children during AVG play and...
was therefore included to allow for comparisons between studies. VO₂ and MET levels provide a more accurate representation of energy levels in a CP population.⁴⁰

3.5.3 Future Work

Given that Wii Boxing and DDR elicited moderate levels of physical activity in the majority of children in this study, it may be of value to further investigate the use of AVGs in the home environment. For AVGs to be integrated as part of a physical activity regime for children with CP, the best practice strategies to incorporate AVG play into the home environment (i.e. structured regime or non-structured) must be determined. Additionally, the use of these games over time must be evaluated in order to assess their long-term efficacy with respect to increasing activity levels. At this time, it is not clear if factors such as boredom or frustration would prevent prolonged and continued home use of AVGs. This is a real risk for AVGs that has been observed in typically developing children. Three long term studies (10-24 weeks) reported decreased AVG play over time when AVGs were integrated into the home environment for the purpose of increasing physical activity.¹⁸,⁴¹-⁴²

Additionally, it is unclear how AVGs affect current activity patterns. For example, if AVGs supplant sedentary screen time, then they may positively contribute to a child’s health and activity levels. If, however, they displace participation in more active pastimes, then they may be regarded as a negative and competing influence in the promotion of physical activity. This is an extremely important area of future study. Given that children with CP generally participate less in physical activity then their typically developing peers⁴³ and peers with other chronic conditions (i.e. asthma)⁴⁴, we hypothesize that AVGs offer a relatively low cost, low pressure, and accessible opportunity for physical activity in the home environment. Future work is needed to further explore this hypothesis.
3.6 Conclusion

AVG play significantly elevates energy levels in children with CP compared to rest. Moderate levels of physical activity can be achieved during Wii Boxing and DDR game play, while games that rely more solely on upper body movements (i.e. Wii Bowling and Wii Tennis) elicit light levels of physical activity. AVGs also appear to be an enjoyable form of physical activity for children with CP. Future research exploring the use of AVGs in the home environment is needed to better understand how/if this growing leisure activity effects the balance of sedentary versus non-sedentary behaviours, and if it could be used to effectively increase daily physical activity.

3.7 Acknowledgements

We would like to thank Elizabeth Han, Delbert Hung, Ajmal Khan, and Jomy Varghese for aiding with data collections throughout this study. We would also like to thank all of the study participants, Holland Bloorview Kids Rehabilitation Hospital, and ErinkoakKids Centre for Treatment and Development. We would like to acknowledge our funding sources: Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, Ontario Ministry of Training, Colleges and Universities, and the Holland Bloorview Kids Rehabilitation Hospital Foundation for their generous support of this study.

3.8 References


Chapter Four: Muscular Involvement during AVG Play

**Dominant arm muscle activation profile during active video game play for children with cerebral palsy**

The results of Chapter 3 indicate the potential of AVGs for achieving moderate physical activity that can count towards the recommended 60 minutes of moderate to vigorous activity per day. In addition to this knowledge, it is also important to better understand the muscles involved and the levels of muscular recruitment during active video game (AVG) play. A complete and thorough understanding of the muscular involvement will allow for an assessment of the potential muscular benefits of AVGs and of the potential musculoskeletal risks (i.e. over-strain and repetitive strain). This chapter provides a profile of dominant arm muscle activation during AVG play in children with cerebral palsy. These findings are then used to provide a preliminary assessment of the potential of the tested games to result in musculoskeletal injuries.
4.1 Abstract

Aim. While a number of studies have looked at the cardiorespiratory benefits of active video game (AVG) play, very little research has explored muscle activity during these activities. This study evaluates levels of muscle activation that occur in the dominant arm of children with cerebral palsy. Methods. Seventeen children (9.43 ± 1.51 years) with cerebral palsy (16 GMFCS Level I and 1 GMFCS Level II) played four AVGs (Wii Bowling, Wii Tennis, Wii Boxing, and DDR Disney Dance Grooves). Muscle activation levels were monitored for the upper trapezius, tricep, bicep, flexor carpi radialis, and wrist extensor bundle using Delsys single differential surface electrodes. Self-reports of muscle soreness were obtained immediately and 24 hours after game play. Results. The highest mean levels of muscle activation were achieved during Wii Boxing for all muscles of interest. The lowest levels of activation were found for the upper trapezius and ranged from 7.92% of the maximum voluntary exertion (MVE) (Wii Bowling) to 11.37% (Wii Boxing). The highest levels of activation were found for the wrist extensor bundle and ranged from 12.73% of the MVE (Wii Bowling) to 18.49% (Wii Boxing). Maximum activation levels did not exceed the MVE for any of the games or muscles. Conclusion. AVG play elicits low levels of muscle activation in the dominant arm of children with cerebral palsy. While overstrain injuries are probably unlikely to occur during typical play, repetitive strain injuries may be a concern when games are played excessively. Future studies should assess muscle activation levels in the non-dominant limbs of children with cerebral palsy, and in different disability subgroups (e.g. stroke patients).
4.2 Introduction

Children with cerebral palsy (CP) tend to have lower endurance, muscle strength, and cardiorespiratory fitness compared to their able-bodied peers.\textsuperscript{1} This can lead to reduced participation in physical activity and sports, which further decreases muscular and cardiorespiratory fitness.\textsuperscript{2} Physical inactivity in children with CP may be associated with a number of negative consequences including: mobility and functional limitations, fatigue, chronic pain, osteoporosis, pressure sores, depression, and social isolation.\textsuperscript{1} These factors can negatively affect health and quality of life by limiting independence, social inclusion, and opportunities for work, leisure, and physical activity.\textsuperscript{2}

Given these risks, it has been suggested that achieving a high level of fitness and physical activity is even more important for individuals with CP than the general population.\textsuperscript{3} It has also been suggested that physical activity may also be important in individuals with CP for improving and maintaining cognitive health.\textsuperscript{4} Motor activity can establish and reinforce neural pathways and improve the functional abilities of these children, making practice of skilled and discrete fine motor tasks arguably more important than muscle strengthening for upper-extremity rehabilitation.\textsuperscript{5-6} In fact, higher levels of corticospinal excitability are associated with complex and challenging motor tasks compared to traditional muscle strengthening activities (i.e. repetitive concentric and eccentric muscle actions intended to achieve muscular hypertrophy).\textsuperscript{7}

While not a replacement to structured physical therapies and recreational programs, active video games (AVGs) may offer additional opportunities as a low-cost, home-based, self-directed alternative for children with CP that might increase cardiorespiratory fitness and provide new and challenging motor activities. AVGs refer to systems such as the Nintendo Wii, which require some degree of physical activity (e.g. swinging arms, stepping, and dancing) beyond that
of conventional, hand-controlled games that use inputs such as a keyboard or mouse. On average, a typical child between 8 and 10 years of age spends approximately 65 minutes per day in video game play. In addition, 83% of American youth have access to at least one video game console in their bedroom. Screen time activities, such as the television, internet, and video games, are highly valued by children with and without disabilities. Therefore, a potentially successful strategy to promote self-directed exercise in this population is to replace sedentary screen time with active screen time via AVGs. This approach may promote health by increasing participation in physical activity and reducing time spent in sedentary activities.

While a number of studies have looked at the cardiorespiratory benefits of AVG play in children and adolescents (≤22 years old), as reviewed previously, only one study has explored muscle activity in healthy children engaged in AVGs. This study established that levels of muscle activity (not normalized to maximum voluntary contractions/exertions) during AVGs were higher than those elicited during sedentary activities (i.e. watching a DVD and playing a computer game). To build upon this line of research, the first objective of this study was to assess in a group of children with CP, the levels of muscle activation elicited during AVG play relative to maximum voluntary exertions (MVEs).

It is also important to ensure that AVG play does not put children with CP at a risk for injury. Five case studies have reported on injuries occurring in the able-bodied population during AVG play that were typically associated with excessive game play. To date, no studies have reported on injuries occurring in a disability population during AVG play. The second objective of this study was therefore to explore the potential for over- and/or repetitive strain injuries (RSI) during AVG play in the CP population based on measured EMG activity and self-reported pain.
4.3 Methods

4.3.1 Participants

Children between the ages of 7 and 13 years with CP and Gross Motor Function Classification System (GMFCS) Level I or II were recruited to participate in this study. The interested reader is directed to Palisano et al. 1997 for information on the GMFCS and Wood et al. 2000 for additional information on validity and reliability. The level of fine motor function in children, measured using the Manual Ability Classification System (MACS), was not restricted but was obtained when available. The interested reader is directed to Eliasson et al. 2006 and Morisson et al. 2006 for information on the MACS and its reliability. All children were recruited from Holland Bloorview Kids Rehabilitation Hospital and ErinoakKids Centre for Treatment and Development.

Children were screened using a modified Physical Activity Readiness Questionnaire (PAR-Q) to ensure that they were able to engage in physical activity. Children were screened for the following exclusion criteria:

- A heart condition or chest pains during exercise,
- Feeling faint or having spells of severe dizziness,
- High blood pressure,
- Broken bones in the last six months,
- Epilepsy,
- Chronic asthma,
- An injury or disability that would make moderate exercise unsafe,
- A visual, cognitive, or auditory disability that would interfere with game play,
• Receiving a botulinum toxin treatment in the last three months,

• Or receiving orthopaedic surgery in the last six months.

Approval for this study was granted by the local ethics committees. Informed assent and consent was obtained from the child and guardian, respectively.

4.3.2 Muscle Activity

The muscles of interest for this study were the upper trapezius, triceps, biceps, flexor carpi radialis (FCR), and wrist extensor bundle (WEB) of the dominant arm, as this would be the arm primarily used during typical AVG play in an unstructured environment (i.e. at home). For all subjects, the dominant arm was the one used for writing (i.e. the non-hemiplegic arm for the children with hemiplegic CP). The electrode sites were prepared by light abrading and cleaning with alcohol. Reusable single differential surface electrodes (Delsys Inc., Boston, MA) with a one centimeter inter-electrode distance were placed centrally over the muscle belly, located via anthropometrics and palpation. Raw surface electromyography (sEMG) signals were sampled at 1250 Hz via the Bagnolia Desktop EMG System (Delsys Inc., Boston, MA) with 1k gain. MVEs were obtained using Biodex System 2 (Biodex Medical Systems, Shirley, NY). The Biodex System 2 was calibrated before each use and positioned for each MVE according to manufacturer instructions. Three isometric MVEs for each of the five muscle groups were obtained. Each contraction lasted for five seconds with a forty five second rest between contractions. The largest contraction was used as the MVE. Verbal encouragement was provided throughout the contractions.
4.3.3 Active Video Games

Four AVGs were investigated in this study. These games were selected in an attempt to assess a wide range of game play styles (i.e. unimanual, bimanual, and lower body involvement). All were played on the Wii gaming platform with Wii Remote and Nunchuck (Nintendo, Inc., Redmond, WA). Three of the games are part of the Wii Sports game: Wii Bowling, Wii Tennis, and Wii Boxing (Nintendo, Inc., Redmond, WA). The fourth game is Dance Dance Revolution (DDR) Disney Dance Grooves (Konami Digital Entertainment, Inc., El Segundo, CA). The Wii Bowling and Wii Tennis games require the use of the Wii Remote. The Wii Boxing game requires the use of the Wii Remote and Nunchuck. The DDR Disney Dance Grooves requires the use of the Wii Remote, Nunchuck, and Dance Mat (Intec, Inc., Miami, FL).

4.3.4 Study Procedure

The experiment consisted of one visit by each child to Holland Bloorview’s Gait Laboratory. Anthropometric measures were taken, and the children were familiarized with the equipment and test procedures. Children were then fitted with sEMG electrodes. MVEs of the five muscles of interest were obtained using the Biodex System 2. Of note, children were also wearing a cardio pulmonary testing unit and motion capture reflective markers. These are described in greater detail in Chapter 3 and 5. Children then played the four AVGs in a randomized order. Randomization was achieved by having the child select their order of game play from an envelope containing all of the possible orders. Selections were made without replacement. The entire game play session was video recorded. Children were allowed to familiarize themselves with the games before playing for a maximum of five minutes. Instructions were kept as simple as possible (i.e. ‘When you move the remote, the arm/tennis racket in the game will copy that movement’) to allow for typical game play. The children then
played each game for eight minutes with a rest period of five minutes between each game. EMG data were collected for the entire eight minutes of game play.

At the completion of the study session, children were asked if they were experiencing any muscle soreness, which was then identified by location and ranked using a FACES scale. The FACES scale present 6 different faces, which offer a cartoon-like representation of differing levels of pain that vary from ‘No hurt’ (score of 0) to ‘Hurts Worst’ (score of 5) and was designed for use in 3 to 18 year olds. FACES scales have demonstrated good to excellent validity and test-retest scores. The children were also contacted 24 hours later and asked to report any muscle soreness using the same method.

4.3.5 Data Analysis

The root mean square (with a moving average window of 75 ms and a 50% overlap) of all raw EMG signals were taken and normalized to MVEs. All values are expressed as mean plus or minus the standard deviation (SD). Standard error bars are displayed on all graphs. Outliers that exceeded 2 standard deviations from the mean were removed. Maximums and minimums in the whisker plots were averaged across subjects. Participants were divided according to whether they used realistic movements or adapted movements to allow for an exploratory assessment of the effect of movement style on muscle activity. Realistic movements (i.e. movements similar to those that would be used during ‘real world’ boxing or tennis that involve more emphasis on proximal upper limb movements) and adapted movements (i.e. changes in movement patterns from those that would be used during ‘real world’ boxing or tennis that involve more emphasis on distal upper limb movements) were identified from the video recordings by two independent reviewers.
All statistical analyses were performed using SPSS v.17.0 with a significance level of p=0.05. A repeated measures ANOVA with a Bonferroni correction was utilized to determine if a significant difference existed in muscle activity measures between the AVGs. Inter-rater reliability of observations distinguishing between realistic and adapted movements was assessed with Cohen’s Kappa (κ). Independent t-tests were used to determine if significant differences existed between participants who used realistic movements and those who used adapted movements. Equality of variance was assessed with Levene’s Test for Equality of Variances for all independent t-tests.

4.4 Results

4.4.1 Participants

Seventeen children (10 boys and 7 girls) participated in the study. Demographic and anthropometric information is presented in Table 3. Fifteen of the 17 participants had hemiplegic CP and two had diplegic CP. Sixteen were GMFCS Level I and one participant was GMFCS Level II. MACS levels were known for 13 of the 17 subjects. Of these 13, 6 were MACS Level 1 and 7 were MACS Level 2. The sample included a representative range of body mass indices (BMI) with an average percentile of 58.53±30.73% and a range of 10th percentile to the 95th percentile.

Table 3: Participant Characteristics

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<td><strong>Age (years)</strong></td>
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<td><strong>Height (cm)</strong></td>
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<td><strong>Weight (kg)</strong></td>
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<td><strong>BMI (kg/m²)</strong></td>
<td>18.60 ± 3.54</td>
<td>18.00 ± 3.00</td>
<td>18.27 ± 3.14</td>
</tr>
</tbody>
</table>
4.4.2 Muscle Activity

Figure 3 depicts mean muscle activation levels (normalized to the MVE) during AVG play for each of the 5 muscle groups of interest. Figure 4 presents a whisker plot to further detail EMG patterns, specifically the frequency and extreme levels of muscle activations observed, associated with each muscle group and game type. The κ coefficient for inter-rater reliability of distinguishing between realistic and adapted movements was 0.731±0.103 indicating good agreement. Of note, adapted movements were only identified for Wii Tennis and Wii Boxing.

![Muscle Activation Levels during AVG Play](image)

Figure 3: Muscle activation levels during AVG play. Error bars depict standard errors. *Wii Boxing is significantly greater than Wii Bowling, Wii Tennis, and DDR (p<0.01). †Wii Boxing is significantly greater than Wii Bowling and DDR (p<0.05). ‡Wii Boxing is significantly greater than Wii Bowling and Wii Tennis (p<0.01). §Wii Tennis is significantly greater than Wii Bowling (p<0.05)
**Upper Trapezius**

Upper trapezius activation levels during Wii Boxing were significantly greater than those during Wii Bowling (p=0.016) and DDR (p=0.016). Although upper trapezius activation levels during Wii Boxing were also higher than those during Wii Tennis, this difference did not reach significance (p=0.24). An increase in upper trapezius activation (p=0.004) was observed in children who used realistic movements (n=9, 14.01±2.59%) to play Wii Boxing (i.e. a large punching movement involving the shoulder and elbow) compared to those who adopted adaptive techniques (n=8, 9.02±3.44%) (i.e. a small punching movement primarily involving the wrist). An increase was also observed for Wii Tennis (realistic: 10.60±3.90%, adapted: 8.45±4.26%), but it did not reach the level of statistical significance (p=0.295).

**Tricep**

Wii Boxing elicited significantly higher tricep activation levels than Wii Bowling (p<0.001) and Wii Tennis (p=0.005). Wii Boxing tricep activation levels were higher than those elicited during DDR, but this difference was not significant (p=0.097). No differences were found between realistic and adapted movements (p≥0.297).

**Bicep**

Bicep activation levels during Wii Boxing were significantly higher than Wii Bowling (p=0.001), Wii Tennis (p=0.003), and DDR (p<0.001). No differences were found between realistic and adapted movements (p≥0.771).

**FCR**

FCR activation levels were significantly higher during Wii Boxing than Wii Bowling (p<0.001), Wii Tennis (p=0.001), and DDR (p=0.001). FCR activation levels were significantly higher during Wii Tennis than Wii Bowling (p=0.023). When comparing children who used
realistic movements (n=9) to play Wii Tennis, to those who had adopted adaptive techniques (n=8), the latter exhibited increased activation of the FCR that was noticeable and statistically significant (i.e. 11.79±4.44% versus 7.43±3.46%, p=0.038). An increase was also observed for Wii Boxing (realistic: 11.68±4.00%, adapted: 14.48±5.59%), but it did not reach the level of statistical significance (p=0.26).

**WEB**

Wii Boxing elicited higher WEB activation levels than Wii Bowling (p<0.001), Wii Tennis (p<0.001), and DDR (p<0.001). No differences were found between realistic and adapted movements (p≥0.24).

![Range of Muscle Activation Levels during AVG Play](image_url)

**Figure 4:** Range of muscle activation levels during AVG Play. Whiskers depict the 10th and 90th percentiles. **+** depict the minimum and maximum activation levels range.
4.4.3 Reported Muscle Soreness

Four participants reported muscle soreness after completing the study. Two participants, one male and one female, reported muscle soreness in their dominant and non-dominant inner forearm, respectively, corresponding to a ‘1’ (i.e. ‘Hurts a Little Bit’) on the 5-point FACES pain scale. The male participant thought the soreness resulted from the MVE testing. The female participant thought the soreness resulted from AVG play. One participant reported a muscle soreness rating of ‘2’ (i.e. ‘Hurts a Little More’) in the back of his neck, which he attributed to the experimental equipment (i.e. the EMG sensor on the upper trapezius). The fourth participant reported muscle soreness of ‘1’ (i.e. ‘Hurts a Little Bit’) in the left bicep of her non-dominant (i.e. hemiplegic) limb, which she believed was from school activities earlier that day.

No participants reported delayed onset muscle soreness when contacted 24 hours after completing the study.

4.5 Discussion

4.5.1 Key Findings

1. Levels of muscle activity

Of the games studied, Wii Boxing elicited the highest degree of muscular effort in the dominant arm of children with CP. Muscle exertions were significantly higher for all muscles during Wii Boxing when compared to Wii Bowling, Wii Tennis (with the exception of the upper trapezius), and DDR (with the exception of the tricep). Conversely, Wii Bowling consistently evoked the lowest level of muscle activity. These findings aligned well with previous studies of the energy expenditure associated with the different AVGs.12
For all games, the WEB was the most active muscle group. The WEB is of particular importance for children with CP, as their natural wrist position often involves a degree of wrist flexion. They often demonstrate difficulties in extending the wrist, and as such it is often in a flexed position when performing grasping activities. This reduces the efficiency and power of the grasp. Therefore, if this relatively high level of WEB activation translates to the hemiplegic arm, AVGS could have potential as a therapeutic motor activity to encourage wrist extension muscle activation and movements. However, care would have to be taken to avoid the adoption of adapted movements, which increased levels of FCR activation during AVG play. Although this increase was only statistically significant for Wii Tennis, a similar pattern was observed with Wii Boxing. Adapted movement patterns were not observed during DDR or Wii Bowling play. Newer game designs, like the PlayStation Move and Xbox Kinect may be better at tracking movements and may make it more difficult to use adapted movement patterns to succeed at in-game tasks.

2. Risk of injury

Mild muscle soreness was reported in the inner forearm (2 subjects), bicep (1 subject), and back of the neck (1 subject) immediately after completing the study. It is unclear whether this soreness was a direct result of AVG play, other study activities, or uncomfortable equipment and sensors. There were no reports of delayed onset muscle soreness.

Given the relatively low levels of muscle activation during AVG play compared to MVE, it is unlikely that an acute muscle strain injury would have occurred in this study, which attempted to replicate typical AVG play. Even the momentary maximums observed never exceeded the MVEs and tended to fall between 70% and 85% of the MVE. However, this does not rule out the possibility of a RSI. A study of RSI in a rat model investigated a repetitive task
involving similar levels of muscle activity (i.e. 15% of maximum pulling force) that was performed 19 times/min for 2 hours/day, 3 days/week for 12 weeks.\textsuperscript{29} In that study, there was evidence of RSI in the rats at the conclusion of the study.\textsuperscript{29} Therefore, it is feasible that RSI could occur with excessive AVG play in children with CP. This is in line with current reports of Wii RSI that have resulted from excessive game play (i.e. ranging from several hours over one day to up to 8hrs/day for 10 days).\textsuperscript{14-16}

While our biomechanical assessments cautiously indicate that risks for acute strain injuries during AVG play are relatively low, future epidemiologic studies exploring injury rates associated with AVG play are needed to fully quantify risks associated with home use of AVG systems.

\textbf{4.5.2 Study Limitations}

Although the results of this study are an important first step in developing a muscle activation profile for AVGS, this study has several limitations. Firstly, a larger number of subjects would increase the validity of the results. Since only one subject with a GMFCS Level of II and only two subjects with diplegic CP participated, results are likely not representative of these sub-populations. Additional studies should be done with larger samples to allow for differences between these sub-populations to be evaluated. It is also unknown how these results will translate to children without CP. While studies of energy expenditure seem to correlate well between children with and without mild CP (GMFCS Level I), there are, to our knowledge, no studies that report comparative measures of muscle activity in either population.

As previously mentioned, all AVGS were played at the beginner level. This means that the muscle activation levels presented are likely a modest representation and higher levels might
be elicited during AVG play at more advanced difficulty levels. Future studies should test different difficulty levels to assess the affect of game difficulty on muscle activation levels.

4.5.3 Future Work

There is a considerable amount of work still required to develop a complete muscle activation profile for AVGs. This study assessed muscles in the dominant arm of children with CP. A study that compares muscle activation levels in the dominant, non-affected arm and the non-dominant, affected arm for children with hemiplegic CP should be performed. Differences in muscle activation levels could reveal important therapeutic information concerning the affected arm. Furthermore, since motor activity can result in therapeutic benefits for children with CP, once muscle activation levels in the hemiplegic arm have been determined, the potential of AVGs to improve motor function through the establishment and/or reinforcement of neural pathways should be assessed.

Only arm muscles were targeted in this study. While this was a good starting point, as the Wii Sports games only require arm movements, some participants incorporated leg movements while playing these games. Furthermore, DDR games specifically require leg movements to succeed. Therefore, future studies should also assess muscle activation levels in key leg muscles. Finally, although one study has assessed muscle activation levels in typically developing children during AVG play, this study (Straker 2009) did not include maximum voluntary contractions/exertions making comparisons with this study impossible. Therefore, it is critical that studies of this type are performed with maximum voluntary contractions/exertions to provide a benchmark for comparisons to disability populations.
4.6 Conclusion

AVG play elicits low levels of muscle activation in the dominant arm of children with CP. Observed muscle activation levels cautiously indicate that AVG play is unlikely to cause acute strain injuries, although the potential may exist for RSI with excessive game play. Of the games tested, Wii Boxing elicited the highest levels of muscle activation. Future studies should assess muscle activation levels in the affected limbs of children with CP and also compare levels in children in different CP subgroups. Future studies also need to investigate changes to muscle activation levels with increasing game difficulty.

4.7 Acknowledgements

We would like to thank Elizabeth Han, Delbert Hung, Ajmal Khan, and Jomy Varghese for aiding with data collections throughout this study. We would also like to thank all of the study participants, Holland Bloorview Kids Rehabilitation Hospital, and ErinkoakKids Centre for Treatment and Development. We would like to acknowledge our funding sources: Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, Ontario Ministry of Training, Colleges and Universities, and the Holland Bloorview Kids Rehabilitation Hospital Foundation for their generous support of this study.

4.8 References


Chapter Five: Upper Limb Kinematics during AVG Play

Upper Limb Kinematics during Active Video Game Play in
Children with Hemiplegic Cerebral Palsy

The previous chapter detailed muscle activity during AVG play and provided a preliminary assessment of associated risks and benefits. A better understanding of the kinematics of AVG play is also important in order to explore the therapeutic value of this activity and how it might be effectively integrated into clinical use. This chapter provides a profile of the upper limb ranges of movement, angular velocities, and accelerations during AVG play in children with cerebral palsy. An initial, exploratory assessment is also performed to determine whether clinically relevant differences in movement patterns exist between individuals with different characteristics.
5.1 Abstract

Aim. Understanding the active ingredients of any potential therapeutic tool is essential for effective integration into clinical use. This study assesses upper limb movement patterns during active video game (AVG) play in children with hemiplegic cerebral palsy. Methods. Fourteen children (9.61±1.73 years) with hemiplegic cerebral palsy (GMFCS Level I) participated in the study. Upper limb movements were monitored using a 7 camera Vicon MX 3D Optical Capture System as they played a variety of AVGs. Results. Shoulder, elbow and wrist activity differed between the AVGs and between the dominant and the hemiplegic limb. In general, angular velocities and accelerations were significantly larger in the dominant than in the hemiplegic arm, particularly for elbow and wrist movements. Some differences in movement patterns (e.g. use of shoulder and wrist) appeared that seemed to be dependent on gender and manual functional ability. Conclusion. Movements exhibited during AVG play appeared to remain within typical ranges of motion in children with cerebral palsy. Strategic game selections may enable more focused therapies that engage target joints and movements. Future studies are needed to examine how AVGs can best be used in rehabilitation therapies and to evaluate their efficacy in terms of functional improvement, enjoyment, and adherence.
5.2 Introduction

Active video games (AVGs) are a subset of video games that require body movements (e.g. swinging arms, stepping, and dancing) beyond that of conventional hand-controlled games.\(^1\) Typically developing children usually achieve light to moderate levels of physical activity while playing these games, as illustrated in a systematic review by Biddiss and Irwin 2010.\(^2\) There is increasing interest in extending the use of AVGs into the rehabilitation arena both for pediatric and geriatric populations.\(^3\) AVGs have been described as “one of the most innovative and promising recent developments in rehabilitation technology”.\(^3\) Rehabilitation is typically a long process involving a variety of repetitive tasks designed to achieve various therapeutic goals.\(^3\) Clinicians are continually challenged to find appealing, meaningful, and motivating tasks to achieve these goals.\(^3\) The strength of AVGs is their potential to provide an entertaining and immersive virtual reality in which repetitive movements can be encouraged with increasing levels of in-game difficulty, and in-game rewards (i.e. trophies, special items, new levels, etc.) for improvements in performance.

Several studies have already attempted to use AVGs as a rehabilitation tool with children and adolescents with cerebral palsy (CP).\(^4\)-\(^10\) Most of these studies used customized games with highly specific therapeutic goals\(^4\)-\(^5,7\)-\(^10\) with only one study\(^6\) using a completely off the shelf system. Deutsch et al. found that Wii Sports games, when used in therapy, could improve visual perceptual processing, postural control, and functional mobility in children with spastic diplegic CP.\(^6\)

While some equipment exists, such as the Interactive Rehabilitation Exercise platform\(^3,5\), to customize rehabilitation exercises, using an off the shelf AVG is considerably less expensive and more accessible for in-home use.\(^6\) In order to increase the use and efficacy of off the shelf
AVGs in rehabilitation, it is necessary to define the “active ingredients”\textsuperscript{11} that are likely to make them effective. These “active ingredients”, (e.g. types of movements elicited, intensity and duration of sessions), should highlight the potential therapeutic aspects of AVGs and lead to the development of therapy programs that capitalize on these promising characteristics.

Unlike pharmaceuticals, where the active ingredients of the treatment are usually quite easily described, attempting to identify all of the potentially relevant characteristics of AVGs is a highly complex task.\textsuperscript{11} In this study, we limit our exploration to the upper limb movements of children with hemiplegic CP during unguided, unrestrained, typical AVG play of Nintendo’s Wii Sports (Wii Boxing, Wii Tennis, and Wii Bowling) and Dance Dance Revolution (DDR). The specific objectives of this study are to (1) describe the upper body ranges of motion, angular velocities, and accelerations elicited during AVG play, (2) identify differences in movement patterns between the dominant and hemiplegic arm during AVG play, and (3) provide a preliminary exploration of characteristics of children with CP that affect their upper limb movement patterns.

\textbf{5.3 Methods}

\textbf{5.3.1 Participants}

Children between the ages of 7 and 13 years with hemiplegic CP and Gross Motor Function Classification System (GMFCS) Level I were recruited to participate in this study.\textsuperscript{12} Manual Ability Classification System (MACS) levels were obtained when available.\textsuperscript{13} Both the GMFCS and MACS have demonstrated good to excellent validity and reliability in this age group.\textsuperscript{12-15} All children were recruited from Holland Bloorview Kids Rehabilitation Hospital and ErinoakKids Centre for Treatment and Development. Approval for this study was granted by the
local ethics committees. Informed assent and consent was obtained from the child and guardian, respectively.

Children were screened using a modified Physical Activity Readiness Questionnaire (PAR-Q) to ensure that they were healthy enough to engage in physical activity.\textsuperscript{16-17} Children were screened for the following exclusion criteria:

- A heart condition or chest pains during exercise,
- Feeling faint or having spells of severe dizziness,
- High blood pressure,
- Broken bones in the last six months,
- Epilepsy,
- Chronic asthma,
- An injury or disability that would make moderate exercise unsafe,
- A visual, cognitive, or auditory disability that would interfere with game play,
- Receiving a botulinum toxin treatment in the last three months,
- Or orthopaedic surgery in the last six months

5.3.2 Anthropometric Measurements

Body mass, in kilograms, and body height, in centimeters, were measured using an upright scale (Health o Meter Inc., Bedford Heights, OH). The children were measured with their shoes removed. Mass to the nearest 0.5 kg and body height to the nearest 0.5 cm were recorded.

5.3.3 Movement

Motion data was collected using a seven camera Vicon MX 3D Optical Capture System (Vicon Inc., Los Angeles, CA). To define the upper body segments, a total of 20 spherical,
reflective markers were positioned on the middle of the clavicle, C7, the right and left acromion (shoulder), the midpoint between the acromion and the elbow joint (right and left, upper arm), the right and left humeralradial (elbow) joint, the midpoint between the elbow and wrist joints (right and left, forearm), the right and left radiocarpal joint (wrist), and the midpoint of the right and left third metacarpal (hand). This model is similar to the one used by Schmidt et al.\textsuperscript{18} Data were sampled at 60 Hz.\textsuperscript{19-20}

5.3.4 Active Video Games

Four active video games were investigated in this study. All were played on the Wii gaming platform with Wii Remote and Nunchuck (Nintendo, Inc., Redmond, WA). Three of the games are part of the Wii Sports game: Bowling, Tennis, and Boxing (Nintendo, Inc., Redmond, WA). The fourth game is DDR Disney Dance Grooves (Konami Digital Entertainment, Inc., El Segundo, CA). The Bowling and Tennis games require the use of the Wii Remote. The Boxing game requires the use of the Wii Remote and Nunchuck. The DDR Disney Dance Grooves requires the use of the Wii Remote, Nunchuck, and Dance Mat (Intec, Inc., Miami, FL).

5.3.5 Study Procedure

The experiment consisted of one visit by each child to Holland Bloorview Kids Rehabilitation Hospital’s Gait Laboratory. Anthropometric measures were taken, and the children were familiarized with the equipment and test procedures, before testing began. Reflective markers were positioned on the children as described previously. Of note, children were also wearing a cardio pulmonary testing unit and surface electromyography sensors. These are described in greater detail in Chapter 3 and 4. Children then played the four active video games in a randomized order. The Wii Remote was held in the dominant hand (i.e. non-affected
hand), and the Nunchuck was held in the hemiplegic hand, when required. The entire game play session was video recorded. Children were allowed to familiarize themselves with the games before playing for a maximum of five minutes. The children played each game for eight minutes with a rest period of five minutes between each game. Movement data were collected for the entire eight minutes of game play.

5.3.6 Data Analysis

A typical one minute segment was analyzed for each game. The 1 minute segments were chosen such that ‘rest’ periods (i.e. restarting the game, instant replays of game activities, and pauses between rounds) were minimized. Joint angles were determined based on the position of the markers and were then processed using a second order Butterworth filter with a 6Hz cutoff. Angles for each upper limb joint (i.e. wrist, elbow, and shoulder) had to be present for at least 70% of the one minute segment to be included in subsequent analyses. The interquartile ranges (IQR, in degrees) of movements elicited during AVG play were calculated and represented in box-and-whisker diagrams along with the minima, medians, and maxima. Means are also reported, where appropriate, along with their standard deviation (SD). Participants were divided into various subgroups to allow for exploratory determinations of differences in movements between gender and MACS level.

All statistical analyses were performed using SPSS v.17 with a significance level set at p<0.05. A repeated ANOVA with a Bonferroni correction was utilized to determine if significant difference existed between the AVGs. Independent t-tests were used to determine if significant differences existed between subject subgroups (i.e. gender and MACS). Equality of variance was assessed with Levene’s Test for Equality of Variances for all independent t-tests.
5.4 Results

5.4.1 Participants

Fourteen participants (10 boys and 4 girls) with hemiplegic CP, GMFCS Level I, were recruited to participate in the study. Demographic and anthropometric information is presented in Table 4. MACS levels were known for 11 of the 14 participants. Of these 11, 4 were MACS Level 1 and 7 were MACS Level 2. The sample included a representative range of body mass indices (BMI) with an average percentile of 56.86 ± 32.53% and a range of 10th percentile to the 95th percentile.

<table>
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<th>Table 4: Participant Characteristics</th>
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5.4.2 Ranges of Motion

The ranges of motion for the upper limb joints can be found in Figure 5 to Figure 9. The dotted lines depict the average ranges of motion for a non-disability population. The following will discuss some of the key observations with respect to the minimum and maximum degrees of motion observed.

(a) Shoulder.

Shoulder flexion/extension and abduction/adduction are presented in Figure 5 and Figure 6, respectively, for each of the games and for both the hemiplegic and dominant limb. While Wii Bowling elicited the greatest range of motion, no significant differences between games were found in the maximum or minimum degrees of shoulder flexion/extension in the dominant (p≥0.224) or hemiplegic arm (p≥0.157).
Shoulder Flexion and Extension during AVG Play

Figure 5: Shoulder Flexion and Extension during AVG Play

Shoulder Abduction and Adduction during AVG Play

Figure 6: Shoulder Abduction and Adduction during AVG Play
(b) Elbow.

Figure 7 summarizes the range of movement associated with the elbow joint. While Wii Bowling elicited the greatest degrees of elbow extension, no statistically significant differences were found between the AVGs with the exception of DDR which involved less dominant elbow extension than the other games (p≤0.037). For the bilateral AVGs, the degree of elbow extension was greater in the dominant than in the hemiplegic arm for , but only reached statistical significance for Wii Boxing (p=0.031).

![Elbow Flexion during AVG Play](image)

**Figure 7: Elbow Flexion during AVG Play**

(c) Wrist.

As depicted in Figure 8 (flexion/extension) and Figure 9 (medial/lateral deviation), Wii Bowling consistently involved the least dominant limb wrist activity with significantly lower
degrees of extension, flexion, and lateral deviation than in Wii Tennis (flexion and extension, \(p \leq 0.021\)) and DDR (flexion and lateral deviation, \(p \leq 0.006\)). Maximum wrist lateral deviation was significantly greater for the dominant arm compared to the hemiplegic arm for the bilateral AVGs (\(p \leq 0.027\)).

![Wrist Flexion and Extension during AVG Play](image)

**Figure 8: Wrist Flexion and Extension during AVG Play**
**5.4.3 Angular Velocities**

The angular velocities of the upper limb joints can be found in Figure 10 to Figure 14. The following will discuss some of the key observations with respect to the minimum and maximum angular velocities observed.

**(a) Shoulder.**

Minimum and maximum angular velocities of the dominant and the hemiplegic shoulder did not differ significantly between the Wii games for either flexion/extension (Figure 10) or abduction/adduction (Figure 11). Angular velocities of the dominant shoulder were consistently...
(although not significantly) larger than those of the hemiplegic shoulder.

Figure 10: Shoulder flexion and extension angular velocity during AVG play
Figure 11: Shoulder abduction and adduction angular velocity during AVG play

As exhibited in Figure 12, elbow extension velocities were significantly greater in Wii Boxing than in Wii Bowling (p=0.03) and DDR (p=0.039) for the dominant arm. Likewise, elbow extension velocities of the hemiplegic limb were also greatest for Wii Boxing. In the bilateral games, angular velocities of the dominant elbow were consistently larger than those of the hemiplegic arm and this difference was statistically significant for Wii Boxing (p≤0.002).
Figure 12: Elbow flexion and extension angular velocity during AVG play

(c) Wrist.

As shown in Figure 13, Wii Boxing elicited the highest angular velocities of the wrist for both flexion and extension of the dominant and hemiplegic limbs. Conversely, flexion and extension velocities of the dominant limb were significantly less in Wii Bowling than in any of the other AVGs (p<0.02). Likewise, angular velocities of medial and lateral deviations of the wrist (Figure 14) were highest in Wii Boxing for both the dominant and hemiplegic limbs, and lowest in Wii Bowling (p≤0.011, dominant limb). In the bilateral games, dominant wrist velocities were significantly higher than that of the hemiplegic wrist in all game scenarios (p≤0.042) with one exception where a level of statistical significance was not reached: minimum medial and lateral wrist angular velocity during Wii Boxing (p=0.172)
Wrist Flexion and Extension Angular Velocity during AVG Play

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Figure 13: Wrist flexion and extension angular velocity during AVG play

Wrist Medial and Lateral Deviation Angular Velocity during AVG Play

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<td>Wii Bowling</td>
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Figure 14: Wrist medial and lateral deviation angular velocity during AVG play
5.4.4 Accelerations

Accelerations of the upper limb joints can be found in Figure 15 to Figure 19. The following will discuss some of the key observations with respect to the minimum and maximum accelerations observed and the IQR of accelerations.

(a) Shoulder.

While the IQR of shoulder flexions/extensions was largest in Wii Boxing, no significant differences were observed for maximum and minimum flexion/extension accelerations of the shoulder (Figure 15) between the AVGs in either the dominant arm (p≥0.311) or the hemiplegic arm (p≥0.236). Similarly, as depicted in Figure 16, no significant differences in minimum and maximum abduction/adduction accelerations were observed for either the dominant (p≥0.135) or the hemiplegic limb (p≥0.262). The IQRs associated with shoulder abduction and adduction accelerations, however, were again greatest for Wii Boxing. Of note, no significant differences in maximum, minimum, or IQR accelerations were seen between the dominant and the hemiplegic arms for any of the shoulder movements (p≥0.074).
Figure 15: Shoulder flexion and extension acceleration during AVG play

Figure 16: Shoulder abduction and adduction acceleration during AVG play
(b) Elbow.

For elbow flexion and extension of the dominant limb, the maximum and minimum accelerations for Wii Bowling were significantly lower than for Wii Tennis ($p \leq 0.011$) and Wii Boxing ($p \leq 0.005$) as depicted in Figure 17. IQRs for elbow flexion and extension accelerations were significantly larger for Wii Boxing compared to the other AVGs in both the dominant ($p \leq 0.037$, all games) and the hemiplegic limbs ($p \leq 0.045$, Wii Tennis and Wii Bowling). In the bilateral games, minimum and maximum accelerations of the dominant elbow were consistently larger than those associated with the hemiplegic arm and this difference was statistically significant for Wii Boxing ($p < 0.001$).

![Figure 17: Elbow flexion and extension acceleration during AVG play](image-url)
(c) **Wrist.**

In the dominant arm, maximum and minimum accelerations for wrist flexion/extension (see Figure 18) and lateral/medial deviation (see Figure 19) were lowest for Wii Bowling compared to the other games ($p \leq 0.026$). Conversely, wrist accelerations were highest during Wii Boxing. In the hemiplegic arm, there were no significant differences in maximum ($p \geq 0.093$) and minimum ($p \geq 0.172$) wrist flexion and extension accelerations between games. As in the dominant hand, maximum and minimum medial and lateral accelerations of the hemiplegic wrist were lowest during Wii Bowling and largest during Wii Boxing. For bilateral games, minimum and maximum accelerations in the dominant arm were consistently and significantly larger than in the hemiplegic arm ($p \leq 0.048$).

![Wrist Flexion and Extension Acceleration during AVG Play](image)

*Figure 18: Wrist flexion and extension acceleration during AVG play*
5.4.5 Individual Factors Affecting Ranges of Motion

The following describes a number of interesting variations in movement patterns resulting from several subgroup analyses exploring gender and MACS level.

Gender

(a) Dominant Arm.

Males (n=10) generally exhibited a greater range of dominant shoulder movement than females (n=4) while playing AVGs. For example, in Wii Bowling, males exhibited significantly greater degrees of dominant shoulder extension (males: -42.69±21.35°; females: -7.21±11.80°, p=0.011) and flexion (males: 85.38±50.38°, females: 29.61±13.66°, =0.012). This trend was observed in the other AVGs as well but did not reach statistical significance (p≥0.070). Increased degrees of shoulder flexion was also evident in the hemiplegic limb for males compared to
females and was statistically higher during Wii Bowling (males: $45.80\pm31.96^\circ$, females: $7.21\pm11.80^\circ$, p=0.042). Males moved through shoulder flexions and extensions with a higher velocity than females (except in DDR) and with greater accelerations and decelerations. These observations were again most prominent in Wii Bowling for both maximum (males: $374.26\pm224.22^\circ/s$, females: $85.00\pm54.34^\circ/s$, p=0.005) and minimum (males: $-253.23\pm165.19^\circ/s$, females: $-75.79\pm30.83^\circ/s$, p=0.012,) velocities, and maximum (males: $3877.62\pm2485.31^\circ/s^2$, females: $1505.43\pm963.89^\circ/s^2$, p=0.095) and minimum (males: $-4237.70\pm2663.06^\circ/s$, females: $-1505.43\pm963.89^\circ/s$, p=0.021) accelerations of the dominant limb.

(b) Hemiplegic Arm.

Conversely, females consistently exhibited higher accelerations of the hemiplegic shoulder in abduction and adduction than males for all AVGs. This trend reached statistical significance in Wii Tennis (females: $4383.46\pm1603.87^\circ/s^2$, males: $2340.39\pm885.96^\circ/s^2$, p=0.022) and Wii Boxing (females: $5584.89\pm2310.25^\circ/s^2$, males: $2336.26\pm990.11^\circ/s^2$, p=0.015). In Wii Tennis, angular velocities of the hemiplegic shoulder in abduction/adduction were also greater for females (females: $239.66\pm36.04^\circ/s$, males: $107.65\pm34.15^\circ/s$, p$\leq0.001$). Lastly, lateral deviations of the hemiplegic wrist were consistently greater for females, and statistically higher during Wii Tennis (females: $-56.12\pm13.83^\circ$, males: $-36.29\pm14.77^\circ$, p=0.044).

MACS Level

(a) Dominant Arm.

Movements of the dominant shoulder were consistently larger and faster for MACS Level 2 children (n=7) as compared to MACS Level 1 (n=4). For instance, maximal shoulder flexion was significantly higher for MACS Level 2 ($88.08\pm21.10^\circ$) compared to MACS Level 1 ($28.85\pm13.13^\circ$) during Wii Bowling (p=0.008). Shoulder flexion and extension angular velocities
were also significantly greater for MACS Level 2 subjects (426.45±169.45°/s) compared to Level 1 (73.63±20.89°/s) during Wii Boxing (p=0.024). This tendency was observed in the other AVGs (except DDR) but did not reach statistical significance (p≥0.235). Maximum and minimum shoulder accelerations (flexion and extension, and abduction and adduction) were also consistently larger for MACS Level 2 subjects compared to MACS Level 1. These observations were statistically significant for (i) maximum shoulder flexion and extension deceleration during Wii Boxing (MACS Level 2: -7774.47±2568.67°/s², MACS Level 1: -1398.36±488.74°/s², p=0.009), (ii) maximum shoulder abduction and adduction deceleration during Wii Bowling (MACS Level 2: -2865.17±820.82°/s², MACS Level 1: -1749.02±646.73°/s², p=0.045) and Wii Tennis (MACS Level 2: -5386.30±1592.76°/s², MACS Level 1: -2764.78±763.42°/s², p=0.025), and (iii) maximum shoulder abduction and adduction acceleration during Wii Tennis (MACS Level 2: 4794.90±1423.78°/s², MACS Level 1: 2556.04±1096.99°/s², p=0.047) and Wii Boxing (MACS Level 2: 4968.24±1594.17°/s², MACS Level 1: 2162.07±530.13°/s², p=0.032).

(b) Hemiplegic Arm.

Similar to the dominant hand, MACS Level 2 subjects also demonstrated significantly greater shoulder movement in their hemiplegic limb. For instance, MACS Level 2 participants engaged in Wii Boxing exhibited significantly higher maximal shoulder flexion (MACS Level 2: 76.22±21.77°; MACS Level 1: 15.18±8.08°, p=0.010). This pattern was found for all AVGs (except shoulder flexion during DDR). The angular velocities of these shoulder flexions and extensions were also greater for MACS Level 2 subjects and reached statistical significance for Wii Bowling for both flexion (MACS Level 2: 219.95±93.35°/s², MACS Level 1: 96.77±50.50°/s², p=0.022,) and extension (MACS Level 2: -203.51±74.18°/s², MACS Level 1: -90.06±43.10°/s², p=0.039) velocities. Likewise, maximum and minimum shoulder accelerations
(flexion and extension, and abduction and adduction), particularly during Bowling (p≤0.015), were also greater for MACS Level 2. Lastly, MACS Level 2 subjects exhibited larger maximal medial deviation of the wrist compared to MACS Level 1 subjects, as particularly evident during Wii Bowling (MACS Level 2: 22.71±7.94°, MACS Level 1: -11.97±24.50°, p=0.011).

Conversely, maximal lateral deviation of the wrist was larger in MACS Level 1 subjects compared to MACS Level 2 subjects, which was particularly evident during Wii Boxing (MACS Level 1: -55.30±17.92°, MACS Level 2: -33.99±7.77°, p=0.030).

5.5 Discussion

5.5.1 Key Findings

This study examined the upper limb movements of children with hemiplegic cerebral palsy while playing four different AVGs: Wii Bowling, Wii Tennis, Wii Boxing, and DDR Disney Dance Grooves.
Table 5 summarizes the key findings with regards to the largest ranges of movements, angular velocities, and accelerations for each of the different joints of the dominant and hemiplegic limbs.
Table 5: AVGS that elicited the largest ranges of movements, angular velocities, and accelerations

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<th>Movement</th>
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<th>Hemiplegic</th>
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<td>Shoulder flexion/extension</td>
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<td>Wii Bowling</td>
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<tr>
<td>Shoulder abduction/adduction</td>
<td>Wii Tennis</td>
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<tr>
<td>Elbow flexion/extension</td>
<td>Wii Boxing</td>
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<tr>
<td>Wrist flexion/extension</td>
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<td>Wrist lateral/medial deviation</td>
<td>Wii Tennis</td>
<td>Wii Boxing</td>
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<th>Angular Velocity</th>
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<th>Hemiplegic</th>
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<td>Shoulder flexion/extension</td>
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<td>Shoulder abduction/adduction</td>
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<td>Elbow flexion/extension</td>
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<td>Shoulder abduction/adduction</td>
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5.5.2 Clinical Implications

The following suggests a number of clinical implications for these findings.

1. Assessing risk for injury. All movements were within the typical, healthy range of motion as reported in Luttgens and Hamilton, 1997, which suggests that risk for overextensions is likely minimal during typical AVG play for the dominant arm of
children with cerebral palsy. The degree of impairment in the hemiplegic arm is specific to the individual and therefore the risk for overextension in the affected limb must be determined on a case-by-case basis. Of note, the degree of wrist radial and ulnar deviation could not be assessed with the current model. The model used in this study outputs medial and lateral wrist deviation, which, during wrist flexion, is a combination of radial and ulnar deviation and wrist rotation. In general, the largest angular velocities and accelerations were achieved during Wii Boxing for the dominant and the hemiplegic limbs. While angular velocities and accelerations are often not commonly reported in movement assessments\textsuperscript{23}, a study by Tanabe and colleagues provides some reference data with respect to angular velocities during real-life tennis serves.\textsuperscript{24} It is noted that the angular velocities elicited during Wii Tennis, which approach $650^\circ$/s for wrist flexion and extension, are well within the range of those elicited during ‘real’ tennis, which approach $1200^\circ$/s.\textsuperscript{24}

2. Planning rehabilitation therapies. Shoulder adduction, elbow flexion, wrist flexion and ulnar deviation of the wrist are characteristic of spastic joint deformities.\textsuperscript{25} This study suggests that Wii Tennis may be a good choice for therapies focused on encouraging shoulder abduction and elbow extension. Meanwhile, Wii Boxing may be the best game for engaging and encouraging wrist movements. However, one of the difficulties in harnessing the therapeutic benefits of AVGs is that considerable variability that exists in the movements elicited during AVG play primarily due to different participant strategies to succeed in-game (i.e. realistic or adapted movements) and different in-game parameters (i.e. opponent difficulty, sequence of in-game events). Therefore, while an AVG may have a specific therapeutic benefit in the majority of cases, this may not be the
case for all individuals or occur every time the game is played. In all games, hemiplegic limb movements were generally carried out at a lower velocity and acceleration than those of the dominant limb. This agrees well with previous reports describing this condition.\textsuperscript{26} Success in Wii Boxing is highly correlated to increased movement speed (e.g. frequency of punches) and bilateral use of the limbs. As such, Wii Boxing, or other comparable AVGs, may be an effective motivational environment for encouraging increased movement speed of the hemiplegic limb as in-game success and rewards are linked to this metric.

3. \textit{Potential generalizability of AVG based therapies.} While the sample size was small, an exploratory evaluation of differences between the genders and MACS Levels also yielded a number of interesting findings. Firstly, male and female players used comparable wrist and elbow movements during AVG play, which suggests that both would attain the same therapeutic benefits with regards to movements of these joints. Conversely, females tended to use their hemiplegic shoulder more actively than males who relied more strongly on their dominant shoulder when engaged in natural, undirected play. This was an interesting and unexpected finding that could have implications for therapies focused on increasing shoulder function. A second set of observations of interest that emerged from sub-group analyses was the differences between MACS Level 1 and 2 children. MACS Level 2 children exhibited greater medial and lateral wrist deviation and shoulder flexion and extension. This may be due to differences in natural posture associated with varying impairment levels. Encouragingly and surprisingly, more medial wrist deviation (i.e. movements involving radial wrist deviation away from the expected joint deformity) was seen in MACS Level 2 children than in Level 1. This suggests that those in greater
need of wrist therapy would attain greater benefits. Furthermore, MACS Level 2 children had increased shoulder angular velocities and accelerations compared to MACS Level 1 children. This may be a compensatory mechanism to offset increased impairment in the elbow and wrist joints. Coaching from clinicians or alternative AVG designs may be required to encourage children with more severe impairments to focus on elbow and wrist movements while reducing compensatory shoulder movements.

5.5.3 Study Limitations

This study is the first to our knowledge to examine range, velocity, and acceleration of movements during AVG play. Understanding the “active ingredients” of this activity with regards to biomechanics is important given the growing interest in AVGs for rehabilitation and therapy. However, the results of this study must be viewed in the context of a number of limitations. Namely, this study had a limited sample size and as such results, particularly of the sub-group analyses, were exploratory in nature and meant to identify critical areas for future investigations with larger sample sizes. The results of this study are also only applicable to children with hemiplegic cerebral palsy GMFCS Level 1. An additional methodological limitation was that all subjects started the AVGs at a beginner level. This was done in an attempt to ensure consistency amongst the subjects. However, the beginner level may have been too easy for some of the experienced players and increasing the difficulty level (i.e. to their actual skill level) may have changed the resultant movements.

5.5.4 Future Work

This study provides preliminary insights into the biomechanics of AVG game play in natural, undirected play. Future work is needed to outline how/if these games can be used in
rehabilitation therapies and to establish an evidence base to support or refute their efficacy in terms of functional improvements, enjoyment, and adherence. Strategies to optimize the therapeutic value of the Wii and other AVG platforms are needed and may include: prescribing that children hold the Wii Remote in their hemiplegic hand and the Nunchuck in the dominant hand, coaching provided from a clinician, or a modified constraint-induced movement therapy (CIMT) where the dominant arm is either virtually or physically constrained in order to encourage use of the hemiplegic limb.27

It is also important to assess whether and how movements change as the difficulty of games increase, and whether game levels and content are appropriate to engage and challenge children over time. The ability to increase the intensity of any therapeutic exercise is an important requirement for rehabilitation therapy11 and key to the successful use of AVGs in therapeutic exercises.

5.6 Conclusion

Movements during AVG play appear to remain within the typical range of motion in children with cerebral palsy. There appears to be a trend of reduced elbow and wrist angular velocity and acceleration in the hemiplegic arm compared to the dominant arm. Some differences in movement patterns did appear that were dependent on gender and manual functional ability (i.e. MACS Level). Further study is needed to explore the efficacy of AVG technologies in rehabilitation therapies.

5.7 Acknowledgements

We would like to thank Elizabeth Han, Delbert Hung, Ajmal Khan, and Jomy Varghese for aiding with data collections throughout this study. We would also like to thank all of the
study participants, Holland Bloorview Kids Rehabilitation Hospital, and ErinkoakKids Centre for Treatment and Development. We would like to acknowledge our funding sources: Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, Ontario Ministry of Training, Colleges and Universities, and the Holland Bloorview Kids Rehabilitation Hospital Foundation for their generous support of this study.

5.8 References


Chapter Six: The Effect of Group Play

A comparison of solo and group active video game play in children with cerebral palsy

The previous chapters have quantified energy expenditure, muscle activity and patterns of movement of children with CP as they play AVGs. In this chapter, we will present an integrated analysis that draws upon energy, muscle, and movement data to explore how/if children’s play behaviours change when playing against a real opponent as opposed to the computer. Social interaction is known to increase childhood participation in physical activity by making it more fun. Fun is also an important motivator for participation in physical activity by children.

Increased social interaction can occur when AVGs are played in groups (i.e. with friends or family) as often occurs in a home environment. Therefore, it is important that the effects of group play versus solo play are assessed.
6.1 Abstract

Aim. This study assesses energy levels, muscle activation levels, and movement patterns during group (GROUP) and solo (SOLO) active video game (AVG) play in children with hemiplegic cerebral palsy. Methods. Fifteen children (9.77±1.78 years) with hemiplegic cerebral palsy (GMFCS Level I) played Wii Boxing. Energy expenditure was monitored using the Cosmed K4b² cardio pulmonary testing unit. Qualitative measures of perceived exertion were obtained using the OMNI scale. Muscle activation levels were monitored for the upper trapezius, tricep, bicep, flexor carpi radialis, and wrist extensor bundle using Delsys single differential surface electrodes. The game play session was video recorded to assess upper body movements. Results. No significant differences were seen in physical activity levels (oxygen consumption, energy expenditure, heart rate, perceived exertion) or muscle activation levels between SOLO and GROUP play. Dominant arm punching frequency was higher than hemiplegic arm punching frequency during SOLO and GROUP play. Dominant arm punching frequency increased during GROUP play from 95.75±37.93 punches/min (SOLO) to 107.77±36.99 punches/min (GROUP). Conversely, the punching frequency of the hemiplegic arm decreased during GROUP play from 39.05±29.57 punches/min (SOLO) to 30.73±24.74 punches/min (GROUP). Children reported enjoying GROUP play more than SOLO play. Conclusion. Both GROUP and SOLO play scenarios increased energy expenditure significantly from rest to moderate levels of physical activity. Children enjoyed GROUP play more, which may translate to more frequent and voluntary participation. However, SOLO play may have therapeutic advantages to GROUP play with increased use of the hemiplegic limb. As such, new strategies and game designs are recommended to promote continued use of the hemiplegic hand during GROUP play.
6.2 Introduction

For children with¹ and without disabilities²,³, excessive screen time has been identified as a causative factor of childhood obesity and physical inactivity. On average, a typical child between 8 and 10 years of age spends approximately 65 minutes per day in video game play.⁴ Eighty three percent of American youth have access to at least one video game console in their bedroom.⁵ Physical inactivity is a risk factor for several chronic conditions including diabetes, cardiovascular disease, and cancer.⁶ In fact, inactivity is estimated to cause 1.9 million premature deaths globally per year.⁷ In 2000, the direct medical costs of physical inactivity in the United States were estimated at $76.6 billion per year.⁸ Children with cerebral palsy have an even higher incidence of physical inactivity and obesity compared to the general population.⁹ As a result, strategies for safely increasing physical activity in this population are needed both for meeting therapy objectives, as well as for promoting general fitness and health.

Screen time activities, such as the television, internet, and video games, are highly valued by children with and without disabilities.¹⁰ Therefore, one potentially successful strategy to promote physical activity is to replace sedentary screen time with active screen time using active video games (AVG). AVGs or “Exergaming” refer to systems such as the Nintendo Wii, which require some degree of physical activity (e.g. swinging arms, stepping, and dancing) beyond that of conventional, hand-controlled games that use inputs such as a keyboard or mouse. This approach may promote health by increasing participation in physical activity and reducing time spent in sedentary activities.¹¹ Furthermore, AVGs may offer a different type of physical activity for children with CP that is less hindered by traditional barriers to exercise including¹²: motivational (e.g. lack of interest) or environmental barriers (e.g. weather, transportation, unsafe neighbourhoods), time constraints, self-consciousness, and accessibility issues. AVGs have the
potential to be a low-cost (compared to physical therapy and recreational programs), home-based, all-season, self-directed, and potentially enjoyable physical activity for children with cerebral palsy.

Several studies have investigated the factors that encourage or discourage participation in physical activity.\textsuperscript{13-16} Social interaction has been found to encourage children to participate in physical activity by making it more “fun”.\textsuperscript{13-15} This is important as the most frequently reported motivator for participation in physical activity by children is “fun”.\textsuperscript{17} Conversely, “impulsive behaviour,” may cause an individual to switch from an activity with long-term or delayed benefits (e.g. improvement in health stemming from physical activity) to one with immediate benefits (e.g. entertainment while watching a movie).\textsuperscript{16} AVGs may be less affected by impulsive behavior, as it provides immediate benefits (i.e. enjoyment, in-game progress such as unlocking a new song or defeating an opponent, etc.) while also having the potential to provide the long-term benefits of increased physical activity as well.

The potential for AVGs to increase physical activity from sedentary levels in able-bodied children has been demonstrated in previous studies. In children and adolescents, under 21 years of age, energy expenditure increased by 222\% (±100\%) during AVG play and heart rate increased by 64\% (±20\%).\textsuperscript{18} Very little research is available pertaining to AVG play with disability populations, such as children with hemiplegic CP, either in group (GROUP) or solo play (SOLO) scenarios. The primary objectives of this study are (1) to investigate whether levels of energy expenditure change in a GROUP versus SOLO play scenarios, and (2) to determine if muscle activation levels and movement patterns change during GROUP game play.
6.3 Methods

6.3.1 Participants

Children between the ages of 7 and 13 years with hemiplegic CP and Gross Motor Function Classification System (GMFCS) Level I were recruited to participate in this study.\(^\text{19}\) The interested reader is directed to Palisano et al. 1997 for information on the GMFCS and Wood et al. 2000 for additional information on validity and reliability.\(^\text{19-20}\) The level of motor function in the children, measured using the Manual Ability Classification System (MACS), was not restricted but was obtained when available. The interested reader is directed to Eliasson et al. 2006 and Morrisson et al. 2006 for information on the MACS and its reliability.\(^\text{21-22}\) All children were recruited from Holland Bloorview Kids Rehabilitation Hospital and ErinoakKids Centre for Treatment and Development.

Children were screened using a modified Physical Activity Readiness Questionnaire (PAR-Q) to ensure that they were healthy enough to engage in physical activity.\(^\text{23-24}\) Children were screened for the following exclusion criteria:

- A heart condition or chest pains during exercise,
- Feeling faint or having spells of severe dizziness,
- High blood pressure,
- Broken bones in the last six months,
- Epilepsy,
- Chronic asthma,
- An injury or disability that would make moderate exercise unsafe,
- A visual, cognitive, or auditory disability that would interfere with game play,
• Receiving a botulinum toxin treatment in the last three months,
• Or receiving orthopaedic surgery in the last six months.

Approval for this study was granted by the local ethics committees. Informed assent and consent was obtained from the child and guardian, respectively.

6.3.2 Anthropometric Measurements

Body mass, in kilograms, and body height, in centimeters, were measured using an upright scale (Health o Meter Inc., Bedford Heights, OH). The children were measured with their shoes removed. Mass to the nearest 0.5 kg and body height to the nearest 0.5 cm were recorded.

6.3.2 Muscle Activity

The muscles of interest for this study were the upper trapezius, triceps, biceps, flexor carpi radialis (FCR), and wrist extensor bundle (WEB) of the dominant arm, as this would be the arm primarily used during typical AVG play in an unstructured environment (i.e. at home). For hemiplegic subjects, the dominant arm was the unaffected arm. For all other subjects, it was the arm used for writing. The electrode sites were prepared by light abrading and cleaning with alcohol. Reusable single differential surface electrodes (Delsys Inc., Boston, MA) with a one centimeter inter-electrode distance were placed centrally over the muscle belly, located via anthropometrics and palpation. Raw surface electromyography (sEMG) signals were sampled at 1250 Hz via the Bagnolia Desktop EMG System (Delsys Inc., Boston, MA) with 1k gain. Maximum voluntary efforts (MVE) were obtained using Biodex System 2 (Biodex Medical Systems, Shirley, NY). The Biodex System 2 was calibrated before each use and positioned for each MVE according to manufacturer instructions. Three isometric MVE for each of the five muscle groups were obtained. Each contraction lasted for five seconds with a forty five second
rest between contractions. The largest contraction was used as the MVE. Verbal encouragement was provided during the contractions.

6.3.3 Energy Measurements

The Cosmed K4b\textsuperscript{2} cardio pulmonary testing unit (Cosmed Inc., Chicago, IL) was used to obtain physiological measures of oxygen consumption (VO\textsubscript{2}), energy expenditure (EE), and heart rate (HR). EE was determined based on measures of VO\textsubscript{2} and carbon dioxide exhalation (VCO\textsubscript{2}) using the following equation: \( EE = 3.781 \times VO_2 + 1.237 \times VCO_2 \). The heart rate monitor was a Polar heart rate monitor (Lake Success, NY). The Cosmed K4b\textsuperscript{2} was calibrated prior to each session using manufacturer protocols. Specifically, calibration of the O\textsubscript{2} and CO\textsubscript{2} sensors was completed using a sample gas of known concentrations. Respiratory volume was calibrated using a 3-liter volume calibration syringe. A delay calibration was also performed to ensure adequate response time to a breathing cycle.

6.3.4 Active Video Game

The AVG of focus in this study was Wii Boxing, which is part of the Wii Sports game package and is played on the Wii gaming platform with the Wii Remote and Nunchuck (Nintendo, Inc., Redmond, WA).

6.3.5 Study Procedure

The study consisted of one visit by each child to the Holland Bloorview Kids Rehab Gait Laboratory. Anthropometric measures were taken, and the child was familiarized with the equipment and test procedures, before testing began. The child was then fitted with sEMG electrodes (Delsys Inc., Boston, MA). MVE of the muscles of interest were obtained using the
Biodex System 2 (Biodex Medical Systems, Shirley, NY). The child was then fitted with the Cosmed K4b² cardio pulmonary testing unit. Of note, children were also wearing motion capture reflective markers. These are described in greater detail in Chapter 5. A DVD was played for the child, who sat quietly for 20 minutes to achieve a baseline state that provided a close approximation of resting energy levels, as recommended in previous studies measuring resting energy expenditure in children.⁵,²⁶ Physiological data were collected for the later ten minutes to obtain the baseline level of energy expenditure. The child then played Wii Boxing twice, once by themselves (i.e. against the computer, SOLO), and a second time in the group scenario (i.e. against a member of the research team, GROUP). The entire game play session was video recorded. The child was allowed to familiarize themselves with the game before playing for a maximum of five minutes. The child played each game for eight minutes with a rest period of five minutes between each game. Muscle activity and energy expenditure data were collected for the entire eight minutes of game play. The child ranked their level of perceived exertion after playing each game using the OMNI Scale of Perceived Exertion (OMNI), which has demonstrated good validity in children.²⁷ After playing both games, the children were asked which scenario they enjoyed more (i.e. GROUP or SOLO).

6.3.6 Data Analysis

All data (except OMNI scores) are expressed as mean plus or minus the standard deviation (SD). The ordinal OMNI scores are expressed as median (interquartile range [IQR]). Standard error bars are displayed on all graphs. For energy measures, the first thirty seconds of data associated with each new game was eliminated to allow the subject to acclimatize. The mean and standard deviation were then calculated for the remaining data. The Metabolic Equivalent for Task (MET) was calculated by normalizing the average rate of oxygen
consumption during AVG play to the baseline oxygen consumption rate. For muscle activity, the root mean square (with a moving average window of 75 ms and a 50% overlap) of all raw EMG signals were taken and normalized to MVEs. The frequency of punching during game play was determined from the collected video data. Three 1 minute segments during the eight minutes of game play were chosen for GROUP and SOLO. The 1 minute segments were chosen such that ‘rest’ periods (i.e. restarting the game, instant replays of game activities, and pauses between rounds) were minimized. The number of punches was counted by two independent, blinded researchers. One of the researchers counted the punches twice (on two different days separated by 1 week) to assess repeatability. The resultant counts for all three 1 minute periods were then averaged to give a frequency of punches per minute, which was used in all subsequent analyses.

All statistical analyses were performed using SPSS v.17.0 with a significance level of p<0.05. Intraclass correlations were performed to assess the inter-rater reliability and repeatability of video obtained frequency data. Paired t-tests were used to determine if significant differences existed between the SOLO and GROUP scenarios. A Wilcoxon test was used to compare OMNI scores for the different AVG play conditions.

6.4 Results

6.4.1 Participants

Fifteen participants (10 boys and 5 girls) with hemiplegic cerebral palsy, GMFCS Level I, were recruited to participate in the study. Demographic and anthropometric information is presented in Table 6. MACS levels were known for 12 of the 15 subjects. Of these 12, 5 were MACS Level 1 and 7 were MACS Level 2. The sample included a representative range of body
mass indices (BMI) with an average percentile of 58.80±32.24% and a range of 10th percentile to the 95th percentile.

### Table 6: Participant Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Females (n=5)</th>
<th>Males (n=10)</th>
<th>All Participants (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>9.60 ± 1.82</td>
<td>9.85 ± 1.86</td>
<td>9.77 ± 1.78</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>139.80 ± 8.98</td>
<td>142.40 ± 11.57</td>
<td>141.53 ± 10.52</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>38.00 ± 10.42</td>
<td>37.15 ± 10.92</td>
<td>37.43 ± 10.38</td>
</tr>
<tr>
<td><strong>BMI (kg/m²)</strong></td>
<td>19.32 ± 4.01</td>
<td>18.04 ± 3.00</td>
<td>18.47 ± 3.28</td>
</tr>
</tbody>
</table>

### 6.4.2 Physical Activity Levels

Only 12 of the 15 participants wore the Cosmed K4b² equipment, and therefore the energy measures presented represent data from this subset. The three participants who did not wear the mask found it too uncomfortable. Mean levels for each of the energy measures (e.g. \(\text{VO}_2\), MET, EE, HR) are presented in Table 7. For all of the energy measures, except \(\text{VO}_2\), levels during the SOLO scenario were slightly lower than those in the GROUP scenario. However, this increase was not significant \((p \geq 0.176)\). The percent increase ranged from 1.51% for MET levels to 3.97% for HR. Perceived exertion, as measured by the OMNI, increased from 4 (‘Just feeling a strain’) during SOLO play to 6 (‘Getting quite hard’) during GROUP play, although this increase was not statistically significant \((p=0.079)\).

### Table 7: Energy Measures during SOLO and GROUP AVG Play

<table>
<thead>
<tr>
<th></th>
<th>SOLO</th>
<th>GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{VO}_2) (mL/min)</td>
<td>551.51 ± 222.06</td>
<td>549.76 ± 200.51</td>
</tr>
<tr>
<td>MET</td>
<td>3.32 ± 1.57</td>
<td>3.37 ± 1.28</td>
</tr>
<tr>
<td>Energy Expenditure (EE, kJ/min)</td>
<td>10.07 ± 3.75</td>
<td>10.29 ± 2.84</td>
</tr>
<tr>
<td>Heart Rate (HR, bpm)</td>
<td>137.04 ± 19.96</td>
<td>142.48 ± 13.44</td>
</tr>
<tr>
<td>OMNI</td>
<td>4.25(5.25)</td>
<td>6(2)</td>
</tr>
</tbody>
</table>

### 6.4.3 Muscle Activation Levels

Mean activation levels for each of the muscles of interest are shown in Table 8. For all the muscles, activation levels during the GROUP scenario were higher than in the SOLO
scenario, but this difference was not statistically significant \((p \geq 0.176)\). The increase in \% MVE was small and ranged from 0.78\% for the tricep to 1.79\% for the bicep.

### Table 8: Muscle Activation (\% MVE) during SOLO and COMP AVG Play

<table>
<thead>
<tr>
<th></th>
<th>SOLO</th>
<th>COMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Trapezius</td>
<td>11.32 ± 3.93</td>
<td>12.34 ± 6.37</td>
</tr>
<tr>
<td>Tricep</td>
<td>12.08 ± 6.13</td>
<td>12.86 ± 7.63</td>
</tr>
<tr>
<td>Bicep</td>
<td>13.30 ± 5.07</td>
<td>15.09 ± 7.11</td>
</tr>
<tr>
<td>Flexor carpi radialis</td>
<td>11.42 ± 4.32</td>
<td>12.45 ± 6.31</td>
</tr>
<tr>
<td>Wrist extensor bundle</td>
<td>17.20 ± 4.07</td>
<td>18.16 ± 5.37</td>
</tr>
</tbody>
</table>

### 6.4.4 Frequency of Punching

Inter-rater reliability for video analyses of punching frequency counts was strong with an intraclass correlation coefficient (ICC) of 0.984 (95\% confidence interval [CI]: 0.910-0.953, \(p<0.001\)) for the dominant (i.e. non-hemiplegic) arm and an ICC of 0.961 (95\% CI: 0.849-0.984, \(p<0.001\)) for the hemiplegic arm. Similarly, the repeatability of the counts was also strong with an ICC of 0.995 (95\% CI: 0.993-0.997, \(p<0.001\)) for the dominant arm and an ICC of 0.979 (95\% CI: 0.959-0.988, \(p<0.001\)) for the hemiplegic arm. The frequency of punching for the dominant arm during GROUP (107.77±36.99 punches/min) and SOLO (95.75±37.93 punches/min) game play was significantly greater \((p<0.001)\) than for the hemiplegic arm during GROUP (30.73±24.74 punches/min) and SOLO (39.05±29.57 punches/min) game play, as shown in Figure 20. The frequency of punching in the dominant arm was significantly increased during GROUP game play compared to SOLO game play \((p=0.008)\). The frequency of punching in the hemiplegic significantly decreased during GROUP game play compared to SOLO game play \((p=0.003)\).
6.4.5 Reported Enjoyment

All participants stated that they preferred playing Wii Boxing in the GROUP as opposed to the SOLO scenario.

6.5 Discussion

6.5.1 Key Findings

This study examined whether there are physiological differences between GROUP and SOLO Wii Boxing game play. The key findings are as follows:

1. No significant increase in energy expenditure and muscle activity was observed during GROUP versus SOLO game play.
2. Dominant arm activity was significantly higher than hemiplegic arm activity in both game play scenarios,
3. Dominant arm activity significantly increased during GROUP game play,
4. Hemiplegic arm activity significantly decreased during GROUP game play, and lastly,
5. Children reported a preference for GROUP game play over SOLO game play.

6.5.2 Implications

The findings of this study have important implications for physical activity and therapeutic benefit as described in the following.

*Promoting Physical Activity.*

To the best of our knowledge, only one other study has investigated differences in energy expenditure between solo and group AVG play.\(^2^8\) The subjects in this study were healthy adult males, and, in line with our study’s findings, no significant differences in energy expenditure, heart rate, and perceived exertion were found between solo and group play scenarios.\(^2^8\)

More importantly, the children in this study unanimously reported having more ‘fun’ playing Wii Boxing against a ‘real’ opponent (i.e. during GROUP game play). Since ‘fun’ is a major motivating factor in children’s activity choices and participation in physical activity\(^1^3\), this suggests that children would be more likely to play Wii Boxing in a group scenario (i.e. with friends and/or family) than by themselves. Therefore, to increase the likelihood of participation and to maximize activity benefits, opportunities for group game play should be promoted.

*Therapeutic Rehabilitation.*

In terms of maximizing the therapeutic benefits for children with hemiplegic CP, a different conclusion is reached. In both game play scenarios, the dominant arm punching frequency was significantly greater than that of the hemiplegic arm. This is in-line with current
understanding of dominant versus hemiplegic arm use in which the dominant arm performs movements with higher velocities and acceleration and is primarily used for activities of daily living and the hemiplegic arm is less frequently used due to ‘developmental disregard’. Developmental disregard refers to the tendency for children with hemiplegic CP to neglect or under-utilize their affected limb regardless of its skill or measured capacity in ideal or test conditions. It is thought to have a neurological basis resulting from a cycle of repeated negative reinforcement associated with use of the hemiplegic hand (e.g. unsuccessful movements, pain, fatigue), and positive reinforcement with non-use of the hemiplegic limb (e.g. successful compensatory behaviours). During GROUP game play, hemiplegic arm activity significantly decreased, while dominant arm activity significantly increased relative to the SOLO play scenario. One probable explanation for this change in arm usage may be that children are more highly motivated to win when playing against a real opponent and therefore tend to rely more exclusively on their more “reliable” limb (i.e. their dominant hand). Therefore, if the therapeutic goal of Wii Boxing game play is to encourage movement and use of the hemiplegic arm, it may be beneficial to avoid group game play scenarios and rather, to encourage children to play against the computer. Encouragingly, since success in Wii Boxing is highly correlated to increased movement speed (e.g. frequency of punches) and bilateral use of the limbs, the constructs of the game itself should promote increased hemiplegic arm use.

6.5.3 Limitations

This study has a relatively small sample size and only assessed children with hemiplegic CP diagnosed as GMFCS Level I, and MACS Level 1 and 2. Results cannot be generalized to children outside of these diagnoses. The equation used to calculate EE were based on data from adults. Inaccuracies are likely present in these calculations when applied to children with
cerebral palsy. However, this equation is currently used to determine EE in children during AVG play\textsuperscript{32-35} and was therefore included to allow for comparisons between studies. VO\textsubscript{2} and MET levels provide a more accurate representation of energy levels in a cerebral palsy population.\textsuperscript{36}

While every attempt was made to match the skill level of the real opponent to that of the participant, this was difficult to do for some who were very skilled at AVG play. Also, all participants started the AVGs at a beginner level in an attempt to ensure consistency between players. This may have decreased energy expenditure levels for experienced players in the SOLO scenario from those they would achieve when playing at home or in the GROUP scenario (i.e. at or closer to their actual skill level).

\textbf{6.5.4 Future Work}

As opposed to encouraging children with CP to play AVGs by themselves, there may be potentially more effective strategies for maximizing children’s enjoyment of the game while meeting therapeutic goals. For example, techniques to increase hemiplegic arm use during group play could include coaching from the clinician or swapping the remotes (i.e. Wii remote in the hemiplegic hand and Nunchuck in the dominant hand). Additionally, new games could be developed that reward children with extra points for using their hemiplegic arm as opposed to their dominant arm. Future studies are needed to assess other AVGs that involve bimanual arm activity to determine if these findings are isolated to Wii Boxing or if these movement patterns also occur in other games. It would also be interesting to investigate group game play with an online opponent (as opposed to a physically present opponent) to determine if the critical element of group game play is the knowledge that another real person is playing or the physical presence of the opponent.
Assessment of AVG play in the home environment is also strongly indicated. While it is likely that children’s increased enjoyment of GROUP play would result in better uptake of GROUP AVG play in the home environment, no studies to our knowledge have observed the use of AVGs in the home environment in the context of GROUP play. If the increase in GROUP game play time is large enough (compared to SOLO play time), it may offset the decrease in hemiplegic arm activity associated with GROUP play and result in more hemiplegic arm movements overall than in the SOLO play scenario.

6.6 Conclusion

In this study, significant differences in energy expenditure and muscle activations were not observed in group versus solo play scenarios. Both play scenarios increased energy levels significantly from rest to moderate levels of physical activity. Significant and clinically relevant changes in punching frequency were observed. Punching frequency increased in the dominant arm and decreased in the hemiplegic arm during group game play. As a result, group play, while more enjoyable for children, may not be optimal for meeting therapeutic goals. Conversely, group play may encourage children to voluntarily participate more frequently in AVG play if a suitable opponent is available. This increase in time spent in group AVG play may lead to increased overall use of the hemiplegic hand (i.e. over multiple sessions) relative to solo play. Future work should focus on developing techniques to increase hemiplegic arm use during group AVG play in order to maximize both children’s enjoyment of the games and their therapeutic value.
6.7 Acknowledgements

We would like to thank Elizabeth Han, Delbert Hung, Ajmal Khan, and Jomy Varghese for aiding with data collections throughout this study. We would also like to thank all of the study participants, Holland Bloorview Kids Rehabilitation Hospital, and ErinkoakKids Centre for Treatment and Development. We would like to acknowledge our funding sources: Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, Ontario Ministry of Training, Colleges and Universities, and the Holland Bloorview Kids Rehabilitation Hospital Foundation for their generous support of this study.

6.8 References


Chapter Seven: Conclusion

7.1 Contributions

In conclusion, the perceived contributions of this research are as follows:

1. Systematic literature review of active video game (AVG) play in children since its inception (i.e. the release of Dance Dance Revolution) in 1998. This review focused on the potential of AVGs to provide physical activity and to promote physical activity in the home environment. Recommendations were made to guide future research efforts in terms of methodology, focus, future game development, and AVG-based activity program design.

2. Quantification of energy expenditure levels during AVG play in children with cerebral palsy (CP) and interpretation of these findings with regards to recommended levels of physical activity and enjoyment of AVG play.

3. Evaluation of the levels of muscle activation achieved during AVG play in the dominant arm of children with CP. Provided a preliminary assessment of the musculoskeletal risks (e.g. over-strain and RSI) of AVG play in children with CP.

4. Provided a quantitative description of the typical movements elicited by AVG play in children with CP and presented potential therapeutic implications.

5. Determined the effects of group AVG play on levels of energy expenditure, muscle activation, and movement patterns in children with CP. Discussed the implications of differences between solo and group play in terms of maximizing physical activity and therapeutic benefits for children with CP.
7.2 Direction for Future Research

While this thesis highlights several important findings in terms of the activity and therapeutic benefits and the potential musculoskeletal risks of AVGs, there are several other areas of investigation that could provide further insights in this field. The recommendations in this section are divided into three categories related to future biomechanical assessments, the need for home-based studies, and the development of therapeutic strategies.

7.2.1 Ideas for Future Biomechanical Assessments

A number of interesting questions and research gaps became evident in the course of this study. Future studies are needed to examine the following:

1. Monitoring leg muscle activity during AVG play. Muscles of interest in the leg should include, but not be limited to, the gastrocnemius-soleus complex, the quadriceps femoris, and the gluteus maximus. This assessment is of particular importance for AVGs, like DDR, that elicit primarily leg movements.

2. Comparing muscle activity in the affected and non-affected (i.e. dominant) arms of children with hemiplegic CP. While dominant arm muscle activity levels were monitored in this thesis, the levels of activity in the hemiplegic arm are currently unknown. It is important that activity levels in the hemiplegic arm are assessed, as there will likely be noteworthy differences between the arms.

3. Identifying compensatory movements. Compensatory movements are often employed by individuals with disabilities to allow them to successfully perform an activity in spite of mobility limitations. These compensatory movements may be therapeutically undesirable (i.e. increased trunk movements and reduced arm movements). Therefore,
identifying and describing these movements may provide important therapeutic information.

4. Examining for and identifying movements that elicit co-contractions. While co-contractions tend to cause higher levels of energy expenditure, it is often a therapeutically undesirable outcome. As such, a concurrent evaluation of muscle activity and movement data would allow for the identification of any movements that elicit co-contraction. This would then allow clinicians and therapists to instruct clients to avoid these undesirable movements during AVG play.

5. While this thesis focused on evaluating each of the biomechanical measures separately as they related to AVG play, an inter-measures assessment would also provide valuable insights. In fact, some observations of-note can already be identified and warrant further investigation:

   a. Muscle activity levels were consistently higher during Wii Boxing game play compared to the other AVGs. Of the games that focused on arm movements for in-game success, Wii Boxing also elicited the highest levels of energy expenditure. Therefore, arm muscle activity may be correlated with energy levels for AVGs that encourage upper body movements. An assessment of leg muscle activity correlated to energy levels would also be of interest for AVGs that encourage lower body movements (i.e. DDR).

   b. The movements required to succeed at the AVGs may also correlate with energy levels. The results of this study suggest that bilateral games (Wii Boxing) and games involving lower body movements (DDR) elicit higher levels of energy expenditure compared to unilateral games (Wii Bowling and
Wii Tennis). The frequency of movements and vertical center of mass deviations could also correlate with energy levels and warrant future investigation.

### 7.2.2 Need for Home-based Studies

The promising results in terms of achieving moderate levels of physical activity in the majority of participants during AVG play (Wii Boxing and DDR) highlight the potential of AVGs as a tool to increase physical activity levels in children with CP. As such, it is highly recommended that future work focus on assessing these AVGs in the home environment to:

1. Monitor changes in activity patterns as a result of AVG play (i.e. determine whether AVG play replace sedentary activities or physically active activities),
2. Assess long-term compliance with a game play regime (i.e. determine whether AVG use decreases with time due to boredom, etc.), and
3. Obtain feedback from the children concerning their enjoyment of AVG physical activity in the home environment and their relative preference between AVG play and other sedentary and active options available to them (i.e. playing outside, watching TV, etc.)

### 7.2.3 Development of Therapeutic Strategies

Differences were observed between dominant and hemiplegic arm use during AVG play in movement frequency (with Wii Boxing) and angular velocities and accelerations (elbow and wrist movements for all tested games). The development of therapeutic strategies that minimize these asymmetries could enhance the benefits of AVG play for children with CP. Some suggestions of strategies include:
1. Instructing the child to play the AVGs with the Wii remote in the hemiplegic hand and the Nunchuck in the dominant hand. This would mean that Wii Bowling and Wii Tennis would require purposeful movements of the hemiplegic arm to succeed in-game. Furthermore, the psychological effect of having the dominant remote in the hemiplegic hand may increase its use during bimanual game play (i.e. DDR and Wii Boxing).

2. Providing a training session with a clinician who would coach the child to adopt the desired movement patterns and avoid undesired movement patterns,

3. Utilizing a modified constraint-induced movement therapy (CIMT). This would likely involve constraining the unaffected, dominant arm (physically or perhaps virtually) while children play uni-manual AVGs (i.e. Wii Bowling and Wii Tennis), which would force them to use their hemiplegic arm, and

4. Developing customized AVGs that reward children with increased in-game success for using their hemiplegic arm instead of their dominant arm.

7.3 Closing Remarks

AVGs have the potential to increase physical activity in children, and its potential in this area has been investigated in typically developing children. Arguably, children with disabilities stand to benefit even more from AVG play, as they have reduced opportunities for physical activity compared to their typically developing peers and could gain therapeutic benefits from AVG play. The goal of this thesis was to assess the physical activity and therapeutic potential of AVGs for children with CP. The results presented should allow for future studies to focus on integrating AVGs effectively into the home environment and maximizing the potential therapeutic benefits of these games. The protocol developed could be applied to assessments in other disability
populations and AVGs in the future.
References


Appendix

**GMFCS**

<table>
<thead>
<tr>
<th>GMFCS Level</th>
<th>Expected gross motor function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Children walk indoors and outdoors, and climb stairs without limitations. Children perform gross motor skills including running and jumping, but speed, balance, and coordination are reduced.</td>
</tr>
<tr>
<td>2</td>
<td>Children walk indoors and outdoors, and climb stairs holding onto a rail, but experience limitations walking on uneven surfaces and inclines, and walking in crowds or confined spaces. Children have at best only minimal ability to perform gross motor skills such as running or jumping.</td>
</tr>
<tr>
<td>3</td>
<td>Children walk indoors or outdoors on a level surface with an assistive mobility device. Children may climb stairs holding onto a rail. Depending on upper-limb function, children propel a wheelchair manually or are transported when travelling for long distances or outdoors on uneven terrain.</td>
</tr>
<tr>
<td>4</td>
<td>Children may maintain levels of function achieved before age 6 years or rely more on wheeled mobility at home, school, and in the community. Children may achieve self-mobility using a powered wheelchair.</td>
</tr>
<tr>
<td>5</td>
<td>Physical impairments restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Functional limitations in sitting and standing are not fully compensated for through the use of adaptive equipment and assistive technology. Children have no means of independent mobility and are transported. Some children achieve self-mobility using a powered wheelchair with extensive adaptations.</td>
</tr>
</tbody>
</table>
### MACS

<table>
<thead>
<tr>
<th>MACS Level</th>
<th>Expected manual ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Handles objects easily and successfully. At most, limitations in the ease of performing manual tasks requiring speed and accuracy. However, any limitations in manual abilities do not restrict independence in daily activities.</td>
</tr>
<tr>
<td>2</td>
<td>Handles most objects but with somewhat reduced quality and/or speed of achievement. Certain activities may be avoided or be achieved with some difficulty; alternative ways of performance might be used but manual abilities do not usually restrict independence in daily activities.</td>
</tr>
<tr>
<td>3</td>
<td>Handles objects with difficulty; needs help to prepare and/or modify activities. The performance is slow and achieved with limited success regarding quality and quantity. Activities are performed independently if they have been set up or adapted.</td>
</tr>
<tr>
<td>4</td>
<td>Handles a limited selection of easily managed objects in adapted situations. Performs parts of activities with effort and with limited success. Requires continuous support and assistance and/or adapted equipment, for even partial achievement of the activity.</td>
</tr>
<tr>
<td>5</td>
<td>Does not handle objects and has severely limited ability to perform even simple actions. Requires total assistance.</td>
</tr>
</tbody>
</table>