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Examining Physical Activity, Adiposity, and Function in Youth with and without Spastic Cerebral Palsy

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Examining Physical Activity, Adiposity, and Function in Youth with and without Spastic
Cerebral Palsy

by

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A THESIS

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Abstract

Objectives: To examine physical activity (PA), body composition, balance, and strength in youth (ages 10-18) with cerebral palsy (CP), compared to age- and sex-matched typically developing (TD) peers.

Methods: Thirty youth with CP [gross motor function classification system (GMFCS) levels I-III; 20 males], were matched to TD youth. PA (minutes in sedentary, light, and moderate-vigorous) was measured using ActiGraph accelerometers. Body composition (fat and lean mass indices) was assessed by dual-energy x-ray absorptiometry. Center of pressure (total path length and 95% ellipse area) on two force plates represented balance. Lower-extremity strength was measured using hand-held dynamometry.

Results: Youth with CP, GMFCS levels II or III, achieved less moderate-vigorous PA, were more sedentary, weaker with all lower-extremity muscle groups, had lower lean mass indices, and had larger 95% ellipse areas than TD youth.

Conclusions: GMFCS level appeared to impact the severity of activity limitations and of body structure and functional impairments.

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Dedication

I am dedicating this thesis to my family. To my amazing parents, Trevor and Lorena, I cannot thank you enough for your love and support, I could not have accomplished this without you. You have taught me the value of hard work and to always give everything I have. To my wonderful siblings, Jonathan, Rebecca, and Benjamin, thank you for always challenging me, teaching me the value of patience and understanding, humoring me, and supporting me. And yes, as promised, I will more than make up for all the time you guys covered my turns loading and unloading the dishwasher, etc. over the upcoming months.

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List of Symbols, Abbreviations and Nomenclature

Symbol	Definition
PA	Physical Activity
CP	Cerebral Palsy
TD	Typically Developing
DOI	Distribution of Involvement
GMFCS	Gross Motor Function Classification System
DXA	Dual-energy X-ray Absorptiometry
COP	Center of Pressure
VGRF	Vertical Ground Reaction Force
MVPA	Moderate-vigorous Physical Activity
FMI	Fat Mass Index
LMI	Lean Mass Index
BMI	Body Mass Index
TPL	Total Path Length
BIA	Bioelectrical Impedance Analysis
ICF	International Classification of Functioning, Disability and Health
TEE	Total daily Energy Expenditure
SMR	Sleeping Metabolic Rate
GMFM	Gross Motor Function Measure
REB	Research Ethics Board
SIPRC	Sport Injury Prevention Research Centre
HICCUP	Healthy Infants and Children Clinical Research Program
USA	United States of America
DOB	Date of Birth
LED	Light Emitting Diode
MET	Metabolic Equivalent
CSV	Comma Separated Values File
N	Newton's
mm	Millimeters
mm ²	Millimeters squared
Nm	Newton meters
Nm/kg	Newton meters per kilogram
STATA	Data Analysis and Statistical Software
ICC	Intra-class correlation coefficients
LOA	Limits of Agreement

Chapter One: **Introduction**

1.1 Problem Statement

The research examining physical activity (PA) levels in people with cerebral palsy (CP) is limited in terms of the number of studies, the means of assessing PA levels, and in the lack of focus on the pediatric population with CP. Similarly, there is only one preliminary study that has used an accurate measurement tool to examine the body composition of youth with CP. Further research is needed to truly understand differences in body composition between youth with CP and their typically developing (TD) peers. Finally, although postural control and muscle strength have been examined in this population, small sample sizes and/or lack of stratification (by functional ability) limit the generalizability of the results to those with specific distributions of involvement (DOI) or specific Gross Motor Function Classification System (GMFCS) levels.

1.2 Research Purpose

This study used objective, valid, reliable, and functionally relevant methods to examine differences in PA levels, body composition, postural control during bipedal stance, and lower-extremity isometric muscle strength in youth with spastic CP compared to their age- and sex-matched TD peers. The purpose of this study is to address knowledge gaps in PA and body composition and provide a greater understanding of the magnitude of balance and strength impairments in youth diagnosed with spastic CP. Accelerometry was used to measure time spent at the different levels of PA intensity. Dual-energy X-ray absorptiometry (DXA) was used to evaluate body composition. Standing postural control was measured by examining kinetic outcomes including center of pressure (COP) and vertical ground reaction force (VGRF) values during bipedal stance on force platforms. Maximum lower-extremity isometric muscle strength

was measured using hand-held dynamometry bilaterally for the hip abductors, adductors, extensors, and flexors, the knee extensors and flexors, and the ankle plantar flexors and dorsiflexors. The objective measurement of any differences in these outcomes between study groups will be beneficial to researchers and clinicians to inform the development of multimodal rehabilitation interventions that will reduce morbidity related to the secondary conditions that develop with CP (e.g., fatigue, contractures, pain, obesity).

1.3 Research Objectives

1.3.1 Primary Objectives

- a) To examine if the amount of daily time (minutes) spent at different PA intensity levels (i.e., sedentary, light PA, and moderate-vigorous PA [MVPA]) and daily step counts differ between youth (age 10 to 18 years) with spastic CP and age- and sex-matched TD youth (age 10 to 18 years).
- b) To evaluate body composition (i.e., fat mass index [FMI], lean mass index [LMI], and body mass index [BMI]) in youth with spastic CP compared to age- and sex-matched TD youth.

1.3.2 Secondary Objectives

- a) To evaluate differences between youth with spastic CP and their age- and sex-matched TD peers during quiet bipedal standing using measures of COP (i.e., 95% ellipse area and total path length [TPL]) and VGRF of both the preferred weight-bearing and non-preferred weight-bearing limb.
- b) To evaluate the reliability of using hand-held dynamometry to measure lower-extremity voluntary isometric muscle strength of the hip abductors, adductors,

- extensors, and flexors, the knee extensors and flexors, and the ankle plantar flexors and dorsiflexors in youth with spastic CP and their age- and sex-matched TD peers.
- c) To examine differences in bilateral lower-extremity voluntary isometric strength using hand-held dynamometry between youth with spastic CP and their age- and sex-matched TD peers.

1.4 Rationale

There is a paucity of research examining PA and body composition in a purely pediatric population with CP. Though there is more research evaluating postural control and lower-extremity strength in this population, there are still questions related to the magnitude of impaired balance and strength that need to be answered to ensure the best possible treatment is available for youth with CP.

Physical Activity and Body Composition

The use of valid and objective outcome measures (e.g., ActiGraph accelerometers and DXA) is still relatively new in this population, and as such, the results will not be directly comparable to the full literature base. However, the more objective tools combined with a more robust sample (with the possibility for stratification based on GMFCS levels) will advance the current state of evidence and provide a more comprehensive picture of these outcomes as they are experienced by individuals with CP to inform future rehabilitation practices. BMI will be used to compare the data gained in this study to the published literature while the DXA data will be used to make inferences as it is the more robust measure of body composition.

Research evaluating body composition in youth with CP is limited. In the existing literature, BMI and bioelectrical impedance analyses (BIA) have been the most commonly used

instruments to measure body composition in youth with CP. BIA is an indicator of percent fat mass and a better indicator of health than BMI. The DXA scan has some capabilities that other methods do not have, such that it can examine specific regions of the body and is capable of distinguishing between the different types of mass (i.e., fat vs. lean vs. bone).

Regarding PA levels, the evidence using objective measurement tools in CP is still emerging. Previous studies measuring intensity level of PA have used daily activity diaries, heart rate monitors, step counters, and more recently accelerometers. Thus, the purpose of examining PA intensity levels and body composition in this study is to determine whether differences between cohorts exist when objective measurement tools are used.

Balance and Strength

Balance and strength have been better researched in youth with CP, yet these studies are plagued with small sample sizes and findings that are confounded by the lack of stratification based on functional ability levels and the distribution of involvement. COP total path length and 95% ellipse area was recorded for each limb to determine how postural control during quiet standing differs between the cohorts. Hand-held dynamometry is a reliable measurement tool to assess maximal muscle strength, however, the testing position, strapping and stabilization, and the use of a “make test” versus a “break test” can influence the reliability of this tool as an outcome measure. In this study, we elected to use different positions for testing strength than have been used in previous research, therefore, it was important to assess the reliability of the protocol for testing maximal voluntary strength that was designed for this study. The decision to use the selected positions was made based on their functional relevance, safety, and the ability to use strapping for stabilization purposes.

The links between physical inactivity and poor health outcomes such as functional deterioration¹ and decreased social involvement² are indications of the need to determine how much PA youth are currently getting and how clinicians can better prescribe PA to increase active participation and healthy life habits. As such, by objectively examining PA levels we may in part gain additional insight as to why previous research has shown that body composition of youth with CP differs, their patterns of postural control during standing are impaired, and their strength is diminished, in comparison to their TD peers.

1.5 Summary of Thesis Format

This thesis is comprised of six chapters including: introduction, literature review, methods, results, discussion, and conclusions. Chapter One is an introduction of the thesis, which contains a problem statement, research purpose, objectives, rationale, and a summary of the thesis format. Chapter Two is an introduction to CP and a narrative review of the literature related to PA, body composition, strength, and balance. The narrative review contains a summary of what is known in each subject area, the arguments for or against different measurement techniques, and the relevance of understanding the outcomes related to each subject area. Chapter Three is a description of the methodology used in this research study. It is comprised of the study design, sample (inclusion/exclusion criteria), data collection procedures, statistical analysis, and ethical considerations. Chapter Four contains results for the primary, secondary, and exploratory objectives. Chapter Five presents a discussion of the results of this study as well as the strength and limitations of this research. Finally, Chapter Six concludes this thesis with final statements and implications for future research.

Chapter Two: Literature Review

2.1 Introduction

2.1.1 Definition and Prevalence of Cerebral Palsy

Cerebral palsy (CP) is an umbrella term used to describe a neurological disorder of movement and posture that results from the occurrence of a non-progressive lesion in the developing fetal or infant brain.³ CP affects an individual's motor control, coordination, and muscle tone,³ as well as reflexes and balance.⁴ As a result, individuals with CP often experience activity limitations and secondary musculoskeletal conditions (e.g., muscle/tendon contractures) that develop during the lifespan and are known to be related to growth, spasticity, and ageing.³

Based on earlier epidemiological studies, it is estimated that for every 1000 live births there are between 2.09 and 2.22 individuals who are diagnosed with CP.⁵⁻⁸ Each individual is affected by CP differently due to the location and timing of the disturbance in the brain. CP has a number of risk factors, some of which include, but are not limited to, multiple births, infections, antepartum vaginal bleeding, second stage of labour lasting longer than 4 hours, premature birth, low birth weight, untreated hyperbilirubinaemia, and fetal anoxic events.⁹⁻¹² Neonatal and perinatal strokes also influence the risk, type, and severity of CP that an individual may be diagnosed with.^{13,14} Premature birth and low birth weight are among the leading risk factors for CP.¹¹

2.1.2 International Classification of Functioning, Disability and Health

The International Classification of Functioning, Disability and Health (ICF) is a framework that provides a common language to document and organize information related to health-related function and disability that can be used by healthcare professionals and persons

who have lived experiences with disability (Figure 2.1).¹⁵ The ICF divides the description of an individual's health condition into different levels, such that, functioning is defined as a “dynamic interaction between a person's health condition, environmental factors and personal factors.”¹⁵ The ICF provides a structured method to explore and describe the interaction between a health condition, contextual factors and the resulting impact on functioning and disability of each individual.¹⁵ This model is intended to describe broader human functioning and does not necessarily imply poor health, disease, or disorder. The first part is functioning and disability, which is divided into two components, body functions and structures and activities and participation.¹⁵ The second part is contextual factors, which is divided into two components, environmental factors and personal factors.¹⁵

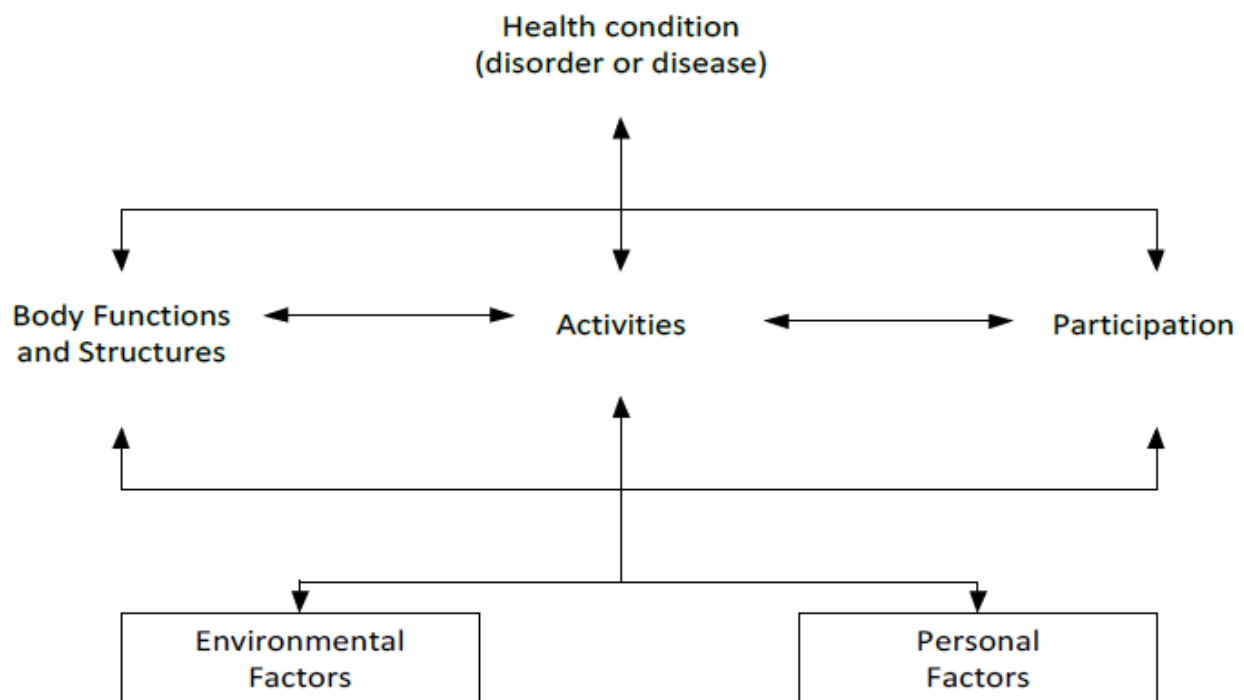


Figure 2.1 The ICF Model: Interaction between ICF components¹⁵

The 2006 consensus definition of CP,³ in this case the health condition, uses the terminology used by the ICF to describe functioning and disability. As such it makes sense to study CP as the interaction between the different ICF components. As such this thesis explores four outcomes at the ICF levels of body structure and function and activities.

2.1.2.1 Classifications within a Diagnosis of Cerebral Palsy

Based on the variety of effects that CP has on function, individuals diagnosed with CP are classified based on different subtypes (movement patterns), distributions of involvement, and the level of gross motor function. Movement patterns of CP include spastic type (affecting 75% to 89% of individuals with CP,^{5,6,16,17} and manifests as jerky movements with muscle stiffness and tightness),¹⁸ dyskinetic, ataxic, and mixed types.¹⁹ Distribution of involvement (DOI) categorizes individuals with CP based on which of their limbs are affected. Unilateral CP refers to either a monoplegia (one affected limb) DOI or a hemiplegia (one affected side of the body [left or right]) DOI. Infants born at term with single hemisphere injuries (e.g., perinatal stroke)¹³ most commonly have a hemiplegia DOI.²⁰ A classification of bilateral CP refers to any one of the following: diplegia (both legs are affected), triplegia (both legs and one arm are affected), or quadriplegia (both arms and both legs are affected).¹⁸ Infants who are born prematurely and have periventricular leukomalacia more commonly have a diplegic DOI, whereas those born with a diffuse central nervous system injury commonly have a quadriplegic DOI.²¹

For the purpose of categorizing individuals based on their (functional) ability to move about their home and community, a five level system called the Gross Motor Function Classification System (GMFCS) is used.²² Youth who are categorized as a GMFCS level I are ambulatory individuals capable of moving throughout their home and community without the use

of assistive devices. An individual with a GMFCS level II is somewhat more restricted in their movement and may be somewhat dependent on mobility aids (i.e., forearm crutches) or assistive devices (i.e., hand rails) to assist them as they navigate their environment. Whereas, youth classified as a GMFCS level III, though ambulatory, will require the use of mobility aids to move around (e.g., arm crutches, manual wheelchair). Youth with GMFCS levels IV or V are considered non-ambulatory individuals who move about their home and community in either a manual or power wheelchair and are often assisted by a caregiver.²² As the disorder known as CP results in a very diverse population, it is difficult to study each of the various combinations of the different classification systems and draw conclusions that apply to anyone of the groups specifically. In the current study, GMFCS levels, were selected for the stratification of the exploratory analyses. The purpose of selecting GMFCS level was in part that past research has explored a number of these outcomes using DOI. Additionally, as GMFCS level impacts an individual's ability to stand and move independent of mobility aids or assistive devices it is likely to drive differences seen between cohorts more than DOI.

2.2 Literature Review

2.2.1 Activity Level

In terms of the ICF, activity refers to an individual's ability to execute a task or action.¹⁵ In the context of this thesis, the physical activity (PA) outcomes, including amount of total sedentary time, light PA, and moderate-vigorous PA (MVPA), are measures of the ICFs activities level. These outcomes are measures of an individual's ability to meet age appropriate PA guidelines. Secondary conditions, such as contractures, are often associated with CP, and can result in activity limitations (the negative term associated with the activity level) that are related

to reduced mobility.³ An aim of this thesis is to determine how a diagnosis of CP limits activity in the sense of how much time is spent moving about ones environment and at what intensity level. A brief examination of what proportion of youth with CP are able to meet the current age appropriate PA guidelines was also included in this thesis. At present, the Canadian Society for Exercise Physiology²³ recommends that children and youth (5-17 years of age) require at least 60 minutes of MVPA per day. The current guidelines suggest that children and youth, 5 to 17 years old, should spend several hours daily in light activities (structured and unstructured) and should not have more than 2 hours daily of recreational screen time.²³ Further, these guidelines address recommended nightly sleep times such that those 5-13 years old should get an uninterrupted 9 to 11 hours of sleep each night, whereas 14-17 year old youth should try to achieve an uninterrupted 8 to 10 hours of sleep each night.²³ Within the preamble of this document it is stated that “these guidelines may be appropriate for children and youth with a disability or medical condition; however, a health professional should be consulted for additional guidance.”²³ With this said, Verschuren et al.²⁴ recommends that individuals with CP should engage in a minimum of two to three cardiorespiratory endurance sessions per week (minimum of 20 minutes long) at an intensity of 60% to 95% of peak heart rate for at least 8 consecutive weeks. In addition, they recommended including strength training in the weekly exercise routine, such that following a short familiarization period individuals with CP perform one to four sets of six to fifteen repetitions for a 12-16 week program.²⁴

2.2.1.1 Cerebral Palsy and Physical Activity

The previous literature has reported that children and youth diagnosed with CP take part in less MVPA than their typically developing peers. Specifically, Ryan et al.²⁵ reported that 66%

of children with CP achieved 90 minutes of MVPA per day compared to the 93.9% of their peers who met the same guidelines. Though this seems like a large percentage of participants meeting the guidelines, this may be due to the young age (6-10 years) of the Irish sample. Similar to the results in all youth, other researchers examining PA in children with CP have actually reported a smaller proportion of children meeting the guidelines than Ryan, et al.,²⁵ yet these proportions were similar to those reported for the typical Canadian youth populations. A study by Mitchell, Ziviani, and Boyd²⁸ reported that on at least one day a week only 25% of children and adolescents with unilateral spastic CP were meeting the recommended guidelines of 60 minutes per day of MVPA. Yet it is important to remember that although several of their participants were meeting the PA guidelines, many of these individuals may only have met the guidelines on a single day during that week, which would likely limit the potential impact of achieving the recommended amount of MVPA. Further, Gorter, et al.²⁹ reported that 26% of youth with CP were meeting MVPA guidelines on 3 to 5 days per week. By comparison, previous research on Canadian youth (12-17 years of age) using accelerometry has estimated that only 5% of all youth met the age appropriate PA guidelines.²⁶ Although slightly higher, Canada's most recent ParticipACTION report card suggests that between 21% and 40% of Canadian youth are getting at least 60 minutes of MVPA per day.²⁷ However, this discrepancy may be due to the use of different methodologies to determine the proportions meeting the guidelines and potentially the examination of different age groups. Despite this evidence there has been little research done that directly compares the PA intensity levels of youth with CP to their TD peers. Due to small sample sizes it has not been possible to stratify based on functional ability level (i.e., GMFCS) or to determine the role that topographical distribution of involvement of CP plays, thus the

generalizability of the results is diminished. Additionally, because of the different ways results have been presented (i.e., on at least one day per week, 3 to 5 days per week, etc., and 60 minute vs. 90 minute guidelines) it is challenging to compare results across studies.

Previously PA levels have been evaluated using many different methodologies and technologies (i.e., total daily energy expenditure to sleeping metabolic rate ratios (TEE/SMR),³⁰ heart rate reserve,³¹ VitaMove System,³² self-report,³² StepWatch activity monitor,³³ ActiGraph GT3X+,²⁸ Activ-PAL,³⁴ and RT3 accelerometer²⁵). In the literature pertaining to PA levels there is only one study has made a direct comparison of this outcome between children with CP and TD children. This study reported significantly lower total daily energy expenditure to sleeping metabolic rate ratios (TEE/SMR) in children with CP.³⁰ Based on these results, van den Berg-Emons and colleagues³⁰ concluded that children with spastic diplegia were much less active than their TD peers. Other studies have compared heart rates or walking activity levels of children with CP to their TD peers. For instance, a study by Robert et al.³¹ found no significant differences in the resting and working heart rates of children with CP compared to their TD peers during involvement in active video games. With this they concluded that children with CP can receive the same health benefits as their peers from playing active video games and that they spend the same amount of time at different PA intensities as their peers.³¹ However, this study did not look at routine (day-to-day) PA and is likely only generalizable to children with a GMFCS level of I or II, as their study did not include those with a GMFCS level III, IV, or V. Using walking activity rates in the United States and the Netherlands, Van Wely, et al.,³³ reported no between country differences in terms of the TD population, however they did report that GMFCS level and home country affected the walking rates of children with CP. Even

though they did not make a direct comparison between CP and TD cohorts, they have suggested that Dutch children with a GMFCS level I or II were less active than their American counterparts whereas Dutch children with a GMFCS level III appeared to be more active.

Understanding how PA levels differ between youth with CP and their TD peers is an important step to determining how participation rates, PA opportunities, and levels of PA during available activities differ between youth with CP and their TD peers. Additionally, by studying daily PA levels we can better explain how PA affects indicators of long-term health concerns (i.e., the link between obesity and heart disease or diabetes) or short-term how to maintain range of motion of a joint. PA habits developed in childhood are known to be predictive of PA practices as an adult.³⁵ Often individuals drop out of structured PA opportunities during their youth. Thus, the study of PA levels of youth is important as it can help to inform the need for increased PA and recreation opportunities. Although the measurement of PA levels does not directly describe participation, but rather an individuals' ability to execute a task (i.e., be physically active), it allows us to infer that if a child is unable to meet the standard criteria/guidelines the opportunities or choice to participate in valued life situations may be lacking. Ultimately, the goal would be to increase the amount of meaningful PA that provides lifelong health benefits to individuals living with CP.

2.2.2 Body Structure and Function Level

Based on the ICF, the body structures and functions are defined as anatomical parts of the body such as organs, limbs and their components and the physiological functions of body systems.¹⁵ In this thesis, body structure refers to the body composition outcomes including fat mass index (FMI), lean mass index (LMI), and body mass index (BMI). In this thesis the body

functions section of this component of the ICF, will include the measurement of postural balance and lower-extremity strength. The balance outcomes, including center of pressure (COP) total path length (TPL) and 95% ellipse area and vertical ground reaction force (VGRF), fit well into this component of the ICF because these are means of measuring whether a significant deviation (i.e., impairment) is present in an individual's postural control. As for the lower-extremity muscle strength outcomes (i.e., hip extensors, flexors, abductors, and adductors; knee extensors and flexors; ankle dorsiflexors and plantar flexors), the body functions component is most appropriate because the aim is to measure whether an impairment is present and the magnitude of such an impairment.

2.2.2.1 Body Composition

A report by Statistics Canada³⁶ notes that 55% of boys (12-17 years) were of a normal weight, 23% overweight, and 21% obese, whereas 68% of girls (12-17 years) were of a normal weight, 18% overweight, and 12% obese. Although a study by Toomey, et al.³⁷ did not include children or adolescents with CP, their report of body composition differences between individuals with and without a history of injury, suggests that these measures may also be sensitive to comparing the body composition of youth with CP to their TD peers. The study by Toomey, et al.³⁷ reported that in their sample, healthy young adults (15-26 years) had a mean BMI of 23.5, with a mean fat mass of 20.2%, and a FMI of 4.6.

2.2.2.1.1 Cerebral Palsy and Body Composition

In the existing literature, the body composition of children and adolescents with CP is poorly understood. Of the few studies that examine body composition in youth with CP only one made a direct comparison between youth with CP and their TD peers, whereas others look at

percentage of youth with CP who are categorized as underweight, normal weight, overweight, or obese. A study by Sison-Williamson and colleagues³⁸ found that the mean percent body fat of children and adolescents with CP ranged from 25% (GMFCS level I) to 29% (GMFCS level III). Additionally, they reported that 10% American children with CP were underweight, 54% of a healthy weight, 21% overweight, and 15% obese.³⁸ Alternatively, an Australian study found that only 7% of children with CP were underweight, 73.6% of a healthy weight, 7.3% overweight, and 12.1% obese.³⁹ Taking this one step further, the study reported that of the those with a GMFCS level I, 72% of children with CP were of a healthy weight compared to 63% (healthy weight) with a GMFCS level III.³⁹ The percentage of obese children with GMFCS level III was higher than the those with a GMFCS level I, 18% and 9%, respectively.³⁹ Although this study did not directly evaluate differences in body composition between children with CP and their TD peers, they did suggest that a smaller proportion of the children with CP were obese than children in the general population, 19.4% compared to 25%, respectively.³⁹ The one study that did directly compare the body composition of children with CP to their TD peers, reported significant differences between cohorts.³⁰ Further a study by Finbråten et al.⁴⁰ using dual-energy X-ray absorptiometry (DXA), found body composition differences based on GMFCS levels, such that children and adolescents with GMFCS levels I or II had lower percent body fat compared to children and adolescents with GMFCS level III, IV, or V (25.3% vs. 33.5%, respectively), higher percent lean mass (72.8% vs. 63.6%), and slightly higher percent bone mass (3.1% vs. 2.9%).

Previously, most studies have used BMI as an indicator of an individuals' weight status, categorizing children as underweight, healthy weight, overweight, or obese,^{38,39} based on the

Centre for Disease Controls Growth Chart criteria.⁴¹ Bioelectrical impedance analysis (BIA) is another system that has been used to assess BC of children with CP.^{38,42,43} Similar to studies that have used BMI, those that have used BIA have not drawn a clear conclusion, such that we can be confident in whether or not there are differences in body composition between children with CP and their peers. One study using BIA reported no difference of extracellular mass, lean body mass, body cell mass, and fat mass between cohorts,⁴² yet another study reported children with CP have less fat free mass and total body water.⁴³ A third study suggested that percent body fat differs between GMFCS levels, such that individuals classified as a GMFCS level III have a higher percent body fat than their peers classified as a level I or II.³⁸ More recently, the study by Finbråten et al.⁴⁰ used DXA to examine body composition, however this research is still at the beginning stages as they authors combined individuals with GMFCS levels I and II and those with GMFCS levels III, IV, and V together.⁴⁰ Unfortunately, by not stratifying by each GMFCS level it is not possible to determine whether differences exist between GMFCS levels, nor would it possible to design targeted interventions for individuals based on their ability to move.

Although BMI and BIA are easy to do and are low risk to the participants, the advantage of using DXA is that it allows for the exploration of the distribution of fat and lean mass as well as having the capability to determine bone mineral density. Though BMI is a commonly used tool it does not tell us anything about type of mass (i.e., fat, lean, bone) and the distribution of said mass. As such it can provide a misguided classification of weight status and is likely to obscure relevant differences in the type of mass and distribution of the different masses that make up the whole body.

Further evaluation of body composition in youth with CP is necessary for a couple of reasons. Body composition is poorly understood in youth with CP and results of previous studies have not provided a definitive answer as to whether the body composition of youth with CP differs from that of their TD peers. Secondly, by using a methodology that allows the exploration of the distribution of mass and type of mass, it may be possible to predict future health status, or at least possible to target changes to prevent long-term poor health.

2.2.2.2 Balance

2.2.2.2.1 Cerebral Palsy and Standing Posture

Balance research in youth with CP has found that children and adolescents with a diplegic DOI have altered balance measures when compared to their TD peers.⁴⁴ For example, a study of ambulatory children with bilateral CP, found the COP path length to be longer, the average radial displacement to be larger, and the mean frequency of sway to be smaller during both eyes open and eyes closed conditions in children and adolescents with CP compared to their TD peers.⁴⁴ Despite these significant differences between cohorts, the authors noted that two-thirds of their participants had “normal” standing balance values for all COP measures, and based on this, they concluded that standing postural control is not necessarily a problem for children and adolescents with spastic diplegic CP.⁴⁴ Unfortunately, the authors did not explore how these COP measures were affected by an individual’s gross motor function. A different study done by Chérng, et al.⁴⁵ found that children with diplegic CP performed markedly different from their matched partner in most sensory conditions such that they had greater variation in their stance and less stability. However, they also made no mention of how gross motor function may have impacted these results. A study by Saxena, et al.⁴⁶ had similar findings to the other two

studies regarding individuals with a diplegic distribution of CP, however, they found children with a hemiplegic distribution of CP had balance patterns similar to their TD peers. It is important to note that not many of their participants had a hemiplegic DOI. Again, gross motor impairment should be investigated to determine whether or not it is an influential factor of postural control.

Balance or postural control have previously been researched in several different ways, these include examining: kinematics data to determine motion of the center of mass,⁴⁷ COP measures as recorded by force platforms,⁴⁴⁻⁴⁶ electromyographic activity to determine muscle activation patterns,⁴ and the Berg Balance Scale.⁴⁸ It seems more common in the balance literature to group for analysis by DOI rather to determine the impact of the impaired gross motor function on balance patterns and abilities. Balance has been researched using very different methodologies and technologies in part because there are several different systems involved in controlling ones' posture. Unfortunately, because of the differences in study designs it is difficult to compare results across studies and to determine how all the different outcomes relate to each other. The Berg Balance Scale is a reliable way to test functional skills in the sense of ones' ability to complete everyday tasks and it can discriminate between individuals who do or not require gait aids during ambulation. Yet it is a subjective measure that does not perform well when comparing individuals with a unilateral DOI CP or those with mild balance deficits to their peers. As such the Berg Balance Scale has reduced sensitivity and is unlikely to be able to provide enough information about a balance function impairment in children with CP.

Balance is a necessary function for most activities throughout daily life, such that an impairment may result in reduced independence, or a dependence on gait aids. Understanding

how balance is impaired and the magnitude of such an impairment is critical to determining how to counteract the possibility of impaired function. A few studies have examined differences between children with CP and their TD peers. Most have focused or grouped based on DOI. However, the findings regarding those with a hemiparetic DOI are more variable and require further clarification. In addition, future balance research should consider grouping based on GMFCS levels rather than DOI to determine whether balance impairments are guided more by the severity of the motor impairment or its distribution. As an impaired function such as balance can affect an individual's ability to execute a task (resulting in an activity limitation), it could also reduce that person's ability or desire to participate, thus having a negative effect on the individual and put them at greater risk for poor long-term health.

2.2.2.3 Strength

2.2.2.3.1 Cerebral Palsy and Lower-extremity Strength

The previous literature pertaining to strength has reported a definitive weakness in the musculature of children with CP.⁴⁹ The reported muscle weakness is such that children with a diplegic DOI were significantly weaker, in eleven of twelve tested muscle groups on their dominant side and all twelve muscle groups on their non-dominant side, compared to their TD peers.⁴⁹ This same study also reported that children with a hemiplegic DOI were significantly weaker than their TD on their non-dominant (affected) side in all twelve muscle groups.⁴⁹ However, only four of twelve muscle groups on their dominant side were found to be significantly weaker than those of their TD peers.⁴⁹ Furthermore, those with a hemiplegic DOI were significantly weaker on their non-dominant (affected) side compared to their own dominant

side with four of twelve muscle groups, whereas no significant side-to-side differences were reported for those with a diplegic DOI.⁴⁹

Formerly, muscle strength has been tested using manual, functional,^{50,51} isokinetic,⁵² and isometric methodologies which have included the use of both hand-held and instrumented dynamometry.^{49,53-55} Although manual muscle tests are easy to perform and do not require equipment they are an inherently subjective means of measuring strength, such that the examiner's experience may influence an individual's results. In addition, functional tests such as the standing heel-rise or the five-times-sit-to-stand tests, though indicative of mortality in elderly populations, do not indicate weakness of muscles (not isolating specific muscle groups). Therefore, it is difficult to determine what exactly needs to be improved to reduce an impairment in function. Although isokinetic testing is more relevant, as it measures power throughout the range of motion, it is a time-consuming process, the equipment consumes space, and it is not the most affordable means of measuring strength.

Previous studies have reported high reliability using hand-held dynamometry for pediatric populations with CP (interclass correlation coefficients [ICC] ranging from 0.86-0.96 for the various muscle groups of the lower-extremity).⁵⁵ They also found that using the average of three measurements added little to the reliability of the measurement and that taking an average of two trials was sufficient.⁵⁵ Hand-held dynamometers are more affordable and can be used to test the strength of many muscle groups in a shorter period of time than isokinetic systems. With this said there are two methods for measuring isometric strength with hand-held dynamometers, the "make test" (participants push as hard as they can for a set period of time into the stationary hand-held dynamometer) and the "break test" (participants push as hard as they

can into a dynamometer that the examiner is also pushing against and the trial is over once the examiner has overpowered the participant). A study by Verschuren, et al.⁵⁴ reported that both methods were questionable, but that “make tests” tended to be slightly more reliable than “break tests.” Although most research using “make tests” have relied on the examiner to hold the hand-held dynamometer in place, a recent study found that fixation of the hand-held dynamometer could negatively influence the reliability of maximal ankle plantar flexors strength measurements.⁵⁶ Davis and colleagues⁵⁶ concluded that when the hand-held dynamometer was fixed to a metal plate, which was fixed in a standard position, participants were able to produce higher forces. However, when their physiotherapists held the hand-held dynamometer the reliability of maximum ankle plantar flexor measurements was increased.

A study by Eek and Beckung⁵⁷ has reported that there is an association between muscle strength and gross motor function measure scores, concluding that weakness is related to decreased walking ability/independence. Yet another study reported that muscle strength cannot explain standing ability.⁵⁸ Though the body function outcome differed in these studies, further research should be done to determine whether muscle weakness has a role in balance impairments or fatigue, which may result in activity limitations and participation restrictions. Other studies have reported that strength of children with CP can be increased with strength training, and/or increased PA,⁵⁹ however lasting changes have not been reported in the literature.⁶⁰ Essentially once participants complete the program, if they do not maintain their involvement in a similar program the health benefits of improved function are lost. Further research into how muscle strength relates to current PA levels may be useful in informing better long-term physical and mental health.

2.2.3 Limitations in the Literature

There are some limitations to the existing literature. Many of the studies have had small sample sizes, thus the researchers are unable to stratify, and their results are not generalizable to individuals classified as a specific GMFCS level or based on distribution of involvement. Further, the lack of stratification makes the design interventions targeted at individuals with CP more difficult, as CP is a disability that impacts each person differently. In addition, most of the previous literature has not stratified based on age or sex, but rather has lumped the data together, which is not a common practice for these outcomes when explored in terms of a TD population. Another limitation of the existing research is that different studies have used different means of measuring the same outcome, particularly with the PA outcomes, causing some contradictory results and conclusions. Also, as a result of the different tools and methodologies used, it is difficult to compare results across studies. Previously, research pertaining to balance which explored COP outcomes only collected data using one force plate and was not able to distinguish impaired balance patterns between limbs.

2.2.4 Summary

To summarize, children with CP are less physically active than their TD peers and body composition seems to differ between GMFCS levels. Additionally, the research has shown that youth with a bilateral distribution of involvement have a significantly altered balance compared to their TD peers, whereas those with a unilateral distribution of involvement do not differ from their peers. With this said the balance patterns of youth with a unilateral distribution of CP has not yet been explored enough to know whether the less/un- affected limb is compensating for their affected side. Lastly, although previous literature has noted a definitive muscle weakness in

those with CP this has yet to be explored by GMFCS level. Additionally, the previous literature has reported that the reliability of testing muscle strength differs based on the protocol that is used and thus it is important to investigate the reliability of new protocols.

Chapter Three: **Methods**

3.1 Study Design

This is a cohort study with a matched-pair design. Participants include youth (ages 10-18 years) with cerebral palsy (CP) and their age- (within 12 months) and sex-matched typically developing (TD) peers. Data were collected between October 2016 and April 2018. This study was approved by the University of Calgary Conjoint Health Research Ethics Board (Ethics ID: REB15-3126). This Master of Science thesis project is embedded within a larger cohort study aimed at examining the functional abilities and current symptoms related to CP for gaining a better understanding of how pain, fatigue, and other symptoms associated with CP affect functional tasks and participation in life activities.

3.2 Study Sample

Participants in this study include ambulatory youth (ages 10-18 years) with CP [Gross Motor Function Classification System (GMFCS) levels I-III] and TD peers. Youth with CP were recruited using three methods: 1) the posting of paper advertisements in the Pain and Rehabilitation Services Neurosciences Clinic at the Alberta Children's Hospital and through community organizations (e.g., Cerebral Palsy Alberta, Cerebral Palsy Kids and Families, Alberta Cerebral Palsy Sport Association); 2) through access to a clinical database of individuals who consented to be contacted about research studies associated with the Pain and Rehabilitation Services Neurosciences Clinic at the Alberta Children's Hospital; and 3) via word-of-mouth from parents of study participants, study staff, and students in the Sport Injury Prevention Research Centre (SIPRC). Eligible participants either contacted study staff to volunteer as a participant or were contacted by a member of their circle of care and who obtained consent to

provide their contact information to the study team. Through convenience sampling we aimed to recruit participants in such a way that our study sample reflected the proportion of youth within the GMFCS levels I, II, and III (indicating degree of independence during walking) in the neuromotor database of the Alberta Children's Hospital Pain and Rehabilitation Services Neurosciences Clinic (i.e., GMFCS level I [59%], II [27%], III [15%]). Age- and sex-matched TD youth were recruited based on eligibility using three methods: 1) snowball sampling of siblings and friends of youth with CP who have agreed to participate; 2) convenience sampling through the Healthy Infants and Children Clinical Research Program (HICCUP); and 3) via word-of-mouth from members of the SIPRC laboratory or the study staff. HICCUP is a program that children in Calgary and area can register with for the purpose of participating in research studies as a healthy control.

Inclusion Criteria for Participants with Cerebral Palsy:

- Youth 10 to 18 years of age;
- With an ongoing clinical diagnosis of CP;
- A GMFCS level I or II or III; and
- The ability to complete self-report questionnaires in English.

Exclusion Criteria for Participants with Cerebral Palsy:

- Received botulinum toxin injections within six months prior to participation;
- Had a surgical procedure within one year prior to participation;
- Has uncontrolled epilepsy;
- A GMFCS level IV or V; or
- Was unable to follow instructions given in English.

Inclusion Criteria for Typically Developing Participants:

- Youth 10 to 18 years of age;

Exclusion Criteria for Typically Developing Participants:

- A current or past diagnosis of a neurological condition;
- A musculoskeletal injury within three months prior to testing from which they had not completely recovered or any current medical condition that prevented their participation in functional testing; and
- Was unable to follow instructions given in English.

3.3 Procedures***3.3.1 Data Collection***

Testing of each participant typically occurred on two days (7-10 days apart), with the first session in the C. H. Riddell Movement Assessment Centre at the Alberta Children's Hospital and the second session in the Human Performance Laboratory and the Sport Medicine Centre at the University of Calgary. The first testing session was scheduled for three hours and began with a review of the consent forms. During the first session, participant's height and waist circumferences (narrowest point and iliac crest) and weight were measured, Center of Pressure (COP) and vertical ground reaction forces (VGRF) during bipedal standing balance were collected, lower-extremity strength was measured bilaterally, and ActiGraphs were fitted and the non-wear time log was explained and provided to the participants. Additionally, as part of the larger study participants completed a six-minute walk test during their first visit, which captured biomechanical, fatigue, and energy expenditure outcomes. The second testing session was scheduled for 75 minutes. During the second testing session participants returned their

ActiGraph Accelerometer with their completed non-wear time logs and participated in a Dual-energy X-ray Absorptiometry (DXA) scan (15 minutes). Participants recruited after March 2017 were asked if they would consent to an additional round of strength testing to determine the reliability of the lower-extremity strength measurements used in this study. Those who consented to the reliability study completed the second round of strength testing during the second testing session (resulting in an additional 60 minutes during the second session).

3.3.2 Outcome Measures

This study compared outcome measures related to some of the components of the international classification of functioning, disability, and health (ICF; the activity level and the body structure and function level) between youth with CP and their age- and sex-matched TD peers. Activity level outcomes include the amount of time, in minutes, that participants spent sedentary, in light physical activity (PA) and moderate-to-vigorous PA (MVPA). The remaining outcomes were body structure and function level outcomes. Body composition included outcomes of fat mass index (FMI), lean mass index (LMI), and body mass index (BMI). Balance included outcomes of center of pressure (COP) total path lengths (TPL) and 95% ellipse areas, and vertical ground reaction forces (VGRF) for both lower-extremities. Strength included outcomes of torque normalized to body mass produced by eight different muscle groups (hip extensors, flexors, abductors, adductors, knee extensors and flexors, and ankle dorsiflexors and plantar flexors) for both lower-extremities.

3.3.2.1 Activity Level Outcomes

3.3.2.1.1 Physical Activity Intensity Levels

We requested that each participant wear an ActiGraph wGT3X-BT accelerometer (ActiGraph, USA) for one week (seven days and nights) around their waist, except for during bathing or swimming activities. The ActiGraph is a small (46 x 33 x 15 mm), lightweight (19 g), battery-powered tri-axial accelerometer (vertical, horizontal, and perpendicular axes) device that recorded time-varying accelerations ranging in magnitude from 0.05 to 2.5 Gs. Prior to fitting the ActiGraph over the right hip of each participant at the end of the first testing session, a member of the study team initialized the ActiGraph as per the SIPRC ActiGraph standard operating procedure using ActiLife software (Appendix A). The ActiGraph was initialized with the participants study ID number, sex, height, weight, DOB, and race; ‘Limb’ was set to waist and ‘Side’ to right. As stated in the SIPRC ActiGraph standard operating procedure the ActiGraph was set to a sample rate of 30Hz, with no LED or wireless options selected and the idle sleep mode was disabled. Additionally, each participant was provided with a non-wear time log that they were to record the time and reason for taking the ActiGraph off (Appendix A).

After one-week, participants returned the ActiGraph to the research team either at the second testing session or via a padded envelop in the mail (for those who lived outside the city). Those participants who lived outside the city completed the DXA scan during the first testing session and did not participate in the second session of strength testing. The study team then downloaded the data using the ActiLife software and the SIPRC ActiGraph standard operating procedure. Data was downloaded with an Epoch length of 10 seconds, number of axes set to three, and ‘Steps’, ‘Lux’, ‘Inclinometer’, and ‘Low Frequency Extension’ were all applied. The

downloaded data were then converted to 15 second epoch files, as previous research had used validated the use of Evenson cut points for the 15 second epoch.^{61–63} Using the ‘Wear Time Validation’ tab in the ActiLife software, the returned non-wear time log, and the SIPRC ActiGraph standard operating procedure, the methods described by Choi et al.⁶⁴ was selected to define ‘Non-wear periods’(i.e., validate wear time), with a ‘Minimum Length’ of 60 minutes, a ‘Small Window Length’ of 30 minutes, and a ‘Spike Tolerance’ of 2 minutes and with ‘Use Vector Magnitude’ selected. Following the calculation of wear times based on the Choi algorithm, wear and non-wear times were confirmed using the completed non-wear time logs provided by the participants. For this thesis the total sedentary time is inclusive of sleep time.

The data were then scored and exported based on the validated wear time. The following variables were scored and exported: Energy Expenditure, METs, Cut Points and MVPA, Bouts, and Sedentary Analysis were extracted from the analysis. The Cut Points and MVPA were determined using the Evenson Children algorithm.⁶¹ The use of ActiGraphs and the Evenson algorithm have been previously validated for use in children who are typically developing as well as those who have a diagnosis of CP.^{61–63} Once the ‘Scoring’ was complete the data was exported into a CSV spreadsheet.

Finally, participant data were checked to ensure there was an adequate number of hours per day (≥ 10 hours) and days per week (≥ 5 days and ≤ 7 days) to be included in the final analysis. Additionally, at least one weekend day had to be included to represent a typical week. Where there was greater than 7 days of valid data to choose from, selection was made based on the following criteria. The decision to include a day in the participant’s average was first based off the amount of time worn, with days with the greatest amount of time worn taking precedence. In

addition, days that occurred earlier in the study time took precedence over those that occurred later if there were more than 7 days of data available for a participant. If a participant did not have a minimum of five valid days of wear time their data were excluded, and their matched pair was not included in further analysis. The final analysis included the following PA outcomes: amount (minutes) of time spent in light PA, MVPA, and sedentary time, average daily step counts, and the proportion of participants who met the current age appropriate MVPA guidelines.

3.3.2.2 Body Structure and Function Level Outcomes

3.3.2.2.1 Body Composition

The height (nearest 0.1 cm using a tape measure taped to the wall) and weight (nearest 0.5 kg using a portable scale) of each participant was measured, and body mass index (BMI; kg/m^2) were calculated. As part of the study each participant was asked to undergo a DXA (Hologic QDR 4500A, Hologic Inc., Waltham, Mass, USA) scan to assess their body composition (lean mass and fat mass). The risk of low radiation exposure was explained to all participants through the consent forms and through the review of the consent forms when they first arrived. Prior to each testing session the DXA scanner was calibrated based on the instructions in the SIPRC DXA standard operating procedure (Appendix B). Each participant was asked to wear loose clothing without metal (zippers, buttons, etc.) and to remove jewellery prior to the whole-body scan. An analysis was then run on each scan to ensure each line for regional analyses was in the correct location. All analyses were completed by the same member of the research team to minimize the potential for error. Following their scan each participant was provided with their personal results (including their body mass index, body fat mass and percentage, lean mass, and bone mineral density) from a quick analysis completed by a member

of the research team. Using the fat and lean masses (measured by the DXA scan) and the participant's height, fat mass and lean mass indices (FMI, LMI) were calculated (fat mass in kg/height² in m).

3.3.2.2.2 Bipedal Standing Postural Control

During the first session participants were asked to stand quietly (as still as possible) with their hands on their hips on two force plates (one foot on each plate; AMTI, USA) for 30 second trials. Participants completed three trials with their eyes open followed by three trials with their eyes closed. Following each balance trial participants were offered a break and were able to decide when they were ready to proceed to the next trial. Vertical ground reaction force (VGRF) data were recorded in Newton's of force in the x (medial/lateral), y (anterior/posterior) and z (vertical) directions at 2400 Hz. The x and y center of pressure (COP) coordinates were computed in EVART (Eva RealTime, Version 5.0.4, Motion Analysis Corp. 2006) using ground reaction force and moment data following instructions by the manufacturer:

$$(i) \text{ COP}_x = - (M_y + F_x * d_z) / F_z$$

$$(ii) \text{ COP}_y = (M_x - F_y * d_z) / F_z$$

where, M_x and M_y are the moments in the x and y directions respectively; F_x and F_y are the forces in the x and y direction respectively; and d_z is the thickness of the plate surface in mm. COP x and y coordinates and the VGRF for all participants were exported as text files. These files were then imported into MATLAB (MathWorks, R2016a) and run through a program written by Brent Edwards and modified by Gregor Kuntze to analyze the COP and VGRF data. This program analyzed the middle 25 seconds of the force plate data that was collected. The data were filtered using an 8Hz, 4th order Butterworth filter. The following outcomes for each lower-

extremity were computed: the COP total path length (TPL; mm); the COP 95% ellipse area (mm^2); and the mean VGRF.

To identify the trial that was most representative of each participant's balance ability, the absolute difference between the VGRF between the two limbs was calculated for each of the 6 trials (i.e., eyes open and eyes closed conditions). The trial that was selected as being representative of each participant's balance ability was based off the trial where the absolute difference of their mean VGRF between their two limbs was the smallest, indicating that it was the trial where they had distributed their weight most evenly between both their right and left leg. Following this selection process, the chosen files were reviewed to ensure that the participant had maintained contact of both feet with the respective force plates throughout the 30 second trials. If it appeared that either foot had left its force plate during the trial, then the trial in which the participant had the next most even weight distribution between limbs was chosen, again assuming both feet remained on their respective force plates throughout the trial.

A preferred limb was then selected for the eyes open condition and for the eyes closed condition. The preferred limb was not always the same limb for both conditions. The preferred limb was defined as the limb that had the higher mean VGRF throughout the analyzed portion of the selected trial for each of the conditions (i.e., the limb that bore the most weight). Each outcome (i.e., COP TPL, COP 95% ellipse area and VGRF) was calculated for both the preferred and non-preferred weight-bearing limbs. The point of determining a limb in the aforementioned way was that when participants were exposed to the same conditions their preferred weight-bearing limb or less affected limb would naturally become apparent. During the first testing session all participants were asked which leg they would kick a ball with. Although this is likely

to be the dominant limb for the TD youth, many of the participants with CP chose their more affected limb, likely because they felt more comfortable balancing on their less affected limb.

COP TPL is a cumulative measure of the total distance that a participant's center of pressure weight moved over the surface of each force plate across the middle 25 seconds of the selected 30 second balance trial. The COP TPL was calculated as follows:

$$(iii) PL (mm) = \sqrt{(COP_x(i) - COP_x(i-1))^2 + (COP_y(i) - COP_y(i-1))^2}$$

$$TPL (mm) = \sum(PL),$$

where, PL is the path length; $COP_x(i)$ and $COP_y(i)$ are the x and y coordinates of the COP frame i and TPL is the total path length. Therefore, the TPL is an indicator of the overall movement magnitude but does not provide information on how much excursion there was in the medio-lateral or antero-posterior direction in isolation. Further, it does not allow us to discriminate between less frequent large movements or more repetitive small movements. Additional information on the total support area is needed to provide context on the individual's balance ability.

The 95% ellipse area is a measure of the total area that the participants COP moved over each of the lower-extremities independently during each of the selected trials. This measure can be used to indicate whether a participant had greater postural control, such that they corrected their posture with less sway, or their control was poorer indicated by a larger 95% ellipse area. The 95% ellipse area was calculated as follows:

$$(iv) 95\% \text{ ellipse area } (mm^2) = 2\pi \sqrt{sd_COP_x^2 \times sd_COP_y^2 - sd_COP_{xy}^2},$$

where, sd_COP_x and sd_COP_y are the standard deviation of the COP x and y coordinates; and sd_COP_{xy} is the covariance of the COP in the x and y direction.

The VGRF was used to determine whether both feet remained on the force plates throughout testing and the mean was calculated for both feet to determine which limb was preferred for supporting bipedal stance. The VGRF was calculated as follows:

$$(v) \quad VGRF (N) = (\text{mean of filtered VGRF})$$

$$VGRF (N) = \frac{\sum(\text{samples})}{60\,000 \text{ samples}}$$

3.3.2.2.3 Maximum Lower-Extremity Isometric Muscle Strength

During the first testing session participants were asked to participate in isometric strength testing of each of the eight lower-extremity muscle groups (hip extensors, flexors, abductors, and adductors, knee extensors and flexors, and ankle dorsiflexors and plantarflexors), bilaterally. Isometric muscle strength over a 5 second “make test” trial was measured using a hand-held dynamometer (Model 01163, Lafayette Instrument, USA) and strapping for stabilization of the hand-held dynamometer as well as for isolating muscle groups. Using a retractable tape measure, the length of the thigh (greater trochanter to 5 cm proximal of the knee joint line), shank (knee joint line to 5 cm proximal of the distal aspect of the lateral malleolus), and foot (posterior aspect of the lateral malleolus to the head of the fifth metatarsal) were measured to later convert force measured by the hand-held dynamometer into torque. The hand-held dynamometer was set to a minimum force threshold of 20N and was set to collect force data for 5 seconds.

To test the hip extensors, participants stood with a 90° bend in their hips, supporting their upper body weight on the height adjustable plinth. A strap was placed around the plinth and the

participants test leg. The hand-held dynamometer was then placed on the posterior side of the participants leg 5 cm proximal to the knee joint line and the strap was placed overtop of the hand-held dynamometer to hold it in place for the 5 second test. The participant was then instructed to lift the foot of their test leg slightly off the ground and kick backwards towards the wall behind them. Hip abductors and adductors were tested with the participant lying in a supine position, with a strap around their waist to hold them to the plinth for safety. Another strap was then placed around their test leg, 5 cm proximal to the knee joint line and placed overtop of the hand-held dynamometer. For the hip abductor tests the dynamometer was placed on the lateral aspect of the leg and participants were instructed to push their leg away from themselves. During the hip adductor tests the dynamometer was placed on the medial side of the leg and participants were instructed to push their test leg towards their other leg, without using their other leg to push against the dynamometer. Hip flexion was tested with participants sitting on the side of the height adjustable plinth. A strap was placed around the plinth and the participants test leg. The hand-held dynamometer was placed 5 cm proximal to the knee joint line on the anterior aspect of the limb. With their knee bent 90° participants were asked to sit as tall as possible and to lift the knee up to the ceiling without leaning their upper body backwards. The knee extensors and flexors were tested with the participants sitting at the end of the plinth, with a 90° bend in their knees. During the knee extension tests the dynamometer was placed on the anterior aspect of the limb 5 cm proximal to the lateral malleolus. The strap was placed around the leg of the plinth and the participants leg. Once the dynamometer was in place the participants were instructed to kick their leg forward into the dynamometer. For hip flexion the dynamometer was placed on the posterior aspect of the ankle, 5 cm proximal to the lateral malleolus. A board was placed at the

base of the plinth and the dynamometer was attached to the board using Velcro. The participants were then instructed to kick their leg back into the dynamometer. Ankle dorsiflexion was tested with the participants sitting at the end of the plinth with a 90° bend in their hips and the knee and ankle of their test leg. Their foot was resting on top of a small stool. The hand-held dynamometer was placed on the top side of their foot, was centered and in line with the head of the fifth metatarsal. The strap was then placed around the stool and overtop of the dynamometer and participants were asked to try to lift their toes up to the roof without lifting their heel off the stool. Ankle plantarflexion was tested with the participants sitting on the side of the plinth, with a 90° bend in their hips and the knee and ankle of their test leg. With their foot resting on a small stool, the strap was wrapped around the plinth and overtop of the hand-held dynamometer, which was placed on the anterior aspect of the test limb, 5 cm proximal to the knee joint line. The participants were then instructed to use their toes to push their heel up off the stool. Testing positions for each muscle group can be seen in figure 3.1.

Stabilization of the hand-held dynamometer was provided by straps. These positions were selected based on their safety, functional relevance, and the ability to stabilize the hand-held dynamometer. Each participant was asked to perform three trials to achieve a maximum measure of their strength for each muscle group, with a 30 second rest between each trial. The rest break was imposed for the purpose of minimizing any residual power from a previous trial, thus not allowing participants the opportunity for substantial increases in force production across trials. Participants were asked to ‘push’ or ‘kick’ into the dynamometer in a controlled manner such that there was not an initial spike in force measured by the hand-held dynamometer, but rather a gradual increase in force over the five seconds. Throughout the five seconds of testing

participants were verbally encouraged to push as hard as they could, using the phrases ‘push, push’, ‘push as hard as you can’, and ‘keep going’. Following each five second trial participants were instructed to relax. During the first testing session participants were asked if they would consent to participate in a second round of strength testing during their second visit. Those who consented completed the entire strength testing procedure a second time to determine the reliability of the positions and procedure used in this study.

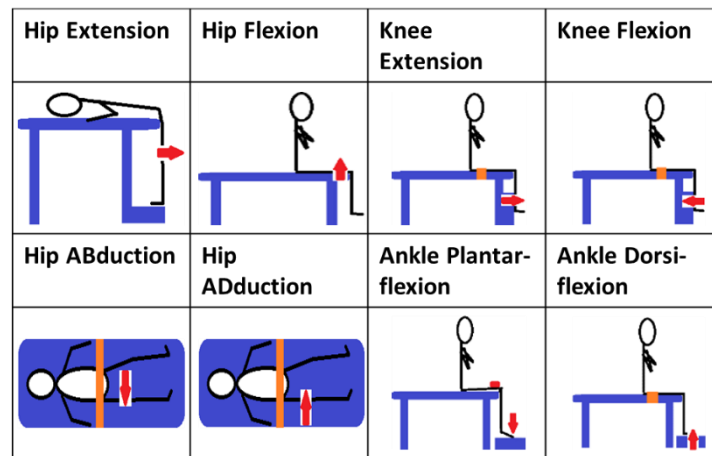


Figure 3.1: Isometric strength testing positions with strapping, indicated by the orange lines, and hand-held dynamometry placement, indicated by the location of the red arrow, the arrow also indicates the direction of the force during the test

For further analysis all force measurements (N) were converted to torque (Nm) based on the length of the appropriate limb segment and normalized to body mass (Nm/kg). An exploratory analysis of the strength data was completed to determine whether an average of all three trials, an average of the top two trials, or the maximum normalized torque was the most reliable and potentially representative of each participant’s strength. Based on a preliminary exploratory analysis (secondary objective 2; Appendix C) it was determined that the most

reliable measure, while still being indicative of the participant's strength, was the average of two trials. Therefore, the within-pair differences analysis for strength data (secondary objective 3) was based on an analysis of each participant's average of their best two trials. This was done for all eight muscle groups for the preferred and non-preferred limb. The preferred weight-bearing limb was determined the same way as was used to selecting the preferred limb for the balance data. If there was a discrepancy between the preferred limb in the eyes-open and eyes closed conditions, the condition with the lowest between limb difference in VGRF (weight was most evenly distributed between legs) was selected and the limb that the participant had on average put more weight on throughout that trial was selected as the preferred weight-bearing limb.

3.4 Statistical Methods

3.4.1 Descriptive Statistics for Primary and Secondary Objectives

To describe the population, the total number of participants in each category and the percentage of participants were stated for categorical variables. Descriptive statistics were reported for youth with spastic CP and age- and sex-matched- study groups. Outcomes for the primary objective include: PA: sedentary time (min), light PA time (min), MVPA time (min), and percentage of participants meeting MVPA criteria; and body composition: FMI (kg/m^2), LMI (kg/m^2), and BMI (kg/m^2). The outcomes for the within-pair differences component of the secondary objective include: balance: COP TPL, COP 95% ellipse area, and VGRF for both the preferred and non-preferred weight-bearing limbs; and strength: hip extensors, flexors, abductors, and adductors, knee extensors and flexors, and ankle dorsiflexors and plantar flexors for both the preferred and non-preferred limbs. A significance level, alpha, of 0.05 was used to assess the significance of each outcome measure.

STATA (v14.0, College Station, Texas 77845, USA) was used to complete all statistical analyses. If data were missing for an outcome, the full matched pair was removed from the matched pair analysis for that specific outcome. In addition, within-pair differences of each outcome were evaluated by GMFCS levels (with GMFCS levels II and III grouped). A Shapiro-Wilk test and a visual assessment of the symmetry of the within-pair differences was used to determine the normality of the data distribution and measures of central tendency (means and medians) were explored. The full group matched pair differences were normally distributed and thus parametric statistics (paired t-tests) were used for the PA, body composition, and strength outcomes. The full group matched pair differences for the balance outcomes and all subgroup analyses by GMFCS demonstrated skew in the distributions. Therefore, non-parametric statistics (i.e., Wilcoxon signed-rank tests) were used for the full group balance outcome and subgroup analyses for each outcome.

3.4.1.1 Reliability

Reliability of the strength testing protocol used in this study was examined in two ways. The intra-class correlation coefficients (ICC) were calculated for the preferred and non-preferred weight-bearing limbs for all muscle groups so that the resulting relative reliability could be compared to literature on previous strength testing protocols. In addition, ICCs were used to describe the variability in the measurements across the two testing sessions, such that values closer to 1.00 will be indicative of stronger reliability, smaller errors, and less variability across time points. Secondly, Bland-Altman Limits of Agreement (LoA) were calculated and plotted as a visual description of the agreement of results from the two testing sessions. Additionally, the

Bland-Altman plots assisted in the interpretation of the type of bias if any bias was present in the errors of the measurements.

3.4.1.1.1 Intra-class Correlation Coefficients

The relative reliability of the isometric strength measurements consisted of the calculation of ICC with 95% confidence intervals (CI).⁶⁵ The ICCs were calculated using the model (3,1) for intra-rater reliability based on the average normalized (to body mass) torque of the top two trials for each muscle group bilaterally generated at each of the testing sessions.⁶⁶

3.4.1.1.2 Bland-Altman Limits of Agreement

Due to procedural differences in the testing of isometric strength compared to those documented in previous literature, Bland-Altman limits of agreement (LoA) were used as a measure of absolute reliability of the strength testing protocol used in this study.⁶⁵ LoA were calculated as the mean difference of the average of the top two recorded strength measurements between the first and second testing sessions ($\pm \text{SD} \cdot 1.96$).⁶⁵

3.5 Ethical Considerations

Informed consent was received from each participant (participants age 15 years or older; Appendix D) or their parent (participants age 14 years or younger; Appendix E). In addition to the signed parental consent form, youth aged 14 years or younger also provided the study team with a completed assent form to confirm their willingness to participate in the study. Those who agreed to participate in the reliability component of the strength testing signed an additional series of consent and assent forms (depending on the age of the participant; Appendix F). Both the participants and their parents were reminded that they had the right to withdraw their participation at any point. As needed, participants were offered the opportunity to take breaks

throughout each of the testing sessions and were offered light refreshments. Parking costs at the Alberta Children's Hospital and at the University of Calgary were covered by the study so there were no direct financial obligations associated with participation.

Chapter Four: **Results**

4.1 Study Participants

In total, 67 participants consented and volunteered to participate in this cohort study. Thirty of the youth had a diagnosis of cerebral palsy (CP) and 37 were typically developing (TD) healthy controls. We were unable to match 7 TD participants, see Table 4.1 for participant demographic information. Thirty age-matched (within 10 months) and sex-matched pairs were formed. The within-pair differences of each outcome between the age- and sex-matched pairs were evaluated using the matched pairs with available data for the respective outcomes (i.e., 27 pairs for physical activity [PA], 29 pairs for body composition, 29 pairs for balance, and generally 30 pairs for strength). Within the 30 matched pairs there were 20 pairs of males (66.7%) and 10 pairs of females (33.3%). The males with CP ranged in age from 10.0 years to 18.9 years with a median age of 14.7 years, their matched pairs ranged in age 10.0 years to 18.8 years with a median age of 14.8 years. The female participants with CP ranged in age from 10.1 years to 17.7 years with a median age of 14.6 years, and their matched pairs ranged in age from 10.5 years to 17.8 years with a median age of 14.5 years. Table 4.1 summarizes the specific participant demographic data.

In recruiting participants with CP, we aimed to gather a sample reflective of the proportion of youth in the Alberta Children's Hospital Pain and Rehabilitation Services Neurosciences Clinics who were within the gross motor function classification system (GMFCS) levels I (59%), II (27%), and III (15%). To this end, 57% of participants with CP were classified as GMFCS level I (n=17), 30% of participants with CP were classified as GMFCS level II (n=9), and 13% of participants with CP were classified as GMFCS level III (n=4). Of the participants

with CP, GMFCS level I, 13 had a unilateral distribution of involvement (DOI; n=1: monoplegia, n=12: hemiplegia) and 4 had a bilateral DOI (n=4: diplegia). Of the participants with CP, GMFCS level II, 3 had a unilateral DOI (n=1: monoplegia, n=2: hemiplegia) and 6 had a bilateral DOI (n=3: diplegia, n=3: quadriplegia). All four participants with CP, GMFCS level III, all 4 had a bilateral DOI (n=2: diplegia, n=2: quadriplegia). No differences were found between anthropometric measures [i.e., weight, height, or body mass index (BMI)] of females with CP and their TD matched peers. Significant differences were found between males with CP and their TD matched peers, such that males with CP weighed less ($z=2.455$, $p=0.014$) and had a lower BMI ($z=2.334$, $p=0.0196$). No height difference was found between the male cohorts.

Table 4.1 Participant characteristics by study cohort

	Variable	Sex	Matched		Unmatched
			CP (n=30)	TD (n=30)	TD (n=7)
Frequency	Sex (n, %)	Male	20 (66.7%)	20 (66.7%)	5 (71.4%)
		Female	10 (33.3%)	10 (33.3%)	2 (28.6%)
	GMFCS (I, II, III)	Male	I: 9; II: 8; III: 3	N/A	N/A
		Female	I: 8; II: 1; III: 1	N/A	N/A
	DOI (M; H; D; Q)	Male	M: 2; H: 6; D: 7; Q: 5	N/A	N/A
		Female	M: 0; H: 8; D: 2; Q: 0	N/A	N/A
Median (range)	Age (years)	Male	14.7 (10.0-18.9)	14.8 (10.0-18.8)	13.7 (10.9-19.2)
		Female	14.6 (10.1-17.7)	14.5 (10.5-17.8)	16.5 (16.3-16.7)
	Weight (kg)	Male	54.3 (23.0-87.5)	67.0 (29.8-99.0)	49.0 (32.0-85.5)
		Female	53.5 (33.0-90.0)	55.5 (31.5-75.0)	51.8 (49.5-54.0)
	Height (cm)	Male	163.1 (134.0-178.5)	173.1 (134.2-183.5)	158.7 (141.0-191.3)
		Female	157.6 (128.0-172.5)	162.8 (143.9-178.3)	156.4 (149.2-163.6)
	BMI (kg/m ²)	Male	19.0 (12.8-28.2)	22.4 (15.4-29.7)	19.5 (16.1-31.6)
		Female	21.5 (16.2-31.9)	21.5 (15.2-24.9)	21.4 (18.5-24.3)

CP = Cerebral palsy; TD = Typically developing; BMI = Body mass index; n = number of participants; GMFCS = Gross Motor Function Classification System (I = level I, II = level II, III = level III); DOI = Distribution of Involvement (M = monoplegia, H = hemiplegia, D = diplegia, Q = quadriplegia); median (range); N/A = not applicable to cohort or no participants met the criteria and therefore no information was available

4.2 Activity Level

4.2.1 Physical Activity Intensity Levels

Three matched pairs were excluded from the statistical analyses associated with PA due to missing or incomplete ActiGraph data. One TD male participant's physical activity (PA) data was lost due to an error in the initialization process and the PA ActiGraph data of two participants (one male and one female) with CP was unusable/incomplete, in that they did not wear their ActiGraphs for 10 or more hours on a minimum of 5 days. Since no within-pair differences were detected for minutes of total or daily wear time (Table 4.2), data were analyzed in minutes per day. The within-pair differences for the PA outcomes of the all participants were normally distributed. However, this was not true of the distribution of the PA within-pair differences for each of the PA outcomes when evaluated by GMFCS level (with GMFCS level II and III grouped). As such paired t-tests were used to evaluate the significance of the within-pair differences of the whole sample and Wilcoxon signed-rank tests were used to evaluate the within-pair differences when considering GMFCS level. Overall there were no significant differences between the total amount of sedentary time and time spent in light PA between the youth with CP and their TD peers (Table 4.2 and Figure 4.1). Moderate-vigorous PA (MVPA), however, did differ significantly between cohorts, such that youth with CP spent significantly less of their daily time at MVPA intensity levels [mean=28.95 minutes (95% CI: 20.97 - 36.94 minutes)] compared to their TD peers [mean=44.16 minutes (95% CI: 37.29 - 51.02 minutes) ($t=-2.679$, $p=0.013$)]. These findings are displayed in Table 4.2 and Figure 4.1.

Table 4.2 Mean within-pair differences with 95% confidence intervals (95% CI) for physical activity (PA) outcomes (minutes or steps/day) in youth with cerebral palsy (CP) and their age- and sex-matched typically developing (TD) peers

PA Outcome Measure	Mean (95% CI)			Test statistic [†] ; p-value
	CP n=27	TD n=27	Mean Within-pair Differences	
Total Sedentary Time (min)	1149.79 (1105.87 - 1193.72)	1101.77 (1073.76 - 1129.78)	48.02 (-4.55 - 100.60)	1.878 [†] ; p=0.072
Light PA (min)	191.52 (164.68 - 218.35)	218.05 (198.26 - 237.84)	-26.53 (-57.21 - 4.14)	-1.778 [†] ; p=0.087
Moderate-Vigorous PA (min)	28.95 (20.97 - 36.94)	44.16 (37.29 - 51.02)	-15.20 (-26.87 - -3.54)	-2.679 [†] ; p=0.013*
Total Wear Time (min)	9155.22 (8707.30 - 9603.15)	8923.41 (8569.07 - 9277.74)	231.81 (-305.12 - 768.75)	0.888 [†] ; p=0.383
Average Daily Wear Time (min)	1370.27 (1335.84 - 1404.69)	1363.98 (1337.63 - 1390.33)	6.29 (-39.37 - 51.95)	0.283 [†] ; p=0.779
Average Daily Step Counts (steps/day)	5523.44 (4470.27 - 6576.62)	7739.91 (6885.51 - 8594.31)	-2216.47 (-3609.57 - -823.36)	-3.270 [†] ; p=0.003*

[†]Test statistic = t (Paired t test), CP – TD, gross motor function classification system (GMFCS) levels I, II, and III

*Significance at $\alpha=0.05$

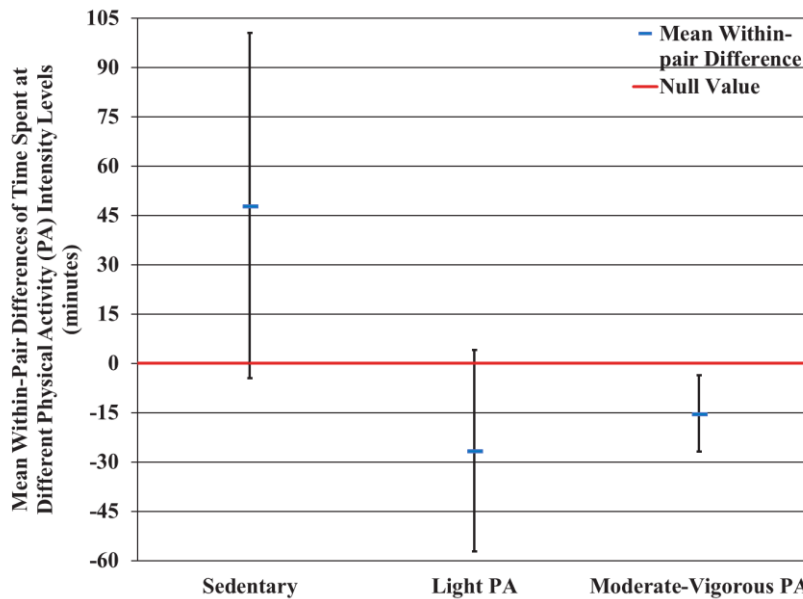


Figure 4.1 Mean within-pair differences and 95% confidence intervals (95% CI) for physical activity (PA) intensity level outcomes, in minutes, for youth with cerebral palsy (CP) and their typically developing (TD) matches; mean within-pair difference values are representative of CP – TD, gross motor function classification system (GMFCS) levels I, II, and III

The within-pair differences of average daily step counts were assessed, and it was determined that there was a statistically significant difference between the cohort with CP and their age- and sex-matched TD peers ($t=-3.270$, $p=0.003$). The youth with CP took on average 5523.44 steps per day (95% CI: 4470.27 - 6576.62 steps per day) compared to the average daily step count of their TD peers [mean=7739.91 steps per day (95% CI: 6885.51 - 8594.31 steps per day)]. Figure 4.2 depicts the within-pair differences for the average daily step counts.

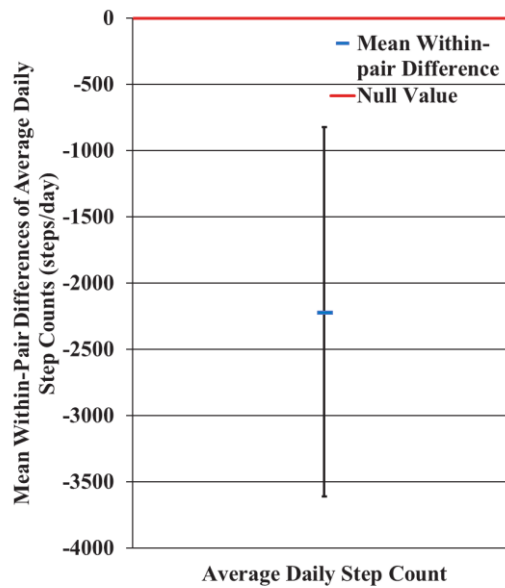


Figure 4.2 Mean of matched-pair differences with 95% confidence intervals (95% CI) for the physical activity (PA) average daily step count outcome (steps/day) as it relates to youth with cerebral palsy (CP) and their typically developing (TD) matches; within-pair difference values are representative of CP – TD, gross motor function classification system (GMFCS) levels I, II, and III

The examination of within-pair differences by GMFCS levels, with levels II and III grouped, was based on 16 pairs in which the participant with CP was classified as a GMFCS level I, and 11 pairs in which the participant with CP was classified as either a GMFCS level II or III. No statistically significant differences were seen between youth with CP, GMFCS level I, and their age- and sex-matched peers. Further information for the PA data of pairs including participants with CP, GMFCS level I, can be found in Table 4.3 and seen in Figures 4.3 and 4.4.

Table 4.3 Median within-pair differences and range for physical activity (PA) outcomes (minutes or steps/day) in youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I, and their age- and sex-matched typically developing (TD) peers

PA Outcome Measure	Median (Range)			Test statistic [^] ; p-value
	CP (GMFCS level I) n=16	TD n=16	Median Within-pair Difference	
Total Sedentary Time (min)	1162 .00 (895.10 - 1301.93)	1101.06 (1003.36 - 1244.54)	14.34 (-262.08 - -251.78)	0.310 [^] ; p=0.756
Light PA (min)	173.54 (131.11 - 333.00)	209 .13 (122.61 - 254.75)	-36.20 (-109.49 - 129.00)	-0.982 [^] ; p=0.326
Moderate-Vigorous PA (min)	34.80 (6.96 - 76.46)	35.15 (16.32 - 65.85)	0.09 (-58.89 - 44.96)	0.052 [^] ; p=0.959
Total Wear Time (min)	9471 .00 (5392.00 - 10080.00)	9057.50 (6783.00 - 10080.00)	195.00 (-4113.00 - 3297.00)	0.724 [^] ; p=0.469
Average Daily Wear Time (min)	1375.79 (1078.40 - 1440.00)	1357.23 (1288.57 - 1440.00)	5.90 (-306.50 - 110.17)	0.207 [^] ; p=0.836
Average Daily Step Counts (steps/day)	6054.17 (2489.43 - 11196.29)	6904.03 (4195.86 - 11115.40)	100.82 (-8625.97 - 5011.43)	-0.414 [^] ; p=0.679

[^]Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, gross motor function classification system (GMFCS) level I

*Significance at $\alpha=0.05$

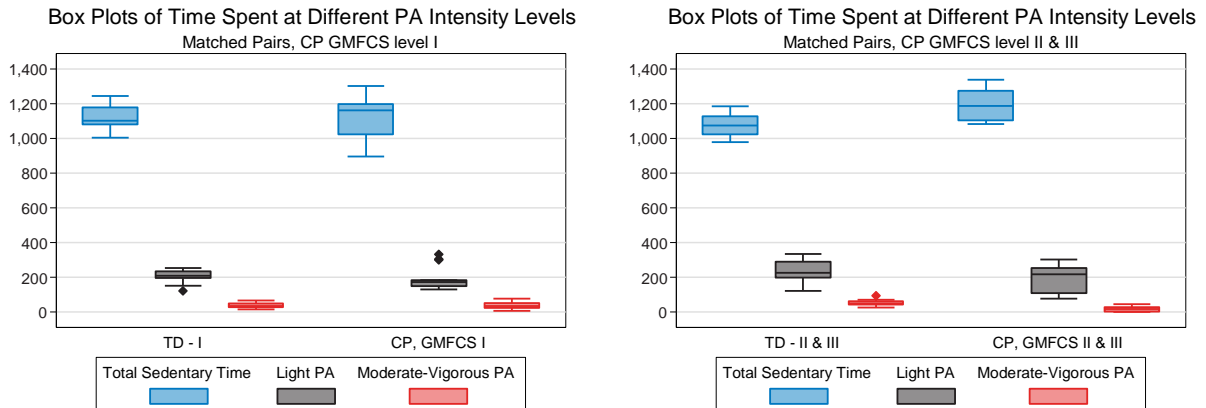


Figure 4.3 Physical activity (PA) intensity level outcomes (minutes) for youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their age- and sex-matched typically developing (TD) peers (Left); and for youth with CP, GMFCS levels II and III and their TD peers (Right)

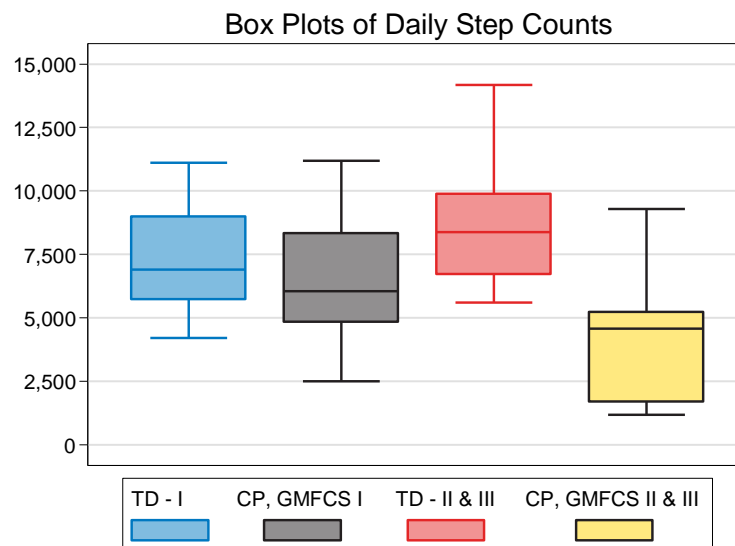


Figure 4.4 Physical activity (PA) daily step counts (steps/day) for youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their age- and sex-matched typically developing (TD) peers

On a typical day, youth with CP who were classified as GMFCS levels II or III, spent significantly more time (median=1 186.86 minutes, range: 1083.54 - 1336.88 minutes) in

sedentary behaviour than their age- and sex-matched TD peers (median=1074.82 minutes, range: 979.39 - 1184.68 minutes). There was no significant difference in the amount of time spent at the light PA intensity level between cohorts when stratified by GMFCS level. These youth with CP, GMFCS levels II or III, also spent significantly less time at MVPA intensity levels (median=18.04 minutes, range: 1.57 - 45.92 minutes) than their TD peers (median=48.86 minutes, range: 26.42 - 94.54 minutes) on a typical day. Additionally, the youth with CP were found to take significantly fewer steps (median=4564.57 steps per day, range: 1185.14 - 9293.67 steps per day) compared to their age- and sex-matched TD peers (median=8377.71 steps per day, range: 5608.50 - 14184.57 steps per day). A summary of the PA data for these cohorts can be found in Table 4.4 and can be seen in Figures 4.3 and 4.4.

Table 4.4 Median within-pair differences and range for physical activity (PA) outcomes (minutes and steps/day) in youth with cerebral palsy (CP), gross motor function classification system (GMFCS) levels II or III and their age- and sex-matched typically developing (TD) peers

	Median (Range)			Test statistic [†] ; p-value
	CP (GMFCS level II & III) n=11	TD n=11	Mean Within-pair Difference	
Total Sedentary Time (min)	1186.86 (1083.54 - 1336.88)	1074.82 (979.39 - 1184.68)	108.82 (-83.68 - 254.05)	2.667 [†] ; p=0.008*
Light PA (min)	218.04 (78.11 - 301.92)	225.61 (122.36 - 335.46)	-43.43 (-185.53 - 75.68)	-1.334 [†] ; p=0.182
Moderate-Vigorous PA (min)	18.04 (1.57 - 45.92)	48.86 (26.42 - 94.54)	-25.96 (-73.89 - 17.50)	-2.934 [†] ; p=0.003*
Total Wear Time (min)	9695.00 (8640.00 - 10080.00)	9359.00 (8327.00 - 10080.00)	62.00 (-900.00 - 1753.00)	0.934 [†] ; p=0.350
Average Daily Wear Time (min)	1407.71 (1284.43 - 1440.00)	1373.57 (1189.57 - 1440.00)	10.33 (-60.71 - 250.43)	1.023 [†] ; p=0.306
Average Daily Step Counts (steps/day)	4564.57 (1185.14 - 9293.67)	8377.71 (5608.50 - 14184.57)	-4011.71 (-8945.00 - -595.50)	-2.934 [†] ; p=0.003*

[†]Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, gross motor function classification system (GMFCS) levels II and III

*Significance at $\alpha=0.05$

Only 1 participant with CP, GMFCS I, and 2 TD met the current MVPA guidelines of greater than or equal to 60 minutes or more of MVPA on at least five days a week. In total, 18 of 27 (67%) TD youth accumulated 60 minutes or more of MVPA on at least one day. In terms of the participants with CP, 10 of 16 (63%) of the participants with GMFCS level I and 2 of 11 (18%) of individuals with a GMFCS level II or III accumulated 60 minutes or more of MVPA on at least one day. The proportion of participants meeting MVPA guidelines on at least one day, on at least 3 days, and on at least 5 days can be found in Table 4.5.

Table 4.5 Frequency and percentage of youth with cerebral palsy (CP) by gross motor function classification system (GMFCS) level and their typically developing (TD) peers meeting the current moderate-vigorous physical activity (MVPA) guidelines (greater than or equal to 60 minutes of MVPA per day)

MVPA criteria (≥ 60 minutes/day)	TD; n=27	CP (GMFCS level I); n=16	CP (GMFCS level II & III); n=11
On at least 1 day	18 (67%)	10 (63%)	2 (18%)
On at least 3 days	8 (30%)	4 (25%)	0 (0%)
On at least 5 days	2 (7%)	1 (6%)	0 (0%)

Frequency (Percent)

4.3 Body Structure and Function Level

4.3.1 Body Composition

Fifty-nine out of the 60 matched participants agreed to undergo a dual-energy X-ray absorptiometry (DXA) scan. The one TD participant did not complete the DXA because their parent did not want them to be exposed to radiation. As a result, the within-pair difference analyses of fat mass index (FMI), lean mass index (LMI), and body mass index (BMI) were based on 29 matched pairs, using paired t tests. Youth with CP were found to have significantly lower LMI (mean=15.79 kg/m², 95% CI: 14.93 - 16.65 kg/m²) compared to their TD (mean=17.03 kg/m², 95% CI: 15.91 - 18.14 kg/m²) peers ($t=-2.5351$, $p=0.017$). FMI and BMI did not differ between matched-pairs. Table 4.6 summarizes the mean within-pair difference for youth with CP compared to their TD peers. Figure 4.5 depicts the overall within-pair differences for the body composition outcomes.

Table 4.6 Mean within-pair differences with 95% confidence interval (95% CI) for body composition outcomes in youth with cerebral palsy (CP), and their age- and sex-matched typically developing (TD) peers

Body Composition Outcome Measure	Mean (95% CI)			Test statistic [^] ; p-value
	CP n=29	TD n=29	Mean Within-pair Differences	
Fat Mass Index (kg/m ²)	5.22 (4.18 - 6.25)	5.13 (4.32 - 5.94)	0.09 (-0.92 - 1.09)	-0.175 [^] ; p=0.862
Lean Mass Index (kg/m ²)	15.79 (14.93 - 16.65)	17.03 (15.91 - 18.14)	-1.24 (-2.24 - -0.24)	-2.535 [^] ; p=0.017*
Body Mass Index (kg/m ²)	20.96 (19.40 - 22.52)	22.29 (20.71 - 23.87)	-1.33 (-3.09 - 0.43)	1.548 [^] ; p=0.133

[^]Test statistic = t (Paired t test), CP – TD, gross motor function classification system (GMFCS) levels I, II, and III

*Significance at $\alpha=0.05$

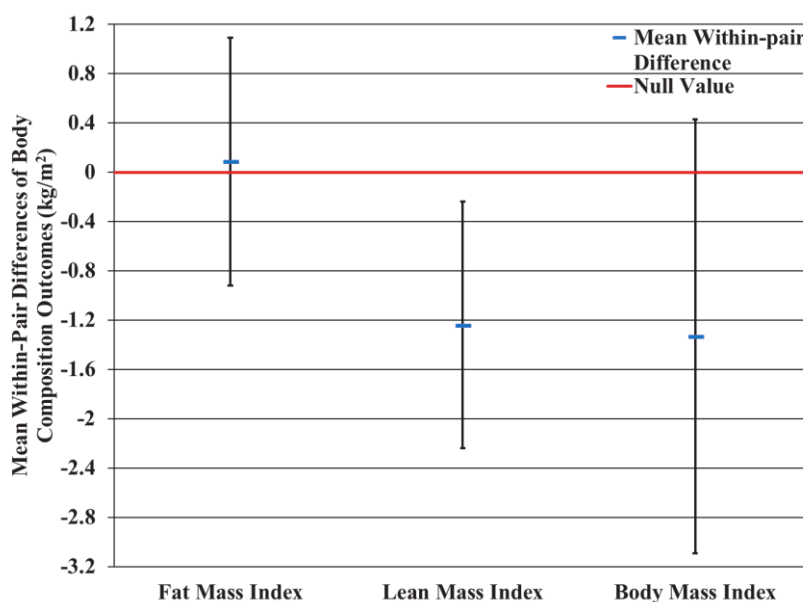


Figure 4.5 Mean matched-pair differences with 95% confidence intervals (95% CI) for body composition outcomes (kg/m²) of youth with cerebral palsy (CP) and their typically developing (TD) matches; within-pair difference values are representative of CP – TD, gross motor function classification system (GMFCS) levels I, II, and III

Body composition was then assessed by GMFCS levels, with GMFCS levels II and III grouped together. The outcomes were described (medians and ranges) by study group, CP, GMFCS level I and their respective TD matches (16 pairs) as seen in Table 4.7, and participants with CP, GMFCS levels II or III and their respective TD matches (13 pairs) as seen in Table 4.8. No differences in body composition outcomes were seen between participants with CP, GMFCS level I, and their TD matched peers. There were no differences in FMI or BMI between the youth with CP, GMFCS level II or III, and their age- and sex-matched TD peers. However, youth with CP, GMFCS level II or III had a significantly lower LMI (median=15.52 kg/m², range: 13.83 – 20.66 kg/m²) than their age- and sex-matched TD peers (median=17.66 kg/m², range: 12.63 – 21.86 kg/m²; z=-1.992, p=0.046). Figure 4.6 shows the medians and ranges for youth with CP, GMFCS level I and levels II and III alongside their respective TD matched cohort.

Table 4.7 Median within-pair difference and range for body composition outcomes (kg/m²) in youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their age- and sex-matched typically developing (TD) peers

Body Composition Outcome Measure	Median (Range)			Test statistic [†] ; p-value
	CP (GMFCS level I) n=16	TD n=16	Median Within-pair Difference	
Fat Mass Index (kg/m ²)	4.60 (2.02 - 12.93)	5.59 (2.82 - 9.38)	0.01 (-3.83 - 5.05)	0.414 [†] ; p=0.679
Lean Mass Index (kg/m ²)	15.14 (11.82 - 20.77)	15.87 (11.79 - 22.15)	-1.30 (-5.83 - 3.53)	-1.344 [†] ; p=0.179
Body Mass Index (kg/m ²)	21.53 (12.81 - 31.89)	23.32 (15.21 - 30.08)	-1.20 (-7.94 - 7.92)	-1.034 [†] ; p=0.301

[†]Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, gross motor function classification system (GMFCS) level I

*Significance at $\alpha=0.05$

Table 4.8 Median within-pair differences and range for body composition outcomes (kg/m²) in youth with cerebral palsy (CP), gross motor function classification system (GMFCS) levels II or III and their age- and sex-matched typically developing (TD) peers

Body Composition Outcome Measure	Median (Range)			Test statistic [†] ; p-value
	CP (GMFCS level II & III) n=13	TD n=13	Median Within-pair Difference	
Fat Mass Index (kg/m ²)	3.82 (1.81-7.77)	3.40 (2.29-8.53)	-0.13 (-4.94 - 3.37)	-0.035 [†] ; p=0.972
Lean Mass Index (kg/m ²)	15.52 (13.83-20.66)	17.66 (12.63-21.86)	-1.39 (-6.78 - 2.97)	-1.992 [†] ; p=0.046*
Body Mass Index (kg/m ²)	19.07 (16.96-28.18)	22.23 (15.42-29.56)	-2.25 (-10.93 - 6.27)	-1.293 [†] ; p=0.196

Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, gross motor function classification system (GMFCS) levels II and III

*Significance at $\alpha=0.05$

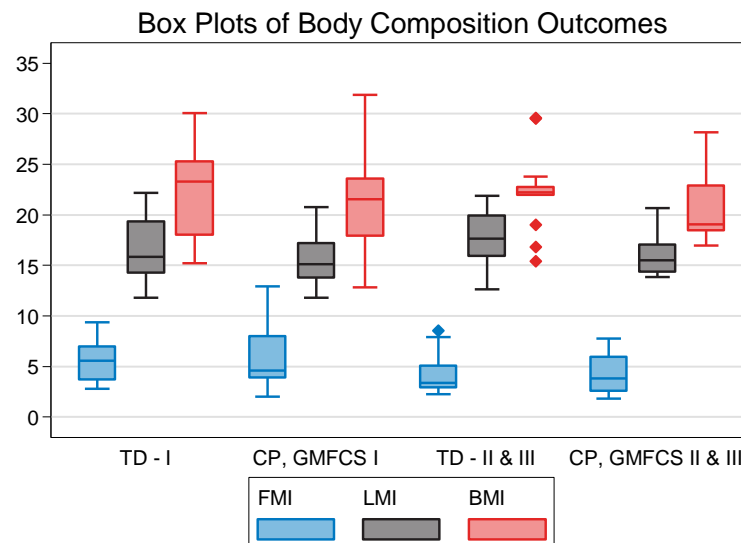


Figure 4.6 Body composition outcomes [kg/m²; Fat Mass Index (FMI), Lean Mass Index (LMI), and Body Mass Index (BMI)] for youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their age- and sex-matched typically developing (TD) peers; and for youth with CP, GMFCS levels II or III and their TD peers

4.3.2 Standing Postural Balance

Balance data were collected for 59 of the 60 matched participants. One participant with CP, GMFCS III would not have been able to maintain a bipedal stance independently for 30 seconds. For this reason, the team determined that to ask the participant to complete the test would have been unsafe or to complete the task while holding onto their walker or a team member would have significantly altered the data such that it would not have been comparable to other participants. A visual inspection of the balance data suggested that it was substantially skewed and, a non-parametric statistics approach was chosen to investigate the within-pair differences.

Youth with CP were found to have significantly longer ($z=2.000$, $p=0.046$) total path lengths (TPL) during standing with their eyes closed (median=306.02 mm, range: 119.02 - 7644.55 mm) with their preferred weight-bearing limb than their TD matched peer (median=285.60 mm, range: 96.02 - 571.66 mm). The median within-pair differences of center of pressure (COP) TPL during both the eyes open and eyes closed conditions for the preferred and non-preferred weight-bearing limbs can be seen in Figure 4.7. During the eyes closed condition, the 95% ellipse areas of the preferred and non-preferred weight-bearing limbs also differed significantly (preferred: $z=3.406$, $p=0.001$; non-preferred: $z=3.514$, $p<0.001$) between youth with CP and their age- and sex-matched peers. The median size of the 95% ellipse area of the preferred limb for youth with CP was 143.01 mm² (range: 14.16 - 6850.15 mm²) larger than their TD peers (median=29.10 mm², range: 5.60 - 170.94 mm²). Additionally, the 95% ellipse area of the non-preferred limb was larger for the youth with CP (median=108.01 mm², range: 7.05 - 8807.53 mm²) compared to the TD youth (median=25.89 mm², range: 3.46 - 283.72 mm²). The

median within-pair differences for the COP 95% ellipse are can be seen in Figure 4.8. The mean vertical ground reaction force (VGRF), in this case the weight put on the non-preferred limb, was significantly lower for the youth with CP (median=226.76 N, range: 117.72 - 422.00 N) when their eyes were closed than their TD (median=273.41 N, range: 140.95 - 459.22 N) peers ($z=-2.930$, $p=0.003$). This indicates that on average during the 30 second trial youth with CP put less of their weight on their non-preferred limb than their TD peers did. Figure 4.9 shows the median within-pair differences of the VGRF for both eyes open and closed conditions as well as for both the preferred and non-preferred weight-bearing limbs.

Although TPL did not differ between cohorts during the eyes open condition, the 95% ellipse area was significantly larger on both the preferred ($z=3.406$, $p=0.001$) and non-preferred ($z=3.816$, $p<0.001$) weight-bearing limbs. The median 95% ellipse area of the preferred limb during the eyes open condition for the youth with CP was 83.55 N (range: 3.50 - 11792.99 N). Whereas, the TD youth had a median 95% ellipse area of 21.44 N (range: 4.68 - 298.36 N). During the eyes open condition, the 95% ellipse area was also significantly larger for the non-preferred limb of the youth with CP (median=103.31 N, range: 12.98 - 6115.06 N) compared to their TD peers (median=20.11 N, range: 5.72 - 137.44 N). There was also a difference in how much weight (mean VGRF) the youth with CP put on their non-preferred limb compared to the TD youth ($z=2.843$, $p=0.005$). Median within-pair differences of the postural control outcomes for the CP and TD cohorts are summarized in Table 4.9.

Table 4.9 Median within-pair differences and range for postural control outcomes (mm or mm² or N) in youth with cerebral palsy (CP) and their age- and sex-matched typically developing (TD) peers

	Postural Control Outcomes	Median (Range)			Test statistic [†] ; p-value
		CP n=29	TD n=29	Median Within-pair Difference	
Eyes Closed	PL-TPL	306.02 (119.02 – 7644.55)	285.60 (96.02 - 571.66)	92.51 (-389.96 - 7459.76)	2.000 [†] ; p=0.046*
	NPL-TPL	294.14 (76.42 – 3556.79)	244.30 (88.01 - 522.29)	78.43 (-267.22 - 3381.53)	1.654 [†] ; p=0.098
	PL-95% ellipse area	143.01 (14.16 – 6850.15)	29.10 (5.60 - 170.94)	103.47 (-127.62 - 6844.55)	3.406 [†] ; p<0.001*
	NPL-95% ellipse area	108.01 (7.05 – 8807.53)	25.89 (3.46 – 283.72)	80.07 (-248.45 – 8783.13)	3.514 [†] ; p<0.001*
	PL-VGRF	280.16 (119.09 – 579.07)	316.79 (146.69 – 491.20)	-3.11 (-250.80 – 165.26)	-0.638 [†] ; p=0.524
	NPL-VGRF	226.76 (117.72 – 422.00)	273.41 (140.95 – 459.22)	-47.36 (-224.65 – 174.18)	-2.930 [†] ; p=0.003*
Eyes Open	PL-TPL	265.62 (49.94 – 5571.36)	227.66 (64.88 – 412.00)	67.85 (-297.43 – 5434.24)	1.957 [†] ; p=0.050
	NPL-TPL	254.90 (111.74 – 2452.62)	180.53 (110.97 - 399.86)	-8.11 (-160.98 – 2272.09)	1.611 [†] ; p=0.107
	PL-95% ellipse area	83.55 (3.50 – 11792.99)	21.44 (4.68 – 298.36)	55.83 (-284.11 – 11758.79)	3.406 [†] ; p<0.001*
	NPL-95% ellipse area	103.31 (12.98 – 6115.06)	20.11 (5.72 – 137.44)	89.09 (-100.83 – 6094.41)	3.816 [†] ; p<0.001*
	PL-VGRF	285.92 (118.38 – 538.35)	318.06 (148.85 – 478.71)	0.58 (-234.31 – 171.50)	-0.573 [†] ; p=0.567
	NPL-VGRF	236.05 (61.44 – 427.15)	282.05 (138.75 – 471.16)	-59.08 (-240.99 – 168.01)	2.843 [†] ; p=0.005*

PL: Preferred limb; NPL: Non-preferred limb; TPL: Total Path Length; VGRF: Vertical Ground Reaction Force; mm: millimeters; mm²: millimeters squared; N: Newtons

[†]Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, gross motor function classification system (GMFCS) levels I, II, and III

*Significance at $\alpha=0.05$

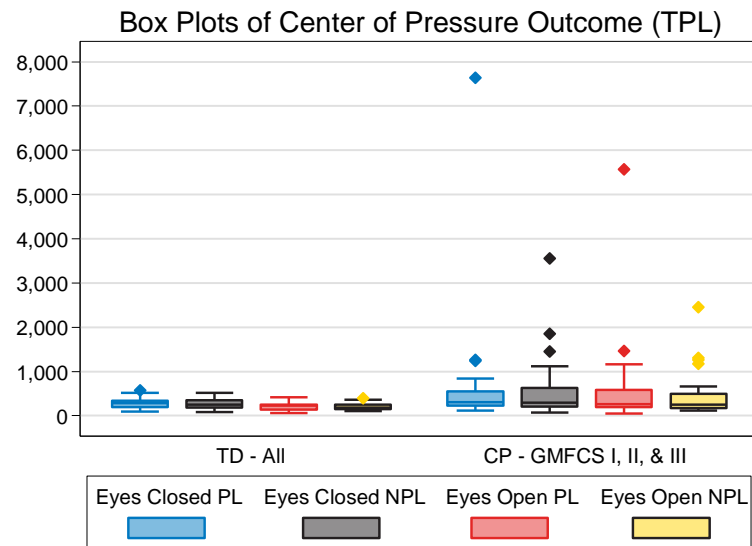


Figure 4.7 Center of pressure (COP) total path length (TPL; mm) for youth with cerebral palsy, and their age- and sex-matched typically developing (TD) peers, for both the preferred limb (PL) and non-preferred limb (NPL)

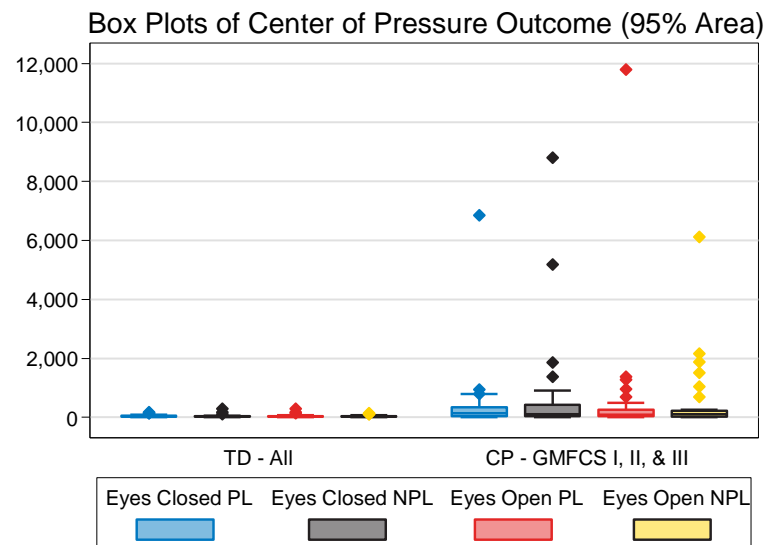


Figure 4.8 Center of pressure (COP) 95% ellipse area (mm²) for youth with cerebral palsy (CP) and their age- and sex-matched typically developing (TD) peers, for both the preferred limb (PL) and non-preferred limb (NPL)

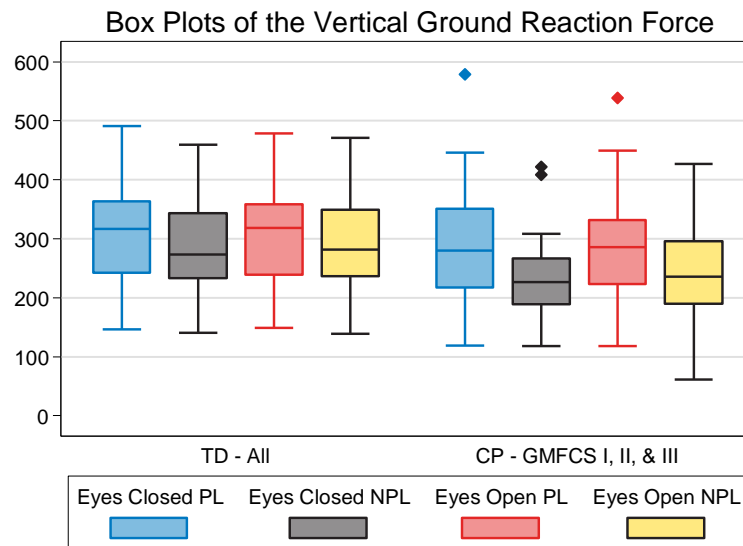


Figure 4.9 Vertical ground reaction force (VGRF; N) for youth with cerebral palsy (CP) and their age- and sex-matched typically developing (TD) peers, for the preferred limb (PL) and the non-preferred limb (NPL)

During bipedal stance with their eyes closed youth with CP, GMFCS level I, differed significantly from their TD peers such that they had a larger median difference in the 95% ellipse area (median=-45.75 mm², range: -248.45 - 1307.72, p=0.031) with their non-preferred weight-bearing limb. Although the median difference in the VGRF (median=40.99 N, range: -184.26 – 174.18 N, z=-2.343, p=0.019) was larger for the non-preferred weight-bearing limb, overall it seemed that the by study cohort median VGRF showed that the youth with CP (median=215.94 N, range: 117.72 - 422.00 N) put less of their weight on their non-preferred weight-bearing limb throughout the test than their TD peers (median=256.35 N, range: 153.43 - 411.55 N). This indicates that youth with CP, GMFCS level I, swayed further on their non-preferred limb before correcting their posture, however as their TPL was not found to be longer than that of their TD peers, they did not sway more. In fact, their VGRF on this same limb was much smaller,

indicating that they had not used their non-preferred limb to support themselves as much as their TD peers had done. With this said, their median TPL also seemed to drop, however not such that a between group difference was found. Further information regarding eyes open and eyes closed trials for the 17 age- and sex-matched pairs (including youth with CP, GMFCS level I) can be found in Table 4.10. During the selected eyes open trial youth with CP, GMFCS level I, once again had a significantly larger median 95% ellipse area (median=31.79 mm², range: 12.98 - 1502.15 mm²) compared to their age- and sex-matched TD peers (median: 17.38 mm², range: 5.72 - 137.44 mm²; $z=2.012$, $p=0.044$) with their non-preferred limb. Like with the eyes closed trials, the youth with CP, GMFCS level I, put less of their weight on their non-preferred weight-bearing limb (median=249.35 N, range: 61.44 - 427.15 N) compared to their TD peers (median: 266.90 N, range: 154.00 - 425.54 N; $z=-2.059$, $p=0.040$). The postural control differences between cohorts can be seen in Figures 4.10, 4.11, and 4.12.

Table 4.10 Median within-pair difference and range for postural control outcomes in youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their age- and sex-matched typically developing (TD) peers

	Postural Control Outcomes	Median (Range)			Test statistic [†] ; p-value
		CP (GMFCS level I) n=17	TD n=17	Median Within-pair Difference	
Eyes Closed	PL-TPL	239.08 (119.02 - 1260.88)	265.14 (96.02 - 423.36)	-26.06 (-255.46 - 1091.04)	0.497 [†] ; p=0.619
	NPL-TPL	218.12 (76.42 - 699.25)	277.76 (88.01 - 476.86)	-62.09 (-267.22 - 580.97)	-0.071 [†] ; p=0.943
	PL-95% ellipse area	52.37 (18.16 - 520.97)	29.10 (6.90 - 170.94)	17.80 (-127.62 - 506.45)	1.633 [†] ; p=0.102
	NPL-95% ellipse area	65.38 (7.05 - 1372.83)	26.03 (3.46 - 283.72)	45.75 (-248.45 - 1307.72)	2.154 [†] ; p=0.031*
	PL-VGRF	280.16 (119.09 - 579.07)	291.70 (164.21 - 446.95)	-3.11 (-124.75 - 165.26)	-0.166 [†] ; p=0.868
	NPL-VGRF	215.94 (117.72 - 422.00)	256.35 (153.43 - 411.55)	-40.99 (-184.26 - 174.18)	-2.343 [†] ; p=0.019*
Eyes Open	PL-TPL	194.48 (49.94 - 724.16)	210.74 (64.88 - 412.00)	27.11 (-297.43 - 659.28)	0.497 [†] ; p=0.619
	NPL-TPL	169.92 (111.74 - 1265.89)	176.91 (119.85 - 399.86)	-24.64 (-160.98 - 1140.30)	-0.686 [†] ; p=0.493
	PL-95% ellipse area	61.07 (3.50 - 484.11)	15.35 (4.68 - 298.36)	37.50 (-284.11 - 479.43)	1.775 [†] ; p=0.076
	NPL-95% ellipse area	31.79 (12.98 - 1502.15)	17.38 (5.72 - 137.44)	16.76 (-100.83 - 1484.77)	2.012 [†] ; p=0.044*
	PL-VGRF	299.81 (118.38 - 538.35)	297.74 (164.04 - 431.72)	0.58 (-115.96 - 171.50)	-0.213 [†] ; p=0.831
	NPL-VGRF	249.35 (61.44 - 427.15)	266.90 (154.00 - 425.54)	-37.69 (-197.12 - 168.01)	-2.059 [†] ; p=0.040*

PL: Preferred limb; NPL: Non-preferred limb; TPL: Total Path Length; VGRF: Vertical Ground Reaction Force; mm: millimeters; mm²: millimeters squared; N: Newtons

[†]Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, GMFCS level I

*Significance at $\alpha=0.05$

The participants with CP, GMFCS level II or III, had significantly longer TPLs (preferred limb [median difference=196.75 mm, range: -389.96 – 7459.76 mm; $z=2.040$, $p=0.041$]; non-preferred limb [median difference=233.77 mm, range: -206.36 – 3381.53 mm; $z=2.197$, $p=0.028$]) and larger 95% ellipse areas (preferred limb [median difference=169.23 mm², range: -30.31 - 6844.55 mm²; $z=2.981$, $p=0.003$]; non-preferred limb [median difference=293.51 mm², range: -26.92 – 8783.13 mm²; $z=2.824$, $p<0.005$]) during eyes closed trials. This indicates that the youth with CP, GMFCS level II or III, swayed a great deal more on both limbs when their eyes were closed compared to their TD peers. As well with their 95% ellipse areas being larger this indicates that their COP deviates further before they correct their posture. During eyes closed VGRF was not found to differ between groups suggesting that the distribution of weight between feet was similar between the TD participants and their respective match.

With respect to the eyes open trial the same pattern held true during for the TPLs (preferred limb [median difference=161.55 mm, range: -178.55 – 5434.24 mm; $z=2.118$, $p=0.034$]; non-preferred limb [median difference=178.31 mm, range: -66.72 – 2272.09 mm; $z=2.589$, $p=0.010$]) of youth with CP, GMFCS level II or III. Again, indicating that youth with CP, GMFCS II or III swayed more during quiet bipedal balance than their peers. Additionally, the median TPL differences for the eyes closed trial were longer than the median difference for the eyes open trial. The 95% ellipse areas of youth with CP, GMFCS level II or III was also significantly larger compared to their TD peers with both their preferred (median difference=242.75 mm², range: -26.54 – 11758.79 mm²; $z=-2.903$, $p=0.004$) and non-preferred weight-bearing limbs (median difference=123.89 mm², range: 8.90 – 6094.41 mm²; $z=-3.059$, $p=0.002$). Again, indicating further sway prior to the correction of posture in these individuals. In

addition to this, the youth with CP, GMFCS level II or III put on average less of their weight (median: 233.11 N, range: 124.74 - 416.90 N) on their non-preferred weight-bearing limb compared to their TD peers (median: 297.91 N, range: 138.75 - 471.16 N, $z=-1.961$, $p=0.050$). Further detail regarding within-pair differences of youth with CP, GMFCS levels II or III and their age- and sex-matched TD peer can be found in Table 4.11 and can be seen in Figures 4.10, 4.11, and 4.12.

Table 4.11 Median within-pair difference and range for postural control outcomes in youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level II or III and their age- and sex-matched typically developing (TD) peers

	Balance Outcome Measures	Median (Range)			Test statistic [†] ; p-value
		CP (GMFCS level II & III) n=12	TD n=12	Median Within-pair Difference	
Eyes Closed	PL-TPL	541.01 (125.37 – 7644.55)	306.95 (123.86 – 571.66)	196.75 (-389.96 – 7459.76)	2.040 [†] ; p=0.041*
	NPL-TPL	438.14 (189.42 – 3556.79)	236.66 (125.48 – 522.29)	233.77 (-206.36 – 3381.53)	2.197 [†] ; p=0.028*
	PL-95% ellipse area	186.47 (14.16 – 6850.15)	29.89 (5.60 – 137.92)	169.23 (-30.31 – 6844.55)	2.981 [†] ; p=0.003*
	NPL-95% ellipse area	312.35 (31.85 – 8807.53)	25.14 (9.01 – 64.01)	293.51 (-26.92 – 8783.13)	2.824 [†] ; p<0.005*
	PL-VGRF	283.08 (201.02 – 440.55)	334.31 (146.69 – 491.20)	-27.40 (-250.80 – 121.59)	-1.020 [†] ; p=0.308
	NPL-VGRF	240.70 (139.07 – 408.39)	299.09 (140.95 – 459.22)	-80.72 (-224.65 – 93.73)	-1.726 [†] ; p=0.084
Eyes Open	PL-TPL	460.53 (153.82 – 5571.36)	241.08 (118.32 – 339.92)	161.55 (-178.55 – 5434.24)	2.118 [†] ; p=0.034*
	NPL-TPL	345.96 (191.63 – 2452.62)	199.09 (110.97 – 311.20)	178.31 (-66.72-2272.09)	2.589 [†] ; P<0.010*
	PL-95% ellipse area	289.75 (40.93 – 11792.99)	34.27 (12.97 – 176.33)	242.75 (-26.54 – 11758.79)	2.903 [†] ; p=0.004*
	NPL-95% ellipse area	176.48 (41.54 – 6115.06)	28.98 (6.22 – 72.09)	123.89 (8.90 – 6094.41)	3.059 [†] ; p=0.002*
	PL-VGRF	281.87 (210.35 – 449.10)	332.67 (148.85 – 478.71)	-26.11 (-234.31 – 112.20)	-0.784 [†] ; p=0.433
	NPL-VGRF	233.11 (124.74 – 416.90)	297.91 (138.75 – 471.16)	-85.63 (-240.99 – 103.65)	-1.961 [†] ; p=0.050*

PL: Preferred limb; NPL: Non-preferred limb; TPL: Total Path Length; VGRF: Vertical Ground Reaction Force; mm: millimeters; mm²: millimeters squared; N: Newtons

[†]Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, GMFCS levels II and III

*Significance at $\alpha=0.05$

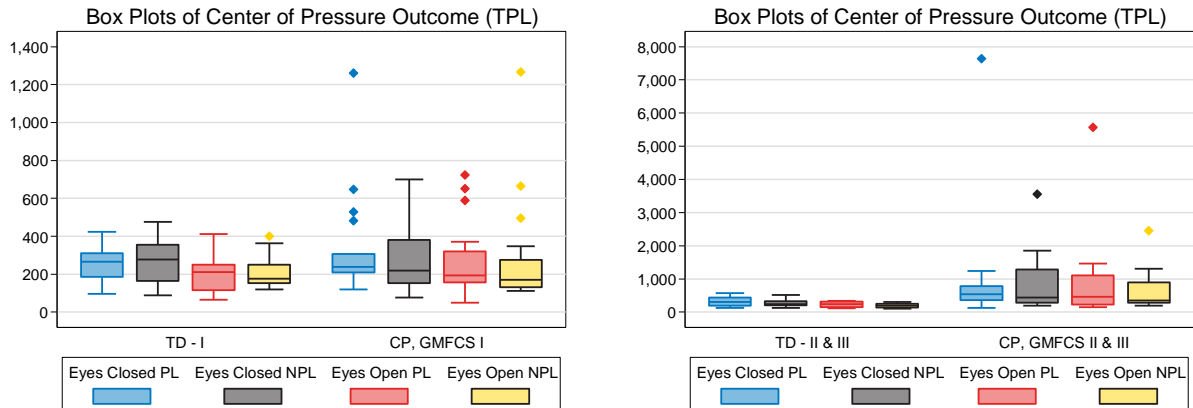


Figure 4.10 Center of pressure (COP) total path length (TPL) outcomes (mm) for youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level and their typically developing (TD) peers (Left); and for youth with CP, GMFCS levels II and III and their TD peers (Right)

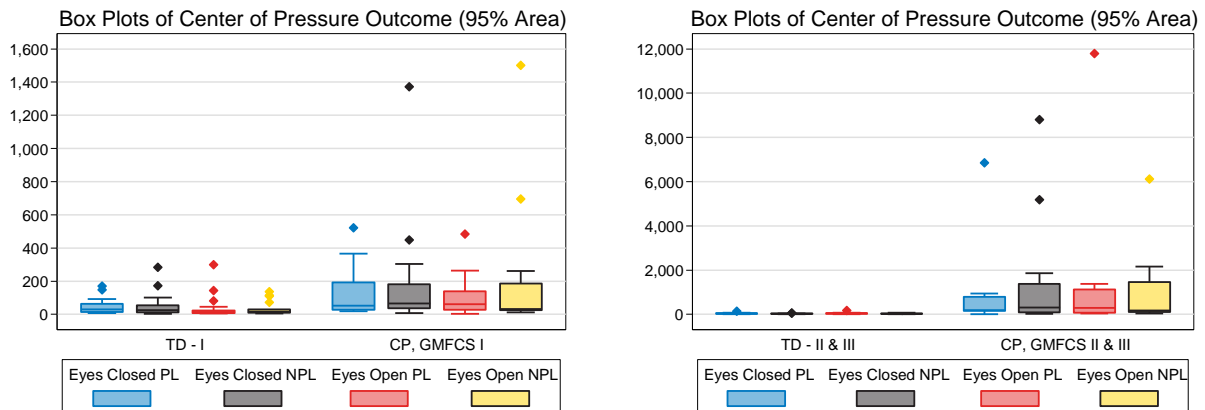


Figure 4.11 Center of pressure (COP) 95% ellipse area outcomes (mm²) for youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level and their typically developing (TD) peers (Left); and for youth with CP, GMFCS levels II and III and their TD peers (Right)

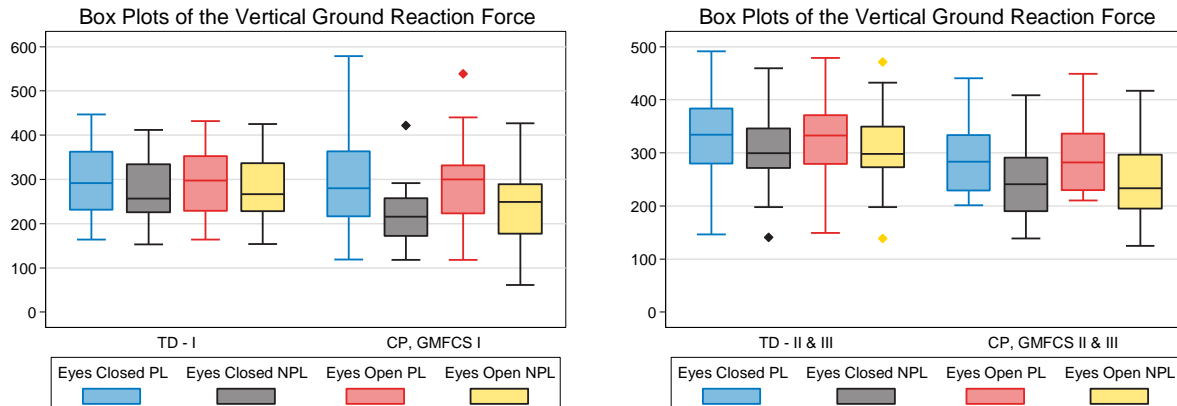


Figure 4.12 Vertical ground reaction force (N) for youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their typically developing peers (Left); and for youth with CP, GMFCS levels II and III and their TD peers (Right)

4.3.3 Lower-Extremity Strength

4.3.3.1 Reliability

4.3.3.1.1 Intra-class Correlation Coefficients

Based on the relative assessment of reliability using the intraclass correlation coefficients (ICCs), the reliability was determined to be strong for 13 of out of the 16 tested muscle groups. Examining the ICCs, testing strength using the protocol found in Chapter Three: Methods (section 3.3.2.2.3) appears to be a highly repeatable means of testing isometric strength for most muscle groups. However, knee flexors were not able to be measured as reliably. There was greater variability in the measures from the first day to the second day for both the preferred (ICC=0.62; 95% CI: 0.35 - 0.79) and non-preferred weight-bearing limb (ICC=0.71; 95% CI: 0.49 - 0.84). Interestingly, the ankle dorsiflexors of the preferred weight-bearing was also only moderately reliable (ICC=0.65; 95% CI: 0.40 - 0.81) whereas the non-preferred leg demonstrated strong reliability (ICC=0.83; 95% CI: 0.68 - 0.91). ICC data is summarized in Table 4.12.

Table 4.12 Intraclass correlation coefficients and 95% confidence intervals (CI) of lower-extremity muscle groups for both the preferred and non-preferred weight-bearing limbs of youth with cerebral palsy (CP) and typically developing (TD) youth

Muscle Group	Preferred Limb ICC (95% CI)	Non-Preferred Limb ICC (95% CI)
Hip Extensors	0.83 (0.69-0.91)	0.83 (0.68-0.91)
Hip Flexors	0.83 (0.69-0.91)	0.82 (0.67-0.90)
Hip Abductors	0.86 (0.74-0.93)	0.96 (0.92-0.98)
Hip Adductors	0.84 (0.70-0.92)	0.85 (0.72-0.92)
Knee Extensors	0.83 (0.68-0.91)	0.77 (0.59-0.88)
Knee Flexors	0.62 (0.35-0.79) [†]	0.71 (0.49-0.84) [†]
Ankle Dorsiflexors	0.65 (0.40-0.81) [†]	0.83 (0.68-0.91)
Ankle Plantar Flexors	0.78 (0.61-0.89)	0.87 (0.75-0.93)

Intraclass Correlation Coefficient (3,1). Based off of guidelines suggested by Portney and Watkins⁶⁶, most ICC's are considered strong relative reliability. [†]ICC indicate moderate relative reliability.

4.3.3.1.2 Bland-Altman Limits of Agreement

Although there is not perfect agreement between testing sessions for any of the 16 muscle groups, regardless of which limb (preferred or non-preferred for weight-bearing) the mean differences are small, very close to zero, and the Bland-Altman limits of agreement (LOA) were mostly quite narrow. In terms of each muscle group, comparing the preferred limb to the non-preferred limb, the LOA were reasonably equal in width. However, there was one exception, the width of the LOA for the non-preferred hip abductors was about half that of the LOA for the preferred limb suggesting that participants had greater variability in the forces they produced with this muscle group between sessions. See Table 4.13 for more information about LOA, mean differences, and 95% CIs.

Based on the Bland-Altman plots in Figures 4.13, 4.14, 4.15, and 4.16, one pattern stays consistent regardless of muscle group or limb preference. This is that youth with CP, as depicted by red diamonds, produce smaller amounts of torque normalized to body mass as seen by their

generally smaller session 1 and session 2 means. This will be presented with more traditional descriptive statistics below. Figure 4.14, specifically the plot for the non-preferred hip abductors, may indicate a slight systematic bias such that both the participants with CP and the TD participants tended to produce more force with this muscle group during the first session than they did during the second. In Figure 4.14, specifically the plot for the preferred limb hip adductor, there appears to be somewhat of a magnitude bias such that those individuals who had a smaller mean torque (normalized to body mass) for the two days had a greater difference between their forces for both days. This same pattern may also be true for the preferred limb knee flexor, seen in Figure 4.15, however, to a lesser extent than the magnitude bias seen for the hip adductors of the preferred limb. Otherwise, there do not appear to be any patterns to the distribution of points in these plots, suggesting that although the agreement is not perfect, there are no systematic biases influencing the results of most muscle groups.

Table 4.13 Bland-Altman Limits of Agreement and 95% confidence intervals (CI) of lower-extremity muscle groups for both the preferred and non-preferred weight-bearing limbs of both youth with cerebral palsy (CP) and typically developing (TD) youth

Muscle Group		Preferred Limb	Non-Preferred Limb
Hip Extensors	Limits of Agreement	-0.988 – 1.166	-1.084 – 1.099
	Mean Difference	0.89	0.008
	95% Confidence Interval	-0.099 – 0.277	-0.183 – 0.198
Hip Flexors	Limits of Agreement	-0.441 – 0.481	-0.521 – 0.466
	Mean Difference	0.020	-0.028
	95% Confidence Interval	-0.061 – 0.100	-0.114 – 0.058
Hip Abductors	Limits of Agreement	-0.453 – 0.481	-0.280 – 0.201
	Mean Difference	0.014	-0.039
	95% Confidence Interval	-0.068 – 0.095	-0.081 – 0.003
Hip Adductors	Limits of Agreement	-0.474 – 0.419	-0.508 – 0.440
	Mean Difference	-0.027	-0.034
	95% Confidence Interval	-0.105 – 0.051	-0.117 – 0.049
Knee Extensors	Limits of Agreement	-0.742 – 0.942	-0.832 – 0.949
	Mean Difference	0.100	0.058
	95% Confidence Interval	-0.047 – 0.247	-0.097 – 0.214
Knee Flexors	Limits of Agreement	-0.441 – 0.455	-0.404 – 0.403
	Mean Difference	0.007	-0.001
	95% Confidence Interval	-0.073 – 0.086	-0.071 – 0.070
Ankle Dorsiflexors	Limits of Agreement	-0.163 – 0.192	-0.122 – 0.153
	Mean Difference	0.015	0.015
	95% Confidence Interval	-0.017 – 0.046	-0.009 – 0.039
Ankle Plantar Flexors	Limits of Agreement	-0.466 – 0.599	-0.387 – 0.498
	Mean Difference	0.066	0.056
	95% Confidence Interval	-0.028 – 0.161	-0.023 – 0.134

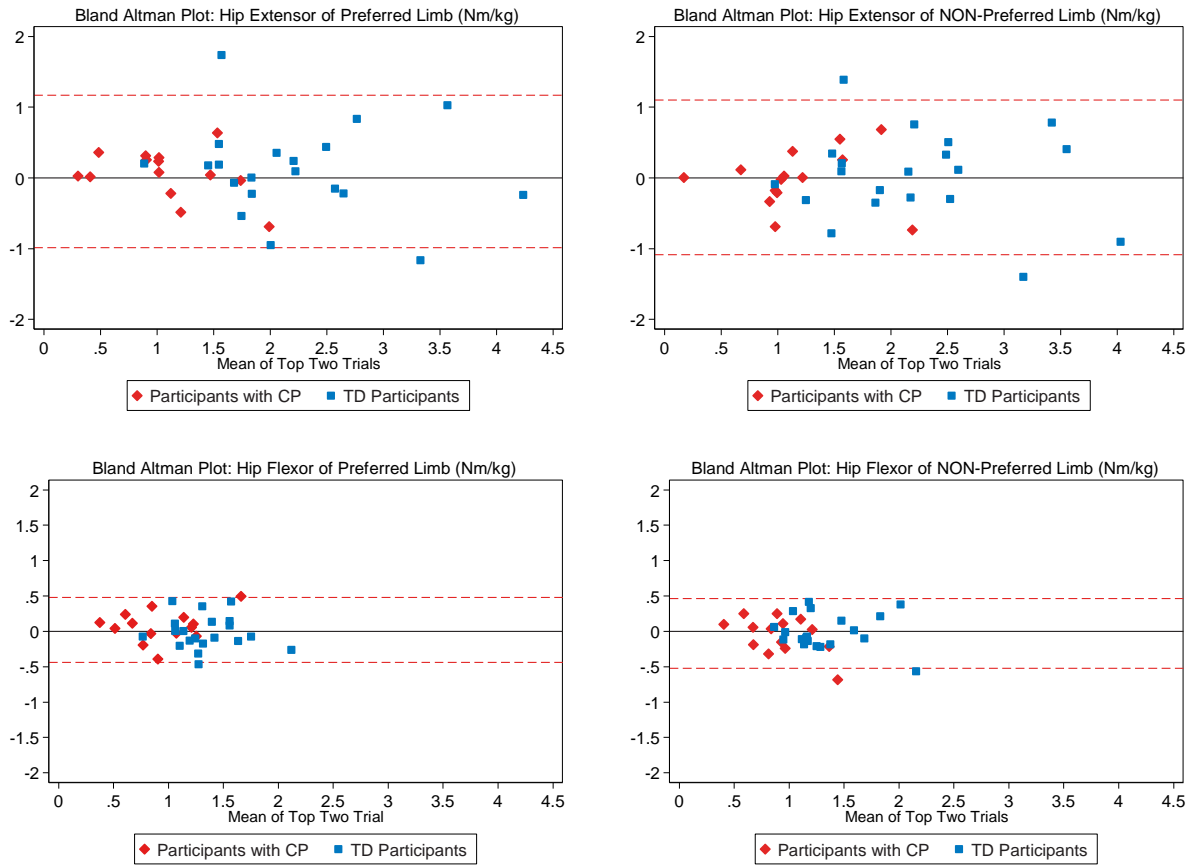


Figure 4.13 Bland-Altman plots of the preferred hip extensor (top left), non-preferred hip extensor (top right), preferred hip flexor (bottom left), and the non-preferred limb hip flexor (bottom right) with the intra-rater agreement of the typically developing (TD) participants denoted by blue squares and the red diamonds denoting the intra-rater agreement of the youth with cerebral palsy (CP)

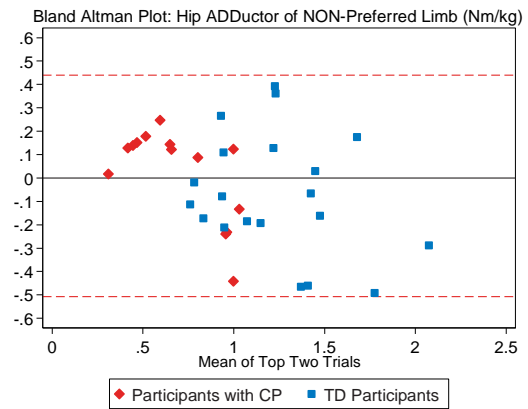
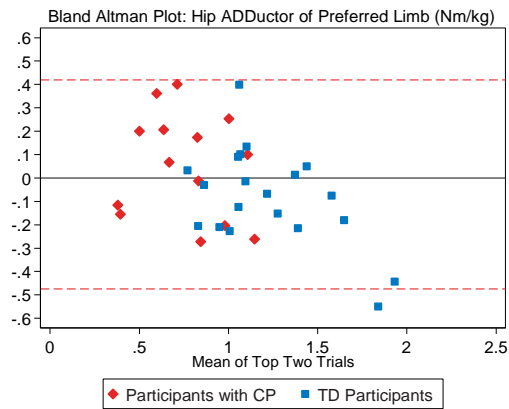
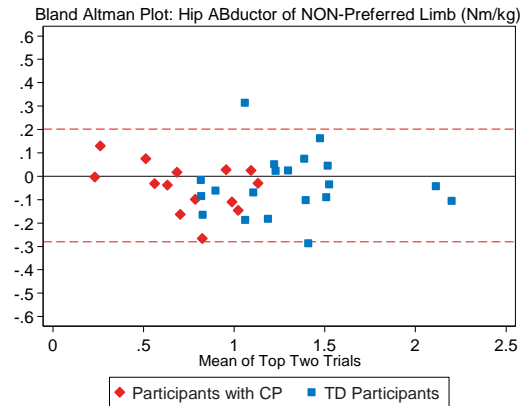
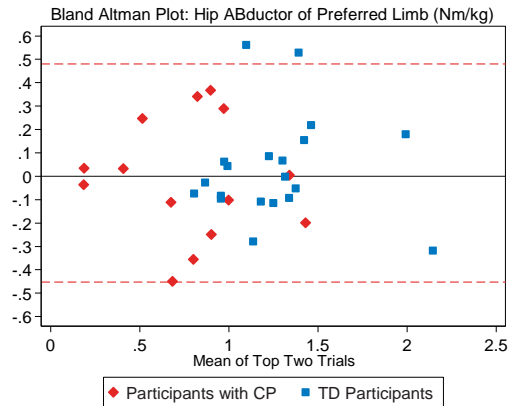


Figure 4.14 Bland-Altman plots of the preferred hip abductor (top left), non-preferred hip abductor (top right), preferred hip adductor (bottom left), and the non-preferred limb hip adductor (bottom right) with the intra-rater agreement of the typically developing (TD) participants denoted by blue squares and the red diamonds denoting the intra-rater agreement of the youth with cerebral palsy (CP)

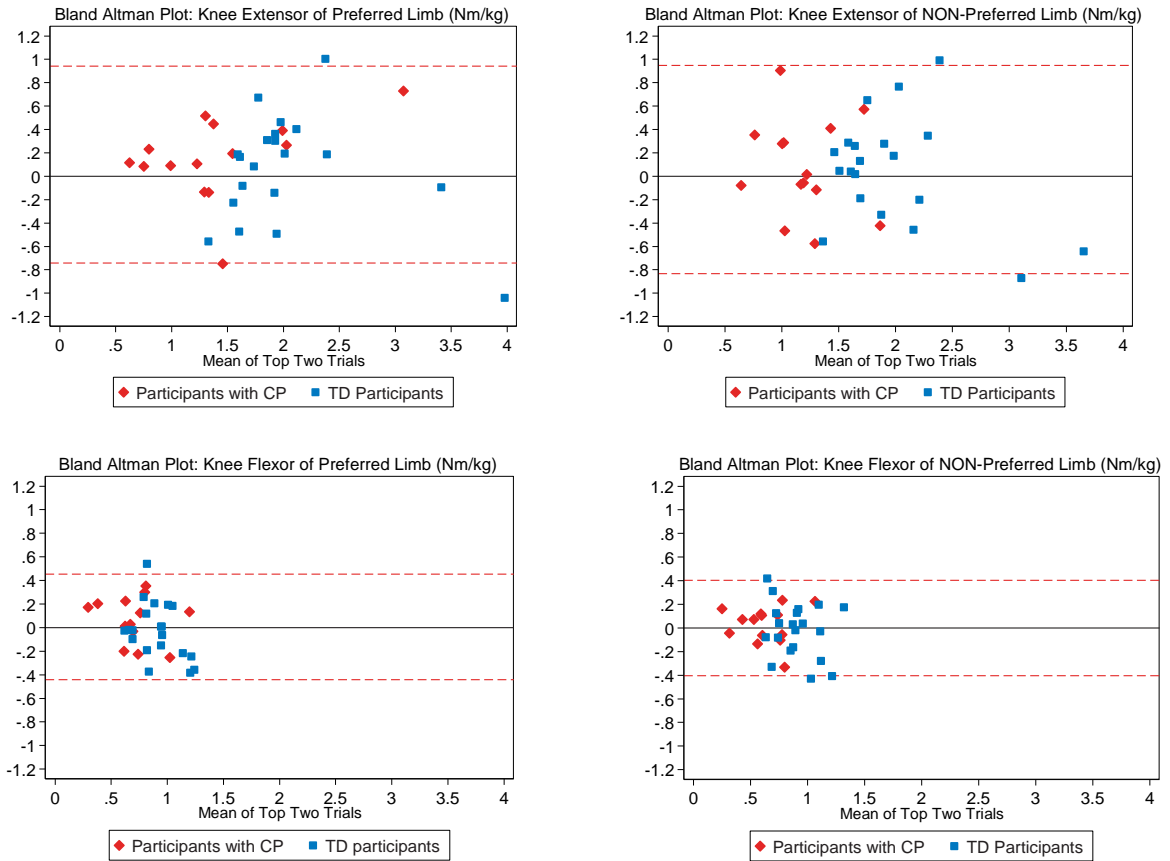


Figure 4.15 Bland-Altman plots of the preferred knee extensor (top left), non-preferred knee extensor (top right), preferred knee flexor (bottom left), and the non-preferred limb knee flexor (bottom right) with the intra-rater agreement of the typically developing (TD) participants denoted by blue squares and the red diamonds denoting the intra-rater agreement of the youth with cerebral palsy (CP)

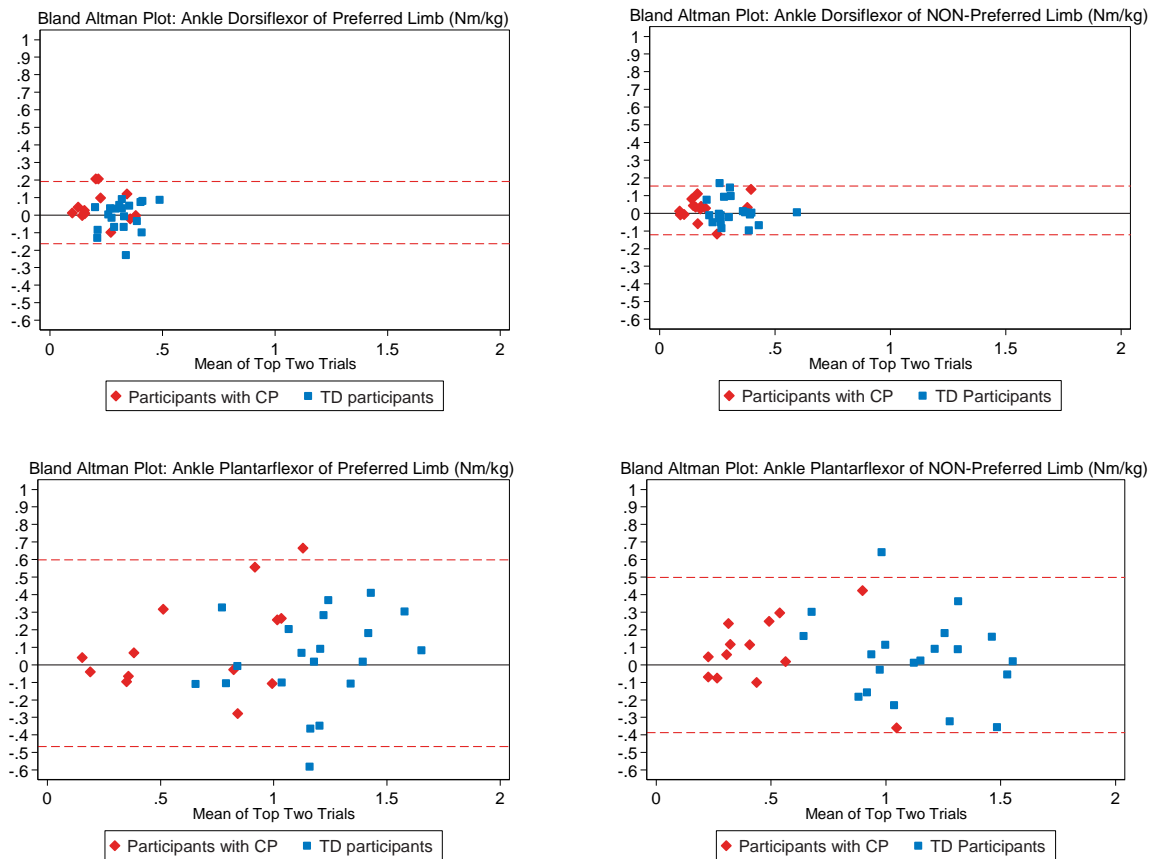


Figure 4.16 Bland-Altman plots of the preferred ankle dorsiflexors (top left), non-preferred ankle dorsiflexors (top right), preferred ankle plantar flexors (bottom left), and the non-preferred limb ankle plantar flexors (bottom right) with the intra-rater agreement of the typically developing (TD) participants denoted by blue squares and the red diamonds denoting the intra-rater agreement of the youth with cerebral palsy (CP)

4.3.3.2 Mean Within-pair Differences

All 30 TD youth and all 30 youth with CP participated in the strength testing component of the study. All TD participants were able to produce enough force to activate the hand-held dynamometer for all three trials with all muscle groups, therefore it was possible to calculate an average of their best two trials. However, some participants with CP were unable to produce sufficient force (20 N) to activate the hand-held dynamometer. As such, the Wilcoxon signed-

rank tests were based off of 29 pairs (17 pairs included GMFCS level I and 12 pairs included GMFCS level II or III) for the preferred limb knee flexors; 27 pairs (16 pairs included GMFCS level I and 11 pairs included GMFCS level II or III) for the preferred limb ankle dorsiflexors; 27 pairs (16 pairs included GMFCS level I and 11 pairs included GMFCS level II or III) for the non-preferred limb ankle dorsiflexors; and 29 pairs (17 pairs included GMFCS level I and 12 pairs included GMFCS level II or III) for the non-preferred limb ankle plantar flexors. Each participant was given three attempts to try to activate the hand-held dynamometer, however some individuals with CP were unable to produce greater than 20 N of force with some of their muscle group(s) or they recruited a different muscle group as they were unable to recruit the appropriate muscle group for the test they were being asked to complete.

Within-pair differences of strength outcomes appeared to be normally distributed and were evaluated using paired t tests. Overall participants with CP were significantly weaker than their TD peers with all 8 of the hip muscle groups. The mean within-pair differences for all the lower-extremity muscle groups can be seen in Figure 4.17. Additionally, youth with CP were found to be significantly weaker with their 2 muscle groups of the knee and the 2 muscle groups with the ankle for both the preferred and non-preferred limbs. The within-pair differences for the knee and ankle muscle groups can be seen in Figure 4.17. The mean within-pair differences for the strength outcomes can be found in Table 4.14.

Table 4.14 Mean within-pair differences with 95% confidence intervals (95% CI) for lower-extremity muscle strength outcomes (Nm/kg) in youth with cerebral palsy (CP) and their age- and sex-matched typically developing (TD) peers

	Strength Outcome Measures	n=	Mean (95% CI)			Test statistic [^] ; p-value
			CP	TD	Mean Within-pair Differences	
Preferred Weight-bearing Limb	Hip Extensors	30	1.24 (0.96 - 1.53)	2.16 (1.87 - 2.46)	-0.92 (-1.35 - -0.49)	-4.345 [^] ; p<0.001*
	Hip Flexors	30	0.98 (0.86 - 1.10)	1.30 (1.21 - 1.38)	-0.31 (-0.46 - -0.16)	-4.298 [^] ; p<0.001*
	Hip Abductors	30	0.83 (0.69 - 0.97)	1.25 (1.11 - 1.39)	-0.42 (-0.58 - -0.25)	-5.189 [^] ; p<0.001*
	Hip Adductors	30	0.78 (0.65 - 0.91)	1.17 (1.04 - 1.31)	-0.39 (-0.58 - -0.20)	-4.178 [^] ; p<0.001*
	Knee Extensors	30	1.28 (1.06 - 1.49)	1.98 (1.71 - 2.26)	-0.71 (-1.08 - -0.34)	-3.903 [^] ; p<0.001*
	Knee Flexors	29	0.68 (0.56 - 0.79)	0.95 (0.84 - 1.05)	-0.27 (-0.44 - -0.10)	-3.327 [^] ; p=0.003*
	Ankle Dorsiflexors	27	0.21 (0.16 - 0.25)	0.30 (0.27 - 0.33)	-0.09 (-0.15 - -0.04)	-3.631 [^] ; p=0.001*
	Ankle Plantar Flexors	30	0.56 (0.44-0.69)	1.14 (1.03-1.24)	-0.57 (-0.74 - -0.40)	-6.886 [^] ; p<0.001*
Non-preferred Weight-bearing Limb	Hip Extensors	30	1.33 (1.04 - 1.62)	2.15 (1.84 - 2.46)	-0.82 (-1.26 - -0.39)	-3.883 [^] ; p<0.001*
	Hip Flexors	30	1.02 (0.89 - 1.15)	1.27 (1.17 - 1.37)	-0.25 (-0.41 - -0.08)	-3.107 [^] ; p=0.004*
	Hip Abductors	30	0.84 (0.68 - 0.99)	1.28 (1.15 - 1.41)	-0.45 (-0.64 - -0.25)	-4.783 [^] ; p<0.001*
	Hip Adductors	30	0.76 (0.62 - 0.90)	1.22 (1.06 - 1.38)	-0.46 (-0.67 - -0.25)	-4.480 [^] ; p<0.001*
	Knee Extensors	30	1.24 (1.05 - 1.44)	1.97 (1.71 - 2.22)	-0.72 (-1.07 - -0.38)	-4.250 [^] ; p<0.001*
	Knee Flexors	30	0.64 (0.53 - 0.76)	0.93 (0.85 - 1.01)	-0.29 (-0.43 - -0.14)	-4.065 [^] ; p<0.001*
	Ankle Dorsiflexors	27	0.21 (0.17 - 0.25)	0.29 (0.26 - 0.32)	-0.08 (-0.14 - -0.02)	-2.766 [^] ; p=0.010*
	Ankle Plantar Flexors	29	0.54 (0.40-0.68)	1.10 (0.98-1.22)	-0.56 (-0.74 - -0.38)	-6.317 [^] ; p<0.001*

[^]Test statistic = t (Paired t test), CP – TD, gross motor function classification system (GMFCS) levels I, II, and III;

*Significance at $\alpha=0.05$

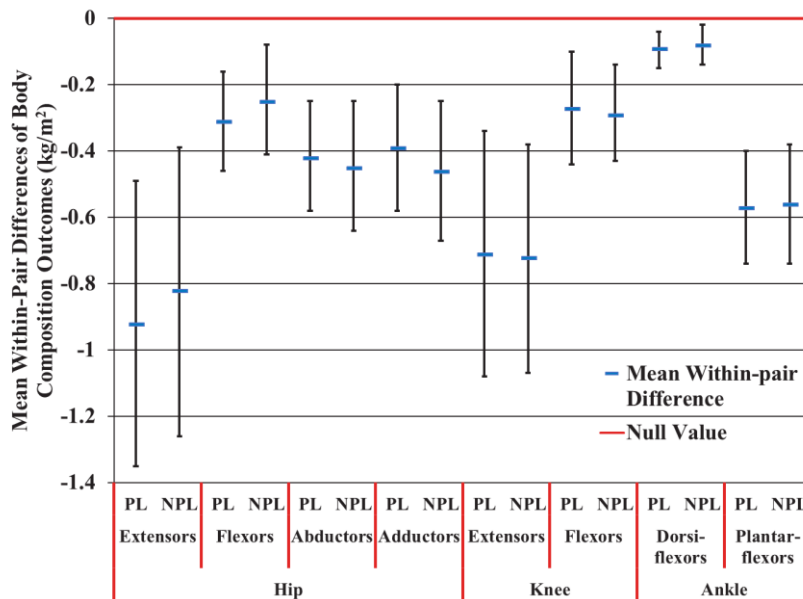


Figure 4.17 Mean within-pair differences with 95% confidence intervals (95% CI) of the lower-extremity strength outcomes (Nm/kg) for youth with cerebral palsy (CP) and their typically developing (TD) matches; within-pair difference values are representative of TD – CP, gross motor function classification system (GMFCS) levels I, II, and III; PL = preferred limb, NPL = non-preferred limb

In terms of the matched pairs including a participant with CP, GMFCS level I, significant within-pair differences were found for the preferred limb hip abductor (median difference=-0.23 Nm/kg, range: -1.32 – 0.68 Nm/kg; $z=-2.154$, $p=0.331$) and the non-preferred limb hip abductor (median difference=-0.21 Nm/kg, range: -1.36 - 0.83 Nm/kg; $z=-2.107$, $p=0.035$). The preferred and non-preferred ankle plantar flexors of youth with CP, GMFCS level I, were also found to be significantly weaker than the respective ankle plantar flexors of their TD peers. These differences were such that the preferred ankle plantar flexors of youth with CP produced a median of 0.50 Nm/kg (range: -1.48 - 0.71 Nm/kg; $z=-2.769$, $p=0.006$) less of torque normalized to body mass. In addition, the non-preferred ankle plantar flexors produced a median of 0.53 Nm/kg (range: -1.27 - 0.78 Nm/kg; $z=-2.580$, $p=0.010$) less torque normalized to body mass

compared to TD youth. In each of these cases TD participants were able to produce significantly more torque (i.e., were stronger), normalized to their body mass, than the participant with CP who they were matched to. Further information about within-pair differences for the lower-extremity strength data of matched pairs including a participant with CP, GMFCS level I can be found in Table 4.15 and can be seen in Figures 4.18 and 4.19.

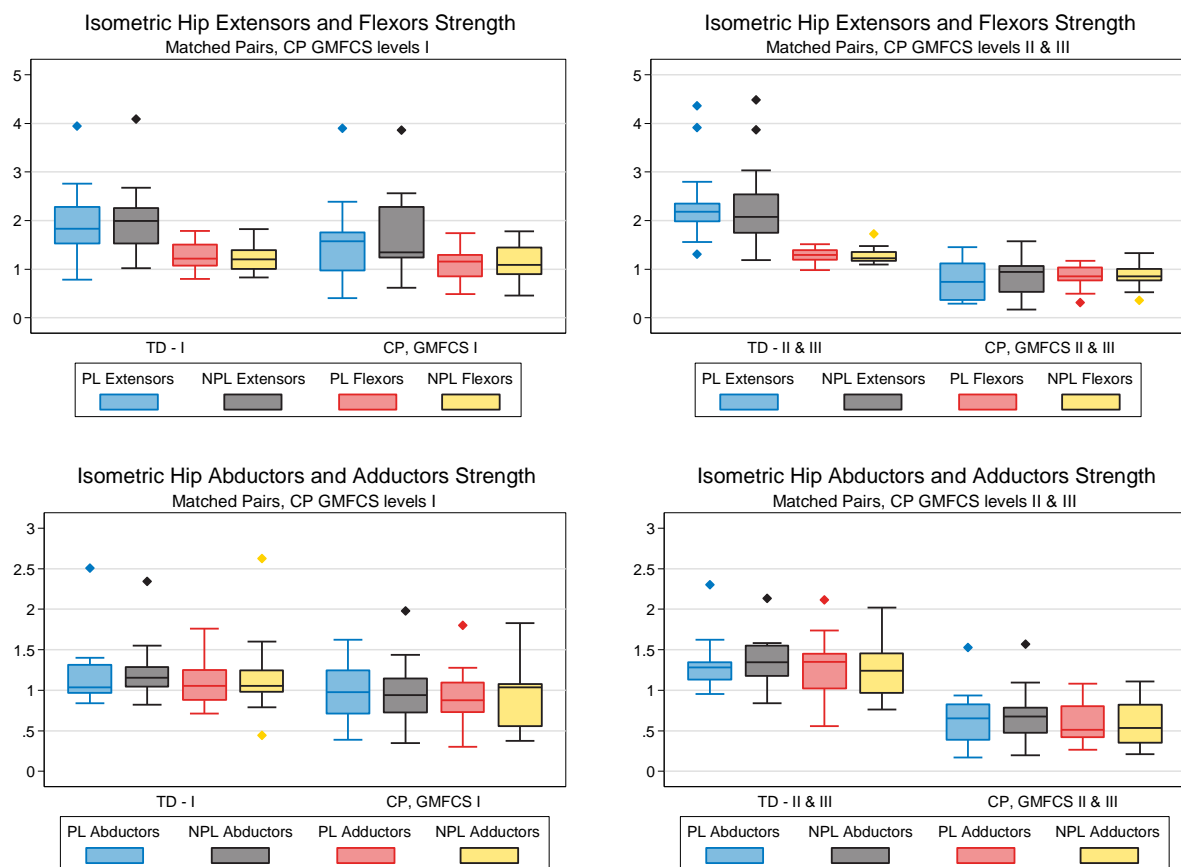


Figure 4.18 Lower-extremity strength outcomes (Nm/kg) for hip extensors and flexors (Top) and hip abductors and adductors (Bottom) of youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their matched typically developing (TD) peers (Left); and for youth with CP, GMFCS levels II or III and their matched TD peers (Right), for the preferred limb (PL) and non-preferred limb (NPL)

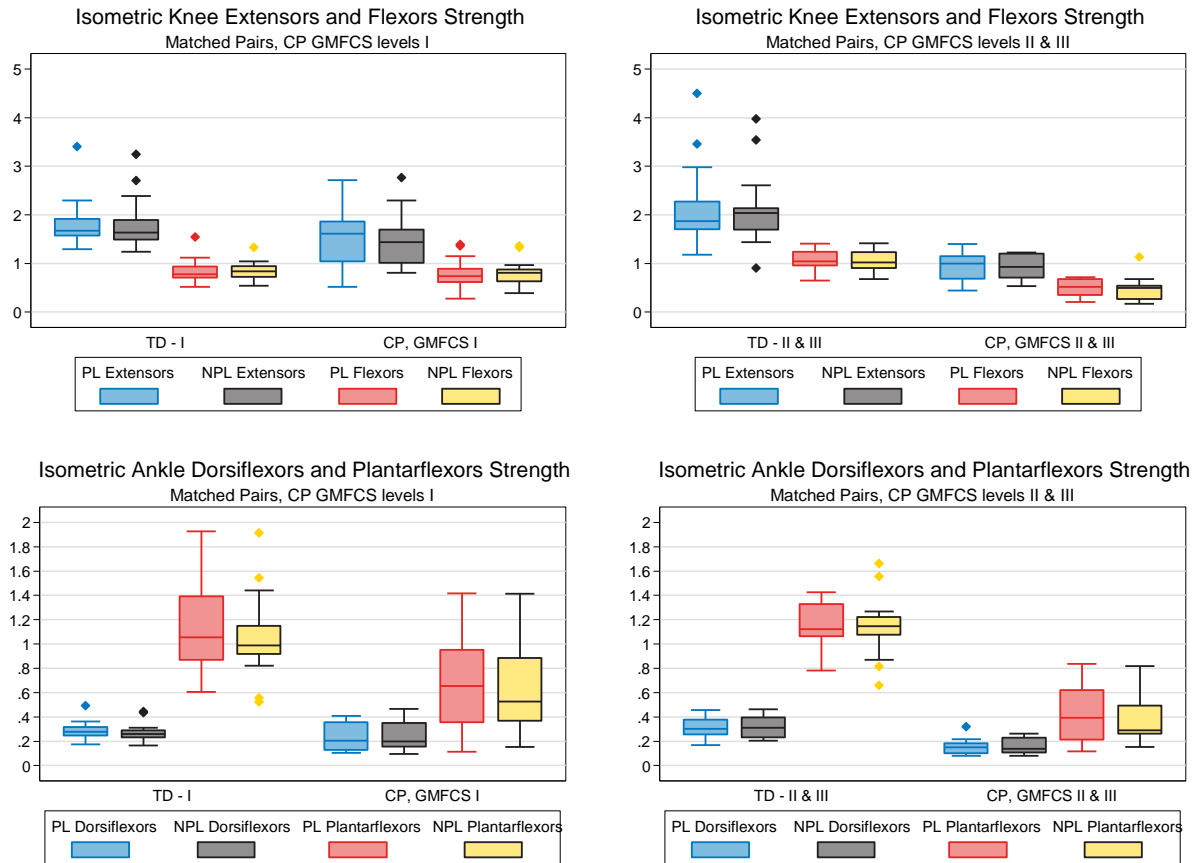


Figure 4.19 Lower-extremity strength outcomes (Nm/kg) for knee extensors and flexors (Top) and ankle dorsiflexors and plantar flexors (Bottom) of youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their matched typically developing (TD) peers (Left); and for youth with CP, GMFCS levels II or III and their matched TD peers (Right), for the preferred limb (PL) and non-preferred limb (NPL)

Table 4.15 Median within-pair differences and range for lower-extremity muscle strength outcomes in youth with cerebral palsy (CP), gross motor function classification system (GMFCS) level I and their age- and sex-matched typically developing (TD) peers

	Strength Outcome Measures	n=	Median (Range)			Test statistic [†] ; p-value
			CP (GMFCS level I)	TD	Median Within-pair Difference	
Preferred Weight-bearing Limb	Hip Extensors	17	1.58 (0.40 - 3.89)	1.83 (0.79 - 3.95)	-0.49 (-2.36 - 1.88)	-1.586 [†] ; p=0.113
	Hip Flexors	17	1.16 (0.49 - 1.74)	1.22 (0.80 - 1.79)	-0.18 (-0.98 - 0.60)	-1.870 [†] ; p=0.062
	Hip Abductors	17	0.98 (0.39 - 1.62)	1.04 (0.84 - 2.51)	-0.23 (-1.32 - 0.68)	-2.154 [†] ; p=0.031*
	Hip Adductors	17	0.88 (0.30 - 1.80)	1.05 (0.71 - 1.76)	-0.17 (-0.92 - 0.77)	-1.681 [†] ; p=0.093
	Knee Extensors	17	1.61 (0.52 - 2.71)	1.67 (1.29 - 3.41)	-0.12 (-2.17 - 0.96)	-1.396 [†] ; p=0.163
	Knee Flexors	17	0.74 (0.28 - 1.40)	0.78 (0.52 - 1.54)	-0.10 (-0.65 - 0.62)	-0.686 [†] ; p=0.493
	Ankle Dorsiflexors	16	0.21 (0.10 - 0.41)	0.28 (0.17 - 0.49)	-0.04 (-0.26 - 0.13)	-1.448 [†] ; p=0.148
	Ankle Plantar Flexors	17	0.65 (0.11 - 1.42)	1.06 (0.61 - 1.93)	-0.50 (-1.48 - 0.71)	-2.769 [†] ; p=0.006*
Non-preferred Weight-bearing Limb	Hip Extensors	17	1.35 (0.62 - 3.86)	1.99 (1.02 - 4.09)	-0.23 (-2.46 - 2.34)	-1.681 [†] ; p=0.093
	Hip Flexors	17	1.09 (0.46 - 1.78)	1.20 (0.83 - 1.82)	-0.15 (-0.80 - 0.95)	-1.302 [†] ; p=0.193
	Hip Abductors	17	0.94 (0.35 - 1.98)	1.15 (0.82 - 2.34)	-0.21 (-1.36 - 0.83)	-2.107 [†] ; p=0.035*
	Hip Adductors	17	1.04 (0.38 - 1.83)	1.05 (0.44 - 2.63)	-0.24 (-1.83 - 0.85)	-1.917 [†] ; p=0.055
	Knee Extensors	17	1.44 (0.81 - 2.76)	1.64 (1.24 - 3.24)	-0.28 (-1.89 - 1.28)	-1.538 [†] ; p=0.124
	Knee Flexors	17	0.81 (0.39 - 1.36)	0.84 (0.54 - 1.33)	-0.07 (-0.52 - 0.55)	-0.923 [†] ; p=0.356
	Ankle Dorsiflexors	16	0.20 (0.09 - 0.46)	0.26 (0.17 - 0.44)	-0.08 (-0.24 - 0.23)	-0.414 [†] ; p=0.679
	Ankle Plantar Flexors	17	0.53 (0.15 - 1.41)	0.99 (0.52 - 1.92)	-0.53 (-1.27 - 0.78)	-2.580 [†] ; p=0.010*

[†]Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, GMFCS level I

*Significance at $\alpha=0.05$

With respect to the matched pairs including a participant with CP, GMFCS level II or III, the youth with CP were found to be significantly weaker than the TD participant matched to them for all 16 muscle groups. These differences were such that the youth with CP, GMFCS level II or III, had a median of 1.72 Nm/kg (range: -3.55 - -0.41 Nm/kg; $z=-3.180$, $p=0.002$) and a median of 1.01 Nm/kg (range: -3.35 - -0.36 Nm/kg; $z=-3.180$, $p=0.002$) less strength compared to the TD participants, with their preferred and non-preferred hip extensors respectively. The hip flexors of the preferred and non-preferred limbs were a median of 0.39 Nm/kg (range: -1.05 – 0.10 Nm/kg; $z=-3.110$, $p=0.002$) and 0.28 Nm/kg (range: -1.11 – 0.02 Nm/kg; $z=3.110$, $p=0.002$) weaker, respectively in the youth with CP, GMFCS level II or III. Hip abductors were weaker such that youth with CP produced a median of 0.59 Nm/kg (range: -1.45 – 0.35 Nm/kg; $z=-3.180$, $p=0.002$; preferred limb) and 0.82 Nm/kg (range: -1.39 - -0.01 Nm/kg; $z=-3.180$, $p=0.002$; non-preferred limb) less body mass normalized torque than their TD peers. The hip adductors were weaker for youth with CP such that their preferred limb was a median of 0.62 Nm/kg (range: -1.25 - 0.38 Nm/kg; $z=-3.040$, $p=0.002$) weaker and the non-preferred limb was a median of 0.85 Nm/kg (range: -1.33 - 0.06 Nm/kg; $z=-3.110$, $p=0.002$) weaker when compared to the TD participants.

The median within-pair difference for knee extensors revealed that a median difference of 0.88 Nm/kg (range: -3.35 - -0.05 Nm/kg; $z=-3.180$, $p=0.002$) for the preferred limb and a median difference of 1.28 Nm/kg (range: -2.75 - 0.17 Nm/kg; $z=-3.110$, $p=0.002$). Knee flexors had a median difference of 0.61 Nm/kg (range: -1.19 - -0.14 Nm/kg; $z=-3.059$, $p=0.002$) and 0.52 Nm/kg (range: -1.14 - -0.19 Nm/kg; $z=-3.180$, $p=0.002$) for the preferred and non-preferred limbs, respectively. The ankle dorsiflexors of youth with CP, GMFCS level II or III were also

found to be significantly weaker than their TD peers such that there was a median difference of 0.16 Nm/kg (range: -0.30 - 0.05 Nm/kg; $z=-2.667$, $p=0.008$) and 0.13 Nm/kg (range: -0.33 - -0.02 Nm/kg; $z=-2.934$, $p=0.003$) for the preferred and non-preferred limbs, respectively. Finally, both the preferred (median difference=-0.74 Nm/kg, range: -1.10 - -0.11 Nm/kg; $z=-3.180$, $p=0.002$) and non-preferred (median difference=0.80 Nm/kg, range: -1.06 - -0.37 Nm/kg; $z=-3.059$, $p=0.002$) ankle plantar flexors of youth with CP, GMFCS level II or III were significantly weaker than their typically developing peers. For more information about the differences between youth with CP, GMFCS level II or III, Table 4.16 provides a complete summary of pairs including youth with CP, GMFCS level II or III, medians and ranges and the median and range for within-pair differences.

Table 4.16 Median within-pair differences and range for lower-extremity muscle strength outcomes in youth with cerebral palsy (CP), gross motor function classification system (GMFCS) levels II or III and their age- and sex-matched typically developing (TD) peers

	Strength Outcome Measures	n=	Median (Range)			Test statistic; p-value
			CP (GMFCS level II & III)	TD	Median Within-pair Difference	
Preferred Weight-bearing Limb	Hip Extensors	13	0.74 (0.29 - 1.45)	2.18 (1.31 - 4.36)	-1.72 (-3.55 - -0.41)	-3.180 [†] ; p=0.002*
	Hip Flexors	13	0.86 (0.31 - 1.17)	1.29 (0.98 - 1.52)	-0.39 (-1.05 - 0.10)	-3.110 [†] ; p=0.002*
	Hip Abductors	13	0.65 (0.17 - 1.53)	1.28 (0.96 - 2.30)	-0.59 (-1.45 - 0.35)	-3.180 [†] ; p=0.002*
	Hip Adductors	13	0.51 (0.27 - 1.08)	1.35 (0.56 - 2.11)	-0.62 (-1.25 - 0.38)	-3.040 [†] ; p=0.002*
	Knee Extensors	13	0.99 (0.45 - 1.40)	1.87 (1.18 - 4.50)	-0.88 (-3.35 - -0.05)	-3.180 [†] ; p=0.002*
	Knee Flexors	12	0.52 (0.21 - 0.72)	1.04 (0.65 - 1.41)	-0.61 (-1.19 - -0.14)	-3.059 [†] ; p=0.002*
	Ankle Dorsiflexors	11	0.15 (0.08 - 0.32)	0.30 (0.17 - 0.46)	-0.16 (-0.30 - 0.05)	-2.667 [†] ; p=0.008*
	Ankle Plantar Flexors	13	0.39 (0.12-0.84)	1.12 (0.78-1.43)	-0.74 (-1.10 - -0.11)	-3.180 [†] ; p=0.002*
Non-preferred Weight-bearing Limb	Hip Extensors	13	0.95 (0.17 - 1.58)	2.07 (1.18 - 4.48)	-1.01 (-3.35 - -0.36)	-3.180 [†] ; p=0.002*
	Hip Flexors	13	0.85 (0.36 - 1.33)	1.23 (1.10 - 1.72)	-0.28 (-1.11 - 0.02)	-3.110 [†] ; p=0.002*
	Hip Abductors	13	0.68 (0.20 - 1.57)	1.35 (0.84 - 2.13)	-0.82 (-1.39 - -0.01)	-3.180 [†] ; p=0.002*
	Hip Adductors	13	0.54 (0.21 - 1.11)	1.24 (0.76 - 2.02)	-0.85 (-1.33 - 0.06)	-3.110 [†] ; p=0.002*
	Knee Extensors	13	0.93 (0.53 - 1.22)	2.04 (0.91 - 3.97)	-1.28 (-2.75 - 0.17)	-3.110 [†] ; p=0.002*
	Knee Flexors	13	0.49 (0.17 - 1.13)	1.02 (0.68 - 1.41)	-0.52 (-1.14 - -0.19)	-3.180 [†] ; p=0.002*
	Ankle Dorsiflexors	11	0.14 (0.08 - 0.26)	0.31 (0.20-0.46)	-0.13 (-0.33 - -0.02)	-2.934 [†] ; p=0.003*
	Ankle Plantar Flexors	12	0.29 (0.15 - 0.82)	1.15 (0.66 - 1.66)	-0.80 (-1.06 - -0.37)	-3.059 [†] ; p=0.002*

[†]Test statistic = z (Wilcoxon Signed-Rank Test), CP – TD, GMFCS levels II and III

*Significance at $\alpha=0.05$

Chapter Five: **Discussion**

The primary objectives of this study were to examine the physical activity (PA) intensity levels [amount of time spent sedentary, in light PA, and in moderate-vigorous PA (MVPA)], and body composition [fat mass index (FMI), lean mass index (LMI), and body mass index (BMI)] of youth with cerebral palsy (CP), compared to their typically developing (TD) peers. To the best of our knowledge, this is the first study to evaluate these outcomes objectively for this population using the methods listed in Chapter Three. The secondary objectives of this study were to examine center of pressure (COP) and lower-extremity strength of youth with CP, compared to their TD peers, as well as to explore the reliability of the strength testing protocol found in Chapter Three. Although strength and balance have previously been examined using similar methodologies, to the best of our knowledge this was the first study to explore these outcomes by gross motor function classification system (GMFCS) level rather than distribution of involvement (DOI). Additionally, it is our understanding that this was the first study to use straps to hold the hand-held dynamometer in place, with the positions listed in Chapter Three, making the examination of reliability imperative.

Findings from this study demonstrated that youth with CP spent significantly less time in MVPA, more time sedentary, and have lower LMI. In addition, postural control was noticeably altered in youth with CP compared to their TD peers. Youth with CP were also significantly weaker than their TD peers in most muscle groups.

5.1 Participant Characteristics

In this study, most of the youth with CP were classified as GMFCS level I (57%). Those classified as a GMFCS level II made up 30% of participants and GMFCS level III made up 13%

of the sample for this study. Although the proportion of participants recruited who were classified as one of GMFCS level I, II, or III were projected to be representative of the proportion of youth in the neuromotor clinic patient population (Alberta Children's Hospital) with these classifications, this may not represent the exact proportions in the general population but are closely aligned.⁶⁷ In the current study most participants were male (67%), however based on one of the directories referenced in the Reid, et al.⁶⁷ research it has been suggested that males make up 56% of the broader CP population. Participants with CP were matched based on age (all were within 10 months) and sex to TD peers, therefore, age did not differ between cohorts. Height and BMI did not differ between cohorts, however participants with CP weighed significantly less than their TD peers.

5.2 Activity Level

5.2.1 Limitations in Engagement in Physical Activity

Based on the accelerometer data, it was determined that only one of 27 (4%) youth with CP was accumulating 60 minutes or more of MVPA, a minimum of 5 days a week. However, the TD youth did not do much better, with only 2 of 27 (7%) participants accumulating the 60 minutes or more of MVPA, at least 5 days a week. Based on the Statistics Canada²⁶ report of the proportion of youth meeting the PA guidelines, this result was not unexpected. This same report showed youth were accumulating around 211 minutes of light PA and 50 minutes of MVPA regularly,²⁶ which was reasonably consistent with the TD sample in the current for light PA (mean: 218.05 minutes, 95% CI:198.26-237.84 minutes) and MVPA (mean: 44.16 minutes, 95% CI: 37.29-51.02 minutes). Forty-four percent of youth with CP in the current study (10 youth with GMFCS level I and 2 youth classified as GMFCS levels II or III out of 27 participants with

CP) met the MVPA guidelines on at least one day per week, which was nearly double what was previously reported by Mitchell, Ziviani, and Boyd (25% of children with CP met the guidelines on at least one day).²⁸ However, it was fewer participants than reported by Ryan, et al (66% of children with CP met the guidelines).²⁵ The consistent finding across all studies is that youth with CP spend significantly more of their time sedentary and significantly less time at MVPA intensity levels daily than TD peers. In addition, the youth with CP, GMFCS levels II or III spent notably more time sedentary and less time in MVPA, with significantly smaller daily step counts compared to their TD peers. To our knowledge, this is the first study to directly compare the PA intensity levels as measured by accelerometry of youth with CP to their TD peers. As youth with CP spent significantly less time in MVPA than their TD peers, one would expect that either light PA or time spent sedentary would differ significantly between cohorts. The absence of a significant differences in both of the other two PA outcomes likely indicates that youth with CP split that time between time spent at light PA and time spent sedentary.

It is known that PA is an important influential factor of health and that habits developed at a young age determine the habits carried into adulthood.³⁵ Neither of the cohorts involved in this study were meeting the age appropriate PA guidelines, intended to prevent long-term morbidity. Yet the activity limitation component of the consensus definition of CP,³ appeared to have a more severe impact on those individuals with CP who were classified as a GMFCS level II or III. For this reason, these individuals are likely to be at higher risk of developing and living with additional health conditions, such as obesity and diabetes.⁶⁸ The knowledge related to the amount of daily time spent sedentary, in light PA, and in MVPA can be used to inform the need for and the design of future PA programs. It may be that youth with CP, GMFCS levels II or III

have fewer opportunities to accumulate the recommended PA. Although participation in adapted PA programs was not assessed in this study, the results suggest that adapted PA programs that meet age appropriate guidelines for PA should be encouraged.

5.3 Body Structure and Function Level

5.3.1 Body Composition Impairment

Using dual-energy X-ray absorptiometry (DXA), it was determined that youth with CP, specifically those with a GMFCS level II or III had significantly lower lean mass indices than their age- and sex-matched pairs. Although no previous studies have used DXA to compare youth with CP to their TD peer, previous studies have suggested that there are body composition differences across GMFCS levels.^{38,40} Most studies have used BMI^{38,39} as a means of assessing body composition. However, Duran, et al.⁶⁹ has suggested that although BMI is a highly specific measure it has poor sensitivity. As such, they concluded that the excess body fat that children with CP were believed to have, has actually been overestimated.⁶⁹ In this cohort study no differences were found for BMI, yet previous studies have suggested body composition differences based on the use of BMI. The previously reported differences may have been due in part to the faults of outcome measures such as BMI or percent body fat. Although these are used frequently and these measures are accessible they may not be the most appropriate way to describe body composition as they cannot take into account age. Additionally, these measures are influenced by bone and lean masses. In the current study participants with CP were matched based on age and sex to a TD youth, in addition, the body composition outcomes were normalized to the participants heights (i.e., fat and lean mass indices) thus taking into account age and making the statistical analyses more appropriate. The current study demonstrated no

body composition differences between youth with CP, GMFCS level I and their age- and sex-matched pair, but did report a difference in LMI between those classified as GMFCS level II or III and their matched peer, suggesting that severity of gross motor function impairment influences body composition. However, the fact that the observed differences were not in fat mass index or body mass index suggests that weight (i.e., obesity) is not an immediate concern, and perhaps interventions should focus on building more lean mass. Despite the current belief that lower levels of PA in youth is associated with increased adiposity, this cohort study found that youth with CP have lower levels of PA and lower LMI, but we did not see differences in adiposity.

5.3.2 Postural Control Impairment

This study demonstrated that youth with CP had poorer balance based on significantly longer total path lengths (TPL) in addition to larger 95% ellipse areas. This indicates that not only were the youth with CP moving more throughout the 30 seconds of the quiet balance tests, they also swayed more, moving further before correcting their posture. Three previous studies have suggested that individuals with a bilateral DOI have significantly alter balance compared to their TD peers,⁴⁴⁻⁴⁶ making this finding not surprising. Though the current study did not examine balance differences based on DOI, but rather by GMFCS level with levels II and III grouped. To the best of our knowledge COP measures have not previously been examined by GMFCS level. The findings in this study suggested GMFCS level also influences the magnitude of the balance function impairment. Saxena, et al.⁴⁶ reported that balance did not differ between individuals with a unilateral DOI, based on the analyses and subgroup analyses used in this cohort study it was not possible to draw conclusions about how DOI influences balance.

It is important to understand the magnitude of the balance impairment and which factors such as DOI or in this case GMFCS level may impact the magnitude of this impairment. This is because balance is a necessary skill required daily movement and can influence an individuals' ability to perform tasks and choice to participate in life situations. Youth who use gait aids to walk in some settings (i.e., GMFCS levels II or III) may do so because of postural instability. This balance impairment may contribute to the lower levels of PA as there may be fewer opportunities to engage in PA. Further, it may be that the individuals themselves, their parents, or their community associations choose not to allow them to engage in PA for safety reasons related to the balance impairment. Understanding the potential for an interaction between these factors, as the international classification of functioning, disability and health (ICF) suggests, will inform the need to increase the accessibility of adapted programs and alter the current design of existing programs to allow youth who are more severely impacted by their CP the opportunity to be physically active.

5.3.3 Lower-Extremity Muscle Strength

5.3.3.1 Reliability

As the literature base pertaining to reliability of isometric strength testing using hand-held dynamometry has some varied outcomes it was important to test the reliability of the current protocol. However, similar to many previous studies,⁵³⁻⁵⁵ this study demonstrated strong reliability of strength testing for most muscle groups using hand-held dynamometers. In agreement with the Willemse, et al.⁵⁵ study, reliability of the average of two trials was determined to be the most appropriate and reliable means of describing an individual's strength. The preliminary examination of reliability comparing the maximum torque, the average of the

top two trials, and the average of all three trials on each day can be found in Appendix C. The purpose of taking the mean of the top two trials is that it showed strong reliability for the examined muscle groups as well as it was deemed to be the best representation of the maximum force an individual can produce consistently. A few participants were unable to produce enough force to activate the hand-held dynamometer for some muscle groups. Reliability was poorer in these participants for select muscle groups (e.g., hip flexors, ankle dorsiflexors). This suggests that perhaps these positions were not optimal for measuring the strength of the hip flexors or ankle dorsiflexors. Further, these tended to be weaker muscles in most participants with CP and a few individuals with CP were unable to selectively control the movement of their ankle dorsiflexors or to produce enough force to surpass the required threshold to activate the hand-held dynamometer. Apart from the ankle dorsiflexors the strength of the reliability did not differ greatly between the preferred and non-preferred limbs. Additionally, ankle dorsiflexors had the narrowest LOA range, however this is likely due to it being one of the muscle groups that produced the least force.

5.3.3.2 Muscle Strength Impairment

Strength has not previously been examined in this population across levels of GMFCS, though an association has been shown with gross motor function measure.⁵⁷ The literature often refers to children with CP as being weaker than their TD peers.⁴⁹ The result of this study did not differ, youth with CP, GMFCS level II or III were significantly weaker than their TD peers with all 16 muscle groups. Whereas, the youth classified as GMFCS level I were only weaker than their TD peers with 4 of 16 muscle groups (i.e., both the preferred and non-preferred limb ankle plantar flexors and hip abductors). Despite the definitive statement made by Wiley and

Damiano,⁴⁹ that children with CP are weaker than their peers, it appears that gross motor function impairment may be associated with muscle weakness.

It is important to inform a better understanding of who is affected by muscle weakness, which muscles are affected, and to what degree they are affected. Although this study has not considered associations between strength and balance, future research should evaluate the relationship between weakness of the ankle plantar flexors and balance (e.g., COP movements). As previous studies⁶⁰ have suggested that it is possible to increase strength it would be interesting to examine how the programs they use impact PA levels. Although the findings of weakness in this study were not unexpected, it is interesting to consider that youth with CP are less physically active and do not reach the MVPA intensity levels regularly, suggesting that future programs should target higher intensity levels of PA. Additionally, the finding that LMI is decreased in youth with CP suggests that there is room for the development of muscles, potentially allowing for better function.⁵⁷

5.4 Strengths of this Cohort Study

To the best of our knowledge this was the first study to compare body composition outcomes between youth with CP and their TD peers using DXA. Additionally, we believe that this was the first study to explore PA, balance, and strength outcomes of youth with CP by GMFCS levels. This study made every attempt to use the most objective means available to measure activity level and body structure and function level outcomes. Although associations between these outcomes are not presented in this thesis, further analysis of the data for publications will explore this.

5.5 Limitations of this Cohort Study

This study has some limitations. Due to a small sample size sub-analyses considering GMFCS levels I, II and III were limited to non-parametric statistical approaches. Future recruitment will allow for parametric analyses within GMFCS subgroups. Subgroup analyses will also consider adjustment for multiple comparisons based on the identification of a-priori outcomes across multiple domains in a larger sample. Matching on age and sex support the analyses focused on GMFCS level. However, sample size restricted the ability to consider additional potential confounders of interest (e.g., distribution, surgeries). It is possible that this study was subject to the selection bias in that most participants lived in Calgary rather than in rural communities. Those from rural areas may have been less likely to participate as the study was less accessible to them. It is likely that the access to facilities, healthcare, and adapted physical activity opportunities are more limited (i.e., less accessible, fewer opportunities) to those youth with CP who live in rural communities. Limitations related to measurement bias were mitigated through the use of valid, reliable, and objective outcome measures. The generalizability of the results from this study may also be limited as youth with CP are representative of youth living in urban centers.

5.5.1 Physical Activity

This study has a few limitations related to the physical activity outcome. As part of recruitment posters (Appendix G) that were placed around the Alberta Children's Hospital, this poster mentioned that PA would be measured. As a result, there was the potential to introduce selection bias, in that individuals interested in learning more about their PA levels, potentially being more active individuals, may have been more likely to volunteer to participate. As such the

amounts of time spent at MVPA and percentage of participants achieving the MVPA guidelines was potentially overestimated in all participants. The potential for misclassification bias was also present in this outcome as the current analysis of sedentary time is inclusive of sleep time. This problem was limited to three participants who removed their ActiGraph for night. As we believe sleep time would only be recorded as sedentary time this analysis assumed that the three youths who had taken off their ActiGraphs for night were completely sedentary for those hours.

However, there is the possibility that the youth took the ActiGraph off for a long period before going to bed and forgot to put it back on right when they woke up, as such there is the possibility that for these individuals their total sedentary time was overestimated and time in light PA and MVPA was underestimated. Further, it is a limitation of this study that for all participants the sedentary time was inclusive of sleep time. This is not optimal nor recommended as it does not allow for sedentary time during waking hours to be compared between cohorts. Lastly, the data was downloaded as a 10 second epoch and later re-integrated as a 15 second epoch so that the cut-point analysis (i.e., scoring) would match the validated Evenson Cut-Points protocol.⁶¹ A preliminary look at the differences in results based on the epoch length used for the analysis suggests that using a 15 second epoch meant youth spent less time sedentary than if a 10 second epoch was used. However, if a 60 second epoch was, as is currently necessary for separating sedentary time from sleep time, the sedentary time was much higher. The reverse was true for the light PA and MVPA outcomes. Step counts were not influenced by epoch length.

5.5.2 *Body composition*

An examination of within-pair differences for weight showed that males with CP were significantly lighter than their TD matched peers. Although this was only seen for the males, it is

important to note that of the males who volunteered to participate there was greater number of the three GMFCS levels, included in this research, represented, whereas, the female cohort included mostly youth with CP classified as GMFCS level I. Further the within-pair difference analyses of body composition outcomes revealed that youth with CP, GMFCS level I did not differ from their peers, but those classified as GMFCS level II or III did have a significantly lower LMI than their peers.

5.5.3 Balance

Previous studies have explored how DOI influences postural control. Unfortunately, this study was limited by a small sample size and it was not possible to explore differences by both GMFCS levels and DOI. In the current study the VGRF outcome was intended to explain how participants distributed their weight between both of their lower-extremities. However, this data should have first been normalized to body weight and then the percentage of weight should have been used to for the within-pair difference statistical analyses rather than the raw VGRF data. As such the conclusions drawn for this outcome may not necessarily represent difference in weight distribution the way they were intended to.

5.5.4 Strength

The second session of strength testing occurred at a different location, though the plinth used during the second day had most of the same supports as the one used on the first day, minor differences could have potentially resulted in a systematic bias in the reliability data. However, based on the absence of a noticeable systematic bias pattern in the Bland-Altman plots (Figures 4.13, 4.14, 4.15, and 4.16) this was likely not the case. Since sample size of the reliability study had not been determine prior based on expected values for this protocol (Chapter Three:

Methods), it was not possible to assess the reliability of the youth with CP separately from the TD youth.

Chapter Six: **Conclusion**

6.1 Summary of Findings

Youth with cerebral palsy (CP) who were classified as a gross motor function classification system (GMFCS) level II or III engaged in significantly less moderate-vigorous physical activity (MVPA) and spent more time sedentary than their typically developing (TD) peers. Though a direct comparison was not made between these TD individuals and their peers classified as GMFCS level I, the proportion of youth with CP classified as a GMFCS level II or III who met MVPA guidelines on even was day was a great deal less. Additionally, although no differences were seen in body composition between youth with CP classified as GMFCS level I and their TD peers, those with CP classified as GMFCS level II or III had significantly lower lean mass index (LMI) compared to their TD peers.

Body function impairments were examined as impairments of balance and lower-extremity muscle strength. Youth with CP were found to have poorer balance based on significantly greater sway and movement during quiet standing compared to their TD peers, especially the youth with CP who were classified as either a GMFCS level II or III. Similarly, youth with CP who were classified as either a GMFCS level II or III were weaker than their TD peers for every muscle group compared to their peers classified as a GMFCS level I who were only significantly weaker hip abductors and ankle plantar flexors compared to their TD peers.

6.2 Public Health Implications

Cerebral palsy is defined as a disorder of movement and posture, with resulting activity limitations.³ This study has provided further evidence that youth with CP, experience activity limitations and live with body structure and function impairments, such that youth who are more

severely impacted by their CP (GMFCS level II or III) experience even greater limitations in activity and the increased severity of body structure and function impairments. The risk of developing poor health long-term and social isolation are enabled by limited MVPA.⁷⁰ A study by Ekelund et al.⁷⁰ reported that higher amounts of time spent at MVPA has a positive effect on cardiometabolic health, regardless of the length of time spent. The current study suggests the need improve accessibility of rehabilitation services and adapted programming especially for youth with CP who are classified as GMFCS levels II or III. At the very least it suggests the need to ramp up availability of programs that allow youth to build up to the current PA guidelines for optimal health benefits. Further, as the PA habits developed during childhood are predictive of adulthood PA levels.³⁵ This study informs the need to improve upon PA habits in childhood.

6.3 Recommendations for Future Research

This study examined how the overall sample of individuals with CP performed on strength and balance function tests and how body structure and PA levels differed from their TD peers. In addition to briefly exploring how these outcomes were impacted by GMFCS level (with GMFCS levels II and III grouped). However, further research is warranted to examine potential associations between body structure and function level outcomes and activity and participation level outcomes. The findings of this study suggest that youth with CP, GMFCS level II or III are substantially less active than their TD peers which likely can in part explain why these youth were weaker with more muscle groups, swayed more during standing, and have lower lean mass indices than both their TD peers and those classified as a GMFCS level I. Longitudinal studies to examine how health conditions progress or can be minimized related to these findings would be useful for informing the development of rehabilitation services as well as healthy life habits.

The results of this study are limited by a small sample size. It is recommended that further research be done to explore individuals classified as a GMFCS level II separately from those classified as a level III to determine the true magnitude of function impairments and activity limitations. Understanding the differences not only between GMFCS levels but also sex is essential to developing rehabilitation programs targeted to individual needs. Improving PA habits during childhood is vital to preventing long-term morbidity, including poor quality of life,^{2,71} deteriorated function, and high rates of obesity.¹ The findings in this study suggest the need for further development, implementation, and evaluation of adapted PA opportunities in the community. Individuals with disabilities are often provided with short-term rehabilitation services following a surgery or are provided with intensive rehabilitation when they are young, as a result they miss out on the opportunity to engage with their peers and learn basic motor skills during their childhood. Future research should explore the effectiveness of increased adapted PA opportunities that may lead to increased PA, strength, LMI, and other longer-term health benefits.

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Appendix A: ActiGraph Standard Operating Procedure



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Standard Operating Procedure (SOP) for Actigraph GT3X+ Accelerometer

All ActiGraph activity monitors are designed to monitor human activity and record energy expenditure (calories spent during normal activity, METs, everyday activity, and exercise). Additionally, these devices can also function as a very accurate sleep assessment tool. While collecting day-to-day energy expenditure data, the device should be affixed securely to the body's center-of-mass to ensure the most accurate caloric measurements.

The GT3X+ based activity monitors provide objective measurements of human activity and are used in many research and clinical applications. They include both a micro-electro-mechanical system (MEMS) based accelerometer and an ambient light sensor.

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Logistics/Instructions for participants

This section contains the information you need to give to the participant and tips to improve compliance.

i. Tracking Actigraphs

- A sticker label should be placed on the back of each monitor to identify the monitor code e.g. ID#01 in addition to lab contact details in the case where the monitor has been lost.
- A second small sticker should be placed on top of the actigraph beside the USB cap to highlight how the monitor should be worn (sticker facing up) (See Figure 1).
- Monitors should be logged in and out via an excel database for each study with the following variables:
 - Serial number/Monitor code
 - Participant ID
 - Date initialized/activated
 - Stop time
 - Researcher
 - Monitor returned
 - Monitor log complete
 - Date/time removed (self-report)
 - Battery Life
 - Notes

ii. Pre-data collection

- To achieve a minimum of 5 valid days of data collection, the participant is asked to wear the monitor for 7 full consecutive days if possible (a valid day is defined as 10 valid hours)
- The participant will complete a monitor log to fill in a start and end wear time and any period of time where the device is removed for more than 10 minutes (see **Appendix A**). This will be an important cross check for validating wear time.
 - Participants are instructed on how to wear the monitor while shown the instructions for wear sheet (see **Appendix B**)
 - The ActiGraph will be given to the participant already threaded onto the elastic belt. The device should be positioned through the belt with the sticker facing up so that it sits on the right hip and so that the 'Actigraph' logo on the plastic clasp is also facing up. It is useful to have the belt longer on one side only for size adjustment (see Figure 2). Participants should be instructed to wear the ActiGraph with the blue sticker facing up, the elastic belt fastened snugly around the waist and the monitor positioned over the right hip bone (right ASIS).
 - The ActiGraph can be worn either over or under clothing, whichever is most comfortable to the participant. The meter does not need to be in direct contact with the body. However, it is essential that the ActiGraph be positioned snugly enough against the body that it cannot move around independent of the body. This will affect the accelerometry results.

- Participants will be instructed to wear the unit all day and night. Some slight repositioning of the device is allowable if the participant has trouble sleeping e.g. if they sleep on their right side, they may slightly reposition to the front
- The only times they should remove the monitor are if the monitor would become completely wet (e.g. swimming, showering). These times should be logged.
- Show participants an example report of the output
- Organize a pick-up time and location for returning the device. If collection or drop-off is not possible, give a stamped, addressed and padded envelope for return mail.
- Some useful examples of what to tell the participant:
 - *“We would like you to wear a movement monitor for 7 days. It is similar to a pedometer, except it measures general movement.”*
 - *“To the best of your ability, go about your usual days -- don't do anything different.”*
 - *“Leave next to your clothes to remind you to put it back on after showering”*
 - *“It runs on a watch battery and isn't a tracking device. It can't tell what type of activity you are doing or where you are.”*
 - *“It's really small, I've worn it myself and after a little while I forgot I was even wearing it.”*



Figure 1. Sticker placement on actigraphs



Figure 2. Actigraph placement on the elastic belt

iii. Optional Self-Report for Non-Wear Time

- There should be a discussion prior to the study on the inclusion of collection of self-reported physical activity data for times when the actigraph is removed (e.g. swimming or activities involving potential contact).
- This requires the participant to fill in an additional log to report on the day and time the device is removed, type of activity and an estimation of exercise intensity using a rate of perceived exertion (RPE) scale or Pictorial Children's Effort Rating Table (PCERT) for children.
- This method will allow the researcher to classify activity into either sedentary/light activity or moderate/vigorous activity for the self-reported data. It is not possible to further classify these domains based on self-report.
- For a detailed description on how to measure and analyze using this methods, please refer to an additional SOP stored in ASIS (author: Colleen Nesbitt MSc.).

iv. Post-data collection

- Thank the participant for completing the research and let them know they will receive their physical activity report via email
- Log the return date into the master database
- Wash the waist band after each use by hand (warm soapy water) or cold cycle. Drip dry
- Download the data and charge for next use. Ensure stickers are intact.

Using Actilife Software

i. Initializing a monitor

This section contains information on how to set up the monitor to begin recording data. For an online tutorial, click [here](#)

1. Open Actilife software. Download the latest version of software if you are prompted to do so. Always work under the latest version to ensure compatibility between computers when using the datavault.
2. Open the actigraph USB cap using the key provided (or a coin) and plug in using USB cable. The monitor should appear under devices. Ensure the battery level is at least 3.85V (>80%) or initialization will not be allowed.
3. Select the check box for the device and click on "Initialize – Regular Initialization" in the toolbar.
4. Select your initialization parameters. First input the recording time by selecting a start time and date and a stop time and date. For a 7-day data collection period, it is recommended to set the device to record at least 8 or 9 days to allow time to make up for periods of non-wear. It is also possible to set the device to record continuously until the data is downloaded. This option may be preferred if the participant is unsure if they will be able to wear the device continuously from the date it is initialized.

5. Set Sample Rate to 30Hz. Under LED options and wireless options, nothing is selected. Idle sleep mode is set to disabled.
6. Enter subject info including participant ID, sex, height weight, DOB and race. 'Limb' is set to waist and 'Side' is set to right.
7. Select 'Initialize 1 device'
8. Check that initialization is complete under 'status' and check recording parameters again under devices before plugging out. You can hover over icons under "mode" to determine if the features you need are activated.
9. Safely remove device, plug out and close cap firmly

ii. Downloading data

This section contains information on how to download the data to your computer after the participant has worn the actigraph. See online tutorial [here](#)

1. Open Actilife software
2. Open the actigraph and plug in using the USB cable. The monitor should be recognized and appear under devices. Confirm that the device contains data for this wear period
3. Click the download option in the toolbar and a new window will open
4. Download naming convention should be set to <Subject Name><Start Date>
5. For Download Options, ensure 'Create AGD File' is checked Epoch length should be set to 10 seconds and # of Axis should be set to 3. Ensure boxes for 'Steps', 'Lux', 'Inclinometer' and 'Low Frequency Extension' are also checked. You can also edit any participant information here under 'Add biometric and user information' here and change the folder to where the data will be saved.
6. Select 'Download All Devices'
7. The progress bar in the main window will show you when the download is complete. Under 'Status' should read 'finished downloading'
8. Click the 'finished downloading' hyperlink and select 'Export GT3X file'. A new window will open. Ensure 'Create AGD', 'Create CSV', 'Create DAT' and 'Low Frequency Extension' are selected. Then click in 'Export RAW Files'
9. These files will save to Actigraph>Actilife>Downloads in your Documents folder

iii. Wear Time Validation

The next step in the analysis process is to set the appropriate wear time for the downloaded data. This is done using a combination of wear period algorithms and using the monitor log provided by the participant.

1. Click on the Wear Time Validation tab
2. 'Define a Non-Wear Period' should be set to Choi (2011). Minimum Length (90 minutes), Small Window Length (30 minutes) and Spike Tolerance (2 minutes). Select 'Use Vector Magnitude'

These parameters can be changed to a lower minimum length (30-60 minutes) if validating wear in children.

3. For 'Optimal Screen Parameters', nothing is selected
4. Uncheck all Data Sets and check the one(s) you wish to analyze. If it is not there, click on 'Add Dataset' and find the AGD file in the downloads folder
5. Hit Calculate and a new window will open
6. At the end of the window, under 'All Periods' contains a list of Wear and Non-Wear periods as calculated using the Choi algorithm. You will need to cross-check these periods with the monitor log provided by the participant. Normally, shower periods are not recognized if the monitor is off for periods shorter than 90 minutes. Also, a very inactive period (often evening time or during deep sleep) can be detected in error as a Non-Wear period.
7. Go to the first Non-Wear period. If the participant has not recorded this date and time as a NonWear period, click on 'Set As Wear' if appropriate. Scroll down and continue this process for all Wear and Non-Wear periods. Use best judgement call to change between 'Wear' and 'NonWear' as appropriate. Also note beginning and end of wear period provided by the participant as the device may continue recording past this time depending on set-up.
8. Click on 'Save' and select the next dataset or click on 'Save and Close'
9. The applied wear time validation will now be written to the saved AGD file. However, if the AGD file is re-opened in wear time validation, it will over-write the validated data again. Be sure to de-select the completed files if you need to validate additional files.

iv. Scoring and Exporting

We now wish to analyze the selected data period and select appropriate algorithms to apply cut-offs for calculation of energy expenditure, METs and exercise intensity. Recommendations are provided below but can be altered depending on the population in question. See

<https://help.theactigraph.com/entries/21452826> for more details.

1. Click on the 'Scoring' tab
2. On the left, under Algorithms, ensure the following boxes are checked:
 - Energy Expenditure
 - METs
 - Cut Points and MVPA
 - Bouts
 - Sedentary Analysis
3. The following algorithms are recommended for use for an adult population:
 - Energy Expenditure – Freedson VM3 (2011)
 - METs – Freedson Adult (1998)
 - Cut Points and MVPA – Troiano Adult (2008)
4. The following algorithms are recommended for use for a pediatric population:
 - Energy Expenditure – Freedson VM3 (2011)
 - METs – Freedson (2005)
 - Cut Points and MVPA – Evenson Children (2008)

5. Under Filters, check 'Exclude Non-Wear Times from Analysis'
6. Select your required dataset from list or go to 'Add Dataset'
7. Click on 'Calculate'
8. Click on 'Export' in right bottom corner
9. Select required or all excel files for export. Choose to export in excel format rather than CSV format and hit export. Name your file. It is better to do an export in bulk, selecting numerous datasets so they will all be contained in one excel file
10. One Summary file and one data file with numerous tabs will be saved under CSVFiles in your Actilife folder

v. ***Working with the Dataset***

The dataset now needs to be cleaned to ensure you are analyzing only the days that contain valid data.

1. Open the Daily or Daily Detailed tab on the exported file.
2. Rename this tab as 'Validation'
3. For each individual participant,
 - a. Scroll across to the 'Time' variable and highlight/change colour any days that contain less than 600 minutes (10 hours)
 - b. Count the number of days that are left and make note in a new column called 'valid days'
 - c. If there are >7 valid days left, proceed to highlight those days with the lowest number of minutes until there are 7 days left (usually first and final days of wear have less minutes).
 - d. If there are still a number of days to choose from, choose to preferentially keep earlier days in the wear time as this will be more comparable with other participants. Wearing for >1 week may lead to behavior change that will be different to those who have <1 week of wear time.
 - e. Save this file if you need to refer back to it at any time.
4. Copy this tab and paste to a new tab. Rename as 'Daily'
5. In this tab, delete any highlighted days for each participant until you are left with 5-7 days for each individual. Keeping participants with <5 days of data is not advised but can be discussed with the PI.
6. This tab can be used to create your outcome variables by creating a row under each participant to find the mean outcome for each variable.
7. New columns should be created to compute daily MVPA (a common primary outcome) and weekly MVPA. This can be computed by summing Moderate + Vigorous variables.
 - a. Average Daily MVPA is the average of these values
 - b. Total Weekly MVPA is the addition of these values

vi. *Sleep Analysis*

The sleep analysis feature on Actilife is not present on all formats of the software. The online tutorial can be found [here](#). The algorithms to analyze sleep are more accurate when the device is worn on the wrist. To attach the wrist strap, pull the strap fully through on one side, then loop through the other side before doubling the strap back to secure the Velcro. Sleep can also be analyzed using waist-worn data but is not as accurate. If sleep quality is a primary outcome variable, participants should be given a log to record time in bed and time out of bed for each day/sleep period.

Analyzing one file:

1. Open the sleep tab in the Actilife software.
2. Click on 'Select Dataset' and find the desired file. Sleep is analyzed in 60-second epochs only so the file may need to re-integrate if it has not been downloaded in this format. You do not want to create a custom algorithm for a shorter epoch so select no if this is prompted. A new AGD file will be created. This may take a few minutes.
3. When the file opens, you can choose the view the graphs in 24hr or 48hr format. At the top left, choose which algorithm you wish to use to detect sleep period. The Sadeh algorithm has been developed for children and the Cole-Kripke algorithm has been developed for adults.
4. Sleep periods can be added manually (if this information has been collected) by clicking on 'add sleep period'
5. Sleep periods can be detected automatically using the Tudor-Locke algorithm by clicking on 'Detect sleep periods'
6. Scroll through each sleep period for validation with participant log or with the wear time validation that has already been completed (if 24/7 wear). This is to make sure you are not adding additional time that has already been marked as a non-wear period. This will be important if you are intending on subtracting sleep time from sedentary time.
7. This data can be exported by clicking 'Export Report' in the bottom right hand corner and choosing CSV Sleep Summary.

Batch Analysis:

1. Open the Batch Sleep tab in the Actilife software
2. Click on 'Add Dataset' and select the desired files. Sleep is analyzed in 60-second epochs only so the file may need to re-integrate if it has not been downloaded in this format. New AGD files will be created. This may take a few minutes so it is best to only select 6/7 files at a time so the software does not crash.
3. Click on 'Open in Sleep Tab' for the first file you wish to analyze. This will take you to the sleep tab where the graph for that file will open.
4. When the file opens, you can choose the view the graphs in 24hr or 48hr format. At the top left, choose which algorithm you wish to use to detect sleep period. The Sadeh algorithm has been developed for children and the Cole-Kripke algorithm has been developed for adults.
5. Sleep periods can be added manually (if this information has been collected) by clicking on 'add sleep period'

6. Sleep periods can be detected automatically using the Tudor-Locke algorithm by clicking on 'Detect sleep periods'
7. Scroll through each sleep period for validation with participant log or with the wear time validation that has already been completed (if 24/7 wear). This is to make sure you are not adding additional time that has already been marked as a non-wear period. This will be important if you are intending on subtracting sleep time from sedentary time.
8. When you are finished, go back to Batch Sleep and click on 'Open in Sleep Tab' for the next file and continue until you are finished detecting sleep periods for all files.
9. In the Batch Sleep tab, ensure the appropriate algorithm is selected on the top left. On the bottom left, ensure 'Sleep period detection' is set to "Use existing sleep periods".
10. Ensure all files are selected and click on 'calculate'. Now export the file.

Creating a report

1. The type of report you want to create will be based on the research study in question. An example report form is in **Appendix C**.
2. To create the graph, a screen grab is taken from the 'Graphing' tab in Actilife software for the relevant days. Use the clipping tool in Windows software. Ensure the checked box for 'Equal Activity Scales' is selected and set in the region 1500-3000 counts, dependent on the activity level for the individual.
3. Create a table in excel to include date, day, wear time (hrs), activity kcals, average kcals/hr, steps and sedentary, light, moderate and vigorous time presents as mins and %. Calculate total and average values. You can also choose to graph these values in a pie chart a % of total time (a template of this table and graph is stored in ASIS).
4. To allow the participant to interpret these values, show how they compare to Canadian physical activity guidelines and refer to the Canadian Society for Exercise Physiology website

Additional Information

This section contains additional useful information on specification and functionality of the Actigraph device. This information and more is available by accessing the Actigraph GT3X [manual](#).

Steps: Step counts are accumulated on a per-epoch basis and are based on accelerometer data collected on the vertical axis. An algorithm present in the device firmware filters out the accelerometer's baseline noise level to help accurately accumulate the steps-per-epoch.

Inclinometer : The post-processed inclinometer feature helps users identify the orientation of the device and, more importantly, when the device itself was taken off. Each epoch is flagged with a number (1 through 4) to indicate the orientation of the device during that epoch.

Important: The inclinometer feature is only valid if the device is worn on the hip with Axis 1 upward facing.

Interpretation of Inclinometer Code (Stored with each Epoch)

0 Device Off (Not Being Worn)

1 Subject Standing

2 Subject Lying Horizontal

3 Subject Sitting

Low Frequency Extension: The Low Frequency Extension (LFE) option, though not a mode or channel, is another data collection option during post-processing for the GT3X+ and wGT3X+. The standard proprietary filter algorithm used in ActiGraph products is used to eliminate any acceleration noise outside of the normal human activity frequency bandwidth. This filter is customized to work with ActiGraph's Energy Expenditure Algorithms. The LFE option, when enabled, increases sensitivity to very low amplitude activities allowing for the study of population groups who move slowly or take very light steps (for example, the elderly). For more details, contact ActiGraph at support@theactigraph.com.

Data Collection: Initialize time options/selections have been reduced significantly due to the new data collection method used by the GT3X+ and beyond devices. During initialization, the user is now only required to select the desired raw data sample frequency (30Hz up to 100Hz in 10Hz increments). Data is automatically collected from all on-board sensors in raw data format. The data recorded includes:

Vertical Axis Activity Acceleration Data (Axis 1)

Horizontal Axis Activity Acceleration Data (Axis 2)

Perpendicular Axis Activity Acceleration Data (Axis 3)

Ambient Light (Lux)

Unlike previous ActiGraph products, the wGT3X+ and wActiSleep+ do not filter or accumulate data into epochs. Raw data is collected at the selected sample rate and is post-processed in the ActiLife. Because these devices collect data from all sensors at all times, users can generate native ActiLife *.agd files containing any desired combination of parametric data at a later time. This helps facilitate backward compatibility and enhances the flexibility of the data by allowing users to compare data to studies which use different filter techniques or accumulation sizes (e.g., 1 second epochs versus 60 second epochs).

Water Resistance: The wGT3X+ and wActiSleep+ are water resistant in accordance with IEC 60529 IPX7, or immersion in one (1) meter of water for up to 30 minutes

Battery: All ActiGraph devices use a lithium ion rechargeable battery that has a maximum voltage of approximately 4.20 volts. At 3.1 volts the devices enter a low voltage mode state (HALT mode).

Low Voltage Mode (HALT): ActiGraph devices enter a "Low Voltage Mode" (or HALT) state when the battery discharges beyond a point of being able to power the device. In this mode, all important variables and data are stored in flash memory to secure the device download. Because the device's internal clock stops in HALT mode, the device cannot be recharged and redeployed; the device must be downloaded and reinitialized to continue use.

Recharging and LED Decoding: Recharging is automatic and is accomplished by connecting the device to a standard USB port. Charging time will depend on the battery life, but typically will not exceed four hours for a fully depleted battery to become fully charged. Once the battery is completely charged, the green LED will remain illuminated. If the battery voltage drops below 3.1 volts while in use, the device will not have sufficient power to collect data and will warn the user through a series of coded flashes. The battery level, reported in volts, can be viewed at any time by starting the ActiLife software and plugging in the device.

Monitor Log**Appendix A**

Wear the physical activity monitor for seven (7) consecutive days. In the table below, write down the dates and days on which you wear the monitor. Note the times, including “a.m.” or “p.m.”, that you put it on and take it off during each day. Also note the reason you took it off. Below is a sample entry:

Date	Day	Time Off	Time On	Reason
e.g. July 15 th 2015	Wednesday	7.30 AM	8.30AM	Swimming
Monitor Off (complete):				
Date	Day	Time Off		

OFFICE USE ONLY	Actigraph ID_____
Start Date and Time:_____	
Participant ID:_____	Valid days_____



How to Wear the Physical Activity Monitor

This small activity monitor records general movement and allows us to get a better understanding of your overall activity level. We will not be able to tell what kind of specific activity you are doing, only the intensity and duration of physical activity. At first, the belt may feel slightly awkward, but after a few hours, you will not notice it as much. It is extremely important for our study that you wear the monitor correctly. Please follow these instructions carefully:

- ✓ Wear the monitor attached to the belt around your waist, just above your right hipbone
- ✓ Wear the monitor so that the sticker is facing up
- ✓ Wear the monitor snug against your body. If you have to, you can adjust the end of the strap to make it tighter. Or, to loosen the belt, push more of the strap through the loop. Wear the monitor tight enough so that it does not move when you are being active
- ✓ The monitor can be worn underneath or on top of your clothes or in your belt loop
- ✓ Keep the monitor on all day and all night for a 7 day period
- ✓ Do not submerge in the water (swimming, bathing etc.) You can remove for showering but remember to put it back on as soon as possible and keep record of each occurrence in your monitor log
- ✓ Do not let anyone else wear it



Details for dropping off/collection of monitor _____

If you have any questions related to the monitor, please call or email:

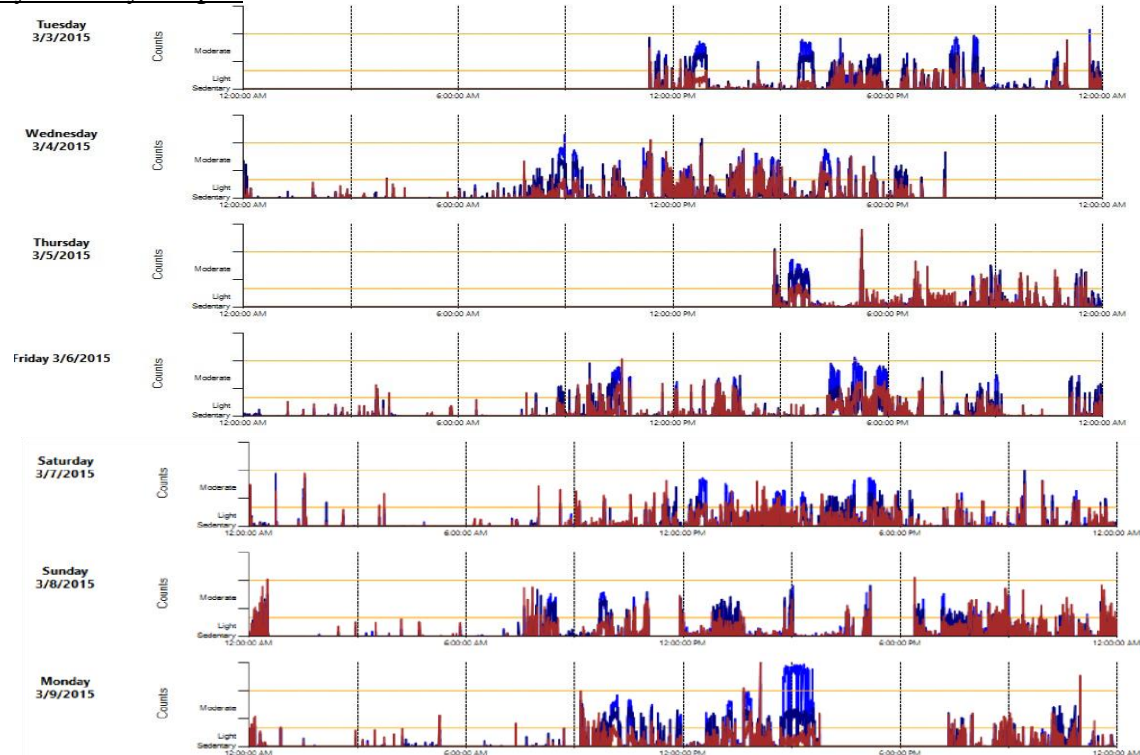
There is no 'ON' or 'OFF' switch that you need to worry about. The activity monitor runs on a battery and is programmed to run continuously from when we give it to you. Please do not try to open the monitor

Physical Activity Report

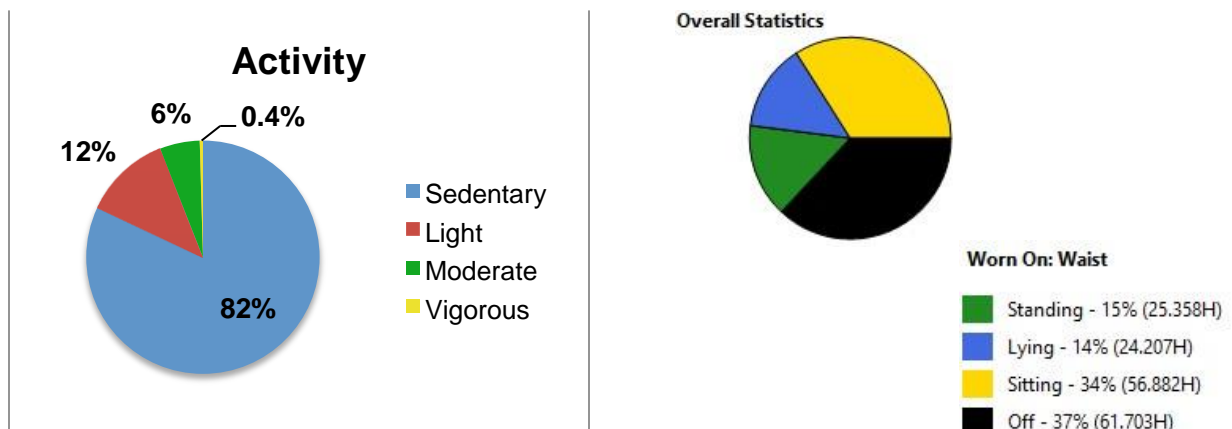
Name:

Days: 7

Daily Activity Graphs



Date Day	Wear (hrs)	Activity kcals	Avg kcals/hr	Steps	Sedentary (min) (%)	Light (min) (%)	Moderate (min) (%)	Vigorous (min)(%)
3-Mar Tue	12.7	548.38	42.18	11276	580.0 76.4	101.7 13.4	77.2 10.2	0.2 0.0
4-Mar Wed	19.6	535.49	22.31	10256	964.0 81.8	145.8 12.4	67.7 5.7	0.5 0.0
5-Mar Thur	9.2	236.81	9.87	4263	439.5 79.8	81.3 14.8	30.2 5.5	0.0 0.0
6-Mar Fri	24.0	591.62	24.65	11502	1243.8 86.4	110.0 7.6	85.8 6.0	0.3 0.0
7-Mar Sat	24.0	392.71	16.36	9216	1230.0 85.4	154.2 10.7	55.8 3.9	0.0 0.0
8-Mar Sun	24.0	423.56	17.65	8434	1181.7 82.1	216.8 15.1	41.5 2.9	0.0 0.0
9-Mar Mon	20.5	817.04	34.04	14956	1006.2 82.0	128.0 10.4	56.3 4.6	36.5 3.0
Total	133.9	3545.61	167.07	69903	6645.2	937.8	414.5	37.5
Average	19.1	506.52	23.87	9986	949.3 82.0	134.0 12.1	59.2 5.5	5.4 0.4



Interpretation

- Basal metabolic calories are the amount of calories your body burns at rest to maintain normal body functions and are calculated based on your age, height, weight and gender. **Activity kcals:** the calories you burned actively all along your day i.e. when walking, running.
- **Step count:** The number of steps recommended for adults have been estimated as:
 - 7,000 to 13,000 steps/day for adults age 20-50y (Tudor-Locke, 2004)
 - Your average daily step count is **9,986**
- Canadian Physical Activity Guidelines suggest that for health benefits, adults aged 18-64 years should accumulate at least 150 minutes of **moderate-vigorous aerobic physical activity** per week
 - You accumulated in **452 minutes** of moderate-vigorous activity over 7 days
- Guidelines also recommend adding muscle and bone strengthening activities using major muscle groups, at least 2 days per week. The intensity of this type of activity is likely not detected accurately using accelerometry devices. If you partake in this type of activity, bear in mind that it may not be reflected in your report.
- Health research recommends minimizing the time you spend being sedentary each day.
 - Minimize the amount of time spent in prolonged sitting
 - Break up periods of sitting as often as possible by standing or walking
 - Your average daily sedentary time is **82% of your day**
- If you would like more information please view the Canadian Society for Exercise Physiology website (www.csep.ca/guidelines) or contact _____

Appendix B: DXA Standard Operating Procedure

Sport Injury Prevention Research Centre



Dual-Energy X-Ray Absorptiometry Scan Acquisition and Analysis for Whole Body Assessment Standard Operating Procedure



Hologic Discovery A
Department of Kinesiology
University of Calgary

Version 2.0
Review Update: December 2017
Author: Clodagh Toomey



All instructions and procedures in this document are in line with the International Society for Clinical Densitometry (ISCD) Position Statements¹ and the International Atomic Energy Agency (IAEA) Human Health Series²

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¹ Hangartner, T. N., Warner, S., Braillon, P., Jankowski, L. and Shepherd, J. (2013) 'The official positions of the international society for clinical densitometry: acquisition of dual-energy x-ray absorptiometry body composition and considerations regarding analysis and repeatability of measures', *J Clin Densitom*, 16(4), 520-36

² Dual energy X ray absorptiometry for bone mineral density and body composition assessment. — Vienna : International Atomic Energy Agency, 2010. p. ; 24 cm. — (IAEA human health series, ISSN 2075-3772 ; no. 15) STI/PUB/1479

1 Daily Calibration check

1.1 Computer/ Program

The computer should be turned on and the QDR program up and running when you enter the room. If not turn the computer on and double click on the QDR program, (note the “System Backup” always seems to be flashing).

1.2 Calibration (10 minute process)

1. Put lead apron on.
2. Click ‘QC’ – ‘Daily QC’
 - a. Center Spine Phantom on bed (in wooden box on shelf)
 - a. Sticker facing computer
 - b. Laser crosshairs need to be in middle of white dot
 - c. Click ‘continue’ – OK’
 - d. Remove spine
3. Click QC – ‘Step Phantom QC’
 - e. Center Large Step Phantom on bed (longitudinally, square with both ends of the bed)
 - f. Sticker facing computer (smallest step facing the door)
 - g. Laser crosshairs 2cm away from smallest step
 - h. Click ‘continue’ – ‘OK’
 - i. Remove step
4. Click ‘continue’ to complete calibration (this next step takes 5 minutes or so).

2 Scan Acquisition

2.1 Contraindications

The scan process should be explained to the participant.

Any contraindications to scanning should also be checked at this point.

Ask subject about any absolute contraindications: these include

- **Pregnancy**
- **Recent radiological or nuclear medicine investigations, or therapies using IV contrasts in the past week**

Or relative contraindications: these include

- metal implants e.g. hip replacements, screws etc (note in analysis)
- Body weight – exceeding 300lbs
- Inability to transfer to/from the scan table safely or lie flat for 5-7 mins

2.2 Pre-Scan Protocol

DXA assumes constant fat-free mass (FFM) hydration of 0.73. Therefore, participants are required to be in a euhydrated (normal hydrated) state for scanning. Food/fluid intake and strenuous exercise will effect hydration status and therefore require standardization.

The following is the ideal pre-scan protocol that should be adhered to where possible. If testing conditions do not allow all conditions to be met, **it is important that the testing conditions are consistent for each scan in the study and any subsequent follow-up scans.**

Standardized conditions:

- After an overnight fast (or fasting for at least 3 hours)
- No strenuous exercise in previous 12 hours
- No alcohol intake in previous 12 hours
- Empty bladder
- Defecate if required

2.3 Subject Preparation/Positioning

Participants should wear loose, comfortable clothing without excessive zippers or buttons. All jewelry, watches, coins, tissues, phones should be removed from the body and pockets.

1. Remove shoes
2. Measure height and body mass if this has not been already done
3. Ask participant to lie on bed within the perimeter line, feet facing computer
4. Arms extended, palms face down. Space should be maintained between the arms and the torso when possible. If necessary, with larger or heavier subjects, the hands may be placed in a lateral position next to the hips (you may need to tuck the thumb under the fingers and/or internally rotate the shoulder).
5. Legs extended, big toes touching (use tape to secure feet together – it is ok to leave socks on).
6. If taller than 195cm, make sure entire foot is within perimeter line. Exclude top of head if needs be.
7. If participant is not lying straight on bed, apply traction at ankles to straighten lumbar spine
8. Ensure head is not tilted, face up with neutral chin. Adjust if necessary.
9. If participant is too wide to fit in the scan field, position ensuring the entire right side is between the boundaries and use hemi-scan analysis after acquisition.



Fig 1. Example of good whole body scan positioning on a Hologic scanner

2.4 Input Patient Information

1. Click 'Perform Exam' – 'New Patient'
2. Input name (In the 'last name' field and 'Patient ID' field enter study ID number e.g. OA001 to OA200, DOB (check that this is consistent with the follow-up questionnaire), height, weight, sex, ethnicity.
3. If participant has been scanned before, create a 'New Patient'. Use the same name and ID with an underscore and the scan number following it e.g. 'OA001_2' if second scan is for participant OA001. This is a very important step when it comes to exporting the data so it should be labelled correctly first time.
4. Click 'Whole Body Scan'
5. **Click Start Scan** (3 minute process)
6. Once scan is finished and participant has left, disinfect and wipe down bed for next scan.

3 Scan Analysis

3.1 Standard Region of Interest (ROI) Analysis

1. Click 'Analyze Scan'
2. Click 'All Scans'
3. Type in participant name (e.g. OA001) - highlight participant name - click 'Next'
4. Choose analysis method: 'Whole Body Fan Beam' - click 'Next'
5. Click 'Regions'
6. Adjust image contrast:
 - a. Click 'sun/moon' icon
 - b. Click 'black dot' in triangle to adjust contrast
 - c. Click 'up/down' arrows to zoom (100 or 150 recommended)
 - d. Click 'sun/moon' icon to exit
7. Click 'Line Mode':
 - a. Outline extremities: drag lines outside the soft tissue of hips, calves, arms and trunk
 - b. Outline spine: drag inside lines as close to spine as possible; drag top line just below jaw
 - c. Outline lumbar spine: drag top line to T12/L1 (last rib attachment); drag bottom line to top of iliac crest
8. Click 'Point Mode':
 - a. Arm Cut: move the upper vertex of the arm lines to ensure they touch the most medial point of the proximal humerus
 - b. Horizontal pelvic cut: ensure top line is a straight line sitting on top of the iliac crests. If crests are not level, maintain the horizontal line using the higher crest as your marker.
 - c. Leg cut: move the upper vertex laterally on both sides to ensure that full leg/hip region is within the line. Move lower vertex to correct any problems with lower leg regions. Make sure central line is between toes
 - d. Vertical pelvic cut: drag point below pelvis so that lines intersect lateral aspect of pelvic bone and femoral head/neck; drag points on outside lines to adjust further – be mindful not to exclude soft tissue.
 - e. Neck Cut; finally position the neck cut at the tip of the lowest bony point of the skull, ensuring neck tissue (e.g. trapezius muscles) remain below the line
9. Click 'Results'
 - a. Check that the Left and Right proportions (area and BMC) of arm, rib, and leg are < 50 points different

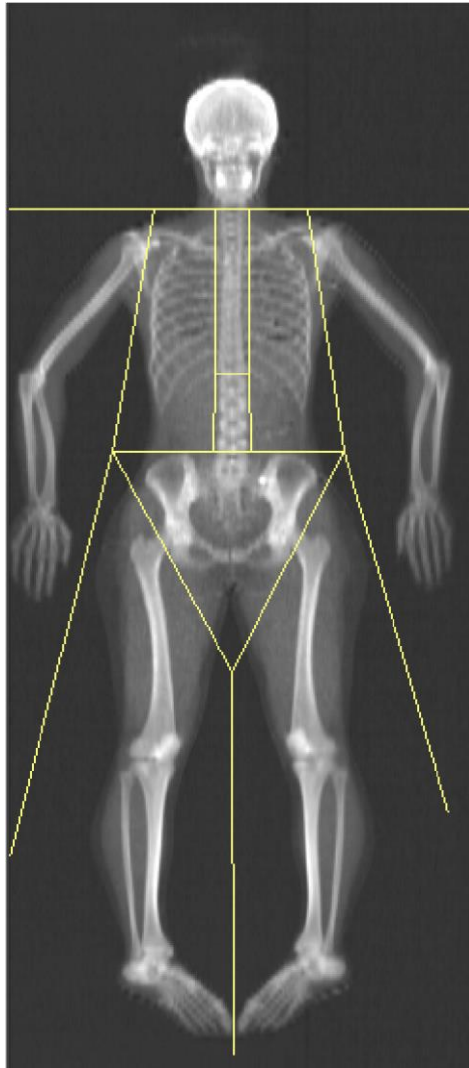


Fig. 2 Standard Segmental Analysis

3.2 Custom Region of Interest (ROI) Analysis

1. Click 'Subregions'
2. Click '+' to add **L1-L4** ROI (R1)
 - a. Move ROI until the bottom line lies just below the L4 vertebrae.
 - b. Using 'Line Mode', drag the top of the ROI until it is just above the L1 vertebrae.
 - c. Drag the sides of the ROI until they lie outside the soft tissue of the abdomen (use 'Point Mode' if required)

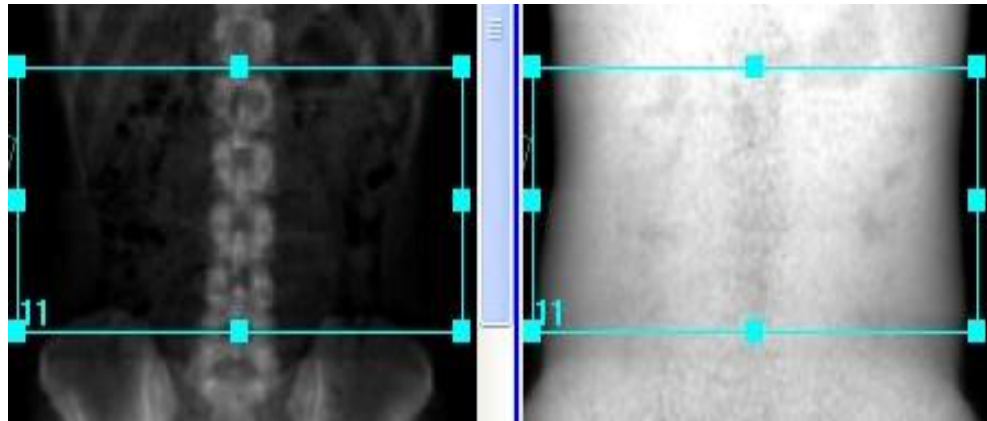


Fig 3. L1-L4 Region of Interest

3. Click '+' to add Right Upper Thigh ROI (R2)
 - a. Move ROI until the bottom line lies just below the right femur (knee joint line).
 - b. Using 'Line Mode', drag the top line until it lies inferior to the lesser trochanter. If the lesser trochanter is not visible, use the ischium as your landmark.
 - c. Drag the sides of the ROI until the medial side is in line with the pubis and the lateral side lies outside the soft tissue.
 - d. Repeat step 2 to add **Left Upper Thigh ROI (R3)**
 - e. Click 'Results'

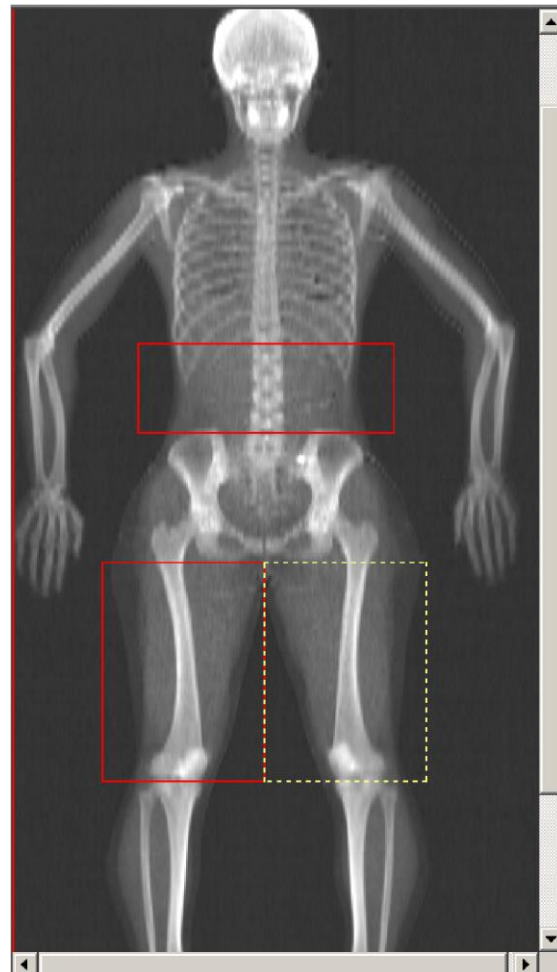


Fig 4. Full Custom Segmental Analysis

3.3 Filing

- a. Click 'Close'
- b. Click 'Report' – 'Next'
 - i. Select 'Filing'
- c. Click 'Print' – select printer: HP1102w – Click 'OK'
- d. Click 'Close'

After you have printed the scan write “testing day report” as well as any metal objects or artefacts that could not be removed (e.g. pacemaker, implant) on the front page and then staple the report together and place on the participants clipboard.

4 Data Extraction

4.1 Moving scans

1. If multiple scans are contained within one Patient ID, they can be moved.
2. First, you will need to make note of the height and weight measurement for each scan. The height and weight detail for Patient ID is the height and weight for the most recent scan. Go to 'Patients', select Patient ID (e.g. OA100) and click on the Patient Scans tab. Click on scan details for each scan to make note of height and weight.
3. Create a new Patient ID (e.g. OA100_2) and use the same participant details and height and weight of the most recent scan.
4. Select the Patient and click on 'Manage Scans' at the bottom left. Choose the scan you wish to move (in this case, the most recent scan) and click on 'Move scans'.
5. Select the Patient ID to move the scan to (OA100_2).
6. Hit Finish
7. Now you will need to go back to change the height and weight of the original Patient ID (OA100) to that of the initial scan.

4.2 Export Data

1. All new scans should be exported at the end of each month
2. Make sure all labeling is correct, that follow-up scans are labeled with participant ID, followed by _2 and ensure that segmental analysis is complete
3. Attach the pen drive to the USB port on the back of the computer tower
4. Home page tool bar: Click 'Utilities'
5. Click 'Database Tools'
6. Click 'Export'
7. Enter either the Participant Name Range you wish to access (e.g. OA100-OA115) or the scan date range (e.g. 01 Nov 2014 – 30 Nov 2014). Using scan date range will export data from other studies too so using a name range is preferable. If you want to export specific scans and not a range, it is advisable to edit patient details and create a naming variable under Identifier 2 e.g. the export date. Then type this name into Identifier 2 and export by that option.

8. Click 'Export'
9. Save file to the USB.
10. Name .mdb file (Microsoft Access file) the date of testing: yearmonthday (e.g. 20140623 OA STUDY DXA)
11. Copy saved .mdb files to ASIS.

4.3 Transfer Data from Access to Excel

- 1 Open Access file on a Windows operating system
 - 2 Tables listed on left side contain extracted data. The 5 tables of interest for body composition analysis are: 'PATIENT', 'ScanAnalysis', 'SubRegionComposition', 'Wbody' and 'WbodyComposition'
 - 3 A Query Design template is available in the Access file named 'OA_DXAextraction_template' on ASIS. Open this file, select the Query labeled 'OA_bodycomp' (on left, below tables), copy and paste into your new Access file 4
- If you need to create a new query, follow steps 5-8. Otherwise, **skip to step 9.**
- 5 **DESIGNING A QUERY:** Go to 'Create' in top tab and click on 'Query Design'
 - 6 Hold CTRL key and add the 5 tables listed above. Select 'close'
 - 7 Enter the desired fields as shown in Table 1 in Appendix. In the second row, select Table (e.g. PATIENT). In the first row, select Field (e.g. Identifier 1). Continue for the rest of the columns.
 - 8 Select 'Run' in upper tab
 - 9 Select all. Copy and paste results into a blank excel document. 10 Close query and save as 'OA_bodycomp'
 - 11 In excel, select all and sort file by "LAST_NAME" or "IDENTIFIER 1".
 - 12 Make sure the correct number of scans are present i.e. no duplicates and followup scans are present. If duplicate scans are present (error in software), check analysis_date and delete oldest record.
 - 13 If needed, create a new column labeled 'Scan_No' and type '1' if first scan and '2' if second (follow-up) scan and so on. Sort by 'Scan_No'.
 - 14 Cut all follow-up scans and paste into second tab labeled 'Follow-Up 2'.
 - 15 Sort for import to RedCap by deleting unnecessary columns.
 - 16 Create a column for height in meters squared by converting cm to m. The following formula can be used = (HEIGHT * 0.01)^2
 - 17 Create a column for FMI and LMI. The following formula can be used for FMI = (WBTOT_FAT * 0.001)/height² and LMI = (WBTOT_LEAN * 0.001)/height².

4.4 Import data to RedCap

1. Once the excel file has been cleaned, the data should be imported to RedCap. For an easy transition, the RedCap template should be set up to almost replicate the exported excel file. Some columns do not align (bone data comes first) so check that the correct variables are being pasted.

2. A RedCap DXA import template in CSV format is available on ASIS. Ensure that participant ID's are in the format 1, 2, 3 etc. and the corresponding redcap event is correct.
3. When the file is complete, save as a CSV file.
4. Click on the Data Import Tool in RedCap.
5. Click on Choose file and select the CSV file for import. Ensure the following fields below are selected.

Record format: The file to be uploaded has its records stored as separate Rows ▾

Format for date and datetime values: MM/DD/YYYY or YYYY-MM-DD ▾

Allow blank values to overwrite existing saved values? No, ignore blank values in the file (default) ▾

6. Upload the file.
7. RedCap will check to ensure that there is no data currently in the fields that are being filled and will highlight any discrepancies for you to check.
8. Click save if you are the fields are correct.
9. The new data will now be saved in RedCap.

5 Repeatability of Measurement

A standardized approach exists for DXA scanning to ensure the random (non-biological) error is kept to a minimum. Calculation of this precision error is critical in serial measurement of body composition or bone mineral density to monitor the change in body composition through longitudinal or intervention studies. Common sources of variation between scans that affect measurement precision include poor or inconsistent positioning and incomplete data acquisition. It is therefore recommended by the International Society for Clinical Densitometry (ISCD) that each technologist carries out an in vivo precision assessment after having performed approximately 100 scans to determine the precision error for BMD at that facility. A similar recommendation has been made for body composition scanning, without indication of prior technologist scanning experience.

5.1 Precision Assessment

Every DXA technologist should conduct a precision assessment on the instrument and patient population they will be scanning on a regular basis. The details are given below:

- . Participants should be informed of the benefits and risks before they are included in a precision assessment.
- . Participants that are representative of the study's typical population should be used.
- . The scan modes in use for clinical or study needs where the change in the parameter is important for individual participants should be used. For whole body composition studies, this is total bone mineral density (BMD), total bone mineral content (BMC), total fat mass (FM) and total lean tissue mass (LTM).

- . Each technologist should scan 30 participants twice or 15 participants three times.
- . The participant should be repositioned between each scan by asking them to get off the table and then back on.
- . Average BMD, BMC, FM and LTM should be calculated.
- . Precision results can be calculated using the DXA precision worksheet located on ASIS and are reported as:
 - . root mean square standard deviation (RMS-SD), calculated as $\sqrt{(\sum SD^2)/n}$;
 - . root mean square coefficient of variance (RMS-CV%), calculated as (RMSSD/mean);
 - . Least significant change (LSC) at the 95% confidence interval (CI) was calculated as (RMS-SD*2.77)

Minimum precision standards for individual technologists are as follows:

<i>Parameter</i>	<i>RMS-CV%</i>
Total BMD	1.5%
Total BMC	2.0%
Total FM	3.0%
Total LTM	2.0%

Precision is also calculated as the ‘least significant change’ (LSC) that has to be seen for there to be 95% statistical confidence that the change in the measure is not just due to chance. This can be useful when monitoring change due to a disease state or intervention.

5.2 Strategies to minimize precision error

1. All operators should be formally trained in positioning and analysis for each scan mode used.
2. Participants should be scanned on the same densitometer. Scans from different makes and model systems cannot be quantitatively compared.
3. The same operator should be used for the baseline and follow-up scans.
4. The participant should be positioned using the standardized procedure suggested by the manufacturer or study protocol.
5. The scan mode should not be changed between baseline and follow-up scans. The scan mode that was used for the baseline should always be used for the follow-up.
6. Identical ROIs should be used for each scan and placed consistently. The ‘compare’ or ‘copy’ function should always be used if available.
7. Auto-analysis algorithms should be used and checked by the operator, and only modified when necessary and at a minimum.

6 Appendix

6.1 Table1. Creating a Query Design: Recommended Fields

<i>Table (2nd Row)</i>	<i>Field (1st Row)</i>
Patient	Identifier 1
Patient	Identifier 2
Patient	Patient_Key
Patient	Birthdate
Patient	Sex
ScanAnalysis	ScanID
ScanAnalysis	Scan_date
ScanAnalysis	Analysis_date
ScanAnalysis	Accession_No
ScanAnalysis	Height
ScanAnalysis	Weight
Wbodycomposition	HEAD_FAT
Wbodycomposition	HEAD_LEAN
Wbodycomposition	HEAD_MASS
Wbodycomposition	HEAD_PFAT
Wbodycomposition	LARM_FAT
Wbodycomposition	LARM_LEAN
Wbodycomposition	LARM_MASS
Wbodycomposition	LARM_PFAT
Wbodycomposition	RARM_FAT
Wbodycomposition	RARM_LEAN
Wbodycomposition	RARM_MASS
Wbodycomposition	RARM_PFAT
Wbodycomposition	TRUNK_FAT
Wbodycomposition	TRUNK_LEAN
Wbodycomposition	TRUNK_MASS
Wbodycomposition	TRUNK_PFAT
Wbodycomposition	L_LEG_FAT
Wbodycomposition	L_LEG_LEAN
Wbodycomposition	L_LEG_MASS
Wbodycomposition	L_LEG_PFAT
Wbodycomposition	R_LEG_FAT
Wbodycomposition	R_LEG_LEAN
Wbodycomposition	R_LEG_MASS
Wbodycomposition	R_LEG_PFAT
Wbodycomposition	SUBTOT_FAT

Wbodycomposition	SUBTOT_LEAN
Wbodycomposition	SUBTOT_MASS
Wbodycomposition	SUBTOT_PFAT
Wbodycomposition	WBTOT_FAT
Wbodycomposition	WBTOT_LEAN
Wbodycomposition	WBTOT_MASS
Wbodycomposition	WBTOT_PFAT
Wbody	WBTOT_AREA
Wbody	WBTOT_BMC
Wbody	WBTOT_BMD
SubRegionComposition	REG1_FAT
SubRegionComposition	REG1_LEAN
SubRegionComposition	REG1_MASS
SubRegionComposition	REG1_PFAT
SubRegionComposition	REG2_FAT
SubRegionComposition	REG2_LEAN
SubRegionComposition	REG2_MASS
SubRegionComposition	REG2_PFAT
SubRegionComposition	REG3_FAT
SubRegionComposition	REG3_LEAN
SubRegionComposition	REG3_MASS
SubRegionComposition	REG3_PFAT

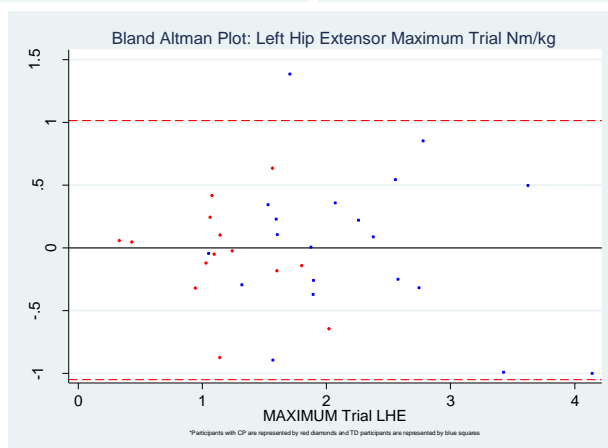
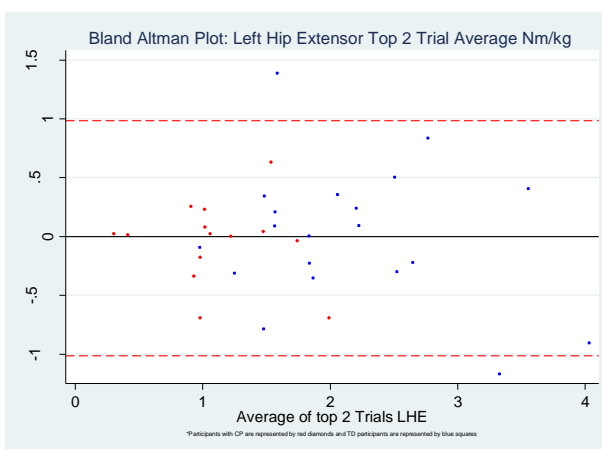
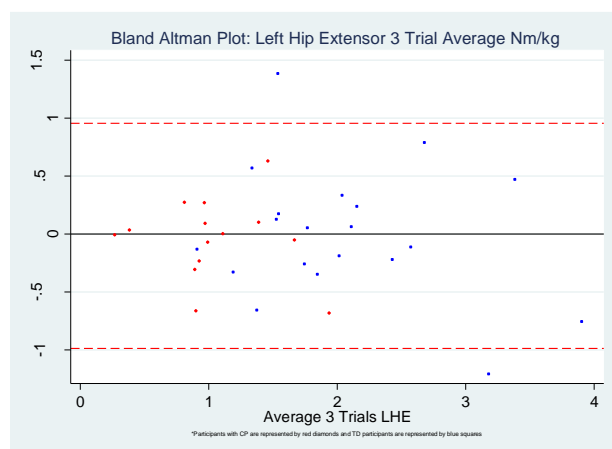
NOTE:

Order is not important. Not all fields are required but are useful for determination of errors/duplicates after extraction. Many may be deleted before import to RedCap. The recommended fields include a full body composition extraction. Additional fields can be added for a full regional bone (BMC and BMD) analysis using ‘Wbody’ and ‘Subregionbone’ tables. Only total BMC and BMD are included in this protocol.

Appendix C: Strength Preliminary Exploratory Analysis

Left Hip Extensor Intraclass Correlation Coefficients

	ICC(3,1) (95% CI)	Interpretation
Average of 3 Trials	0.84 (0.71-0.92)	S
Average of top 2 Trials	0.85 (0.71-0.92)	S
Maximum	0.84 (0.70-0.92)	S

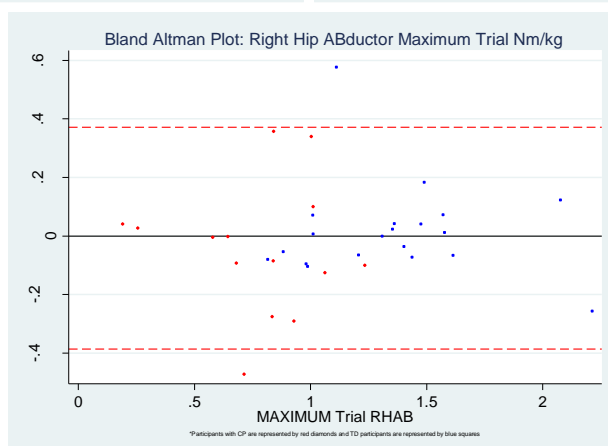
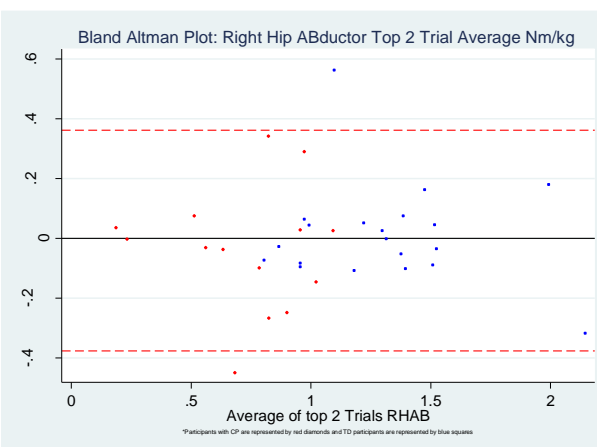
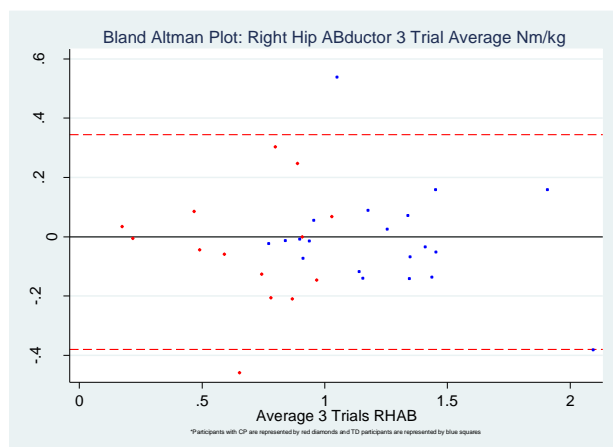


Bland-Altman Plots and Limits of Agreement for the Left Hip Extensors

	LoA	Mean Difference
Average of 3 Trials	-0.990 – 0.953	-0.018
Average of top 2 Trials	-1.014 – 0.985	-0.014
Maximum	-1.051 – 1.012	-0.020

Right Hip Abductor Intraclass Correlation Coefficients

	ICC(3,1) (95% CI)	Interpretation
Average of 3 Trials	0.91 (0.83-0.95)	S
Average of top 2 Trials	0.91 (0.83-0.96)	S
Maximum	0.91 (0.83-0.96)	S

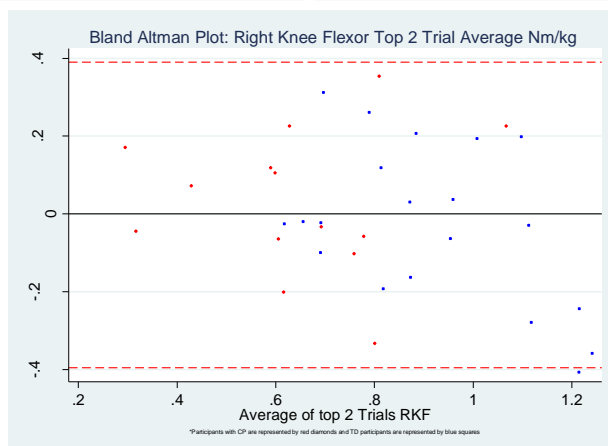
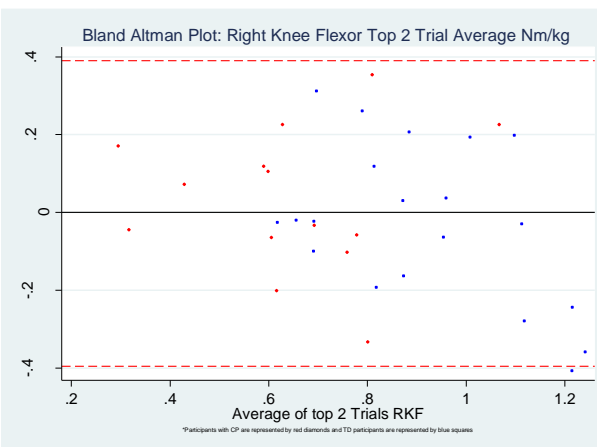
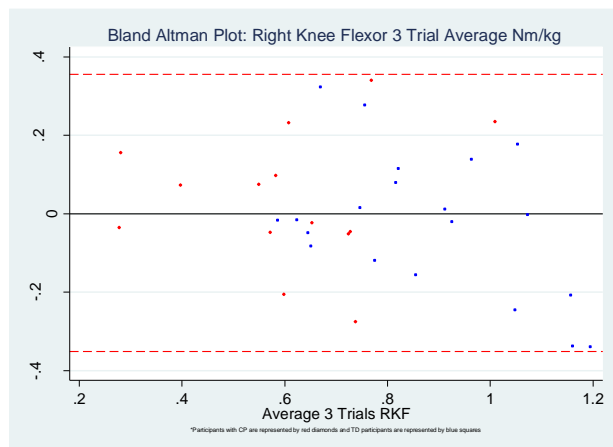


Bland-Altman Plots and Limits of Agreement for the Right Hip Abductors

	LoA	Mean Difference
Average of 3 Trials	-0.380 – 0.344	-0.018
Average of top 2 Trials	-0.377 – 0.361	-0.008
Maximum	-0.386 – 0.371	-0.007

Right Knee Flexor Intraclass Correlation Coefficients

	ICC(3,1) (95% CI)	Interpretation
Average of 3 Trials	0.75 (0.56-0.87)	S
Average of top 2 Trials	0.72 (0.51-0.85)	M
Maximum	0.66 (0.42-0.82)	M

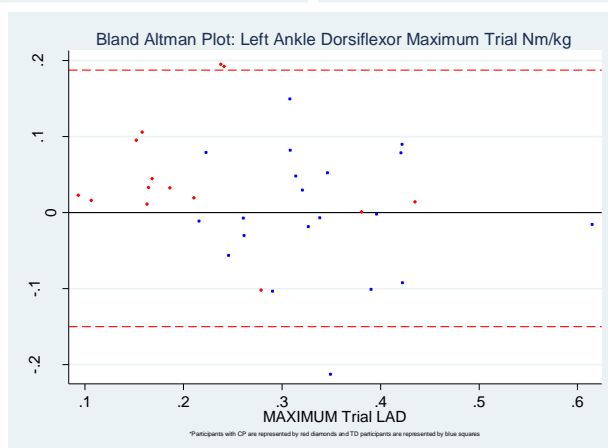
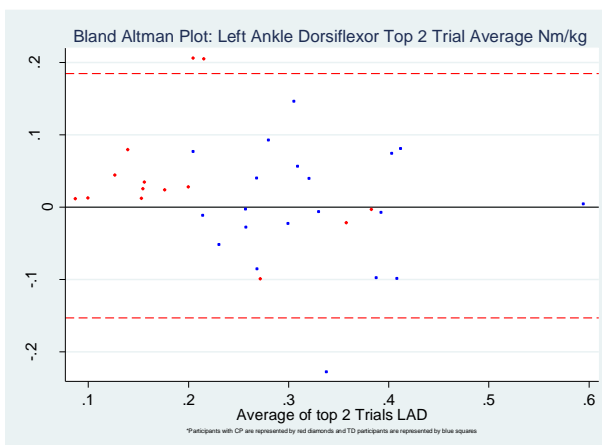
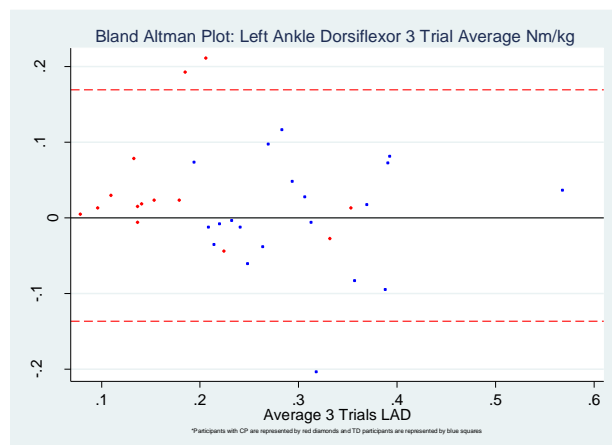


Bland-Altman Plots and Limits of Agreement for the Right Knee Flexors

	LoA	Mean Difference
Average of 3 Trials	-0.351 – 0.355	0.002
Average of top 2 Trials	-0.395 – 0.390	-0.003
Maximum	-0.466 – 0.446	-0.010

Left Ankle Dorsiflexor Intraclass Correlation Coefficients

	ICC(3,1) (95% CI)	Interpretation
Average of 3 Trials	0.77 (0.58-0.88)	S
Average of top 2 Trials	0.74 (0.54-0.86)	M
Maximum	0.75 (0.55-0.86)	S



Bland-Altman Plots and Limits of Agreement for the Left Ankle Dorsiflexors

	LoA	Mean Difference
Average of 3 Trials	-0.137 – 0.169	0.016
Average of top 2 Trials	-0.153 – 0.185	0.016
Maximum	-0.150 – 0.187	0.018

Appendix D: Participant Consent (15 year or over)



Consent Form for Participants (Adolescents 15 and Over)

TITLE: Establishing a Comprehensive Motor and Behavioural Profile for Spastic Cerebral Palsy
Funding: Alberta Children's Hospital Research Institute, Vi Riddell Pediatric Rehabilitation Research Program

INVESTIGATORS:

Principal Investigators: Dr. Carolyn Emery

Co-Investigators (University of Calgary): Dr. Laura Brunton, Dr. Lee Burkholder, Dr. Kelly Kaiser, Dr. Adam Kirton, Dr. Gregor Kuntze, Dr. Alberto Nettel-Aguirre, Dr. Clodagh Toomey, Shane Esau

Co-Investigators (University of Alberta): Dr. Lesley Wiart

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what you will be asked to do. If you have questions or want more information please contact us. Please take the time to read this carefully and make sure you understand everything. If you choose to be in the study, please keep your copy of this form (the white one) and sign and return the study copy (the yellow one) to your team designate or the research staff.

BACKGROUND

Cerebral palsy is the most commonly experienced neurological condition in childhood. Cerebral palsy has an impact on many different areas of a child's abilities and life. We want to learn more about the influence cerebral palsy has on different life areas such as their physical, psychological and social health and well-being. Understanding how children with cerebral palsy are different from their peers in regards to physical activity, pain, fatigue for example will help us determine better options to treat ongoing symptoms of cerebral palsy.

We would like to invite you to participate in this study to get a better understanding of cerebral palsy.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to determine how children and youth with cerebral palsy differ in physical activity level, pain, fatigue, psychological health, exercise capacity, muscle size, structure and strength, balance, body composition, and sleep from those who do not have cerebral palsy.

WHAT WOULD MY CHILD HAVE TO DO?

If you choose to participate in the study you will undergo a short phone interview (approximately 10-15 minutes) with a research coordinator to determine if you are eligible to participate and if you are willing to consent to participating in the study. This study involves two testing sessions separated by about a week. The first session will take place at the Alberta Children's Hospital and will be approximately two (2) hours in length. The second session will take place at the University of Calgary, Kinesiology Building, and will be approximately forty-five (45) minutes in length. You will be provided with precise directions and appointment times that suit both yourself and the researchers. Upon arrival at the Alberta Children's Hospital or the University of Calgary, you will be met by a researcher who will provide you with a parking pass and instructions for parking.

At the first visit you will be asked to participate in various testing stations these include:

1. Completion of the following questionnaires (as applicable):
 - a. Patient Reported Outcomes Measurement Information System Pediatric Profile
 - b. PedsQL Pediatric Quality of Life Inventory
 - c. Fatigue Impact and Severity Self-Assessment
 - d. Sleep Disturbances Scale for Children
 - e. Healthcare Utilization Survey
 - f. Parent Demographic Form
 - g. Participant Demographic Form
2. 6 Minute Walk Test
For this test, you'll be asked to walk on a platform track between two cones for 6 minutes. The object of this test is to walk as far as possible for 6 minutes. You are permitted to slow down, to stop, and to rest as necessary. You may sit down as needed and you may use any gait aid you regularly use to walk. Motion analysis and a wearable metabolic cart will be used during these tests. Please let us know if you have an allergy to adhesives such as tape or bandages. If so, motion analysis will not be used.
3. Balance tests including:
 - a. Eyes open static standing, which involves standing quietly for 30 seconds on a force plate with two feet together and your eyes open
 - b. Eyes closed static standing, which involves standing quietly for 30 seconds on a force plate with two feet together and your eyes closed
 - c. Eyes open tandem standing, which involves standing quietly for 30 seconds on a force plate with one foot in front of the other with your eyes open
 - d. Eyes closed tandem standing, which involves standing quietly for 30 seconds on a force plate with one foot in front of the other with your eyes closed
 - e. Single Leg Balance, which will involve balancing on one leg on a force plate with your eyes open. Three repetitions will be done on each leg.

NOTE: Motion analysis will be used during these tests. PLEASE LET US KNOW IF YOU HAVE AN ALLERGY TO ADHESIVES (such as tape or bandages). IF SO, MOTION ANALYSIS WILL NOT BE USED.
4. Leg strength testing. You will be asked to lay sideways on an exam table and be instructed to push your leg up, against a dynamometer (measurement tool) with maximal force, three times for each leg.
5. You will be asked to participate in a physical activity monitoring assessment using an accelerometer device (ActiGraph GT3X). Specifically, you will be asked to wear a small, lightweight device attached via an elastic belt around your waist for a period of 7 days.

At the second testing session you return the physical activity monitor and participate in 3 testing stations:

1. Height, weight, and waist circumference measurements.
2. A dual energy x-ray absorptiometry scan (DXA). For the scan you will be asked to lay flat on an exam table while the arm of a machine passes over you from head to toe to measure your fat and muscle mass. This test is an x-ray. It will take about 10 minutes and should not give you any discomfort.
3. Completion of the Fatigue Impact and Severity Self-Assessment Questionnaire.

Finally, a member of the study team will perform a chart review of your electronic health record to obtain a cause related to your cerebral palsy.

WHAT ARE THE RISKS?

There are no expected risks associated with participating in this study. The measurements described above will be done under close supervision and every effort will be made to ensure your safety. As with any physical activity there is the possibility of a muscle pull or strain and soreness for the strength, balance and walking tests. The risk of injury will be reduced by careful supervision during the testing procedures.

The estimated dose of radiation from the DEXA scan is less than 25 mrad. No amount of radiation is considered to be completely safe. For the sake of comparison, the dose from a chest x-ray is 25 mrad, from a dental x-ray is 750 mrad, natural living at sea level exposes you to 100 mrad and watching TV one hour per day exposes a person to 1 mrad per year. The actual health risks from exposure to low x-ray doses are difficult to determine. Conservatively, health experts assume radiation health risks are proportional to exposure. This leads to pessimistic estimates of a 0.01% chance of developing cancer due to a 10 000 μSv x-ray dose, compared to a normal lifetime risk of cancer for women in the US of 33% (Reference: Kalender WA. Effective dose values in bone mineral measurements by photon absorptiometry and computed tomography. *Osteoporosis Int* 2:82-87, 1992).

WILL THE STUDY HELP YOU?

If you agree to take part in this study it may or may not directly help you. However, the information gathered in this study will help to inform future treatments and practices for individuals with cerebral palsy.

DO I HAVE TO PARTICIPATE?

No, you do not have to participate. Participation is completely voluntary. If you agree to participate, we require you to sign and return this form to us. Two copies of this form have been provided. Please keep one for your records, and return the other to us.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in this research project and agree to be a participant. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities.

You are free to withdraw from the study at any time by contacting the Research Coordinator at ____-____-____ or _____. Continued participation should be as informed as your initial consent, so feel free to ask for clarification or new information, throughout your participation in the study. If there is new information available throughout this study period, you will be informed as soon as possible.

WHAT DO I GET FOR BEING IN THE STUDY?

Participants will not be paid to participate in the study, and there will be no costs (parking permits will be provided) to the participants.

WILL MY RECORDS BE KEPT PRIVATE?

All of the information collected will remain strictly confidential. Your privacy will be assured. Only the investigators responsible for this study, the research assistants who will be doing the assessments and data analysis, and the University of Calgary Conjoint Health Research Ethics Board will have access to this information. Data will be kept in a secure, either locked, or password protected location, for five years after completion of the study. Confidentiality will be protected by using a study identification number in the database. Any results reported from the study will in no way identify study participants.

SIGNATURES

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health. If you have further questions concerning matters related to this research, please contact:

Shane Esau (research coordinator) at _____ or
Dr. Laura Brunton (co-investigator) at _____

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair, Conjoint health Research Ethics Board, University of Calgary, at ____-____-____.

Participant Signature

Witness Signature

Participant Name (Print)

Witness Name (Print)

Date

Date

Contact information

Parent/Guardian Name (Print)

Email address (Participant or Parent/Guardian)

Phone (Participant or Parent/Guardian)

Office use only

Investigator/Delegate Signature

Investigator/Delegate Name (Print)

Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

**PLEASE SIGN THIS PAGE AND RETURN THE FULL DOCUMENT TO YOUR
TEAM DESIGNATE OR STUDY PERSONNEL.
*KEEP THE OTHER COPY FOR YOUR RECORDS***

Appendix E: Parent and Participant Consent (14 years or younger)



Parent/Guardian Consent Form for Participants

TITLE: Establishing a Comprehensive Motor and Behavioural Profile for Spastic Cerebral Palsy

Funding: Alberta Children's Hospital Research Institute, Vi Riddell Pediatric Rehabilitation Research Program

INVESTIGATORS:

Principal Investigators: Dr. Carolyn Emery
Co-Investigators (University of Calgary): Dr. Laura Brunton, Dr. Lee Burkholder, Dr. Kelly Kaiser, Dr. Adam Kirton, Dr. Gregor Kuntze, Dr. Alberto Nettel-Aguirre, Dr. Clodagh Toomey, Shane Esau
Co-Investigators (University of Alberta): Dr. Lesley Wiart

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what you will be asked to do. If you have questions or want more information please contact us. Please take the time to read this carefully and make sure you understand everything. If you choose to be in the study, please keep your copy of this form (the white one) and sign and return the study copy (the yellow one) to your team designate or the research staff.

BACKGROUND

Cerebral palsy is the most commonly experienced neurological condition in childhood. Cerebral palsy has an impact on many different areas of a child's abilities and life. We want to learn more about the influence cerebral palsy has on different life areas such as their physical, psychological and social health and well-being. Understanding how children with cerebral palsy are different from their peers in regards to physical activity, pain, fatigue for example will help us determine better options to treat ongoing symptoms of cerebral palsy.

We would like to invite you to participate in this study to get a better understanding of cerebral palsy. The pronouns "you" and "your" in this letter should be read as referring to the participant and not the parent and/or guardian who is signing the consent form for the participant.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to determine how children and youth with cerebral palsy differ in physical activity level, pain, fatigue, psychological health, exercise capacity, muscle size, structure and strength, balance, body composition, and sleep from those who do not have cerebral palsy.

WHAT WOULD MY CHILD HAVE TO DO?

If you choose for your child to participate in the study you will undergo a short phone interview (approximately 10-15 minutes) with a research coordinator to determine if they are eligible to participate and if you are willing to consent to your child participating in the study. This study involves two testing sessions separated by about a week. The first session will take place at the Alberta Children's Hospital and will be approximately two (2) hours in length. The second session will take place at the University of Calgary, Kinesiology Building, and will be approximately forty-five (45) minutes in length. You will be provided with precise directions and appointment times that suit both yourself and the researchers. Upon arrival at the Alberta Children's Hospital or the University of Calgary, you will be met by a researcher who will provide you with a parking pass and instructions for parking.

At the first visit you will be asked to participate in various testing stations these include:

Completion of the following questionnaires (as applicable):

Patient Reported Outcomes Measurement Information System Pediatric Profile

PedsQL Pediatric Quality of Life Inventory

Fatigue Impact and Severity Self-Assessment

Sleep Disturbances Scale for Children

Healthcare Utilization Survey

Parent Demographic Form

Participant Demographic Form

6 Minute Walk Test

For this test, you'll be asked to walk on a platform track between two cones for 6 minutes. The object of this test is to walk as far as possible for 6 minutes. You are permitted to slow down, to stop, and to rest as necessary. You may sit down as needed and you may use any gait aid you regularly use to walk. Motion analysis and a wearable metabolic cart will be used during these tests. Please let us know if you have an allergy to adhesives such as tape or bandages. If so, motion analysis will not be used.

Balance tests including;

Eyes open static standing, which involves standing quietly for 30 seconds on a force plate with two feet together and your eyes open

Eyes closed static standing, which involves standing quietly for 30 seconds on a force plate with two feet together and your eyes closed

Eyes open tandem standing, which involves standing quietly for 30 seconds on a force plate with one foot in front of the other with your eyes open

Eyes closed tandem standing, which involves standing quietly for 30 seconds on a force plate with one foot in front of the other with your eyes closed

Single Leg Balance, which will involve balancing on one leg on a force plate with your eyes open.

Three repetitions will be done on each leg.

NOTE: Motion analysis will be used during these tests. PLEASE LET US KNOW IF YOU HAVE AN ALLERGY TO ADHESIVES (such as tape or bandages). IF SO, MOTION ANALYSIS WILL NOT BE USED.

Leg strength testing. You will be asked to lay sideways on an exam table and be instructed to push your leg up, against a dynamometer (measurement tool) with maximal force, three times for each leg.

You will be asked to participate in a physical activity monitoring assessment using an accelerometer device (ActiGraph GT3X). Specifically, you will be asked to wear a small, lightweight device attached via an elastic belt around your waist for a period of 7 days.

At the second testing session you return the physical activity monitor and participate in 3 testing stations:

Height, weight, and waist circumference measurements.

A dual energy x-ray absorptiometry scan (DXA). For the scan you will be asked to lay flat on an exam table while the arm of a machine passes over you from head to toe to measure your fat and muscle mass. This test is an x-ray. It will take about 10 minutes and should not give you any discomfort.

Completion of the Fatigue Impact and Severity Self-Assessment Questionnaire.

Finally, a member of the study team will perform a chart review of your electronic health record to obtain a cause related to your cerebral palsy.

WHAT ARE THE RISKS?

There are no expected risks associated with participating in this study. The measurements described above will be done under close supervision and every effort will be made to ensure your safety. As with any physical activity there is the possibility of a muscle pull or strain and soreness for the strength, balance and walking tests. The risk of injury will be reduced by careful supervision during the testing procedures.

The estimated dose of radiation from the DEXA scan is less than 25 mrad. No amount of radiation is considered to be completely safe. For the sake of comparison, the dose from a chest x-ray is 25 mrad, from a dental x-ray is 750 mrad, natural living at sea level exposes you to 100 mrad and watching TV one hour per day exposes a person to 1 mrad per year. The actual health risks from exposure to low x-ray doses are difficult to determine. Conservatively, health experts assume radiation health risks are proportional to exposure. This leads to pessimistic estimates of a 0.01% chance of developing cancer due to a 10 000 μ Sv x-ray dose, compared to a normal lifetime risk of cancer for women in the US of 33% (Reference: Kalender WA. Effective dose values in bone mineral measurements by photon absorptiometry and computed tomography. *Osteoporosis Int* 2:82-87, 1992).

WILL THE STUDY HELP YOU?

If you agree to take part in this study it may or may not directly help you. However, the information gathered in this study will help to inform future treatments and practices for individuals with cerebral palsy.

DO I HAVE TO PARTICIPATE?

No, you do not have to participate. Participation is completely voluntary. If you agree to participate, we require you to sign and return this form to us. Two copies of this form have been provided. Please keep one for your records, and return the other to us.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in this research project and agree to be a participant. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities.

You are free to withdraw from the study at any time by contacting the Research Coordinator at ____ - ____ - ____ or _____. Continued participation should be as informed as your initial consent, so feel free to ask for clarification or new information, throughout your participation in the study. If there is new information available throughout this study period, you will be informed as soon as possible.

WHAT DO I GET FOR BEING IN THE STUDY?

Participants will not be paid to participate in the study, and there will be no costs (parking permits will be provided) to the participants.

WILL MY RECORDS BE KEPT PRIVATE?

All of the information collected will remain strictly confidential. Your privacy will be assured. Only the investigators responsible for this study, the research assistants who will be doing the assessments and data analysis, and the University of Calgary Conjoint Health Research Ethics Board will have access to this information. Data will be kept in a secure, either locked, or password protected location, for five years after completion of the study. Confidentiality will be protected by using a study identification number in the database. Any results reported from the study will in no way identify study participants.

SIGNATURES

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health. If you have further questions concerning matters related to this research, please contact:

Shane Esau (research coordinator) at _____ or
Dr. Laura Brunton (co-investigator) at _____

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair, Conjoint health Research Ethics Board, University of Calgary, at ____-____-____.

Participant Signature

Witness Signature

Participant Name (Print)

Witness Name (Print)

Date

Date

Contact information

Parent/Guardian Name (Print)

Email address (Participant or Parent/Guardian)

Phone (Participant or Parent/Guardian)

Office use only

Investigator/Delegate Signature

Investigator/Delegate Name (Print)

Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

**PLEASE SIGN THIS PAGE AND RETURN THE FULL DOCUMENT TO YOUR
TEAM DESIGNATE OR STUDY PERSONNEL.
*KEEP THE OTHER COPY FOR YOUR RECORDS***

Child Consent Form

TITLE: Establishing a Comprehensive Motor and Behavioural Profile for Spastic Cerebral Palsy

PRINCIPAL INVESTIGATORS: Dr. Carolyn Emery, Dr. Laura Brunton, Dr. Lee Burkholder, Dr. Kelly Kaiser, Dr. Adam Kirton, Dr. Gregor Kuntze, Dr. Alberto Nettel-Aguirre, Dr. Clodagh Toomey, Dr. Lesley Wiart, Shane Esau

WHAT IS A RESEARCH STUDY?

A research study is a way to find out new information about something. You do not need to be in a research study if you don't want to.

WHY ARE YOU BEING ASKED TO BE PART OF THIS RESEARCH STUDY?

You are being asked to take part in this research study because we are trying to learn more about cerebral palsy in children your age.

IF YOU WANT TO JOIN THE STUDY, WHAT WILL HAPPEN TO YOU?

We want to tell you about some of the things that will happen to you if you are in this study. You will come see us two (2) times. The first time you come you will:

- Fill out some questionnaires, which will ask questions about your health, your fatigue and your pain. The study team will help you with these questionnaires if you need it.
- Participate in a walking test and some balances tests. During these tests you will have small objects called "markers" attached to parts of your body so we can record your movement with cameras.
- Participate in a strength test where you push as hard as you can against a tool called a dynamometer.
- Be asked to wear an accelerometer around your waist for 7 days to collect information about your physical activity.

The second time you come in you will hand in your accelerometer and:

- Participate in some testing where a group of researchers will take your height, weight, and measure your waist.
- Have a special test called a dual energy x-ray absorptiometry scan done, this will take an x-ray of your body while you lie still.
- Complete one questionnaire about your level of fatigue.

Finally, a member of the study team will read your electronic health record to know what caused your cerebral palsy.

WILL ANY PART OF THE STUDY HURT?

This study will not hurt you. The activities you do in this study will not be very different from the things you might do in physical therapy or gym class. There is the chance that you might get tired or sore after the testing.

WILL THE STUDY HELP YOU?

If you agree to participate in this study, it may or may not help you.

WILL THE STUDY HELP OTHERS?

The information that we get from this study may help us to provide more programs and treatments for children with cerebral palsy and improve their health in the future.

DO YOUR PARENTS KNOW ABOUT THE STUDY?

We have also given a consent form to your parents to read that will let them know about this study. You can talk this over with them before you decide.

WHO WILL SEE THE INFORMATION COLLECTED ABOUT YOU?

The information collected about you during this study will be kept safely locked up. Nobody will know about it except for the people doing the research. The study information about you will not be given to your parents. The researchers will not tell your friends, your school or anyone else.

WHAT DO YOU GET FROM BEING IN THIS STUDY?

You do not have to pay for anything to be in this study. You will not receive anything for participating in this study.

DO YOU HAVE TO BE IN THE STUDY?

No, you do not have to be in this study. No one will be upset if you don't want to do this study. If you don't want to be in this study, you just have to tell us. It's up to you.

WHAT IF YOU HAVE ANY QUESTIONS?

You can ask any questions that you may have about the study. If you have a question later that you didn't think of now, either you can call or have your parents call the Research Coordinator at ____-____-____, or the Co-Investigator (Laura Brunton) at ____-____-____. You can also take more time to think about being in the study and also talk some more with your parents about being in the study.

WHAT CHOICES DO YOU HAVE IF YOU SAY NO TO THIS STUDY?

This study is optional, so if you don't want to do it, nothing will change.

OTHER INFORMATION ABOUT THIS STUDY:

If you decide to be in the study, please write your name below. You can change your mind and stop being part of it at any time. All you have to do is tell the person in charge. The researchers and your parents won't be upset. You can keep one copy of this paper.

Would you like to take part in this study? (Please ☒ one)

_____ Yes, I will be in this research study.

_____ No, I don't want to do this.

Child's full name (Print clearly)

Signature of the Child

Date

Office use only

Research Staff

Signature

Date

Appendix F: Reliability Study Consent Forms



CONSENT ADDENDUM FORM for Participants (Adolescents 15 and Over)

TITLE: Establishing a Comprehensive Motor and Behavioural Profile for Spastic Cerebral Palsy

Pilot Study: Reliability of Testing Isometric Muscle Strength Using Hand-held Dynamometry in Children with and without Spastic Cerebral Palsy

Funding: Alberta Children's Hospital Research Institute, Vi Riddell Pediatric Rehabilitation Research Program

INVESTIGATORS:

Principal Investigators: Dr. Carolyn Emery

Co-Investigators (University of Calgary): Dr. Laura Brunton, Dr. Lee Burkholder, Dr. Kelly Kaiser, Dr.

Adam Kirton, Dr. Gregor Kuntze, Dr. Alberto Nettel-Aguirre, Dr. Clodagh Toomey, Shane Esau

Co-Investigators (University of Alberta): Dr. Lesley Wiart

Prior to starting this research study, you signed an Informed Consent Form describing the study and your rights as a study participant. Below you will find information for an additional component of this study, which you are invited to take part in. This additional component is intended to determine the reliability (consistency/repeatability of a measure) of isometric strength testing using strapping and hand-held dynamometry, which is currently being used in the larger study. Participation is voluntary and you are free to withdraw from the study at any time. All data collected will be kept confidential as described in the original consent form. Please read the information below and sign the bottom of the Informed Consent Addendum Form if you wish to continue.

BACKGROUND

You are part of a large cohort study that investigates the effects of spastic cerebral palsy on a number of different outcome variables, including maximal isometric muscle strength. For this purpose, we are currently measuring the strength produced by eight different muscle groups in both of the legs. When measurements are taken on different days and by different experimenters, a measurement error may be introduced. In order to interpret the significance of these results, we have to determine this measurement error by investigating how repeatable our maximal isometric strength measurements are between different testing sessions.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to determine the repeatability between testing sessions for measuring the maximal isometric muscle strength of the hip flexors, extensors, abductors, and adductors, the knee flexors and extensors, and the ankle plantarflexors and dorsiflexors in children with and without cerebral palsy.

WHAT WOULD I HAVE TO DO?

Your participation in this study will still involve two visits separated by about a week (7-10 days) as part of the larger study. The first testing session will take place in the Movement Assessment Centre on the Lower Level of the Alberta Children's Hospital and the second testing session will be at the Human Performance Laboratory (HPL) at the University of Calgary. As described in the full study consent form, in the first testing session (approximately 3 hours) at the Alberta Children's Hospital you will complete strength tests. During this session you will be asked to perform a total of 3 maximal efforts for each of the eight tested muscle groups.

The second session (approximately 1.5 hours) at the Human Performance Laboratory (HPL), will be scheduled 7-10 days after your first testing session. During this session, you will complete the DXA scan that is part of the larger study and we will ask you to perform a second round of the same isometric strength tests you did during the first session.

We will collect the following data during both sessions:

Leg segment lengths using a measuring tape

Force/strength measurements of both your legs using a hand-held dynamometer

You will be provided with precise direction and appointment times that suit both yourself and the researchers.

Upon arrival at the Alberta Children's Hospital or the University of Calgary, you will be met by a researcher who will provide you with a parking pass and instructions for parking.

WHAT ARE THE RISKS?

There are no expected risks associated with participating in this study. The measurements described above will be done under close supervision and every effort will be made to ensure your safety. As with any physical activity there is the possibility of a muscle pull or strain and soreness from the strength tests. The risk of injury will be reduced by careful supervision during the testing procedures.

IF I SUFFER A RESEARCH-RELATED INJURY, WILL I BE COMPENSATED?

In the event that you suffer injury as a result of participating in this research, no compensation will be provided to you by the University of Calgary, Alberta Health Services, or the Researchers. You still have all your legal rights. Nothing said in this consent form alters your right to seek damages.

SIGNATURES

Your signature on this form indicates that you have understood to your satisfaction the new information in this addendum concerning the research project you are currently participating in. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health care. If you have further questions concerning matters related to this research, please contact:

Shane Esau (research coordinator) at _____ or
Dr. Laura Brunton (co-investigator) at _____

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair, Conjoint health Research Ethics Board, University of Calgary, at ____-____-____.

Participant Signature

Witness Signature

Participant Name (Print)

Witness Name (Print)

Date

Date

Contact information

Parent/Guardian Name (Print)

Email address (Participant or Parent/Guardian)

Phone (Participant or Parent/Guardian)

Office use only

Investigator/Delegate Signature

Investigator/Delegate Name (Print)

Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

PLEASE SIGN THIS PAGE AND RETURN THE FULL DOCUMENT TO YOUR TEAM DESIGNATE OR STUDY PERSONNEL.

KEEP THE OTHER COPY FOR YOUR RECORDS

CONSENT ADDENDUM FORM for the Parent/Guardian

TITLE: Establishing a Comprehensive Motor and Behavioural Profile for Spastic Cerebral Palsy

Pilot Study: Reliability of Testing Isometric Muscle Strength Using Handheld Dynamometry in Children with and without Spastic Cerebral Palsy

Funding: Alberta Children's Hospital Research Institute, Vi Riddell Pediatric Rehabilitation Research Program

INVESTIGATORS:

Principal Investigators: Dr. Carolyn Emery
Co-Investigators (University of Calgary): Dr. Laura Brunton, Dr. Lee Burkholder, Dr. Kelly Kaiser, Dr. Adam Kirton, Dr. Gregor Kuntze, Dr. Alberto Nettel-Aguirre, Dr. Clodagh Toomey, Shane Esau
Co-Investigators (University of Alberta): Dr. Lesley Wiart

Prior to starting this research study, you and your child signed Informed Consent Forms describing the study and your rights as a study participant. Below you will find information for an additional component of this study, which you are invited to take part in. This additional component is intended to determine the reliability (consistency/repeatability of a measure) of isometric strength testing using strapping and hand-held dynamometry, which is currently being used in the larger study. Participation is voluntary and you and your child is free to withdraw from the study at any time. All data collected will be kept confidential as described in the original consent form. Please read the information below and sign the bottom of the Informed Consent Addendum Form if you wish to continue.

BACKGROUND

Your child is participating in a large cohort study that investigates the effects of spastic cerebral palsy on a number of different outcome variables, including maximal isometric muscle strength. For this purpose, we are currently measuring the strength produced by eight different muscle groups in both of the legs. When measurements are taken on different days and by different experimenters, a measurement error may be introduced. In order to interpret the significance of these results, we have to determine this measurement error by investigating how repeatable our maximal isometric strength measurements are between different testing sessions.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to determine the reliability between testing sessions within and across days for measuring the maximal isometric muscle strength of the hip flexors, extensors, abductors, and adductors, the knee flexors and extensors, and the ankle plantarflexors and dorsiflexors in children with and without cerebral palsy.

WHAT WOULD MY CHILD HAVE TO DO?

If you choose for your child to participate in this study it will still involve two visits separated by about a week (7-10 days) as part of the larger study. The first testing session will take place in the Movement Assessment Centre on the Lower Level of the Alberta Children's Hospital and the second testing session will be at the Human Performance Laboratory (HPL) at the University of Calgary. As described in the full study consent form, in the first testing session (approximately 3 hours) at the Alberta Children's Hospital your child will complete strength tests. During this session your child will be asked to perform a total of 3 maximal efforts for each of the eight tested muscle groups.

The second session (approximately 1.5 hours) at the Human Performance Laboratory (HPL), will be scheduled 7-10 days after your child's first testing session. During this session, your child will complete the DXA scan that is part of the larger study and complete a second round of the same isometric strength tests they did during the first session.

We will collect the following data during both sessions:

Leg segment lengths using a measuring tape

Force/strength measurements of both your legs using a hand-held dynamometer

You will be provided with precise direction and appointment times that suit both yourself/your child and the researchers. Upon arrival at the Alberta Children's Hospital or the University of Calgary, you will be met by a researcher who will provide you with a parking pass and instructions for parking.

WHAT ARE THE RISKS?

There are no expected risks associated with participating in this study. The measurements described above will be done under close supervision and every effort will be made to ensure your child's safety. As with any physical activity there is the possibility of a muscle pull or strain and soreness from the strength tests. The risk of injury will be reduced by careful supervision during the testing procedures.

IF MY CHILD SUFFERS A RESEARCH-RELATED INJURY, WILL I BE COMPENSATED?

In the event that your child suffers an injury as a result of participating in this research, no compensation will be provided to you by the University of Calgary, Alberta Health Services, or the Researchers. You still have all your legal rights. Nothing said in this consent for alters your right to seek damages.

SIGNATURES

Your signature on this form indicates that you have understood to your satisfaction the new information in this addendum concerning the research project your child is currently participating in. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your child's health care. If you have further questions concerning matters related to this research, please contact:

Shane Esau (research coordinator) at _____ or
Dr. Laura Brunton (co-investigator) at _____

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair, Conjoint health Research Ethics Board, University of Calgary, at ____-____- ____.

Parent/Guardian Signature

Witness Signature

Parent/Guardian Name (Print)

Witness Name (Print)

Date

Date

Contact information

Parent/Guardian Name (Print)

Email address (Participant or Parent/Guardian)

Phone (Participant or Parent/Guardian)

Office use only

Investigator/Delegate Signature

Investigator/Delegate Name (Print)

Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

PLEASE SIGN THIS PAGE AND RETURN THE FULL DOCUMENT TO YOUR TEAM DESIGNATE OR STUDY PERSONNEL.

KEEP THE OTHER COPY FOR YOUR RECORDS

CHILD CONSENT ADDENDUM FORM

TITLE: Establishing a Comprehensive Motor and Behavioural Profile for Spastic Cerebral Palsy

Pilot Study: Reliability of Testing Isometric Muscle Strength Using Hand-held Dynamometry in Children with and without Spastic Cerebral Palsy

PRINCIPAL INVESTIGATORS: Dr. Carolyn Emery, Dr. Laura Brunton, Dr. Lee Burkholder, Dr. Kelly Kaiser,
Dr. Adam Kirton, Dr. Gregor Kuntze, Dr. Alberto Nettel-Aguirre, Dr. Clodagh Toomey, Dr. Lesley Wiart,
Shane Esau

WHY ARE YOU BEING ASKED TO BE PART OF THIS RESEARCH STUDY?

You are being asked to take part in this research study because you are taking part in a larger study that our group is doing to learn more about cerebral palsy in children your age. As part of this study we will need to check the reliability (repeatability) of testing muscle strength using a tool called a hand-held dynamometer.

IF YOU WANT TO JOIN THE STUDY, WHAT WILL HAPPEN TO YOU?

We want to tell you about what some of the things you will do if you are in this study. As outlined in the full study you will come to see us twice, both times you will:

- ☐ Have your legs measured for length with a tape measure
- ☐ Participate in strength tests where you push as hard as you can against a tool called a dynamometer.

WILL ANY PART OF THE STUDY HURT?

This study will not hurt you. The activities you do in this study will not be very different from the things you might do in physical therapy or gym class. There is the chance that you might get tired or sore after the testing. The tests described above will be supervised and every effort will be made to ensure your safety.

DO YOUR PARENTS KNOW ABOUT THE STUDY?

We have also given a consent form to your parents to read that will let them know about this study. You can talk to your parents about the study before you decide.

DO YOU HAVE TO BE IN THE STUDY?

No, you do not have to be in this study. No one will be upset if you don't want to do this study. If you don't want to be in this study, you just have to tell us. It's up to you.

WHAT IF YOU HAVE ANY QUESTIONS?

You can ask any questions that you may have about the study. If you have a question later that you didn't think of now, either you can call or have your parents call the Research Coordinator at ____-____-____, or the Co-Investigator (Laura Brunton) at ____-____-____. You can also take more time to think about being in the study and also talk some more with your parents about being in the study.

OTHER INFORMATION ABOUT THIS STUDY:

If you decide to be in the study, please write your name below. You can change your mind and stop being part of it at any time. All you have to do is tell the person in charge. The researchers and your parents won't be upset. You can keep one copy of this paper.

Would you like to take part in this study? (Please ✓ one)

_____ Yes, I will be in this research study.

_____ No, I don't want to do this.

Child's full name (Print clearly)

Signature of the Child

Date

Office use only


Research Staff

Signature

Date

Appendix G: Recruitment Poster

Recruiting Participants for the Cerebral Palsy Cohort Study



Vi Riddell
Pediatric Rehabilitation
Research Program

Who:

- Youth with Cerebral Palsy Aged 10-18 Years
- GMFCS Levels I - III

Primary Investigator: Dr. Carolyn Emery
Co-Investigators: Dr. Laura Brunton, Dr. Adam Kirton, Dr. Lee Burkholder

What: 2 Visits At Least 1 Week Apart



Visit 1: 3 Hours (Movement Assessment Centre)


- Balance Tests with Motion Analysis
- 6 Minute Walk Test with Electromyography and Gait Analysis
- Questionnaires about Fatigue, Pain, Quality of Life, Mobility, Sleep and Health Care Use
- Strength Measurements of both legs
- Fit with an Activity Monitor to wear for 1 week

Visit 2: 30 minutes (University of Calgary)


- Return Activity Monitor
- DXA Scan for Body Composition

* Siblings between the ages of 10-18 welcome as control participants and can be tested together*

For more information contact  or
Shane Esau at 



Children's
HOSPITAL
RESEARCH INSTITUTE



UNIVERSITY OF
CALGARY

Ethics ID: REB15-3126
This study has been approved by the University of Calgary Conjoint Faculties Research Ethics Board