EXAMINING EARLY CHILDHOOD GROSS MOTOR SKILL PROFICIENCY IN CHILDREN BORN PRETERM

by

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Abstract

Preterm birth (<37 weeks) is a public health concern in Canada. Long-term developmental concerns have been documented, however less is known about the relationship between preterm birth and gross motor development. Understanding the acquisition of fundamental motor skills in early childhood is important as it lays the foundation for movement experiences across the lifespan. Although children born early preterm (<32 weeks) show marked gross motor delays, children born preterm at later gestational ages receive little follow-up and are often excluded from research, limiting our knowledge. The purpose of this research was to examine the relationship between gestational age and gross motor skill performance of children (4-6 years of age) born preterm. Eighteen children (n = 11 f, 7 m; mean age = 5.2 ± 0.7 y) born preterm (mean gestational age = 31.6 ± 3.3 wks) were recruited and assessed in one session on gross motor skill proficiency (Test of Gross Motor Development–Second Edition; TGMD-2), balance (single-leg static balance), and muscular strength (grip strength, standing long jump). Anthropometric measurements were also collected. Pearson product correlations, as well as regression analyses, were conducted to examine relationships of predictors and performance variables. Findings showed that gestational age was not significantly correlated to the TGMD-2 overall Gross Motor Quotient score ($r = 0.409$, $n = 18$, $p > .05$). Irrespective of gestational age, gross motor proficiency was low. Holding age constant, gestational age was found to be a significant predictor of both balance time and standing long jump distance. Children born at later gestational ages balanced longer and jumped further; however balance was still poorly performed by the participants. The findings of this investigation indicate the need for further research into the gross motor skill development of children born preterm throughout the early childhood years. These findings suggest that difficulties in fundamental gross motor skills are exhibited across gestational age and difficulties are not constrained to the first years of life, but also exhibited at preschool and kindergarten-age. This work has implications for the design and implementation of developmentally appropriate programming for the preterm population in the early childhood years.

Lay Summary

It is important to develop critical motor skills and patterns in early childhood that use large muscle groups to move. Unfortunately, children born early (preterm) are at risk for delayed development of gross motor skills. To date, most of the research has focused on children born very early, and there is little information about children who are born preterm but closer to full term. This investigation assessed the gross motor skills of children born preterm at age 4-6 years. Eighteen children with an average age of 5.2 years who were born at an average gestational age of 31.6 weeks participated. The children exhibited poor movement skills, as well as balance skills. These results suggest that children who are born preterm should be followed-up for motor development delay throughout childhood, regardless of how early they are born. In addition, balance may be an important part of movement development in these children.

Preface

Beth M.M. Rizzardo was the primary author of this thesis under the supervision of Dr. Shannon Bredin, who helped develop the thesis structure and offered substantial input and edits. As supervisory committee members, Dr. Darren Warburton and Dr. Carolyn McEwen provided assistance in the direction of this thesis, in addition to providing editorial feedback. All research was conducted in the Cognitive and Motor Learning Laboratory, Physical Activity Promotion and Chronic Disease Prevention Unit in the School of Kinesiology at the University of British Columbia.

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The data of 10 participants were presented on June 6th, 2018 at the 2018 International Society of Behavioral Nutrition and Physical Activity Annual Meeting in Hong Kong, China:

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A version of Chapter 5 is in editing for submission at the time of thesis acceptance. Beth M.M. Rizzardo initiated the concept of this study and was responsible for participant recruitment, data collection, statistical analysis, and was primary author of the manuscript. Dr. Shannon Bredin was responsible for overseeing and supervising the study and was involved throughout, including concept formation, manuscript edits, and providing significant input. Dr. Darren Warburton and Dr. Carolyn McEwen both contributed to formation of the study protocol, offered guidance, and provided feedback and manuscript edits. Dr. Carolyn McEwen also provided statistical guidance in the analysis and discussion of the data. Kai Kaufman and Nikol Grishin assisted with data collection, and Nikol Grishin performed the interrater reliability TGMD–2 scoring.

Ethical approval for this investigation was received from the University of British Columbia Behavioural Research Ethics Board, under the title Gross Motor Skill Proficiency in Children Born Young-for-Date, UBC Ethics Certificate H17-01599.

Table of Contents

List of Tables

List of Figures

Glossary

Conceptual age	Time period of pregnancy from date of conception to birth date, assuming conception occurs 14 days after the first day of the last menstrual cycle
Constraint	A factor that limits motor development or motor performance
Early preterm birth	Birth before 32 weeks gestational age
Extremely low birthweight	Birthweight <1,000 g
Extremely preterm birth	Birth before 28 weeks gestational age
Full-term birth	Live birth at or after 37 completed weeks of gestation
Fundamental movement/motor skills	Gross motor movement patterns using large muscle groups of two or more body parts to achieve an essential movement consisting of stability, object control, and/or locomotion
Gestational age	Completed weeks of pregnancy measured between the first day of the mother's last menstrual cycle and the date of birth
Gross motor competence	Proficiency across a range of various fundamental movement skills

Gross motor skills	The use of large muscle groups to perform coordinated movement
Late preterm birth	Birth at 34 to < 37 weeks gestational age
Low birthweight	Birthweight < 2,500 g
Moderate preterm birth	Birth at 32 to < 34 weeks gestational age
Moderate to late preterm birth	Birth at 32 to < 37 weeks gestational age
Motor development	The physical development of a child which allows them to move within and manipulate their environment using gross motor skills and fine motor skills
Preterm birth	Live birth of an infant before 37 completed weeks of gestation; also known as young-for-date
Threshold of fetal viability	The gestational age at birth at which an infant has a reasonable chance of survival
Very low birthweight	Birthweight <1,500 g
Very preterm birth	Birth at 28 to < 32 weeks gestational age
Window of opportunity	Time period of increased sensitivity to acquire a given skill

List of Abbreviations

APEAS II	Los Angeles Unified School District Adapted Physical Assessment Scale II
BOT-2	Bruininks-Oseretsky Test of Motor Proficiency-2nd Edition
FMS	Fundamental motor skills
KTK	Körperkoordinations Test fur Kinder
M-FUN	Miller Function & Participation Scales
MABC-2	Movement Assessment Battery for Children–Second Edition
MAND	McCarron Assessment of Neuromuscular Development
MMT	Maastrichtse Motoriek Test
MOT 4-6	Motoriktest für vier-bis Sechjärige Kinder
OSU-SIGMA	Ohio State University Scale of Intra-Gross Motor Assessment
PDMS-2	Peabody Developmental Motor Scales–Second Edition
TGMD-2	Test of Gross Motor Development – Second Edition
WHO	World Health Organization

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I would first like to thank my supervisor Dr. Shannon Bredin for her guidance throughout my graduate career, both as her student and as her graduate teaching assistant. She afforded me the opportunity to address a topic I am truly passionate about and challenged me to continually learn within my chosen area of study. My other supervisory committee members also offered their time, assistance, and expertise throughout the process. Thank you to Dr. Darren Warburton for his support and enthusiasm towards my work, as well as to Dr. Carolyn McEwen for her encouragement and unparalleled statistical knowledge.

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Dedication

To every baby born early

CHAPTER 1: Introduction

1.1 Preterm Birth Rate

According to the World Health Organization (WHO), an estimated 15 million preterm births occur per year and this number continues to rise, deeming preterm birth a worldwide crisis (March of Dimes, PMNCH, Save the Children, & WHO, 2012; The Lancet, 2006). North American preterm birth rates have risen in recent decades, and it is now considered one of the most important perinatal challenges that developed countries (such as Canada) face (British Columbia Perinatal Health Program, 2008; Canadian Institute for Health Information (CIHI), 2009). The Canadian preterm birth rate was approximately 6.0% in the 1980s and has risen to 8.1% in the 2000s, with British Columbia's provincial rate at 7.7% (CIHI, 2009). Although the preterm birth rate includes all children born less than 37 weeks gestation or 259 days gestation, late preterm births (34 to 36 weeks completed gestation) account for three-quarters of all Canadian preterm births, while moderate to late preterm births (32 to 36 completed weeks gestation), account for approximately 85% of the prevalence rate (CIHI, 2009; March of Dimes et al., 2012; Public Health Agency of Canada, 2013). In contrast, early preterm births (<32 weeks gestational age) represent the much smaller remaining rate of approximately 15% (Public Health Agency of Canada, 2013). Additionally, low birthweight concurrently occurs with over half of preterm births in Canada, and three quarters of all infants born low birthweight are also preterm (CIHI, 2009).

1.2 Outcomes of Preterm Birth

Preterm birth is of concern due to its association with mortality as well as serious neonatal morbidities, which are common in children born preterm (British Columbia Perinatal Health Program, 2008). Although the rates of such neonatal mortality and morbidity have declined, negative short and long-term outcomes associated with preterm birth remain and are extensive (British Columbia Perinatal Health Program, 2008). Short-term consequences of preterm birth include neonatal gastrointestinal issues, skin-related infections, cardiovascular disorders, anemia, central nervous system injury, brain hemorrhaging, respiratory issues, and visual and hearing impairments (Behrman & Stith Butler, 2007; British Columbia Perinatal Health Program, 2008).

Research has suggested that the long-term negative outcomes of preterm birth are likely to increase as birthweight and/or gestational age decreases (Williams, Lee, & Anderson, 2010). In the extremely early preterm population (<28 weeks gestation), developmental and sensory impairments, behavioural issues, socioemotional difficulties, autism spectrum disorder, cognitive deficits, and psychiatric disorders, are all examples of prevalent issues that are associated with preterm birth in the childhood and adolescence years (Johnson & Marlow, 2017). It is also suggested that children born low birthweight may exhibit lower anthropometric measurements in adolescence than children born at expected birthweights (Behrman & Stith Butler, 2007).

Moderate to late preterm children have been considered previously a low-risk cohort in regards to long-term negative developmental consequences (Kerstjens et al., 2011), receiving either little or no follow-up during the childhood years (Pitcher et al., 2012). In accordance, children both moderate to late preterm have received limited attention in the research (Morse, Zheng, Tang, & Roth, 2009). However, more recently it has been shown that children born in the moderate (32-33 weeks gestational age) and late (34-36 weeks gestational age) preterm categories demonstrate higher rates of neurodevelopmental and motor milestone delay, hyperactivity attention deficit hyperactive disorder (ADHD), difficulty in mathematics, reading, writing, and speaking, fine motor difficulties in childhood, deficits in cognitive functioning, behavioural issues, and special education needs in formal schooling (Behrman & Stith Butler, 2007; Blaggan et al., 2014) compared to children born at term. Rates of neurodevelopmental disability are higher for moderate preterm birth compared to full-term birth, but lower than early preterm gestational ages (Behrman & Stith Butler, 2007); while, a child born moderate to late preterm may not exhibit as marked of a difference as a child born early preterm, the child may present with poorer developmental outcomes in association with gestational age at birth versus full-term birth.

Poor gross motor outcomes are consistently found in preterm cohorts (Moreira, Magalhães, & Alves, 2014; Silva, Sargi, Andrade, Araújo, & Antonio, 2016) even when major neurodevelopmental delay does not present in infancy (Hughes, Redsell, & Glazebrook, 2016). The evidence for gross motor difficulties persists into adulthood in the early preterm cohort (Husby, Skranes, Olsen, Brubakk, & Evensen, 2013), however such data has not been collected with regards to moderate to late preterm populations. Recently, research has shown that children born moderate to late preterm may also exhibit higher rates of gross motor issues than full term

peers (Kerstjens et al., 2011); therefore, examination of the development and retention of gross motor issues is warranted across the entire preterm gestational age range.

1.3 Brain Injury, Motor Development, and Preterm Birth

The developmental implications of preterm birth are important for the motor domain. Early childhood is an optimal time for the development of gross motor skills, the competence of which is required to perform movement activities across the lifespan, including basic daily tasks, physical activity, and participation in sports and recreation (Barnett et al., 2016). In the first six years of life, the brain exhibits an increased sensitivity to environmental stimuli, providing a window of opportunity for the development of gross motor competencies. This time frame is not only critical for gross motor skill acquisition, but also for the detection of gross motor difficulties and establishing subsequent intervention (Ferrari et al., 2012) when appropriate.

Common neurological consequences of preterm birth, including immaturity of the nervous system, neonatal brain injury, white matter injury, and atypical myelination development, are believed to be factors in the prevalence of delays in motor skill development exhibited in the preterm population (Back, 2017; Ferrari et al., 2012; Husby et al., 2013; Jongbloed-Pereboom, Janssen, Steenbergen, & Nijhuis-van der Sanden, 2012; Van Hus, Potharst, Jeukens-Visser, Kok, & Van Wassenaer-Leemhuis, 2014; Williams et al., 2010). For example, injury to the developing brain, a common occurrence in children born preterm, is the cause of cerebral palsy and other neurodevelopmental disabilities that are prominent (Back, 2017; Behrman & Stith Butler, 2007; Johnson & Marlow, 2017). However, less severe (or more subtle) impairments of central nervous system functioning can present; yet have significant impact on the child's life (e.g., in relation to academics, social relationships, and self-esteem; Behrman & Stith Butler, 2007). Difficulties which may stem from minor central nervous system deficits include learning disabilities, ADHD, language disorders, behavioural difficulties, social-emotional problems, as well as minor neuromotor dysfunction, developmental coordination disorder, fine motor issues, and gross motor difficulties (Behrman & Stith Butler, 2007).

Children born at the youngest of gestational ages and at the lightest of birthweights have the greatest risk of serious motor disorders such as cerebral palsy, the rates of which appear to decrease as gestational age or birthweight category increases (Behrman & Stith Butler, 2007). It has yet to be shown however, whether the prevalence of minor gross motor difficulties follows

this same trend. Although poor performance of gross motor tasks, as well as motor impairment, have consistently been found in children born at very and extremely low birthweight (Wocadlo & Rieger, 2008), it is unclear whether this association occurs across all preterm gestational age categories. As such, more information is needed regarding the long-term gross motor complications of moderate to late preterm birth during the childhood years. This information in turn affects decisions on the appropriate gestational age for obstetric delivery practices, as well as follow-up and intervention practice in pediatrics (British Columbia Perinatal Health Program, 2008).

1.4 The Issue

Preterm birth is an important consideration for those planning healthcare initiatives. Prematurity results in higher healthcare costs related to increased medical and health-related issues, and requires greater use of resources and support (British Columbia Perinatal Health Program, 2008; CIHI, 2009). Unfortunately, prevention efforts for the reduction of preterm births have been largely unsuccessful (British Columbia Perinatal Health Program, 2008), increasing the urgency to better understand the implications of premature birth on childhood health and wellbeing. To date, it is largely unknown whether moderate to late preterm children exhibit similar developmental risks as early preterm children (Kerstjens et al., 2011). In consideration of the large proportion of late preterm births contributing to preterm birth statistics (British Columbia Perinatal Health Program, 2008), greater attention to this population is required. Due to the important role gross motor development plays in early childhood, as well as the gross motor difficulties that have been exhibited by the early preterm population, examination of gross motor skill development of children across preterm gestational ages is warranted.

1.5 Purpose and Overview of Research Investigation

The purpose of the thesis investigation was to examine gestational age and the relationship between gross motor development (locomotor and object control), static balance, and muscular strength of 4-6 year old children born preterm. A total of 18 children were recruited with a mean age of 5.2 ± 0.7 years and a mean gestational age of 31.6 ± 3.3 weeks. Gross motor development was measured by the 12-item Test of Gross Motor Development–Second Edition (TGMD-2; Ulrich, 2000). Balance capability was measured using a timed single-

leg static balance assessment. Muscular strength of the upper body was determined using grip strength, while lower body muscular strength was assessed using standing long jump distance. It was hypothesized that:

(1) poorer gross motor skill proficiency (as determined by the TGMD-2 gross motor quotient) would be associated with earlier gestational age at birth; yet children born preterm across the gestational age range would exhibit low gross motor quotient scores as compared to TGMD-2 normative data; and
(2) shorter static balance times, shorter standing long jump distances, and weaker grip strength values would be associated with earlier gestational age at birth.

1.6 Overview of the Document

This document is organized into seven chapters. Following the introduction, Chapter 2 presents the theoretical principles underlying gross motor skill development in early childhood and Chapter 3 presents a narrative review of the literature regarding preterm birth and gross motor development. Chapter 4 provides background rationale regarding decisions made throughout the research process, including participant recruitment, choice of assessment tools, and the inclusion of strength and balance measures. The research methodology, results, and discussion of the thesis investigation are presented in Chapter 5, with a separate presentation and discussion on the sets of twins, who participated in the study (Chapter 6). Finally, Chapter 7 offers a concluding summary, identifies limitations in the research, describes knowledge translation strategies, and offers recommendations for future research investigations.

CHAPTER 2: Foundational Concepts of Motor Development

2.1 Introduction

This chapter presents long-standing theoretical perspectives in motor development, particularly as it relates to gross motor development. Presenting a theoretical framework provides a greater context as to the rationale for studying gross motor development. Specifically, the purpose of this chapter is to explain the concept of motor competence and fundamental motor skills, how fundamental motor skills are represented in commonly used models of motor development, and the importance of age in gross motor skill acquisition. Children born preterm are considered a special population because of their early age at birth and may develop according to a different motor development trajectory or motor milestone timeline than their peers born full-term. Therefore, the need to examine gross motor development in the preterm population is important. Introducing key motor development concepts and theoretical foundations provides a framework for the research presented in this thesis.

2.2 Motor Competence

Motor competence plays an important role in growth and development across the lifespan (Barnett et al., 2016). Motor development in the early years forms the basis of skills used for all areas of life including self-care, leisure activities, play, and learning (Goyen & Lui, 2002). An important progression in the development of the motor system is the acquisition of gross motor competence, which refers to proficiency across a number of fundamental movement skills (Barnett et al., 2016). Research has demonstrated a relationship between competence in the gross motor domain with many beneficial health outcomes (Barnett et al., 2016). For example, higher physical competence is associated with better cardio-respiratory fitness and higher levels of physical activity, and demonstrates a negative association with weight status (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). In contrast, poor motor competence can influence one's life at school and at home, affecting one's self-concept, social inclusion, and motivation for activity (Barnett et al., 2016; Lin & Yang, 2015; Ulrich, 2000; Yoon, Scott, Hill, Levitt, & Lambert, 2006). Particularly, opportunities for developing physical fitness decrease when a child's motor competence is poor, as their capability for activity participation is limited (Rivilis et al., 2011) due to motor-based constraints. Decreased flexibility and lower body explosive strength are

examples of deficits that have been found in children with gross motor coordination difficulties (de Chaves et al., 2016). There is also a consensus that the social and emotional wellbeing of a child can be negatively impacted through deficits in motor coordination, which is a contributor to motor competence (Piek, Bradbury, Elsley, & Tate, 2016). These findings demonstrate the need to provide developmentally appropriate environments and opportunities for children to learn to be proficient movers through instruction and practice in early childhood.

2.3 Fundamental Motor Skills

A key component of movement proficiency in childhood is the acquisition of fundamental motor skills (FMS). Fundamental motor skills are the use of the large muscle groups of two or more body parts to achieve an essential movement consisting of stability, object control, and/or locomotion (Barnett et al., 2016). Fundamental motor skills can be considered the movement vocabulary of the human body and are comparable to the ABC's of the English language (Stodden et al., 2012). Just as you must know the complete alphabet to be literate, you must be able to perform basic movements to be physically literate and to perform more complex activities throughout the lifespan. Fundamental movement skills act as building blocks of human motion and gross motor proficiency, from which more skilled movements are built upon. Proficiency in a range of fundamental movement skills allows for active participation across the lifespan. This includes participation in the standard activities of daily living, in addition to physical activity, sports, games, and play (Pang & Fong, 2009). To be a proficient mover, it is critical that fundamental movement skills are taught through instruction, practice, and feedback (Lubans et al., 2010). Children must be instructed on how to perform fundamental movement skills specifically, as they are not naturally developed as is often assumed (Pang & Fong, 2009).

In the field, fundamental movement skill development has been situated within the larger processes of human motor development. As a result, a number of models or frameworks in motor development have been presented, which aid in conceptualizing the process of motor development through childhood and how it is carried on through the lifespan. Within these models, fundamental movement skill acquisition plays a critical role with regards to healthy developmental trajectories. Moreover, the assessment of fundamental movement skills is important, as the acquisition of fundamental motor skills are considered a pivotal point in motor development, determining the direction of the developmental path thereafter.

2.4 Gallahue's (2012) Model of Motor Development

The theoretical model of motor development by Gallahue et al. (2012) explains motor development in four phases, with a set of developmental stages associated with each phase (see Figure 1). Although the literature often uses the terms phase and stage interchangeably, these terms do in fact refer to different aspects of development. For the purpose of this discussion, a phase encompasses a set of similar continual characteristics that change over time in the developmental process. Phases are cumulative and can be overlapping. Stages, however, are the developmental segments within a given phase, which identify distinct steps in behaviour that begin and end as one progresses through a phase. As both phases and stages are behaviours that follow a predictable sequence over time, these processes are generally associated with age-related periods, however they are neither strictly dependent on age nor time.

The first phase of the model is the reflexive movement phase, in which involuntary, sub-cortically controlled reflexive movements assist infants in learning about their own bodies and environment. For the first four months, information is gathered in the information encoding stage, after which reflexes start to become inhibited, and the processing of information begins in the information decoding stage. As the higher brain centres of the central nervous system continues to mature and movements become voluntary, individuals progress to the rudimentary movement phase.

The rudimentary phase represents the first basic forms of voluntary movement, which are characterized by a highly predictable sequence of motor milestones in the first two years of life (e.g., the acquisition of sitting). In the first stage, the reflex inhibition stage, development of the cortex allows for many reflexes to be inhibited, while voluntary movement increases. However, at this stage, movements are unrefined, and lack control or accuracy. At the end of the first year of life, individuals gain more control as the individual progresses to the precontrol stage. At this stage, increased processing occurs and perceptual and motor information are becoming integrated in a more meaningful manner. Rapid gains in movement capability also emerges as individuals begin to maintain equilibrium, manipulate objects, and start to locomote through the environment.

An outgrowth of the rudimentary phase is the fundamental movement phase. During this phase, children learn to actively respond to and explore their environment and bodies with greater proficiency in motor control and movement competence. Lifelong fundamental motor

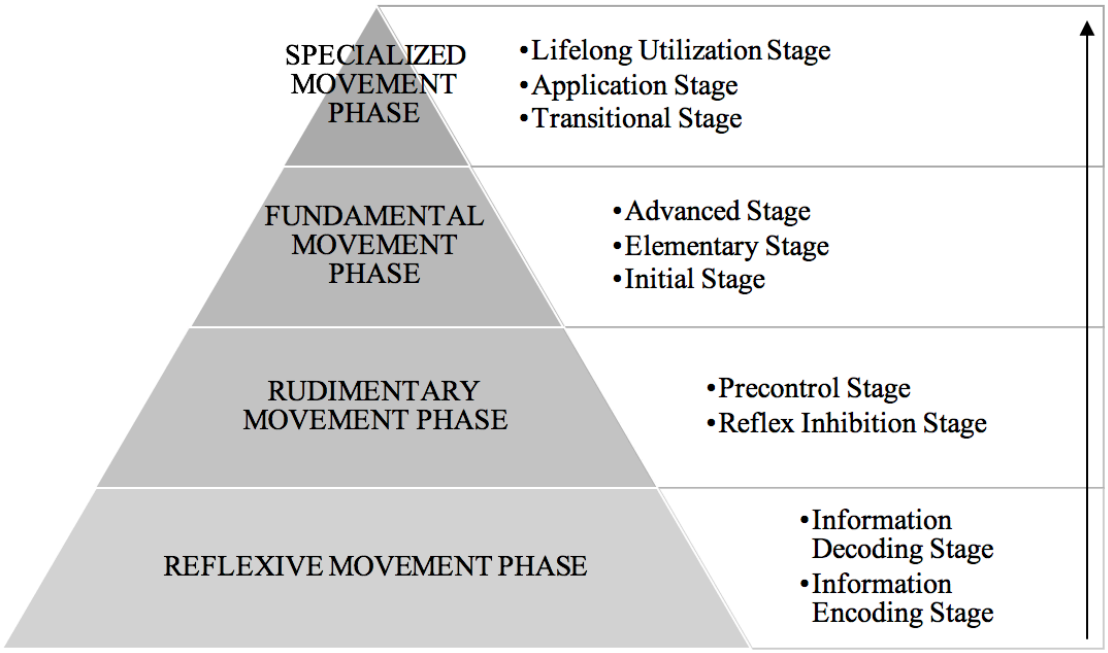


Figure 1. The phases and stages of motor development (adapted from Gallahue et al. (2012))

patterns are established in this phase, which are basic patterns of behaviour. These patterns can be classified into three main categories and include: nonlocomotor or stabilizing movements (e.g., one-foot balance), locomotor (e.g., running), or manipulative (e.g., throwing) movements, with many movements using a combination of these. More specifically, stability movements refer to movements for maintaining equilibrium of one's body relative to gravity, and although they can exist on their own, they tend to also be involved in many locomotor and gross motor manipulative tasks. Locomotor movements are movements used to change the body's location, by transporting oneself from one fixed point to another using a locomotor task. Gross motor manipulative movements are those in which one applies force to an object, or alternatively receives force from an incoming object to perform a task.

Acquisition of a fundamental motor skill progresses through three stages: the initial stage, the elementary stage, and the advanced stage. The initial stage includes the first attempts a child makes at performing a motor skill, and tends to be inaccurate and uncoordinated. The elementary stage involves better control of the movement pattern; however restrictions or exaggerations of the movement are often seen. Finally, the child progresses to the advanced stage, the skill can be

performed purposeful, planned, and also with precision. Reaching an advanced stage represents proficiency in the task. What constitutes proficiency may vary by factors such as sociocultural environment, gender, and age (Wall, McClements, Bouffard, Findlay, & Taylor, 1985).

The final phase after the fundamental movement phase is the specialized movement phase, whereby movements are used to perform more complex activities of recreation and daily living. Movements are combined, refined, and expanded upon to be used in various movement situations. In this phase, a transitional stage of combining movement skills and applying them to accomplish tasks is followed by the application stage (where skills are more highly refined to the individual's activities of choice), and finally the lifelong utilization stage, which is where the acquired movement skills one has developed are utilized across the life span. In summary, the fundamental motor phase of Gallahue's (2012) model is critical for the acquisition of basic physical movement capabilities, in addition to providing a set of skills that are mandatory for performing more complex tasks later on.

2.5 Mountain of Motor Development Metaphor

The process of motor development can also be described using the mountain of motor development metaphor by Clarke and Metcalfe (2000), which is visually displayed in Figure 2. According to this concept, each individual's movement experiences can be compared to a mountain range with different peaks, each of which represents a skilled movement. The mountain is built using six developmental periods: the reflexive, preadapted, fundamental movement patterns, context-specific, skillful, and compensation period. Individual, task, and environmental constraints (see 2.6 Newell's Model of Constraints) all influence an individual's nonlinear path up the mountain. In the reflexive period, infants are first introduced to the mountain or movement through spontaneous and reflexive movements, before journeying to the preadapted period. In the preadapted period, a child begins using voluntary movement patterns, progressing further up the mountain until they can independently function enough to feed themselves and move through their environment by walking.

Then, the fundamental patterns period is entered, whereby fundamental movement skills act as the ground layer upon which further movement skills are built upon (Barnett et al., 2016; Stodden et al., 2012). Having a stable foundation of fundamental movement skills serves as a base camp on this mountain range, a starting point from which an individual metaphorically

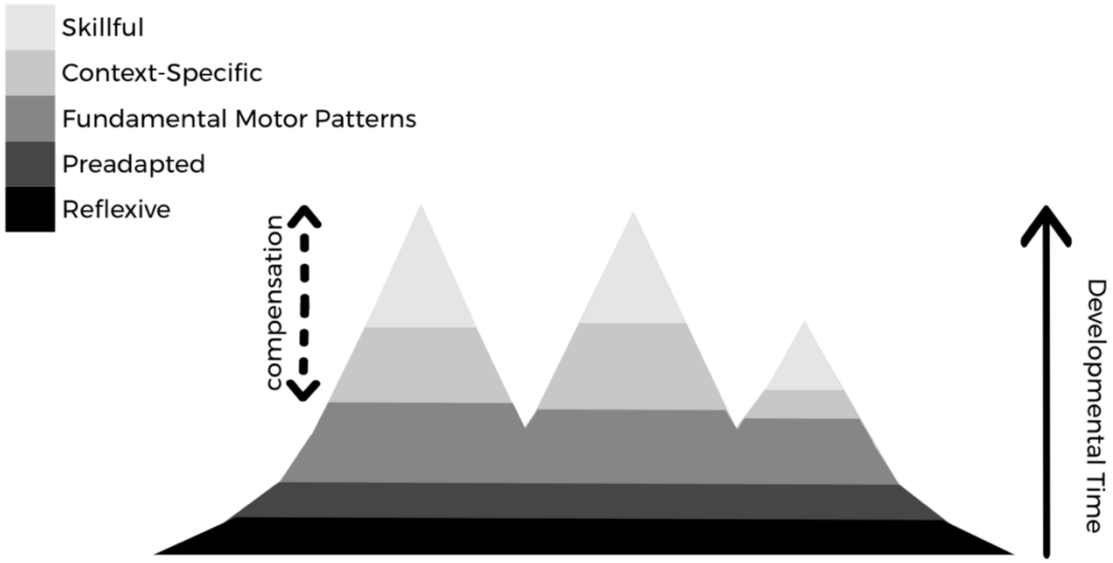


Figure 2. A representation of the mountain of motor development metaphor (adapted from Clarke and Metcalfe (2000))

continues on the journey, climbing various mountains (novel skills), with each peak representing attainment of a given skill. The context-specific period is entered when the fundamental movements are used to purposefully perform a task, or begin to climb up a new mountain from the base camp. With adequate context-specific practice, one's movement finally becomes efficient and adaptive, entering the skillful period, which is the metaphorical peak of an individual's own mountain of progression. Along this journey, the compensation period is entered if one's movement requires adaptation due to injury or aging, which requires navigating his or her path on the mountain with new constraints.

The concept of the mountain metaphor is useful when investigating the motor development of particular populations and age groups, such as children 4-6 years old who were born preterm. The examination of children born preterm requires particular consideration for how the mountain has been built thus far and assesses how solid the fundamental motor pattern period is as a base level. Understanding if a child at age 4-6 years has the foundational skill level therefore helps indicate whether or not the child is ready to progress towards climbing up the

mountain on skill-specific peaks. Alternatively, if children at this age range do not have a solid foundation of gross motor skills, it indicates that they will require more time at the level of fundamental motor patterns before they are capable of climbing the peaks. By not obtaining a solid mountain base, a child's potential to embark on climbing various peaks of the mountain range throughout their lifespan is therefore reduced.

2.6 Newell's Model of Constraints

Newell's (1986) Model of Constraints discusses the emergence of a movement as a dynamic interaction between three factors: the individual, the task, and the environment. Newell referred to these factors as constraints. Therefore, constraints are the limiters that determine the emergence of motor behaviours, and are an important consideration due to their impact on gross motor development.

Individual constraints describe limiters unique to the individual themselves and are classified as either functional or structural. A functional constraint is related to one's behaviour. For example, a functional constraint when learning to walk may be a fear for falling. In contrast, a structural constraint is related to the physical structure of the body. For example, low muscle strength may be a structural constraint for jumping capability, as the individual's body structure is the limiting factor to completing the task. Task constraints refer to the aspects of a movement task such as the goals, equipment, and rules. Task constraints may be manipulated to lower their restraining nature on emergence of a movement. For example, a young child is likely more successful at hitting a baseball if the rules and equipment are altered so that the child hits the ball off of a stationary tee rather than attempting to hitting a moving ball from a pitcher when learning to strike. Finally, environmental constraints refer to the social and physical surroundings that can have an impact on a movement outcome. Examples of environmental constraints therefore may be weather conditions or socio-cultural expectations.

All three constraints contribute and interact to shape a resulting movement behaviour (see Figure 3). The constraints can be manipulated to subsequently alter the movement pattern, either making it more difficult or easier to perform. Addressing such constraints is therefore important in intervention and therapy settings with regards to sub-optimal movement. The identification of constraints is assessed in this study through outcomes such as balance and strength, which may

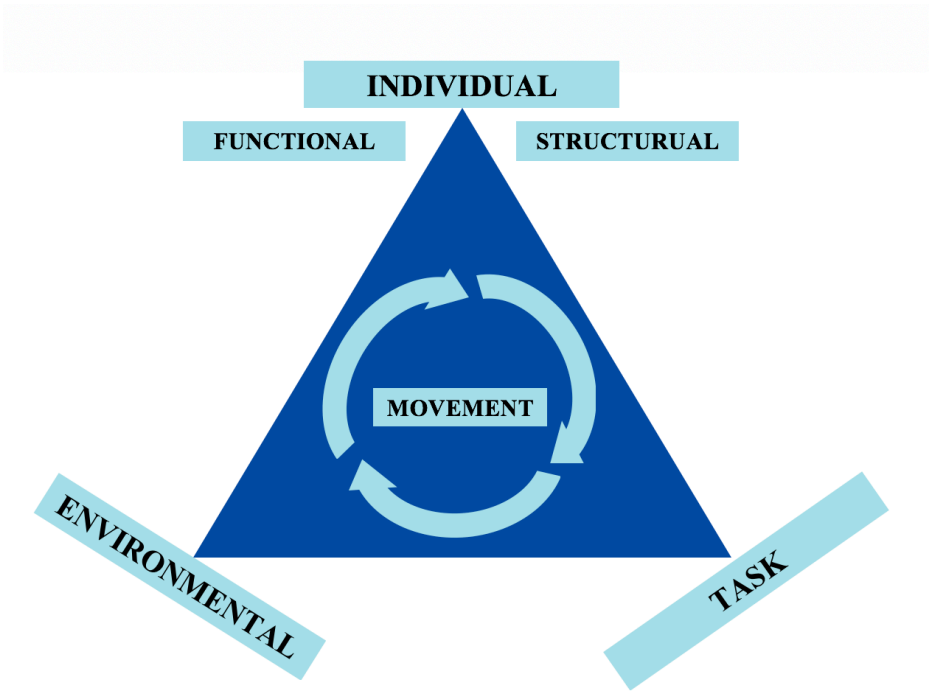


Figure 3. Visual Representation of Newell's (1986) Model of Constraints

in fact indicate other underlying constraints such as neurological maturity and neurodevelopment, which are of particular importance in the preterm population.

2.7 Age and movement skill acquisition

The childhood years are an important time for the development of gross motor skills. According to Piek and colleagues (2012) children need to lay the foundation by acquiring fundamental movement skills in the first 8 years. Ulrich (2000) supports this notion and suggests that children's gross motor capabilities develop and change the most between birth and the age of eight (Ulrich, 2000). This time frame reflects the concept of a window of opportunity in development, which is a critical period where receptivity of a certain experience (such as gross motor or language development) is greatest due to high brain plasticity, after which the development of certain functions may not be acquired to their fullest potential (Gabbard, 1998). Although eight years is commonly used as the upper limit of the window of opportunity to learn gross motor skills, children can and should be proficient in most fundamental movement skills well before this age. Children possess the capability to establish fundamental movement skills

between the ages of four and six years, and can demonstrate mature fundamental movement skill patterns by five to six years of age (Gallahue et al., 2012; Vandaele, Cools, de Decker, & de Martelaer, 2011). Furthermore, children between the ages of three and eight also show less fear of being injured or failing, and therefore are shown to be able to maintain higher levels of motivation to learn and practice new skills compared to the later years of childhood (Lin & Yang, 2015).

Unfortunately, research suggests that mastery of fundamental movement skills among children in various countries is strikingly sub-standard (Barnett et al., 2016). Across a range of skills, both children and adolescents display low motor competence (Barnett et al., 2016), and it is not uncommon for individuals to never progress beyond the elementary stage of at least one fundamental movement skill (Gallahue et al., 2012). For example, movements such as hopping and throwing are often exhibited with low mastery (Cliff et al., 2012; Mukherjee, Ting Jamie, & Fong, 2017).

It is therefore important to consider the age of assessment for fundamental movement skill acquisition in higher-risk populations (e.g., children born preterm). For example, if a child was examined and found to possess low gross motor competence at 8 years of age after difficulties were first noticed in school, the window of opportunity for acquiring these skills is already closing, making effective intervention more difficult. However, if a child is examined between the ages of 4 and 6 years, there is still a window to attain mastery across various fundamental movement skills.

2.8 The Preterm Population and Motor Milestone Acquisition

A child's early motor development is observed and monitored over time according to established motor milestones, which provide a framework as to which movement tasks are expected to be accomplished and when (Gerber, Wilks, & Erdie-Lalena, 2010). Early motor milestone attainment generally refers to the major motor tasks acquired in the first two years of life, which are part of the rudimentary movement phase. These include such milestones as learning to roll, sit, and stand. The predictable, sequential manner and mild variability of gross motor milestone attainment offers a way for physicians and allied health professionals to detect potential motor impairments if a child deviates significantly off the expected timeline (Allen & Alexander, 1990). However, commonly available milestone charts are based on typically-

developing children born full-term (37-42 weeks gestation), and do not adequately represent the developmental trajectories of children born preterm (<37 weeks gestation). Research has shown that children born preterm may acquire early motor milestones at later chronological ages (i.e., the age in months or years from date of birth) compared to their peers born full term. The early delays exhibited in motor milestone acquisition in the preterm population are often attributed to immaturity of the central nervous system, the maturity of which determines motor development (Wilson & Cradock, 2004). With preterm birth, the central nervous system has less time to mature in-utero, and therefore children born preterm require additional time for their system to catch up to that of their full-term peers (Wilson & Cradock, 2004).

Infants born premature develop milestones sequentially just as term infants do (e.g., sitting unassisted is acquired before walking unassisted). However, using adjusted age as it relates to motor milestone attainment is recommended as a more appropriate measure of developmental status compared to chronological age (Allen & Alexander, 1990). Adjusted age of a child born preterm takes into consideration the age that the child would be if carried to his/her full-term due date (40 weeks gestational age). While adjusted age is the preferred term, other terms that have been used synonymously are gestation-adjusted age, post conceptual age, and term-equivalent age (D'Agostino, 2010).

Adjusted age is calculated by subtracting how many weeks preterm (of 40 weeks gestational age) the child was born, from the child's chronological age in weeks (American Academy of Pediatrics, 2004). For example, a child born at 34 weeks gestational age was born 6 weeks early (40 minus 34), and the child's adjusted age would be 6 weeks younger than his or her chronological age. If the chronological age of the child in this example is 12 weeks, the adjusted age would therefore be 6 weeks (12 minus 6). Age can also be adjusted in months, by simply dividing the number of weeks preterm the child was born by 4 weeks/month, and subtracting this number from the child's chronological age in months. For example, if the child from the above example was born 1.5 months preterm (6 weeks divided by 4 weeks/month), age is adjusted by 1.5 months. Therefore, at the chronological age of 12 months, this child would have an adjusted age of 10.5 months (12 minus 1.5). As the calculations of adjusted age are based upon how early a child was born, adjusted age is a method used only for children born preterm (American Academy of Pediatrics, 2004).

Today, the age of an infant born premature is adjusted across almost all outcomes in follow-up monitoring, as it is accepted that adjusted age offers a more accurate reflection of the developmental expectations for a child born young-for-date at a given point in time (D'Agostino, 2010). This is particularly salient for motor milestones. Adjusted age offers more accurate reflections of motor milestone attainment of children born preterm in early life (D'Agostino, 2010). Adjusting for age is an important consideration when monitoring a preterm population, as it has the potential to impact interpretations of physical growth and motor milestone achievement, which can influence level of care, and future accessibility to services (D'Agostino, 2010).

Evidence of adjusting age for prematurity has been documented in practice as early as the 1930's (D'Agostino, 2010), and remains the recommended practice of today. However, the field still lacks a single concrete evidence-based recommendation to follow when adjusting for age in children born preterm (Wilson & Cradock, 2004), and there are still debates as to the optimal level of correction (den Ouden, Rijken, Brand, Verloove-Vanhorick, & Ruys, 1991; Lems, Hopkins, & Samsom, 1993). There is also debate as to how long age should be adjusted for, as opinions on when use of adjusted age should be ceased are also somewhat heterogeneous (Wilson & Cradock, 2004). Varied opinions include such notions as: infants born earlier and lighter should be corrected for longer than infants born heavier and later (Lems et al., 1993), and recommendations on the maximum length of full adjustment have included 1 y, 1.5 y, 2 y, and as late as 3 y (American Academy of Pediatrics, 2004; D'Agostino, 2010; den Ouden et al., 1991; Lems et al., 1993). Using full adjustment of age for motor skill assessment continues to be of preference for a minimum of 1 year (D'Agostino, 2010; den Ouden et al., 1991; Wilson & Cradock, 2004). By 2 years, it is suggested that children born preterm may 'catch up' to their full-term peers to a point that adjusted age may no longer be warranted (den Ouden et al., 1991). Further, as there is wide variability in the motor development of typically-developing full-term 2 year olds (den Ouden et al., 1991), the use of adjusted age at 2 years may no longer be an appropriate tool to use for tracking adequate growth and development of children born premature.

Although the use of adjusted age during the rudimentary phase is warranted to allow the system to catch up, using adjusted age into the fundamental movement phase for children born preterm may not be appropriate. There have been studies that have used adjusted age in children

born preterm at 5 years of age (Van Hus et al., 2014), however use of adjusted age is not recommended for research at age 4-6 years. In practice, adjusted age is not used past 3 years (Engle & American Academy of Pediatrics Committee on Fetus and Newborn, 2004), after which time use of adjusted age may hide a true delay in motor skill development.

2.9 Chapter Summary

This chapter provided a framework upon which the investigation of this thesis was built upon. The impact of acquiring gross motor competence in childhood is carried with an individual throughout their lifespan. Particularly, the development of fundamental motor skills (FMS) is of interest, as capability in FMS tasks act as a platform for the basic movement requirements of life and are required to progress to more complex movements. By providing models of motor development, the role of fundamental movement skills is examined within a broader context. The age of acquisition of gross motor skills follows a predictable sequence and is therefore used to help track developmental status. However, children born preterm may not follow gross motor developmental sequencing at the same rate as children born at term. Considerations such as adjusted age should therefore be taken into account when assessing motor skill development in the first years of life of children born preterm; however, by the age of fundamental motor skill acquisition, the use of such practices may no longer be appropriate. Moreover, the identification of constraints is critical for the understanding of motor difficulties' origins, as well as to direct programming to appropriately address the specific issues underlying such difficulties.

CHAPTER 3: Narrative Review of Preterm Birth and Gross Motor Competence

3.1 Introduction

Although global rates of serious neonatal morbidity, stillbirth, and perinatal mortality have decreased dramatically in recent decades, rates of preterm birth are increasing worldwide which is a major health concern even in high income countries, including Canada (see Figure 4 for examples of global rates of preterm birth; Blencowe et al., 2013; British Columbia Perinatal Health Program, 2008). In large part, this is due to the increased trends of older maternal age, higher maternal weight status prior to pregnancy, and the use of technology-assisted reproduction in high income countries (British Columbia Perinatal Health Program, 2008).

In Canada, approximately 8.0% of infants are born preterm, wherein a 'preterm' birth refers to the live birth of an infant before 259 days or 37 completed weeks of gestation (Public Health Agency of Canada [PHAC], 2013). Additional categories are used to further classify preterm birth according to gestational age. Early preterm birth refers to infants born at less than 32 weeks gestational age, and can be split into very preterm and extremely early preterm (Blencowe et al., 2013; PHAC, 2013). A moderate to late preterm birth refers to children who are born between 32 but less than 37 weeks gestational age, which includes both moderate and late preterm (Blencowe et al., 2013). Figure 5 provides a visual representation of preterm birth classifications in accordance with gestational age. Moderate to late preterm births account for the greatest proportion of preterm births, representing 6.4-7.0% of all live births in Canada, as compared to early preterm births which account for only 1.1-1.2% of Canadian live births (CIHI, 2009; PHAC, 2013).

Research has shown consistently a number of developmental concerns associated with premature birth, which can be burdensome and have an impact across the lifespan (Blencowe et al., 2013). Children born preterm may demonstrate a variety of deficits across multiple domains (such as sensory, behavioural, cognitive, and/or motor-based difficulties) in relation to development, including motor development (March of Dimes et al., 2012; Van Hus et al., 2014). In particular, the gross motor competence of children born preterm is of interest in early childhood, as gross motor skill acquisition in the early childhood years is required for lifelong movement opportunities and can affect outcomes related to health and wellbeing

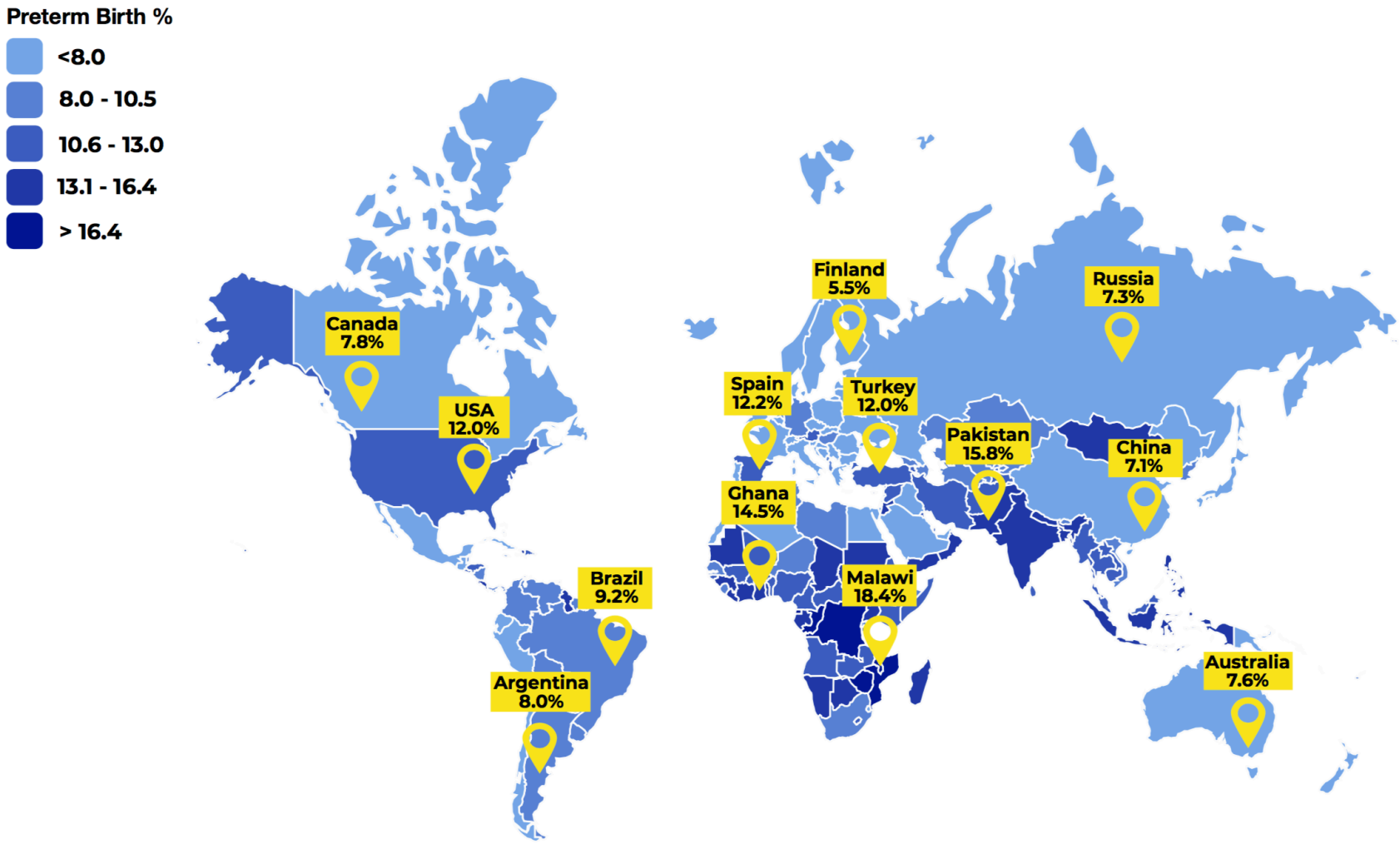


Figure 4. Global preterm birth rate estimates, 2010. Adapted with permission from Born Too Soon: The Global Action Report on Preterm Birth (March of Dimes et al., 2012)

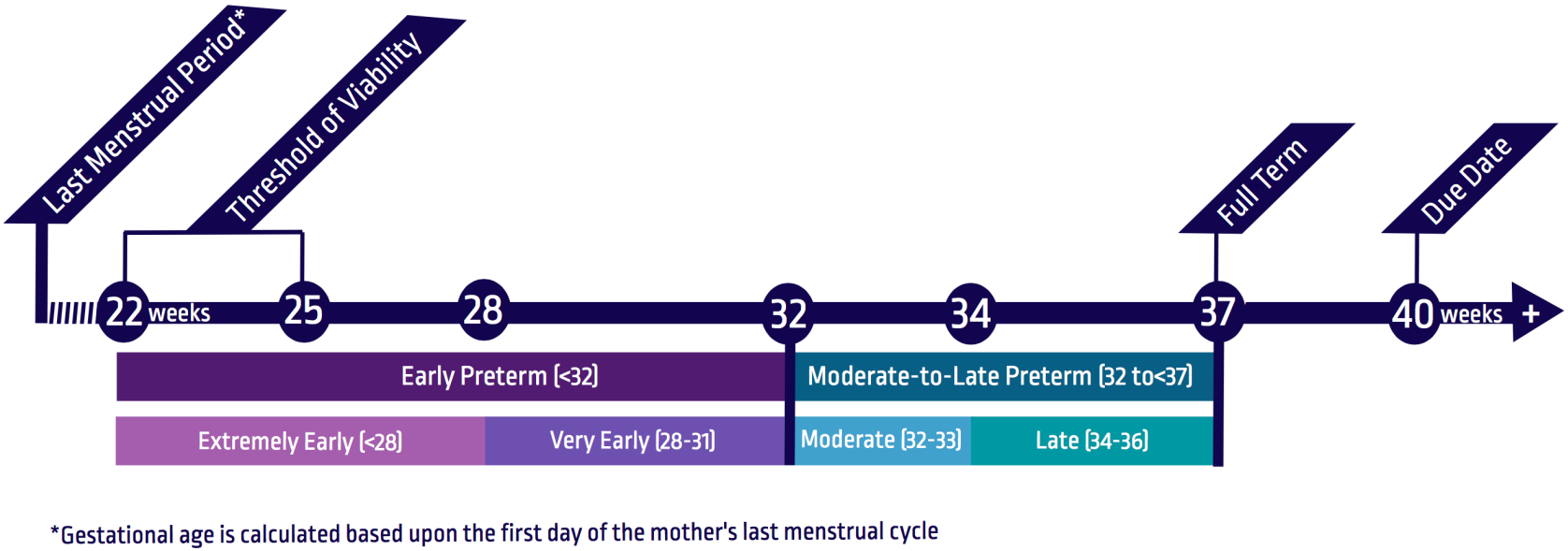


Figure 5. Preterm categorization based upon completed weeks gestational age at birth

*Gestational age is calculated based upon the first day of the mother's last menstrual cycle

(Pang & Fong, 2009). The purpose of this chapter is to provide a narrative review of the research to date examining the gross motor development of children born preterm.

3.2 Neurological Considerations: Motor Development and Preterm Birth

Gross motor skill development largely depends on the development of the nervous system and such processes as myelination (the insulation of axons with myelin to promote rapid transition of nerve impulse conduction; Tierney & Nelson, 2009). Myelinated axon bundles largely make up the white matter of the brain, allowing for optimal functioning of the cognitive, sensory, and motor systems (Fields, 2010). Areas of the central and peripheral nervous system responsible for the control of motor function begin the process of myelination prenatally, which continues after birth until approximately preschool age (Tierney & Nelson, 2009; van de Bor et al., 1990). In the prenatal period specifically, myelination and significant white matter development occurs between 24 and 32 weeks gestation, and there is also a sudden increase in white matter volume between 36 and 41 weeks gestation (Dubois et al., 2014). Therefore, the prenatal period represents an important time for motor-related brain development, however this time is shortened when a child is born preterm. Although not completely understood, the connection between preterm birth and motor skill delay is postulated to originate from alterations to the neonatal brain structure (specifically, damage to the white matter), a less mature central nervous system, and disruption (due to susceptibility to white matter injury) to the typical myelination process at the time of birth, resulting in myelination deficits (Back, 2017; Ferrari et al., 2012; Husby et al., 2013; Jongbloed-Pereboom et al., 2012; Van Hus et al., 2014; Williams et al., 2010). Further, brain injury is a common occurrence in infants born preterm, with an increasing prevalence at younger gestational ages (Jongbloed-Pereboom et al., 2012). General alterations to the white matter of children born preterm include reduced cortical folding and white matter volumes (Ferrari et al., 2012).

In addition to minor motor difficulties, children born preterm (with no major disability) may also exhibit behavioural and learning difficulties when attending mainstream schools (Bracewell & Marlow, 2002; Foulder-Hughes & Cooke, 2003b), which lends support to the hypothesis that such issues have neurological origins. Moreover, detection is usually delayed until a child enters school when formal academic and physical education begins (Goyen & Lui, 2002). For example, van Hus et al. (2014) showed an association between non-cerebral palsy

motor impairment in children born very preterm at age 5 with complex minor neurological dysfunction, cognitive impairment, slow processing speed, and poor visuomotor coordination. These findings demonstrate the broad context of the school setting in which motor difficulties may co-exist with other impairments, making the source of the constraint challenging to isolate.

3.3 Gross Motor Proficiency and Preterm Birth

To date, research consistently indicates that during early development, the preterm population demonstrates motor impairment or atypical motor patterns (Bracewell & Marlow, 2002; de Kieviet, Piek, Cornelieke, & Oosterlaan, 2009), with a particular focus on children born early preterm as compared to full term peers in infancy and toddlerhood. For example, children under 18 months born preterm were found to exhibit lower gross motor proficiency scores and difficulty with anti-gravity movements when compared to full term peers (van Haastert, de Vries, Helders, & Jongmans, 2006). Toddlers born moderate to late preterm have scored below full-term children in gross motor skills, demonstrating higher gross motor developmental delays (de Jong, Verhoeven, & van Baar, 2012). Delayed gross motor milestones in the preterm population can include motor skills like walking, which has been found to be delayed in 18 month old children born preterm with very low birthweight (Jeng, Yau, Liao, Chen, & Chen, 2000).

In the early years of development, children born early preterm show both quantitative and qualitative differences in early gross motor development. For example, Hemgren and Persson (2004) showed that early preterm children at 3 years exhibited greater hyperextension of the head, knees, and trunk (and a lack of rotation of the trunk) during locomotion, walking on tiptoes, and retention of outward rotation and plantar flexion of the feet from infancy when compared to both moderate preterm and full term children. Such qualitative indicators may be useful for healthcare professionals to target in early intervention strategies if they are affecting movement quality.

Research has also shown that difficulties in motor functioning do not dissipate with age, as evidence of poor motor proficiency throughout childhood has been reported. For example, a cohort of children born extremely preterm and less than 1,000 g were assessed at 1.5 years and then again at age 3 and 5 years. Results showed a decrease in gross motor skill proficiency at 3 years compared to 16 months, which declined even further by age 5, when 81.1% of the cohort scored below the accepted range of typical values (Goyen & Lui, 2002). Similarly, Prins and

colleagues (2010) examined children born moderate preterm at 3 mo, 9 mo, and at 4 years of age. While results showed no correlation between motor development at 3 mo, 9 mo and 4 years, one fifth of the children demonstrated atypical motor outcomes at 4 years of age (Prins et al., 2010).

These findings suggest that gross motor proficiency should be monitored throughout early childhood for all children born preterm, irrespective of gestational age. While some children may exhibit poor motor skills throughout early childhood, minor motor problems may not be detected in other children until the age of school entry at approximately age 5 (Goyen & Lui, 2002). Reports of motor difficulties in 5 year old children born very preterm have been cited to range from 30-40% (Van Hus et al., 2014). In a Dutch study of 5 year old children formerly admitted to a neonatal intensive care unit born early preterm or less than 1,500 g (but without severe handicaps), below age-expected scores were present on at least one of three motor assessments (De Kleine, Nijhuis-Van Der Sanden, & den Ouden, 2006). Jongmans and colleagues (1998) have also shown that children born less than 35 weeks gestational age (and admitted to neonatal intensive care in infancy) demonstrated lower overall scores on motor assessments at 6 years of age, with 44% of the children scoring within a motor impairment range (Jongmans, Mercuri, Dubowitz, & Henderson, 1998). This research provides support for examining motor proficiency at the age of school entry in children born preterm.

Research suggests that low movement skill proficiency in children born preterm continues to persist into later school grades across gestational ages (e.g., early preterm, see Folder-Hughes & Cooke, 2003a; moderate to late preterm, see Odd, Lingam, Emond, & Whitelaw, 2013) and even adolescence into adulthood (Husby, Skranes,Olsen, Brubakk, & Evensen, 2013). For example, in a UK study of 7 to 8 year old children born early preterm in mainstream schooling, 30.7% of children born preterm scored below the 5th percentile on a movement battery as compared to 6.7% of children born at term who scored within the same range (Foulder-Hughes & Cooke, 2003a). Similarly, in a different group of infants born less than 30 weeks gestational age (who had spent time in an intensive care unit), 31.3% of the children showed motor impairment when assessed at 8 years of age. Of the children who were identified as having a motor impairment, 51.5% were further classified as having a severe motor impairment (Wocadlo & Rieger, 2008). Qualitative analysis of 8 year old children born before 35 weeks gestation has shown more compensatory movements through their arms and trunks when compared to full term participants on a balance task (Forslund, 1992). Further, Husby and

colleagues (2013) has shown poor gross motor skills into adolescence and adulthood for individuals born preterm and very low birthweight as compared to matched controls at age 14 and 23 years. This finding demonstrates the potential for lifelong impact on one's movement behavior.

While there is some evidence for developmental delays across gestational age, a limitation of the research to date is that it has focused largely on early preterm birth, with participant eligibility often restricted to children born less than 32 weeks gestation, or born at a very low birthweight (even though this cohort typically accounts for only one fifth of the preterm population; Pitcher et al., 2012). Yet, when motor proficiency of the preterm population is discussed, it is often described as a homogenous group, which is not representative of the range of preterm gestational ages. Further research examining motor proficiency and children born moderate and late-preterm is critical for knowledge generation and warrants attention.

3.4 Assessing Gross Motor Proficiency

Although rates for major conditions influencing motor capabilities (e.g., cerebral palsy) have decreased with advancing technologies in children born very preterm, the prevalence of minor motor impairments, and the impact of the impairment remains a prominent issue (Goyen & Lui, 2002). Currently there is no definitive definition for the term, 'minor gross motor impairment'. It would be of benefit to provide a more concrete framework around this term, as mild motor difficulties may in fact fall on the lower end of the disability spectrum (Bracewell & Marlow, 2002). Reporting of gross motor difficulties remains vague in the literature, as it often encompasses poor performance below a given percentile or score on a developmental assessment battery, which may test a range of items. For example, scores lower than the 15th percentile on the Movement Assessment Battery for Children (MABC) are often considered to represent mild motor impairment, with scores less than the 5th percentile indicating definite moderate to severe impairment that potentially may indicate Developmental Coordination Disorder (Foulder-Hughes & Cooke, 2003a; Spittle et al., 2011). However, for the purpose of this review, an example of a minor gross motor impairment includes difficulties or delays with gross motor tasks (De Kleine et al., 2006). Skills that may be affected (quantitatively or qualitatively) can include those requiring coordination (for example bilateral coordination or upper limb coordination); object manipulation and ball skills (for example, catching, throwing, or kicking); postural control (such

as dynamic and static balance); and/or locomotor movement (for example, running or skipping; Carmosino et al., 2014; Foulder-Hughes & Cooke, 2003a; Piek, Hands, & Licari, 2012; Rosenbaum, Missiuna, & Johnson, 2004).

To assess a child's motor proficiency, appropriate test batteries should be utilized, taking care that the outcomes provided from the assessment offer relevant information for the motor tasks of interest (i.e., gross motor-specific skills). However, a limitation of previous research examining motor capabilities in the preterm population is the use of motor items from global neurodevelopmental batteries rather than utilizing motor-specific assessment tools (Jongmans et al., 1998). As such, using gross-motor-specific tools should be considered in movement-related research and to better inform the development of individualized intervention strategies at the practical level. If a gross motor delay is suspected using a more general assessment battery, a more specific gross motor skill tool should be implemented to better identify areas of movement difficulty.

Common assessment batteries used for the motor skill assessment of children in childhood include such assessments as the Bruininks-Oseretsky Test of Motor Proficiency-2nd Edition (BOT-2; Bruininks & Bruininks, 2005; Zimmer & Volkamer, 1987), the Körperkoordinations Test fur Kinder (KTK; Kiphard & Schilling, 2007), the Movement Assessment Battery for Children–Second Edition (MABC-2; Henderson, Sugden, & Barnett, 2007), the Peabody Developmental Motor Scales–Second Edition (PDMS-2; Folio & Fewell, 2000), and the Test of Gross Motor Development–Second Edition (TGMD-2; Ulrich, 2000). Although each of these assessments has unique benefits and limitations for the assessment of gross motor proficiency, the TGMD-2 is a commonly used assessment in the research literature due to its usability and gross motor specificity.

Before the age of 2, movement specialists should also consider (when appropriate) the use of adjusted age versus chronological age when assessing for gross motor milestone acquisition. Commonly available milestone charts are based on typically developing children born full term, and do not adequately represent time to acquisition of children born preterm. Using adjusted age (see Chapter 2) as it relates to motor milestone acquisition is recommended as a more appropriate measure of developmental status whenever using age-dependent tools (Allen & Alexander, 1990; D'Agostino, 2010).

3.5 Considerations for Intervention

There is a particular need to better understand the motor difficulties of children born preterm to better inform screening and intervention strategies (Williams et al., 2010). However, investigations examining effective intervention protocols are currently limited. Further, much of the literature has focused on the infant and toddler years, with less work examining the school years and motor difficulties in the preterm population. Identifying specific areas of concern for the acquisition of fundamental motor skills is particularly salient from a practitioner's perspective. For example, Foulder-Hughes & Cooke (2003a) showed that 7-8 year old children born preterm demonstrated a high incidence of motor impairment when compared to their full-term peers (matched for age), with significant differences found in ball skills and dynamic balance, which included tasks such as bouncing and catching, standing on one leg, and walking heel-to-toe. Examining the consistency of motor difficulties across preterm children and the underlying constraints on the emergence of fundamental movement patterns is an important area for research and further translation to the applied setting.

It is also important that children born preterm are monitored throughout their childhood years for motor skill proficiency. Qualified professionals are vital in offering developmentally appropriate environments and opportunities for children to learn to be proficient movers, and to assist a child in overcoming physical limitations. It is recommended that children with suspected motor delays work with physical therapists, occupational therapists, and/or movement specialists (e.g., qualified exercise professionals) as early intervention is critical when motor impairments emerge (Noritz & Murphy, 2013). As such, professionals specializing in movement play an important role in designing and implementing timely, individualized, developmentally appropriate programming for children born preterm for overcoming motor development delays (Foulder-Hughes & Cooke, 2003a). It is important that health professionals and movement specialists can assess and identify delays in the acquisition of gross motor milestones, and subsequently offer evidence-based and/or best practice treatment strategies to manage and mitigate the impact on a child's movement capabilities.

The qualified exercise professional plays a potentially important role in working with a preterm population given their scope of practice and expertise in exercise physiology. While research has shown an association between low health-related physical fitness and poor motor skill proficiency (Haga, 2008; Rivilis et al., 2011; Robinson et al., 2015), there are also

physiological considerations specific to a preterm population. For example, lung function and subsequent exercise capacity has been shown to be impaired in preadolescents born before 28 weeks (MacLean et al., 2016). Extremely preterm birth has also been reported to impact peak oxygen consumption with poor exercise capacity (Welsh et al., 2010). Such physiological factors should be considered when planning intervention strategies for children born preterm who exhibit motor difficulties. Activities may need to be tailored in consideration of these issues whilst promoting the child's motivation and participation in physical activities across the lifespan. Incorporating strategies to concurrently address components of health-related fitness and gross motor impairments, is important for developmentally appropriate programming that comprehensively considers the health and wellness needs of the child.

3.6 Conclusion

As preterm birth continues to be a contemporary concern in developed countries such as Canada, the gross motor developmental implications of preterm birth are important to address. Research has shown that preterm children may exhibit minor gross motor impairments (such as coordination), and are likely due in part to neurological constraints on development. Moreover, emerging research also suggests that later movement proficiency may not be predicted from assessments during toddlerhood. Therefore, children born preterm at various gestational ages should be monitored for gross motor proficiency into the school years, when movement difficulties may emerge. Proficiency in gross motor skills is important for establishing a foundation and perceived competence for physically active behavior, engaging in tasks of daily living, as well as for maintaining health-related physical fitness across the lifespan. Effective knowledge translation efforts to practitioners who may work with children born preterm is important to assist in early identification and in the design and implementation of developmentally appropriate programming for overcoming motor developmental delays.

This investigation targets particular gaps in the literature. First, it addresses and reports on the gross motor capabilities of children born premature, rather than reporting on fine and gross motor skills as a homogenous outcome. This is important because the development of fine and gross motor development should be considered separately. In addition, the thesis research addresses the lack of information regarding the gross motor development of the moderate to late preterm population and how they compare to the early preterm population. Similarly, the present

investigation does not exclude participants on the criteria of birthweight, which offers a more comprehensive assessment of children born across a spectrum of gestational ages and birthweights versus the narrow ranges that have previously been examined in the literature. Finally, this investigation will help address a gap in the evidence regarding gross motor skill competence of children born preterm across gestational ages within the age range of 4-6 years.

CHAPTER 4: The Research Process

4.1 Introduction

The purpose of this chapter is to offer background into considerations involved in the research process. A detailed description is provided as it relates to decisions made on methodology while taking into account feasibility of the study with regards to time and resources. Providing information about the research process gives a greater understanding as to the participant sample that was recruited, as well as the assessment measures chosen for the work presented in this thesis.

4.2 Participant Recruitment Process

Multiple recruitment strategies were employed in an attempt to recruit children born preterm, including public distribution, social media distribution, and word of mouth. Purposive sampling through the Canadian Premature Babies Foundation, along with a component of snowball sampling through word-of-mouth recruitment was employed. Distribution of recruitment posts through social media proved to be the most effective recruitment strategy, and a similar targeted approach would be recommended if a similar study with this population were to be conducted in the future.

With approval from each location, recruitment flyers were posted at over 40 public locations within the City of Vancouver. These included almost all Vancouver community centres and neighborhood houses, as well as additional facilities and public facilities such as the YMCA and UBC Active Kids, and all 22 Vancouver Public Library Locations. Recruitment flyers were also shared with various groups, such as BC Developmental Disabilities Association and UBC Child Care Services.

The social media approach to recruitment was conducted with the assistance of the Canadian Premature Babies Foundation. A recruitment announcement with an accompanying photo of a recruitment flyer was posted by the Canadian Premature Babies Foundation (CPBF) to their public Facebook page, as well as their private Facebook support group page. The CPBF posts were shared by numerous individuals and groups (including Preeclampsia Foundation Canada), and to closed Facebook groups by administrators, including those for parents of Vancouver children born premature, BC children who spent time in a neonatal intensive care unit, and those for parents of twins or multiple gestation births, among others. Word of mouth

and posts by parents (once they had participated in the study) also contributed to recruitment.

Although efforts were made to recruit participants through flyers in public and accessible locations, most of the children who participated in this study were accessed either through social media, with some accessed by word of mouth as described above. Barriers to recruitment for this study were largely due to difficulty in recruiting the population. Children born preterm make up a small proportion of all children at a given age; further, children born preterm with no known neurological or physical disabilities impeding movement, are a challenge to recruit, as these children are less likely to be followed into the childhood years. Parents of children born at older preterm gestational ages, with less complications at birth, and/or at later childhood years may not seek out support online group pages, particularly as their child gets older. Also, this type of recruitment method would not reach parents who do no not use social media.

Many studies of children born preterm use birthweight rather than, or in addition to, gestational age as inclusion criteria, as infants born at lower weights are generally born preterm; however, this may exclude children with heavier birthweights who are still born preterm and lowers the average gestational age of participants (Foulder-Hughes & Cooke, 2003a). Research has shown no motor milestone differences between children born preterm who are small for gestational age and children born preterm who are appropriate for gestational age by 2 years (Gortner et al., 2003). Birthweight was therefore purposely not used as eligibility criteria.

4.3 Assessment of Movement Skill Proficiency

When observing movement behaviour, researchers are able to take a snapshot of the motor outcome of a child through their performance on various physical tasks in an effort to identify the underlying motor processes guiding the movement (Gallahue et al., 2012). To give meaning to these observations, assessment batteries are utilized and are an essential component to the process. As each assessment tool is unique, determining the best option for a given research goal requires exploration into what makes an assessment a best fit for a given scenario.

Research in the area has been limited as it relates to generating knowledge on gross motor proficiency partly because the assessments utilized have not distinguished between fine motor skill competence and gross motor skill competence (e.g., the Movement Assessment Battery—Second Edition (MABC-2; Henderson et al., 2007). Further, a large proportion of studies examining motor capabilities in the preterm population use the motor items on global

neurodevelopmental batteries rather than utilizing a motor-specific assessment tool (Jongmans et al., 1998). This is evident in longitudinal studies of children born preterm where tracking of overall development is the focus. Although such long-term and all-encompassing studies are important, these global development assessment tools include a limited number of gross motor items, which results in a lack of in-depth assessment of preterm gross movement proficiency. Dewey and colleagues (2011) argue that any pediatric assessment of motor function with a non-standardized basis do not have the sensitivity for detecting motor issues in 5 year olds who were born preterm, and despite a number of tests being available to identify motor impairment, a gold standard tool is lacking (Brantner, Piek, & Smith, 2009). In addition, there is no gold standard for measuring an individual across the spectrum of motor skill proficiency (Piek et al., 2012), and the number of appropriate assessment tools are limited for the examination of gross motor proficiency specifically. Classifying motor performance as typical, suspected atypical, or atypical according to a gold standard has yet to be determined (Janssen et al., 2009), which exemplifies the issues that arise around the topic of motor skill assessment. There is also a lack of motor tests specifically appropriate for children at 4 to 6 years of age, despite this population being of particular importance to clinicians, with entry to kindergarten (Kakebeeke et al., 2016). Finally, there is a lack of early childhood gross motor assessment tools that account for preterm birth. Therefore, choosing a tool that can best satisfy the population and assessment area of interest requires careful consideration.

4.3.1 Assessment tools: Considerations

Tests vary in how their scores are interpreted. If a test is norm-referenced it will compare the results of the child to other children of the same age. The use of norm-referenced standards are generally used in tools designed for screening and diagnosis (Zittel, 1994). Norm-referenced tests often offer quantitative information which can be useful for the determination of special education service eligibility (Zittel, 1994). Tests which are norm-referenced provide a raw score which can then be converted into a percentile rank, age equivalent, or standard score, depending on what is provided in the manual of the assessment tool (Piek et al., 2012). Discriminative measures are also norm-referenced tools, meaning the score a child receives is analyzed with respect to the average results of a normative sample of typically-developing, same-age children (Piek et al., 2012). Discriminative measures should be employed when determining delays in

development or identifying whether or not a child is eligible for assistance.

In contrast, tests which are criterion-based, use a pre-determined standard to compare the child's score to, and are often used for determining the level of mastery of a skill, or the objectives of instructional programming (Zittel, 1994). Criterion-referenced tools are less commonly used in the assessment of fundamental movement skills compared to norm-referenced scales because criterion-referenced scales provide generally qualitative information regarding FMS (Vameghi, Shams, & Dehkordi, 2013). In contrast, most assessment tools used to identify motor development impairment are quantitative in nature, with the primary focus of early detection and tracking of one's development (however qualitative tools are still used and available; Cools, de Martelaer, Vandaele, Samaey, & Andries, 2010). Pupil monitoring instruments are another type of assessment tool currently available, which are useful for the identification of a child's issues with a specific task; however, they lack the ability to offer an overall estimate of a child's movement skill development (Cools et al., 2010), and therefore are not as popular.

Assessment and monitoring of movement skills on both the individual and population level requires tools which offer reliable and valid scores (Cools et al., 2010), key aspects to take into consideration when deciding which measure to utilize for assessment purposes (Piek et al., 2012). Any tool used should provide evidence of validity and reliability, and if assessing gross motor capabilities, construct, content, and concurrent validity should all be included in the body of evidence of the test (Zittel, 1994). Content validity of the test will show that the items in the test are appropriate choices for the age of the child, construct validity will indicate whether gross motor skills are in fact being measured, and concurrent validity is shown when there is high correlation between the test in question and another tool that has already been shown to assess gross motor skills of children (Zittel, 1994). Reliability can be reported through internal consistency, test-retest, or observer reliability (Zittel, 1994). Considering these psychometric properties is key when choosing an assessment tool, as they provide various pieces of information that can be used to make an informed decision.

Test manuals should clearly state all adequate information, such as the intended use of the tool so that those examining a cohort of children understand how to follow proper procedure in the administration, scoring, and interpretation of results of the test to ensure it is appropriately implemented (Zittel, 1994). The difference in performance on motor performance assessment

outcomes between females and males is affected by sex-based differences that appear at an early age, and therefore there is a need for determining whether a battery makes the appropriate accommodations for sex and culture-based differences (Hands, Larkin, & Rose, 2013). Using the norms for a test in a population other than the one the norms are provided for is a risk. For example, one should not assume that the data collected in one country for a test can be used to analyze another country's population, as culture and common activities can influence test transferability (Kambas et al., 2012).

4.3.2 Motor Development Assessments

There are a number of tools to consider for the motor skill assessment of young children (excluding infancy and toddlerhood), which include (but are not limited to): the Los Angeles Unified School District Adapted Physical Assessment Scale II (APEAS II; *Adapted Physical Education Assessment Scale II*, 2007), Ohio State University Scale of Intra-Gross Motor Assessment (OSU-SIGMA; Loovis & Ersing, 1979). Miller Function & Participation Scales (M-FUN; Miller, 2006), McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1997), Bruininks-Oseretsky Test of Motor Proficiency-2nd Edition (BOT-2; Bruininks & Bruininks, 2005), Maastrichtse Motoriek Test (MMT; Vles, Kroes, & Feron, 2004), Motoriktest für vier-bis Sechjärige Kinder (MOT 4-6; Zimmer & Volkamer, 1987), Körperkoordinations Test fur Kinder (KTK; Kiphard & Shilling, 2007), Movement Assessment Battery for Children-Second Edition (MABC-2; Henderson et al., 2007), and The Peabody Developmental Motor Scales-Second Edition (PDMS-2; Folio & Fewell, 2000).

The APEAS II is meant for use in a school setting and assesses motor performance through 23 items (*Adapted Physical Education Assessment Scale II*, 2007). The purpose of the test is to measure motor performance of school children, and is used commonly to determine eligibility for special education services (*Adapted Physical Education Assessment Scale II*, 2007). The APEAS II is not used extensively in the literature, and lacks studies addressing its validity and reliability. Due to its limited use in research and clinical setting, lack of psychometric properties, and higher compatibility as a test for children with disabilities than those with minor impairments, the APEAS II is not an ideal choice for measuring accurately gross motor competence in a preterm population.

The Ohio State University Scale of Intra-Gross Motor Assessment (OSU-SIGMA) is designed to assess gross motor development by testing 11 fundamental movement skills in children aged 2 ½ to 14 years (Loovis, Butterfield, & Bagaka's, 2008; Vameghi et al., 2013; Zittel, 1994). The OSU-SIGMA is a qualitative process-oriented assessment tool which is criterion-referenced (Loovis et al., 2008; Vameghi et al., 2013; Zittel, 1994). The OSU-SIGMA cannot be used for diagnosis; however, as a curriculum-based tool it can provide information for programming, screening, and prescription (Zittel, 1994). It is reported to be standardized and reference-based, with evidence to suggest that it has construct and content validity, test-retest reliability, inter-rater reliability, and intra-rater reliability (Zittel, 1994); however, there is a lack of literature to support its use.

The Miller Function & Participation Scales (M-FUN) is an American tool developed in 2006 to assess mild to moderate visual motor skill, fine motor skill, or gross motor skill developmental delays in children aged 2.5 to 7 years (*Review of the Miller Function & Participation Scales (M−FUN)*, 2011). The M-FUN may aid in the identification of visual motor, fine motor, and gross motor skill difficulties, the presence of underlying neuromotor deficits, determination of service eligibility, and the tracking of progress through an intervention program. The M-FUN has specific requirements as to who is qualified to buy and administer the test, strictly limiting its accessibility, which may explain why its use is nonexistent in the research literature.

The McCarron Assessment of Neuromuscular Development (MAND) is an American assessment with the purpose of screening and evaluating fine and gross motor skills for administration by clinicians, health professionals, researchers, and educators (Brantner et al., 2009; Hands, Licari, & Piek, 2015). The MAND is appropriate for assessment from 3 ½ years to young adulthood, and it assesses 5 fine motor skills and 5 gross motor skills (Hands et al., 2015; Piek et al., 2012; Slater, Hillier, & Civetta, 2010). In addition, the MAND measures balance (dynamic and static), postural control, and hand dexterity (Piek et al., 2012). The MAND is reported to be reproducible and to offer valid scores (Pérez, 2013); however, only two Australian studies have been published to date that investigate the MAND's psychometric properties (Piek et al., 2012). The normative sample of the MAND was based on data from 3 to 35 year olds in the United States, and interpretation of the fine and gross motor subtests' psychometric properties should be taken with caution as the sample used was small and consisted of adults

living with intellectual disabilities (Hands et al., 2015; Piek et al., 2012). The MAND's advantages include its wide age range of use, small amount of space required for administration, and ability to generate a separate gross motor skill score (Hands et al., 2013; Pérez, 2013; Slater et al., 2010). In a review of performance-based gross motor assessments for developmental coordination disorder by Slater et al. (2010) the MAND did not score high in comparison to other tests. Weaknesses include the extensive time for training required for test administration, the unconventional test items, the challenging nature of score interpretations, and the lack of psychometric properties for kindergarten-age children (Hands et al., 2015; Pérez, 2013).

The Bruininks-Oseretsky Test of Motor Proficiency-2nd Edition (BOT-2) is an assessment tool intended to assess fine motor and gross motor skills between the ages of 4 and 21 years (Deitz, Kartin, & Kopp, 2007; Slater et al., 2010). The aim of the BOT-2 is to identify mild to moderate deficits in motor coordination (Cools, De Martelaer, Samaey, & Andries, 2009), with the purpose of use as a support tool when diagnosing motor impairment, screening for potential impairments, evaluating the effectiveness of an intervention, and determining appropriate program placement (Deitz et al., 2007). There is a Complete Form and Short Form of the BOT-2, with 4 motor areas assessed on each (fine manual control, manual coordination, body coordination, and strength and agility; Deitz et al., 2007). Overall, Deitz et al. (2007) determined the BOT-2 to be clinically useful for the assessment of 6-21 year olds who are suspected to have general motor delays. The assessment cannot be administered to children younger than 6 years as item difficulty may be too high for typical 4-5 year olds who have delays (Deitz et al., 2007), thereby limiting the usability of the tool. Other limitations of the BOT-2 include a long time interval needed for administration (Slater et al., 2010) and difficulty in acquiring the BOT-2 testing kit (Cools et al., 2009).

The Maastrichtse Motoriek Test (MMT; or "Maastricht Motor Test" in English) was created in the Netherlands and is appropriate for children aged 5-6 years (Cools et al., 2009). Assessment of both fine and gross movement skills are evaluated through the MMT (Piek et al., 2012), which distinguishes children with motor behaviour issues from children without motor behaviour issues and is believed to be useful for the identification of children at risk for developmental issues and attention deficit hyperactive disorder (ADHD; Cools et al., 2009; Pérez, 2013; Vissers et al., 2004). There are 70 movement skill performance items, which assess static balance, dynamic balance, ball skills, diadochokinesis, and manual dexterity. However, the

MMT does not include an assessment of locomotor movement (Cools et al., 2009; Vissers et al., 2004). Validity is addressed in the MMT through both criterion and norm-referenced standards, and each skill is assessed quantitatively and qualitatively (Cools et al., 2009; Vissers et al., 2004) offering skill mastery information both above and below skill level (Cools et al., 2009). Limitations of the MMT include the lack of English translation, lack of items testing locomotor skills, and its limited use in the literature (Cools et al., 2009).

The German tool Motoriktest für vier-bis Sechjärige Kinder (MOT 4-6; or the "Motor Test for Children Aged 4 to 6 Years" in English) was designed in 1987 to aid in assessment of FMS development, movement competence, and early detection of deficiencies and/or delays in FMS (Cools et al., 2009, 2010; Pérez, 2013). The MOT 4-6 assesses both fine motor and gross motor skills, and consists of 18 items covering 4 areas: fine movement skills, locomotion, stability, and object control. However, separate subscales for gross and fine motor skills are not provided (Cools et al., 2009, 2010). High inter-rater reliability, test-retest reliability, and internal consistency has been reported, in addition to high concurrent validity using the Körperkoordinations Test fur Kinder (KTK) as a reference (Cools et al., 2009, 2010). However, the MOT 4-6 assessment has not been used in the English literature, which may largely be explained by a lack of English translation (Cools et al., 2010).

Another German tool, the Körperkoordinations Test fur Kinder (KTK, or Body Coordination Test for Children; Vandorpe et al., 2011) is designed to provide indications regarding sensory-motor integration of body coordination and control (Iivonen, Sääkslahti, & Laukkanen, 2015). The KTK is intended for diagnosis of motor impairment among children 5 to 15 years who are typically developing, have behavioural or learning deficiencies, or brain damage (Bardid et al., 2016; Cools et al., 2009; Smits-Engelsman, Henderson, & Michels, 1998; Vandorpe et al., 2011). The KTK does not assess object control or locomotion (Cools et al., 2009). The KTK is a product assessment tool, with outcome scores determined quantitatively (Rudd et al., 2016). The KTK has been reported to be oversensitive in identifying impairment, has limited application with its focus on coordination, and is purported to make use of out of date normative data (Cools et al., 2009; Iivonen et al., 2015; Smits-Engelsman et al., 1998).

The Movement Assessment Battery for Children-Second Edition (MABC-2) is a UK-based assessment tool that was revised in 2007 (from the original 1992 version; Hands et al., 2015). The purpose of the MABC-2 is to identify and describe motor performance impairments

in children 3 to 17 years of age (Brown & Lalor, 2009). The 8 items that comprise the MABC-2 Performance Test are split into aiming and catching, manual dexterity, and static and dynamic balance, with 2, 3, and 3 items respectively, and norms available for each of the 3 age bands (Brown & Lalor, 2009; Piek et al., 2012). Dynamic and static balance may be used to infer gross motor skill ability, whereas manual dexterity may be used to infer fine motor skill proficiency (Piek et al., 2012). Although the authors of the MABC-2 equivocate the revised version to the original MABC in terms of reliability and the validity, the MABC-2 is lacking evidence of reliability and validity (Piek et al., 2012); there is also limited information regarding the validity and reliability of the MABC-2 Checklist (a shorter version of the full test; Brown & Lalor, 2009; Smits-Engelsman, Niemeijer, & Waelvelde, 2011). Reasonable test-retest reliability has been shown by the authors of the battery, however limited test-retest reliability studies have been performed by other authors (Brown & Lalor, 2009). Despite the limited research that has been conducted on the reliability and validity of the MABC-2, it still remains a popular tool for motor functioning and has been used extensively in the health community (Piek et al., 2012). However, the inclusion of fine motor skill assessment, and lack of equivalency to the MABC deem the MABC-2 less favourable for the gross motor assessment of children born preterm.

The Peabody Developmental Motor Scales-Second Edition (PDMS-2) by Folio & Fewell (2000) is another example of a second-edition assessment tool (Cools et al., 2009). The intention of the 249-item PDMS-2 is to determine whether motor development is delayed in children from birth to 6 years and 11 months of age (Cools et al., 2009; Tieman, Palisano, & Sutlive, 2005; Van Waelvelde, Peersman, Lenoir, & Smits-Engelsman, 2007). A popular developmental assessment battery (Burton & Rodgerson, 2001), the PDMS-2 is frequently cited in research and in practice. The purpose of the original and subsequent version of the test was to assess children with severe motor impairments, however the purpose of the test extends beyond this to determine relative movement competence in comparison to peers, need for intervention, and for tracking progress over time (Van Waelvelde et al., 2007). The gross motor component of the test consists of 127 items, compared to 122 items which assess fine motor skills (Cools et al., 2009). Strengths of the PDMS-2 include mastery information both above and below skill level, qualitative components, and separate scores for gross and fine motor skills (Cools et al., 2009; Piek et al., 2012; Tieman et al., 2005; Van Waelvelde et al., 2007). While it is recommended that

the assessment be used to screen for integrated motor skills' development (Rosenbaum et al., 2004), the PDMS/PDMS-2 is only recommended for children under 4 years of age.

Although the tools outlined above may be favourable for the study of various populations, each presented limitations for the assessment of gross motor skill competence of preterm-born children at age 4-6 years. For example, the APEAS II, OSU-SIGMA, and M-FUN have not been used in the literature with enough consistency to be considered a preferred choice for the assessment of preterm children at school age, whereas the MAND, BOT-2, and PDMS-2 are examples of assessments that contain a high number of test items and/or extensive time required for training. Assessments such as the BOT-2, MMT, and MOT 4-6 are difficult to access, are not offered in an English translation, and are not based on North American data. Furthermore, many of the tests that assess motor competence (including the BOT-2, MABC-2, MAND, MOT 4-6, and PDMS-2) are not solely focused on gross motor skills, containing items for other measurements such as fine motor skills.

4.3.3 Test of Gross Motor Development—Second Edition

The Test of Gross Motor Development-Second Edition (TGMD-2) was released in 2000 as the second edition to the original 1985 TGMD (Cools et al., 2009; Ulrich, 2000). The TGMD-2 originated in the United States and assesses locomotor and object control skills of children aged 3-11 years (Ulrich, 2000). The 5 primary uses of the TGMD-2 are: (1) identification of children whose gross motor skill development is significantly below that of their peers, (2) for use in gross motor development research as a tool, (3) to track progress of the development of gross motor skills, (4) to assess instructional interventions programs, and (5) to help plan such gross motor development programming (Ulrich, 2000).

Twelve gross motor skills are used in the assessment, six of which are locomotor skills and six of which are object control skills (Ulrich, 2000). Three to five performance criteria are used per item (i.e., motor skill), including both qualitative and quantitative analyses to generate a total of 24 performance criteria for the locomotor subsection and 24 performance criteria for the object control subsection (Ulrich, 2000). The locomotor skills tested are the run, gallop, hop, leap, horizontal jump, and slide, while the object control subtest consists of striking a stationary ball, stationary dribbling, catching, kicking, overhand throwing, and underhand rolling (Ulrich, 2000). To administer the assessment, each skill is demonstrated, then the child is given 1 practice

trial, followed by 2 attempts on the task. A score of 1 indicates the child met the performance criteria, whereas a child is provided a score of 0 when the child does not meet the performance criteria for an attempt on an item. The overall score of one's gross motor capabilities is then calculated as a Gross Motor Quotient (GMQ), which is determined by adding the age-dependent standard scores of the 2 subtests (locomotor + object control; Ulrich, 2000). The TGMD-2 can be administered to a child within 15-20 minutes (Cools et al., 2009).

Over 1, 200 children from 10 states in the United States were used to determine the normative data for the TGMD-2 (Cools et al., 2009; Ulrich, 2000). For each 6-month difference in age, norms are provided, along with object control norms according to gender (Cools et al., 2009). These aspects were changes from the original TGMD, as was the addition of underhand rolling, the removal of skipping, and the re-drawing of the illustrations (Cools et al., 2009). The TGMD-2 is both criterion and normative-referenced (Ulrich, 2000). Different scores can be determined through the tool, including the overall Gross Motor Quotient (GMQ) score, and is accompanied by directions regarding scoring. The reliability of the TGMD-2 is based upon the test error of time, content, and scorer, and was evaluated for ages 3-5 years, 6-8 years, and 9-10 years, as well as a total sample, with the 2 subtests and GMQ within each age group analyzed (Ulrich, 2000). Based upon the minimum appropriate coefficient standard of 0.70 and desired coefficient standard of 0.90, the 3 types of reliability all showed high reliability in each age group for the TGMD-2 (Ulrich, 2000). Although Ulrich (2000) indicates that the test is valid in measuring gross motor ability, others are encouraged to continue analyzing the validity of the test through their own findings.

The TGMD-2 is a popular test for researching various pediatric populations, and has been recommended as a gross motor tool for assessing children (Slater et al., 2010; Ulrich, 2000). The process-oriented nature of the TGMD-2 makes it a favourable tool to use. The TGMD-2 was validated, and inter-rater reliability was shown to be $r = 0.88$ ($\alpha = 0.85$) and $r = 0.93$ ($\alpha = 0.88$), for the locomotor and object control subtests, respectively (Ulrich, 2000). Test-retest reliability was found to be $r = 0.88$, $r = 0.93$, and $r = 0.96$ for the locomotor subtest, object control subtest, and gross motor composite, respectively, and when examined for factor analysis, the six goodness of fit indexes (degrees of freedom, chi square, relative chi square, Tucker and Lewis's index of fit, Joreskog and Sorbom's goodness-of fit and adjusted goodness-of-fit indexes) ranged between 0.90 to 0.96 (Ulrich, 2000).

After comparing all of the available tests of motor performance, the Test of Gross Motor Development—Second Edition (TGMD-2) was selected for use in this investigation. The TGMD-2 normative data is of North American origin, reducing sociocultural differences, as many of the other gross motor assessment tools originate outside of North America. In addition, the tool examines specifically gross motor skill proficiency, is easily accessible, and is widely administered in the literature. While the development of a third edition of this assessment is underway, the third edition was not released in time for this investigation.

4.4 Inclusion of Strength and Balance Assessments

Three measures were chosen in addition to the TGMD-2 in the current study: grip strength, standing long jump, and single-leg static balance. The purpose of including strength and balance measures was to capture gross motor skill proficiency more comprehensively. Collecting data on the balance and muscular strength of the upper and lower body provides a more thorough picture of the movement capabilities of the participants, and may offer insight into the constraints acting on the development of gross motor competence. Examining the influence of such factors on fundamental movement skill development is important for creating effective prevention and intervention strategies targeted towards children born preterm who exhibit poor gross motor skill proficiency.

Grip strength can be used as a measure of a child's upper body strength (Stodden et al., 2008) and is a useful marker of physical growth and development (Butterfield, Lehnhard, Loovis, Coladarci, & Saucier, 2009). Force production through grip is necessary for independence in childhood daily activities, such as play and eating (Häger-Ross & Rösblad, 2002). With regards to gross motor skill competence in particular, upper body strength is a necessary physical component for successfully performing object control tasks (such as throwing or striking a stationary ball). To quickly scan either a patient or a group, grip strength can be used as a measure of overall strength, as total body muscle strength and grip strength have been found to have a high correlation (Wind, Takken, Helders, & Engelbert, 2010). Grip strength has therefore been a simple tool to determine muscular strength across the lifespan, including the later childhood years, adolescence (Wind et al., 2010), and adulthood, when it is particularly useful as a simple measure of musculoskeletal fitness and subsequent functional status

(Warburton, Nicol, & Bredin, 2006) and in older adulthood when it is a predictor of outcomes such as survival (Bohannon, 2008).

The standing long jump (also termed 'standing broad jump' or 'horizontal jump') was administered to assess the muscular power, or explosive strength, of the lower body (Condon & Cremin, 2014; Ortega et al., 2015), wherein performance is assessed by the distance achieved from a child's attempt at a two-footed takeoff and landing. Standing long jump measures important muscular health-related physical fitness markers of young children (Ayán-Pérez, Cancela-Carral, Lago-Ballesteros, & Martínez-Lemos, 2017). When a child's strength is inadequate compared to their body weight, physical functioning may be decreased due to the strenuous effort required to perform fundamental movements such as jumping, running, and walking (Oeffinger et al., 2014). Furthermore, standing long jump is a measure often recommended in talent identification of children in sport (e.g., youth soccer players; Deprez et al., 2015). As muscular strength and power are important components of health-related physical fitness and can affect functioning of daily activities throughout the lifespan, measures such as the standing long jump are recommended for the assessment of health status (Warburton et al., 2006). Standing long jump's ease of administration coupled with the predictive information it offers, makes it an appropriate measure to administer in the preterm pediatric population.

As identified above, this investigation will utilize both grip strength and standing long jump to examine muscular strength. It has been previously shown that assessing multiple muscle groups of an individual may be beneficial when the goal is to gain greater detail in information (Wind et al., 2010). For example, the battery PREFIT, which assesses preschoolers' physical fitness, uses both standing long jump and grip strength as strength measures, and both measures have been found to reliable measures of muscular strength, particularly for children age 4-5 years (Ortega et al., 2015).

When discussing delays in motor development, balance control is an important consideration, as control of one's posture is broadly assumed to be a requirement for motor skill development (Geuze, 2003; e.g., balance is critical for gait performance). Therefore, it is beneficial to assess balance, in addition to gross motor proficiency, for diagnosis of motor-based issues and in the planning of intervention strategies (Zumbrunn, MacWilliams, & Johnson, 2011) for minor gross motor difficulties. Some assessments of general motor development such as the MABC and BOT-2 include balance, however it is usually assessed in relation to functional

capacity and not as its own entity (Condon & Cremin, 2014). As the TGMD-2 does not have a balance-specific assessment, we elected to include a measure of single-leg static balance as an assessment measure.

Single-leg balance protocols are commonly used to determine the static balance capabilities of children, on a narrow base of support (Condon & Cremin, 2014), and may be a more effective assessment than double-leg balance when examining the functional balance capabilities of one's musculoskeletal system during movement (Zumbrunn et al., 2011). Balance requires sensory input reception and integration as well as movement and execution to achieve the complex task of maintaining an upright posture (Zumbrunn et al., 2011). Therefore, when assessing balance, the integration and coordination of the vestibular system, somatosensory system from muscles and joints, and vision, are all evaluated (Dhanani & Parmar, 2014). Balance development is related to prenatal neurodevelopment, whereby brain regions develop independently of each other before connecting (Dhanani & Parmar, 2014), making it a particularly important assessment when discussing children born preterm, due to neurodevelopmental considerations.

4.5 Chapter Summary

Various factors were considered in the design of this investigation. The most effective form of participant recruitment proved to be through social media channels. Choosing an appropriate assessment of gross motor skill proficiency required the comparison of various batteries and their suitability for the population being examined. The TGMD-2 was chosen as the most appropriate assessment measure at this time for 4-6 year old children born preterm. However, since the TGMD-2 has limitations (such as a lack of balance assessment) three additional movement outcomes were included. The balance and strength measures chosen were fitting for the age of the participants and feasible within the scope of the study. As a result, the performance measures of the TGMD-2, single-leg static balance, grip strength, and standing long jump, were selected to assess various dimensions of gross motor performance of the children.

CHAPTER 5: The Research

5.1 Introduction

Advancements in medical practices for obstetric neonatal care made in the 1980's and 1990's significantly improved survival rates of children born preterm (<37 weeks gestation; British Columbia Perinatal Health Program, 2008; Shapiro-Mendoza & Lackritz, 2012). However, while infant mortality rates have declined there has been an observed increase in rates of preterm births and related morbidity, particularly in high-income countries (Bhutta, Cleves, Casey, Cradock, & Anand, 2002; March of Dimes et al., 2012; The Lancet, 2006). For example, in Canada, rates of preterm birth have risen, representing 7.7% of all 2010 Canadian live births, 84% of which were moderate to late preterm, with late preterm birth largely responsible for this increase (CIHI, 2009; Public Health Agency of Canada, 2013). The high incidence of preterm births is a public health concern, as preterm birth has been associated with infant mortality, childhood neurologic disabilities, and developmental delays (Shapiro-Mendoza & Lackritz, 2012), resulting in short-term and long-term morbidities and contributing to considerable health care costs (CIHI, 2009).

Children born preterm (<37 weeks gestation) are often considered at-risk for poor motor development outcomes. The existing research on children born early preterm (at <32 weeks gestation) supports this, demonstrating marked differences between children born early preterm compared to children born at term in various developmental domains (e.g., sensory, behavioural, cognitive, social, and/or learning), including motor development (e.g., motor-based difficulties; Johnson & Marlow, 2017; March of Dimes et al., 2012; Van Hus et al., 2014; Wilson-Costello, 2007).

Within the motor domain, gross motor competence describes an individual's proficiency in performing various fundamental movement skills (Barnett et al., 2016). Mastery across these skills provides children with a set of essential movement patterns using large muscles of the body to complete a movement task. Early childhood provides a time-sensitive opportunity for children to develop gross motor competence, which is postulated to be critical for establishing a foundation for participation in sports and physical activity, as well as for tasks of daily living across the lifespan (Barnett et al., 2016). In the first six years of life, the brain exhibits an increased sensitivity to environmental stimuli, providing a window of opportunity for the

development of gross motor competencies. This time frame is not only critical for gross motor skill acquisition, but also for the detection of gross motor difficulties and to offer subsequent intervention strategies in a timely manner (Ferrari et al., 2012). Although fundamental movement skills can be achieved by age 6 (Vandaele et al., 2011), the ages between 2 and 7 years is considered an optimal time frame for children to develop fundamental motor skills (Culjak, Miletic, Delas Kalinski, Kezić, & Zuvela, 2014). By age 8, most fundamental movement skills should be learned, after which children can learn more complex skills (Piek et al., 2012), however when young children exhibit low motor skill competence, findings suggest limited 'catch-up' to the performance of age-matched peers (Hands, 2008). Therefore, addressing motor performance difficulties in the early years is critical.

With respect to gross motor development, there is evidence that children born early preterm exhibit repeatedly delayed motor development and poor motor competence in early childhood (Bracewell & Marlow, 2002; de Kieviet et al., 2009; De Kleine et al., 2006; Dewey et al., 2011; Foulder-Hughes & Cooke, 2003b; Goyen & Lui, 2002; Hemgren & Persson, 2004; Jongmans et al., 1998; Schonhaut, Armijo, & Perez, 2015; Van Hus et al., 2014; Wocadlo & Rieger, 2008). However, given an increased vulnerability at birth to both short and long term serious medical and developmental outcomes (Lawn et al., 2014), the literature on motor outcomes of preterm birth has focused almost exclusively on children born early preterm, which does not represent the full spectrum of preterm gestational ages. Children born preterm at later gestational ages were previously considered a low-risk cohort with regards to long-term negative developmental consequences (Kerstjens et al., 2011; Valentin-Gudiol et al., 2011). As a result the moderate to late preterm population has received limited research attention. Although it is often suggested that the long-term negative outcomes of preterm birth are likely to increase as birthweight and gestational age decrease (Williams et al., 2010), it is largely unknown whether children born moderate to late preterm children (32 to <27 weeks gestation) exhibit similar developmental risks as children born early preterm (< 32 weeks gestation; Kerstjens et al., 2011).

More recently, perinatal researchers have increased their focus on examining children born moderate to late preterm (Blaggan et al., 2014; Odd, Lingam, Emond, & Whitelaw, 2013). This research suggests that gross motor impairments are not exclusive to those born early preterm; rather gross motor impairments may also present in the later preterm births of the moderate to late preterm population, persisting through the childhood period (Odd et al., 2013;

Prins et al., 2010). Given the rising rates of moderate to late preterm births and implications for a child's health and well-being, as well as the public health and educational systems (Blaggan et al., 2014), examining children born preterm at later gestational ages with respect to gross motor capabilities warrants attention.

To date, when assessing motor competence in the preterm population, gross motor assessments do not determine proficiency of each type of fundamental movement skill: stabilizing (e.g., twisting, pushing, pulling), locomotor (e.g., running, leaping, galloping), and manipulative (e.g., catching, throwing, kicking) skills. Although many movements use a combination of fundamental movement skills to accomplish a task, stability skills are often required within manipulative and locomotor skills to execute the motor task. For example, successfully hopping on one foot requires a child to also possess balance capabilities. As such, in addition to examining qualitative and quantitative proficiency of gross motor skills, balance itself is an important capability to consider when assessing movement skill performance.

In addition to balance, mastery of gross motor skills requires adequate muscular strength. Researchers have demonstrated a relationship between motor performance and muscular strength (Reeves, Ce, East, & Matney, 1999), with strength required to perform physical activities and sport (de Chaves et al., 2016), particularly those that are locomotive. For example, poor strength through a child's core may lead to instability through the trunk when performing a gross motor task, resulting in the skill being more difficult to perform (Hands & Larkin, 2006), Similarly, children who have difficulty with gross motor coordination are also more likely to exhibit decreased explosive strength regardless of age, BMI, sex, or maturational status (de Chaves et al., 2016). Therefore, comprehensively assessing gross motor competence is beneficial for determining which skills contribute to poor gross motor competence for the development of effective intervention strategies.

The primary purpose of this investigation was to examine gross motor development in relation to gestational age at birth in preterm children aged 4 to 6, with no known or diagnosed neurological disorder or physical disability. In addition, this investigation aimed to gain information regarding the static balance capability and muscular strength of the population. It was hypothesized that earlier preterm gestational age would be associated with poorer gross motor competence than later preterm gestational age; however, the gross motor proficiency for

children born preterm at later gestational ages was also expected to be below normative standards.

5.2 Methods

5.2.1 Participants

Participants were between the ages of 4 to 6 years, born preterm (<37 weeks gestational age), and had no diagnosed neurological disorder or major physical disability that altered movement. Written informed consent was received from a parent or guardian of the child prior to participation. Ethics approval for this investigation was received from the University of British Columbia Behavioural Research Ethics Board (BREB), and the research was carried out in exact accordance with the ethical guidelines set forth by the BREB for research involving human participants.

5.2.2 Assessments

Participant demographic information was collected via a questionnaire (see Appendix A). Assessments included measurements of anthropometrics, balance, muscular strength, and gross motor development as it relates to locomotor and object control fundamental motor skill acquisition.

Participant Questionnaire. An online information questionnaire was completed by a parent or legal guardian for each participant. Items on the questionnaire included the child's birthdate, expected due date, birthweight, and length of neonatal intensive care unit stay. Items also included maternal age at birth and type of delivery, parental/guardian level of education, and annual household family income.

Anthropometric Measurements. The anthropometric measurements of height, weight, and waist circumference were collected for each participant using research-grade instruments. A Seca 213 Portable Standiometer (*Multilingual manual for portable standiometer*, 2014) was used to measure the height of participants. Children were asked to stand (without shoes) with their back and heels against the standiometer. Participants were asked to put their feet together, straighten their legs, stand up straight, and look straight forwards, at which point the sliding head piece was lowered until it was flat against the vertex of the head. Height measurement was recorded to the nearest tenth of a centimeter.

A Tanita BC-534 InnerScan Body Composition Monitor (*Manual for InnerScan Body Composition Monitor, Model BC-534*, 2005) was used to assess body mass. Without shoes, participants were instructed to stand in the middle of the scale on both feet. Body mass was recorded to the nearest tenth of a kilogram. A tape measure was used to measure waist circumference. The tape measure was aligned horizontally on the uppermost edge of each side of the lateral iliac crest so that it was level and around the body. Waist circumference was recorded to the nearest tenth of a centimeter.

Balance. A single leg standing balance assessment was used to determine the unipedal balance capabilities of children with their eyes open. The single leg standing balance task is a widely used static balance assessment tool (test-retest reliability (r = 0.68-0.95), interrater reliability (r = 0.96; Atwater, Crowe, Deitz, Richardson, & K., 1990; Burns et al., 2009; Condon & Cremin, 2014; Dhanani & Parmar, 2014; Emery, 2003; Springer, Marin, Cyhan, Roberts, & Gill, 2016). Children were asked to stand on their dominant foot (on a marker on the floor) with their hands on their hips. Participants were then asked to stand in this position for as long as possible while being timed. Timing began when the non-standing leg left the ground to a flexed position at 90 degrees of both the hip and knee, and was stopped when the child moved off the mark, lost position, or the foot touched the floor or standing leg (Condon & Cremin, 2014). Leg dominance was determined by asking the parent present and confirmed by having the child kick a ball. Children were given a demonstration and one practice attempt, after which the task was performed three times, and the longest time of the three trials was recorded to the nearest tenth of a second.

Muscular Strength. Muscular strength was assessed via measurements of grip strength and standing long jump. Grip strength was measured on the dominant hand of participants using a JAMAR 5030J1 hydraulic hand dynamometer. JAMAR dynamometers are the most widely dynamometer used to assess the grip strength of children (Wind et al., 2010) and scores from testing has been shown to be both reliable and valid (Butterfield et al., 2009; Omar, Alghadir, Zafar, & Al Baker, 2018). The participants were asked to sit in a child-sized chair with their feet flat or touching the floor and dominant elbow bent at a 90 degree angle. The grip handle distance was adjusted for the participant to the lowest or second lowest ring, depending on what the child felt was the most comfortable. The child was instructed to hold the dynamometer vertically with a comfortable grip as it rested in the researcher's hand and then squeezed it as hard as possible

without moving their body. The researcher followed standard squeezing encouragement. Participants received a practice trial, followed by three trials with a break between trials. Grip strength was measured to the nearest kilogram, and the highest reading of the three trials was used. Attempts in which the child did not follow protocol were disregarded. Hand dominance was determined for grip strength by asking the parent present the hand dominance option they chose on the questionnaire, and confirmed by asking the child to draw (Butterfield et al., 2009).

To assess standing long jump, children were asked to jump as far as they could with two feet from a starting line on the ground. The distance was measured between the starting line and the most posterior point of contact from the furthest back foot upon landing. Children were given one demonstration and were allowed one practice attempt, after which the farthest distance of three trials, measured to the nearest centimeter, was recorded.

Gross Motor Skill Proficiency. The Test of Gross Motor Development – Second Edition (TGMD-2) was used to assess motor skill proficiency (Ulrich, 2000). The TGMD-2 is a popular test for researching various pediatric populations and has been recommended as a gross motor tool for assessing children (Slater et al., 2010; Ulrich, 2000). The TGMD-2 assesses 12 movement skills, six locomotor (run, gallop, hop, leap, horizontal jump, and slide) and six object control skills (striking a stationary ball, stationary dribble, catch, kick, overhand throw, and underhand roll). Participants were shown the skill once and performed one practice attempt before performing two scored attempts at each skill. The children's TGMD-2 performances were digitally recorded for analysis at a later time. The TGMD-2 has been shown to produce valid scores, and inter-rater reliability has been shown to be between $r = 0.88$ ($\alpha = 0.85$) and $r = 0.93$ ($\alpha = 0.88$), for the locomotor and object control subtests, respectively (Ulrich, 2000). Test-retest reliability was found to be $r = 0.88$, $r = 0.93$, and $r = 0.96$ for the locomotor subtest, object control subtest, and gross motor composite, respectively, and when examined for factor analysis, the six goodness of fit indexes (degrees of freedom, chi square, relative chi square, Tucker and Lewis's index of fit, Joreskog and Sorbom's goodness-of fit and adjusted goodness-of-fit indexes) ranged between 0.90 to 0.96 (Ulrich, 2000).

5.2.3 Procedure

Participants attended one data collection session (30-45 minutes) at the Cognitive and Motor Learning Laboratory, University of British Columbia. Parents were asked to first complete the parental questionnaire. Following this, anthropometric measurements were taken, followed

by measurements of balance and grip strength, and finally the TGMD-2 was administered. The standing long jump distance was measured after the horizontal jump during the administration of the TGMD-2.

5.3 Data Analysis

5.3.1 Preliminary Analysis

Participants' height and weight were plotted according to age on the 2-19 years World Health Organization Growth Charts for Canada. Specifically, the height-for age and weight-for-age charts for females and males ("WHO Growth Charts," n.d.) were used to determine each child's height-for-age and weight-for-age percentiles.

For gross motor proficiency, the digital recordings were analysed according to standard procedures of the TGMD-2 (Ulrich, 2000). On the TGMD-2, each item was scored on 3-5 performance criteria, wherein each criterion was given a 1 for correct performance, or a 0 if the criterion was executed incorrectly. The raw skill scores for each of the subtests (locomotor and object control) were summed and transformed into locomotor standard score and object control standard score, based on the child's age. The locomotor and object control standard scores were then summed and transformed into a Gross Motor Quotient (GMQ), which therefore also accounts for a child's age. High scores on this composite represents greater gross motor skill proficiency, whereas low scores on the General Motor Quotient indicates less proficient skills. Each GMQ score has an associated percentile which provides information on the child's gross motor development proficiency as determined by the TGMD-2 normative data. As the maximum possible score per skill varied, the skill proficiency of each TGMD-2 skill was calculated for skill comparisons. To determine skill proficiency, a skill's mean score was divided by the total possible score for the skill and multiplied by 100, resulting in a percentage. The skill proficiency percentage reflects the participant mean as a percentage of the total maximum score, with higher percentages indicating better proficiency.

Inter-rater reliability was conducted by two independent observers, who independently coded the TGMD-2 skills of 33% randomly-chosen participants. The interrater reliability between the original rater and the secondary rater using intraclass correlations (ICC) as has been used in other studies assessing the interrater reliability of the TGMD-2 (Barnett, Minto, Lander,

& Hardy, 2014; Houwen, Hartman, Jonker, & Visscher, 2010). Inter-rater reliability was determined for raw and locomotor subtest scores as well as the GMQ.

5.3.2 Main Analysis

Data were statistically analyzed using SPSS version 22.0 ("IBM SPSS Statistics for Windows," n.d.). Statistical significance was set to the 0.05 level, and all tests were 2-tailed. Means and standard deviations were calculated for anthropometric measurements, TGMD-2 scores (skill, subtest, and total), strength and balance measurements, as well as age, gestational age, birthweight, length of stay in NICU, and maternal age at birth. Pearson product-moment correlations were calculated to determine the relationship of the continuous variables (GMQ, locomotor standard score, object control standard score, balance, standing long jump, gestational age, birthweight, length of stay in NICU). Regression analyses were conducted to examine the relationships between performance measures (balance, standing long jump, GMQ, locomotor standard score, and object control score), and various predictors (GMQ, locomotor standard score, balance, standing long jump, gestational age, birthweight, length of stay in NICU). Prior to regression analysis, assumptions of normality, multicollinearity, homoscedasticity, and linearity were checked. Variables such as birthweight and gestational age that were highly correlated were not used together in the regression models to avoid violating multicollinearity, and balance was transformed to account for positive skew. The predictive effect of gestational age on the performance outcomes of balance and standing long jump was analyzed using hierarchical multiple regression. The predictive effect of birthweight was also analyzed using hierarchical multiple regression. In the hierarchical models, age was added first to control for the expected increase in proficiency that is expected with increasing age, followed by the addition of either gestational age or birthweight. Simple linear regressions were used to analyze the relationship between gestational age and the TGMD-2 performance measures of GMQ, locomotor standard score, and object control standard score. Simple linear regressions were also used to analyze birthweight and TGMD-2 performance measures.

5.4 Results

5.4.1 Participant Characteristics

Eighteen children participated in the research (*n* female = 11, *n* male = 7), ten of which were born as a twin. Both children of a twin set participated; therefore, 5 sets of twins were represented in the sample. The age of participants ranged from 4.1 to 6.6 yr, gestational age ranged from 25.6 to 36.0 weeks, and birthweight ranged from 595.0 to 2560.0 g. Seventeen participants were classified as low birthweight (<2,500 g), with 3 participants further classified as very low birthweight (<1,500 g), and 5 as extremely low birthweight (<1,000 g). Most participants stayed in the neonatal intensive care unit but stay ranged from 0 days to 152 days. A summary of participant, maternal, and family characteristics is presented in Table 1.

5.4.2 Anthropometric Measurements

Mean height, weight, and waist circumference of participants was 107.7 ± 6.9 cm, 17.8 ± 2.9 kg, and 51.8 ± 5.7 cm, respectively (see Table 2). When converting height-for-age and weight-for-age to percentiles, findings showed 72% of participants measured at or below the 50th height-for-age percentile and 89% measured at or below the 50th weight-for-age percentile (see Table 1, Figure 6, and Figure 7).

5.4.3 Performance Measures

Descriptive statistics for all performance measures is presented in Table 2. Interrater reliability was determined for GMQ and subtest raw score, subtest standard scores, and GMQ, using both intraclass correlations (ICC), and Pearson correlations, as per TGMD-2 guidelines (Ulrich, 2000). A high degree of interrater reliability was found for subtest raw and standard scores, as well as for the GMQ. The intra-class correlations for interrater reliability ranged from 0.93 to 0.97.

Participants demonstrated a mean single-leg standing balance time of 9.5 ± 8.9 s, a mean grip strength of 8.4 ± 1.9 kg, and a mean standing long jump distance of 85.1 ± 17.1 cm. The mean TGMD-2 overall Gross Motor Quotient (GMQ) was 83 ± 11 out of a maximum of 160. After converting GMQ scores to percentiles (Figure 8), findings revealed that one-third of participants scored at or below the 5th percentile, one-half of participants scored at or below the 8th percentile, and two-thirds of participants scored at or below the 12th percentile, with 89% of participants scoring below the 50th percentile.

Table 1

Descriptive Statistics for Participant Age, Anthropometric Percentiles, Birth Characteristics, and Family Demographics

Characteristic	No. (%)
Age	
Participant Age Distribution (y) (m = 5.2 ± 0.7 y) (*n* = 18)	
4	7 (38.9%)
5	9 (50.0%)
6	2 (11.1%)
Anthropometric Percentiles	
Height-for-age (*n* = 18)	
≤ 25th percentile	8 (44.4%)
26th to 50th percentile	5 (27.8%)
51st to 75th percentile	5 (27.8%)
76th to 100th percentile	0 (0.0%)
Weight-for-age (*n* = 18)	
≤ 25th percentile	8 (44.4%)
26th to 50th percentile	8 (44.4%)
51st to 75th percentile	0 (0.0%)
76th to 100th percentile	2 (11.1%)
Birth Characteristics	
Gestational Age (wks) (m = 31.6 ± 3.3 wks)(*n* = 18)	
Early Preterm (<32 wks)	9 (50.0%)
Moderate to Late Preterm (32 to 33 wks)	9 (50.0%)
Maternal Age at Birth (y) (m = 33.9 ± 4.1 y) (*n* = 18)	
25-29	2(11.1%)
30-34	7(39.9%)
35-40	7(38.9%)
41-44	2(11.1%)
Type of Delivery (*n* = 18)	
Vaginal	6 (33.3%)
Cesarean	12 (66.7%)
Neonate Birthweight (g) (m = 1550.1 ± 614.1 g) (*n* = 18)	
Standard Birthweight	1 (5.5%)
Low Birthweight (<2,500 g)	9 (50.0%)
Very Low Birthweight (<1,500 g)	3 (16.7%)
Extremely Low Birthweight (<1,000 g)	5 (27.8%)
Length of Stay in NICU (m = 48.3 ± 4.1 days) (*n* = 18)	
No Stay Required	2 (11.1%)
1 to 30 days	6 (33.3%)
31 to 60 days	4 (22.2%)
61 to 120 days	4 (22.2%)
>120 days	2 (11.1%)
Family Demographics	
Highest Parental Education Level (*n* = 18)	
High School Graduate or Equivalency	1 (5.5%)
Trade/Technical/Vocational Training	3 (16.7%)
Some College/University, no degree	2 (11.1%)
Bachelor's Degree	3 (16.7%)
Post Graduate or Professional Degree	9 (50.0%)
Yearly Household Income (*n* = 18)	
<$25,000	2 (11.1%)

$25,000-$49,999	1 (5.5%)
$50,000-$74,999	4 (22.2%)
$75,000-$99,999	2 (11.1%)
$100,000-$199,999	8 (44.4%)
$200,000-$299,999	1 (5.5%)

* NICU = Neonatal Intensive Care Unit

Table 2

Summary of Anthropometric and Performance Measures

Measure	Mean	Standard Deviation	Minimum	Maximum
Height (cm)	107.7	6.9	94.0	117.9
Weight (kg)	17.8	2.9	13.2	23.7
Waist Circumference (cm)	51.8	5.7	43.5	68.0
Balance (s)	5.5	8.9	1.5	29.9
Grip Strength (kg)	8.4	1.9	6.0	12.0
Standing Long Jump (cm)	85.1	17.1	47.0	115.0
TGMD-2 GMQ	83.0	11.5	67.0	109.0
TGMD-2 Locomotor Standard Score	7.3	2.3	4.0	13.0
TGMD-2 Object Control Standard Score	7.1	1.8	5.0	10.0

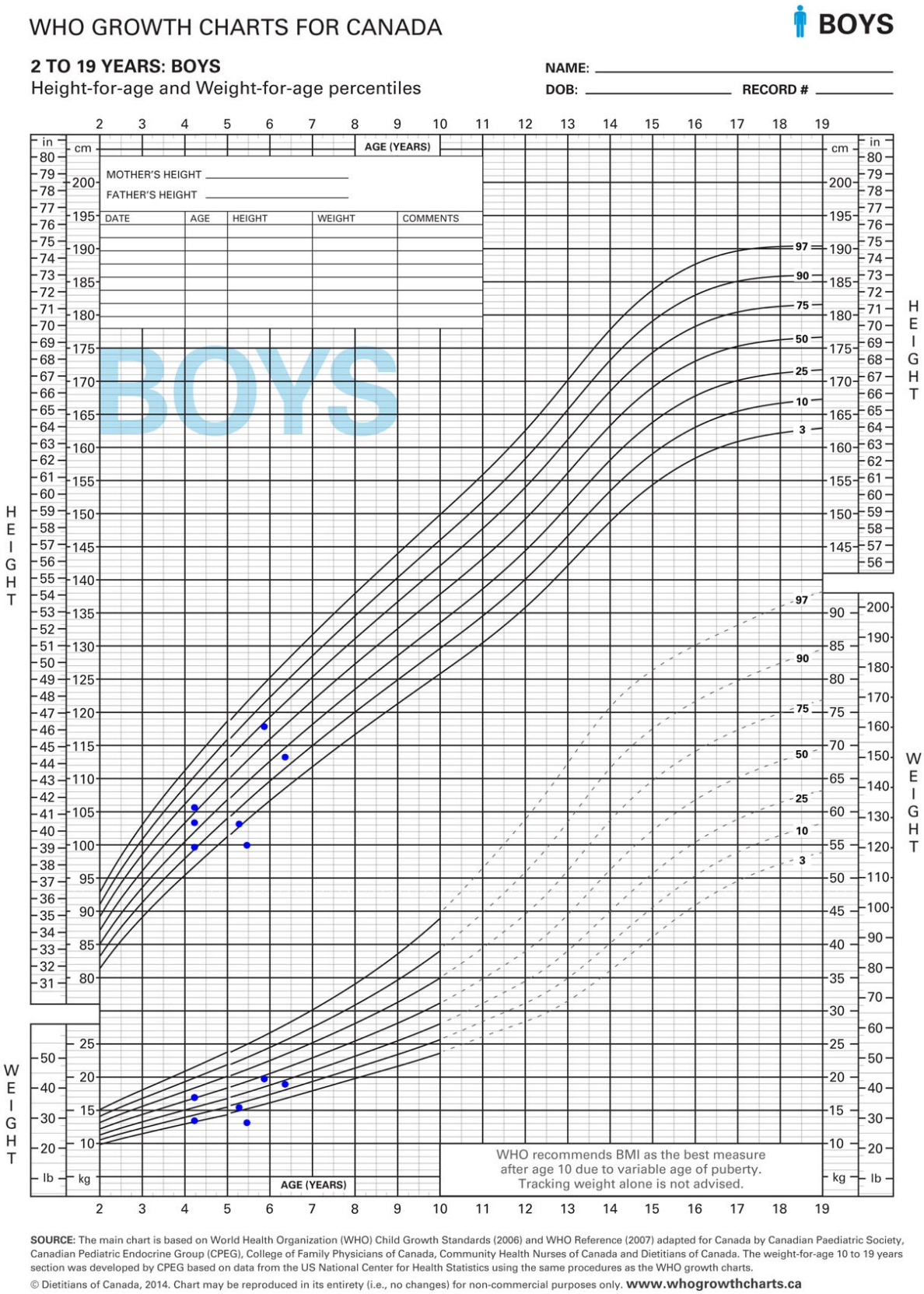
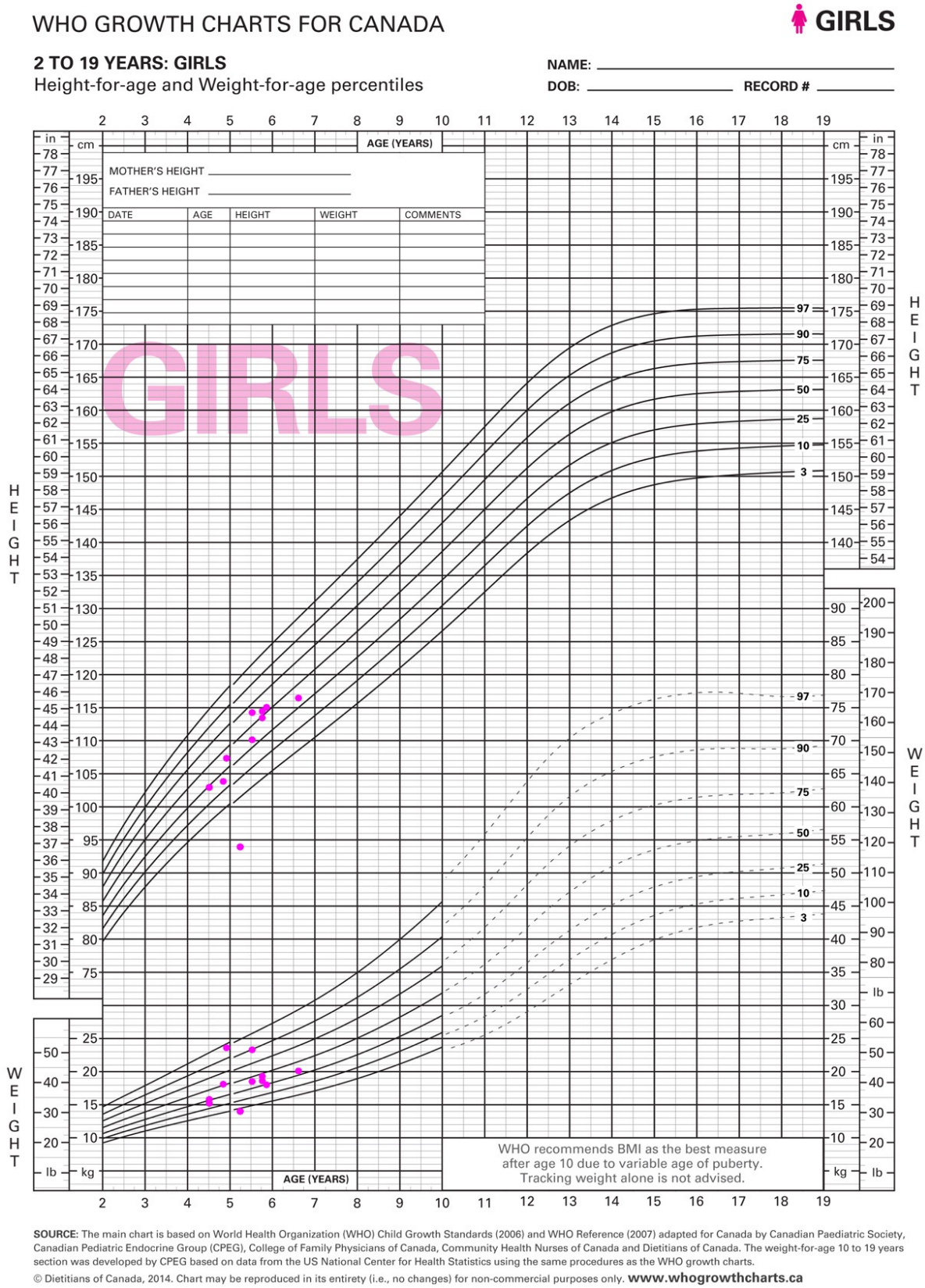


Figure 6. Summary of Boys' Height-for-Age and Weight-for-Age



SOURCE: The main chart is based on World Health Organization (WHO) Child Growth Standards (2006) and WHO Reference (2007) adapted for Canada by Canadian Paediatric Society, Canadian Pediatric Endocrine Group (CPEG), College of Family Physicians of Canada, Community Health Nurses of Canada and Dietitians of Canada. The weight-for-age 10 to 19 years section was developed by CPEG based on data from the US National Center for Health Statistics using the same procedures as the WHO growth charts.

Figure 7. Summary of Girls' Height-for-Age and Weight-for-Age

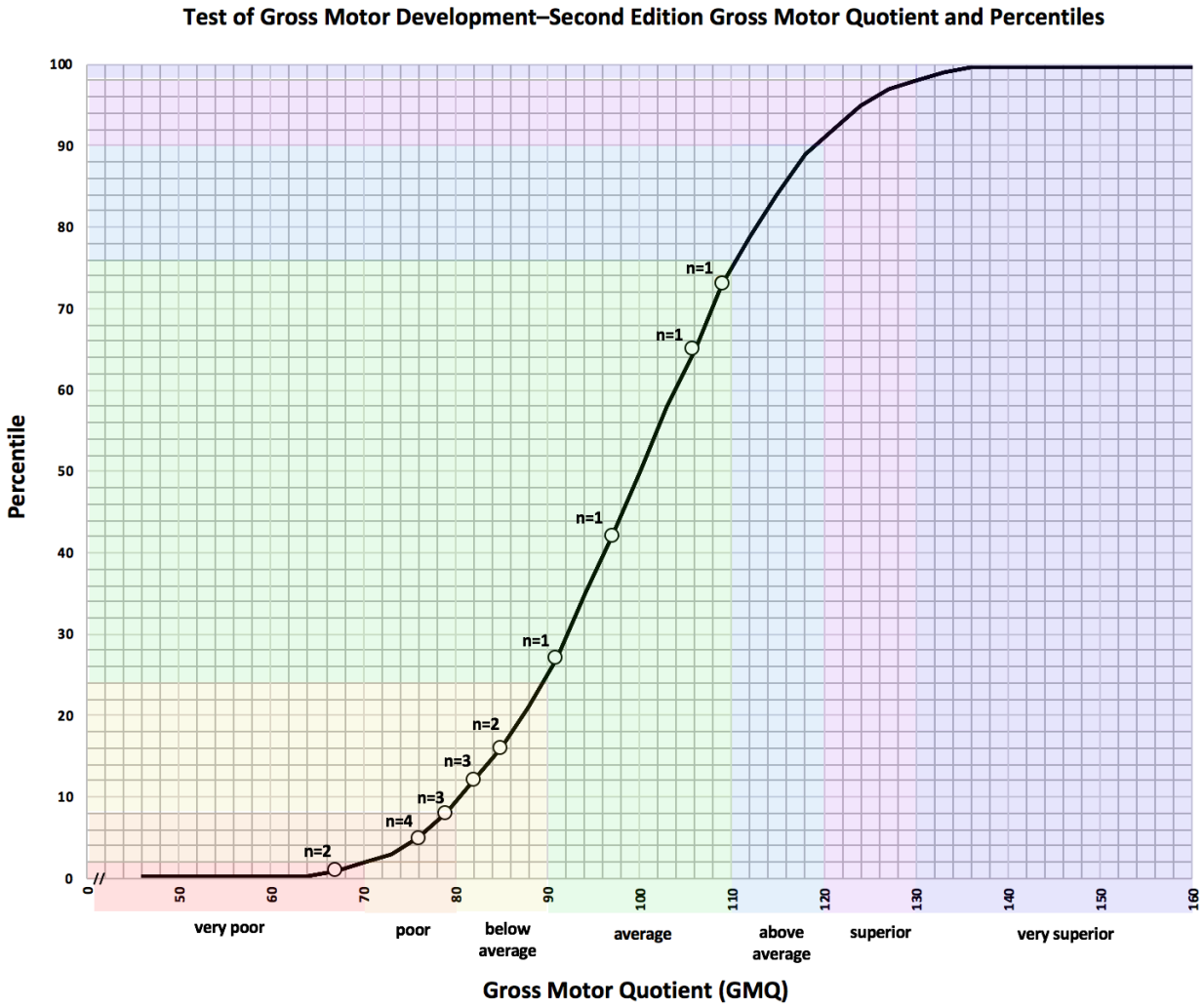


Figure 8. Frequency of Participant GMQ Scores and Associated Percentiles and Descriptor Categories according to the Test of Gross Motor Development–Second Edition

Although the TGMD-2 subtest scores are provided in raw scores, standard scores are more informative as they take a participant's age into account. Participants performed poorly on both subtests, exhibiting a mean locomotor standard score of 7.3 ± 2.3 out of a maximum of 20, whereas the object control subtest had a mean standard score of 7.1 ± 1.8 out of a maximum of 20. The 3 individual skills (out of a total of 12 assessed) with the lowest performance were all object control skills: the stationary dribble (M = 1.8 ± 1.8), underhand roll (M = 2.3 ± 1.7), and overhand throw (M = 2.4 ± 1.8). The 3 individual skills with the highest performance were the kick (M = 5.1 ± 1.8), run (M = 5.5 ± 1.3), and slide (M = 5.5 ± 2.1). Four of the 6 lowest scoring skills were object control skills, and 4 of the 6 highest scoring skills were locomotor skills (see Table 3). Locomotor age equivalencies and object control age equivalencies were lower by an average of 18 months in 15 of 18 participants. The largest locomotor age difference was an age equivalency more than 34 months lower than age, while the largest object control age difference was an age difference of more than 29 months.

5.4.5 Correlational Analysis

Findings of the correlational analysis can be found in Table 4. Gestational age was significantly correlated with balance ($r = 0.612$, n =18, $p < 0.01$), standing long jump ($r = 0.584$, $n = 18$, $p < 0.05$), birthweight ($r = 0.892$, $n = 18$, $p < 0.01$), and length of stay in the NICU ($r = -0.885$, $n = 18$, $p < 0.01$). Gestational age was not found to be significantly correlated to GMQ score ($r = 0.409$, $n = 18$, p > .05).

5.4.6 Regression Analysis

The summaries of hierarchical regressions can be seen in Table 5. A hierarchical regression analysis was performed to determine gestational age's ability to predict balance and standing long jump (separately), after controlling for age. Gestational age was found to significantly predict variance in both balance and standing long jump outcomes. Thirty eight percent of the variance in standing long jump ($p < 0.05$) and 39.2% of the variance in balance performance can be explained by gestational age over-and-above age ($p < 0.05$). Hierarchical regression analyses were similarly performed to determine birthweight's ability to predict balance and standing long jump after controlling for age. Holding age constant, birthweight was found to be a statistically significant predictor of both balance time and standing long jump

Table 3

Gross Motor Performance by Fundamental Motor Skill

	Mean Score	Standard Deviation	Minimum Score	Maximum Score	Maximum Possible Score	Mean Skill Score as a Percentage of Maximum Possible Skill Score
TGMD-2 Locomotor						
Hop	3.4	3.1	0.0	10.0	10.0	34.0%
Horizontal Jump	3.4	1.8	0.0	6.0	8.0	42.5%
Gallop	3.7	1.4	0.0	6.0	8.0	46.3%
Leap	3.2	1.5	0.0	6.0	6.0	53.3%
Run	5.5	1.3	3.0	7.0	8.0	68.8%
Slide	5.5	2.1	2.0	8.0	8.0	68.8%
TGMD-2 Object Control						
Stationary Dribble	1.8	1.8	0.0	5.0	8.0	22.5%
Underhand Roll	2.3	1.7	0.0	7.0	8.0	28.8%
Overhand Throw	2.4	1.8	0.0	6.0	8.0	30.0%
Catch	2.7	1.0	1.0	5.0	6.0	45.0%
Striking a Stationary Ball	5.4	1.8	2.0	8.0	10.0	54.0%
Kick	5.1	1.8	2.0	8.0	8.0	63.8%

Table 4

Pearson Product Correlations

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
1. TGMD-2 GMQ	-												
2. TGMD-2 Locomotor Standard Score	0.945**	-											
3. TGMD-2 Object Control Standard Score	0.914**	0.732**	-										
4. Balance (s)	0.561*	0.592**	0.437	-									
5. Standing Long Jump Distance (cm)	0.600**	0.615**	0.489*	0.719**	-								
6. Grip strength (kg)	-0.114	-0.186	-0.007	-0.171	-0.025	-							
7. Gestational Age (wk)	0.409	0.432	0.318	0.612**	0.584*	-0.417	-						
8. Birthweight (g)	0.562*	0.564*	0.473*	0.671**	0.492*	-0.249	0.892**	-					
9. NICU Stay (days)	-0.358	-0.338	-0.328	-0.499*	-0.405	0.293	-0.885**	-0.892**	-				
10. Height (cm)	-0.153	-0.171	-0.108	0.103	0.213	0.751**	-0.162	-0.041	-0.040	-			
11. Weight (kg)	-0.108	-0.118	-0.079	-0.094	-0.256	0.669**	-0.459	-0.158	0.114	0.739**	-		
12. Waist Circumference (cm)	-0.184	-0.191	-0.147	-0.103	-0.482*	0.376	-0.443	-0.148	0.094	0.432	0.889*	-	
13. Age	-0.315	-0.327	-0.252	0.057	0.218	0.470*	-0.138	-0.111	0.068	0.683**	0.416	0.196	-

**Correlation is statistically significant to the 0.01 level (2-tailed)
* Correlation is statistically significant to the 0.05 level (2-tailed

Table 5

Hierarchical Regression for Balance and Standing Long Jump (n = 18)

	Performance Outcome Measure							
	Balance				Standing Long Jump			
	R^2	Adjusted R^2	ΔR^2	β	R^2	Adjusted R^2	ΔR^2	β
Model 1	0.010	-0.052	0.010		0.047	-0.012	0.047	
Age				0.101				0.218
Model 2	0.402	0.323	0.392**		0.431	0.356	0.384**	
Age				0.189				0.304
Gestational Age				0.632**				0.626**

	Performance Outcome Measure							
	Balance				Standing Long Jump			
	R^2	Adjusted R^2	ΔR^2	β	R^2	Adjusted R^2	ΔR^2	β
Model 1	0.010	-0.052	0.010		0.047	-0.012	0.047	
Age				0.101				0.218
Model 2	0.469	0.398	0.458**		0.317	0.226	0.269*	
Age				0.177				0.276
Birthweight				0.681**				0.522*

Note. Balance was transformed to account for skewness
*statistically significant to the 0.05 level (2-tailed)
**statistically significant to the 0.01 level (2-tailed)

distance, explaining 45.8% ($p < 0.05$) and 26.9% ($p < 0.05$) of variance in balance time and standing long jump distance, respectively.

Simple linear regression analyses found gestational age to not be a significant predictor of GMQ score ($p = 0.092$; see Figure 9 for scatterplot of gestational age and GMQ), locomotor standard score ($p = 0.073$), or object control standard score ($p = 0.199$; see Table 6). However, birthweight was found to predict GMQ score ($p < 0.05$; see Figure 10 for scatterplot of birthweight and GMQ), locomotor standard score ($p < 0.05$), and object control standard score ($p < 0.05$) using simple linear regression (see Table 6).

Table 6

Simple Linear Regression Summaries (n = 18)

	GMQ			Locomotor Standard Score			Object Control Standard Score		
Predictor	*B*	SE *B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Gestational Age	1.407	0.785	0.409	0.294	0.154	0.432	0.175	0.130	0.318
Birthweight	0.010	0.004	0.562*	0.002	0.001	0.564*	0.001	0.001	0.473*

*statistically significant to the 0.05 level (2-tailed)

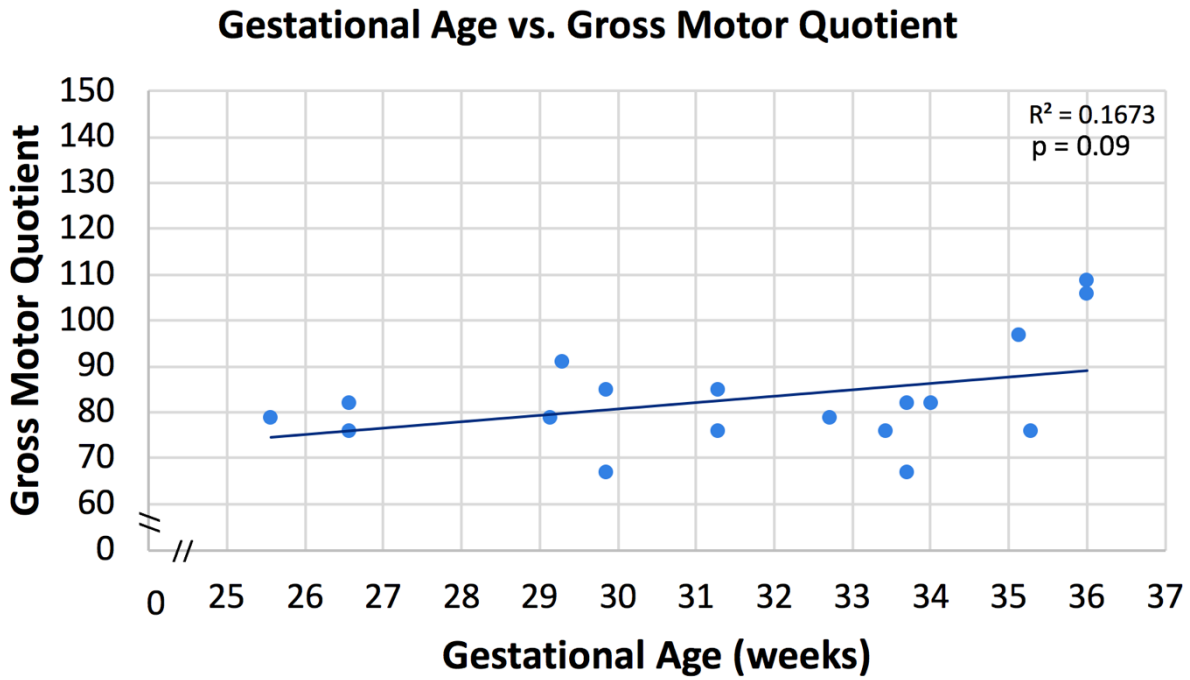


Figure 9. Scatterplot of Gestational Age and Gross Motor Quotient

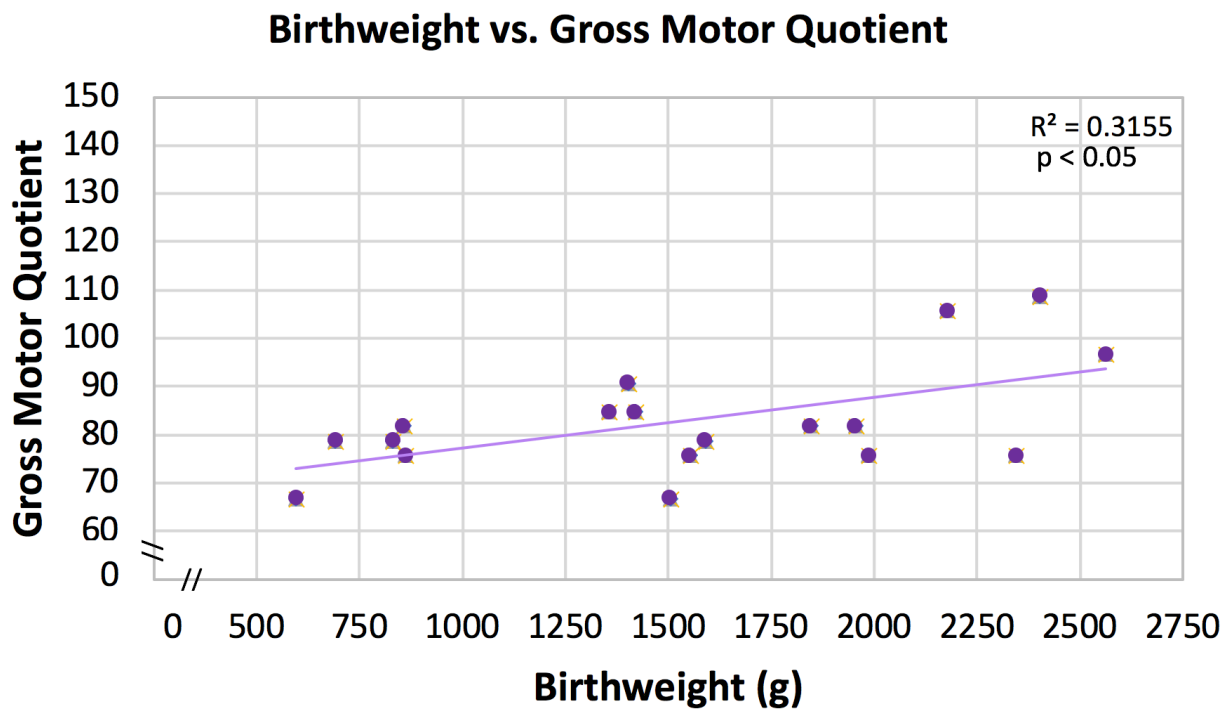


Figure 10. Scatterplot of Birthweight and Gross Motor Quotient

5.5 Discussion

The purpose of this investigation was to assess the gross motor performance for children born preterm, at age 4-6 years. Although it has been suggested that the long term negative outcomes of preterm birth are likely to increase as birthweight and gestational age decrease (Williams et al., 2010), it is still largely unknown whether children born moderate to late preterm children exhibit similar developmental risks (such as gross motor difficulties) as children born early preterm (Kerstjens et al., 2011). This investigation examined motor skill performance of children across the spectrum of preterm gestational ages. Our results showed that children born preterm exhibited poor gross motor competence at the later years of the early childhood period (4 to 6 years) regardless of gestational age at birth, and gross motor difficulties were not exclusive to those born early preterm. Such results are particularly important due to their consideration for children born at later gestational ages.

As the threshold of fetal viability is cited to range from approximately 22-25 weeks (Behrman & Stith Butler, 2007; Costeloe et al., 2000; Johnson & Marlow, 2017) in high-income countries (Blencowe et al., 2013), our participants represented the full range of preterm gestational ages, from 25 to 36 weeks gestational age. This is contrary to most studies which tend to recruit and assess those born at earlier preterm gestational ages, and therefore these findings offer novel information. In our sample, there was a high prevalence of participants born low birthweight, as 17 of the 18 participants were born <2,500 g. A low birthweight is likely associated with the infants' level of physical maturation when delivered early, and low birthweight concurrently occurs with over half of preterm births in Canada, with three quarters of all infants born low birthweight also being preterm (CIHI, 2009). Similarly, birthweight and gestational age were correlated in this study. Further, infants born very preterm and extremely preterm often require stays in neonatal intensive units (NICU) due to immaturity of body systems with early exposure to the extrauterine environment (Lowe, Cousins, Kotecha, & Kotecha, 2017). This was exhibited in our results, where the mean length of NICU stay for our participants was 48.3 ± 47.7 days, ranging 9 from 0-152 days, and over half of participants spent more than 30 days in neonatal intensive care. Overall, our findings showed high correlations between gestational age, birthweight, and length of stay in the NICU. Children born at younger gestational ages had lower birthweights and spent longer lengths of time in neonatal intensive care.

5.5.1 Physical Growth

The mean height and weight exhibited by our participants are consistent with previous mean height and weight findings of children born preterm at 5 years of age (Pierrat et al., 2011). At age 5, children born preterm have shown shorter stature and are lighter than children born at term (Pilviniene, Tutkuviene, & Baksiene, 2003) and demonstrate lower rates of catch-up growth, particularly for children born at younger gestational ages (Itabashi et al., 2007). Descriptive statistics support these trends in the research. The study cohort as a whole did not exhibit overweight or obesity; rather the sample as a group was between short in stature and light for their age, particularly for males. Seventy-two percent of participants had a height at or less than the 50th percentile for their age, with 44.4% measuring at or below the 25th percentile-for-age. Nearly 90% of participants fell at or below the 50th percentile for weight-for-age.

5.5.2 Gross Motor Performance

Gestational age was not found to be a predictor of gross motor development as measured by the Test of Gross Motor Development–Second Edition score composites. These scores (GMQ score, locomotor standard score, and object control standard score) are determined based upon the child' age. However, birthweight was found to predict 27%, 28%, and 18% of variance in the GMQ, locomotor standard score, and object control standard score, respectively. In addition, birthweight was found to predict balance and standing long jump measures. The strong relationship between gestational age and birthweight made it difficult to determine the relative contributions of these two variables, however it may be possible that birthweight is a mediating factor for the poor gross motor performance exhibited in this sample. As an infant's weight is likely to be lighter the earlier it is born (almost all participants were classified as low birthweight), it is possible that such gross motor competencies are affected by the combination of birthweight and gestational age. However, due to the children in this study performing gross motor tasks poorly even at the higher preterm gestational ages and birthweights, a child born preterm at a slightly larger birthweight should not be considered immune from motor difficulties that may present.

Overall, participants scored poorly on the TGMD-2 as determined by the established normative data, with only 12% of participants scoring "average", 11% participants scoring above the 50th percentile, and 0% of participants scoring higher than average. Other movement tests (such as the MABC-2, MAND, and BOTMP) suggest cutoff scores at the 15th and 5th percentiles,

to indicate at-risk motor impairment and severe motor impairment as determined by the specific test battery (Dewey et al., 2011; Piek et al., 2008, 2012; Wocadlo & Rieger, 2008). One third of participants scored below the 5th percentile; while, two-thirds of participants scored below the 15th percentile. The TGMD-2 uses descriptor categories, wherein the 'very poor' category represents performance at or below the 1st percentile and the 'poor' category represents performance between the 2nd and 8th percentile (see User Manual; Ulrich, 2000). Half of the participants fell within the categories of 'poor' or 'very poor'. The TGMD-2 also assigns an age equivalency of both locomotor skills and object control skills based upon the raw score. Age equivalency for locomotor skills was lower for child age in 83% of participants and lower in 89% of participants for object control skills. The subtests of locomotor skills and object control skills had mean age-dependent standard scores of 7.3 and 7.1, respectively. These findings are lower than standard scores reported in other studies of children at preschool and kindergarten age, which have been found to range from 8.9 to 10.8 for locomotor and 8.1 to 9.1 for object control skills, respectively (Kit, Akinbami, Isfahani, & Ulrich, 2017; Kordi, Nourian, Ghayour, Kordi, & Younesian, 2012).

Motor difficulties and/or impairment in the later years of the early childhood period have been reported previously in the literature for children born early preterm, consistently showing a high incidence of motor impairment when compared to full-term peers (Foulder-Hughes & Cooke, 2003a). For example, reports of motor difficulties of preschool and school-age children without severe handicaps have been cited to range from 30-40% and up to as high as 81% in those born early preterm as compared to children born at term, with low motor performance exhibited across early preterm gestational ages and birthweights (De Kleine et al., 2006; Foulder-Hughes & Cooke, 2003a; Goyen & Lui, 2002; Van Hus et al., 2014; Wocadlo & Rieger, 2008). When compared to full-term children, research has shown that toddlers born moderate to late preterm also score lower and demonstrate gross motor developmental delays (de Jong et al., 2012). Research also suggests lower gross motor performance throughout early and middle childhood. For example, Prins and colleagues (Prins et al., 2010) found 20% of moderate preterm-born children demonstrate atypical motor development scores when assessed at 4 years and Odd et al. (2013) showed moderate to late preterm-born children at an increased risk of lower movement proficiency and coordination as compared to peers born at term when assessed at age 7-8 years. Such evidence indicates that although the early preterm population exhibited

motor issues, children born at later gestational ages are not excluded from having movement difficulties, which is supported in our results; specifically, there was no correlation between gestational age and gross motor performance as measured on the TGMD-2.

An increasing amount of evidence suggests that fundamental motor skills are not being developed with proficiency in non-preterm populations. For example, Hardy and colleagues (Hardy, King, Farrell, Macniven, & Howlett, 2010) have shown that 4 year old Australian children demonstrate low gross motor skill development using the TGMD-2, particularly for object control items such as the throw and catch. Poor proficiency on fundamental movement skills has also been demonstrated by non-preterm-specific samples in childhood and adolescence, and object control skills tend be mastered at lower rates than locomotor skills (O' Brien, Belton, & Issartel, 2016; Okely & Booth, 2004; Vandaele et al., 2011), which is consistent with the results of this study. Such evidence indicates that fundamental movement skill development requires improvement in both non-preterm and preterm populations. While it has been suggested that children born preterm exhibit higher rates of gross motor difficulties versus full-term peers (Foulder-Hughes & Cooke, 2003a), non-preterm populations too are demonstrating low levels of fundamental motor skill acquisition in early childhood.

5.5.3 Balance and Muscular Strength

The mean grip strength measured by participants in this study appears consistent with other studies providing grip strength of 4-6 year old children (Butterfield et al., 2009; Häger-Ross & Rösblad, 2002; Sanchez-Delgado et al., 2015). The distance accomplished by participants in the standing long jump assessment similarly seems to be consistent with values reported in other studies (Ayán-Pérez et al., 2017; Iivonen, Sääkslahtia, & Nissinenb, 2011). Although grip strength can be a useful, easy measure of muscular strength in later childhood years and adolescence (Wind et al., 2010), as well as throughout adulthood to indicate musculoskeletal fitness (Warburton et al., 2006), this study indicates that standing long jump may be a better measure of strength than grip strength in populations of very young children. The JAMAR dynamometer has been cited as the most popular for clinical practice and research (Sanchez-Delgado et al., 2015); however even the shortest grip handle distance appeared too large for many of the participants, particularly as many were physically petite given their age. A dynamometer made specifically for the small size of children's hands may offer more accurate

grip strength of young children and may offer more accurate insight as to the contribution of grip strength in early childhood period to gross motor competence. Grip strength itself may not have found to be particularly relevant in this study due to the limited number of TGMD-2 items (other than perhaps strike and throw), that directly require a strong grip in order to be scored at a mastery level. Although standing long jump distance appeared within an adequate range for children of this age, longer distance achieved was found to be associated with better gross motor competence. This may indicate that standing long jump is important, however the complexity of the long jump movement may have a less direct impact on fundamental movement skills. This may be because standing long jump requires multiple skills such as coordination, balance, and strength (rather than strength alone) to complete the movement.

The balance of children in this study was skewed positively towards low static balance times, with participants as a whole demonstrating short balance time capabilities. Our findings show that there was a significant correlation found between balance and GMQ, locomotor standard score, as well as with standing long jump. When comparing the mean balance time of participants to other studies providing static balance of children the same age and using similar protocols, children in this study appear to have poor balance capabilities for their age (Condon & Cremin, 2014; Latorre Román, Mora López, Robles Fuentes, & García Pinillos, 2017). The significant findings between better static balance capability and various variables (such as higher GMQ score, locomotor standard score, and gestational age) in this study provide insight as to the importance of postural control when discussing gross motor capabilities of children born preterm. The preschool years before formal school entry are an important time period for the development of balance (Eshaghi, Jafari, & Jalaie, 2015). Between the ages of 3 and 10, the development of the somatosensory becomes involved in greater amounts until balance control at an adult level is reached (Forseth & Sigmundsson, 2003; Geuze, 2005; Mickle, Munro, & Steele, 2011). Standing postural control is a process that begins to develop in early childhood, and requires organized muscular responses to external stimuli (Liao, Mao, & Hwang, 2001), in addition to the coordination of complex sensory input from the somatosensory, kinesthetic, vestibular, and visual system, in order to maintain one's balance (Cumberworth, Patel, Rogers, & Kenyon, 2007; Geuze, 2005). Difficulties with coordinating such information subsequently affects skills requiring posture (Forseth & Sigmundsson, 2003). Static balance therefore plays an essential role in the proper development of gross motor movement (such as locomotor skills) due

to its contributions to bodily control (Latorre Román et al., 2017). As mastery of balance in early childhood is critical for the performance of movement skills, without acquiring balance during these years children may not have the capability to perform movements such as jumping and running adequately (Mickle et al., 2011). How much postural control a child has developed can therefore act as a constraint for the child's development of motor skills (Geuze, 2005).

Children born preterm (particularly those born very preterm) are postulated to exhibit static balance difficulties due to neurological consequences of preterm birth for the central nervous system, such as neural pathway immaturity, defects in neural transmission, myelination defects or delays neuropathological factors, and neurodevelopmental impairment (Eshaghi et al., 2015). The impact of younger gestational age on poorer balance capability when controlling for age found in this study is therefore supported by literature with regards to preterm populations and children with motor difficulties. Poor static balance as exhibited by the 4-6 year old children in this study is consistent with other populations of children with motor difficulties, such as poor postural and balance control that has been found in children with developmental coordination disorder (Geuze, 2005). Furthermore, when static balance is assessed through vestibular functioning using vestibular-evoked myogenic potentials in early childhood, children born very preterm have shown more severe issues than children born moderate preterm, with both very preterm and moderate preterm demonstrating poorer static balance capability as compared to term-born peers (Eshaghi et al., 2015), which is in agreeance with the findings of this study. It has been recommended that when static balance performance is low compared to normative data in 3-6 year olds, children be assessed further to determine if motor delays are also present (Latorre Román et al., 2017), lending to the important role that balance plays in both gross motor capability and the identification of such issues.

To balance, one requires a certain amount of muscular strength to be possessed in order to stabilize the body (Logan, Robinson, Rudisill, Wadsworth, & Morera, 2014), however it is also suggested that balance may be an underlying mechanism controlling muscle strength's contribution to locomotor movement (Castro-Pinero et al., 2010). As fundamental motor skills are those that require force production through use of large muscles, muscular strength is an inherent requirement. The relationship found between the performance measures of balance and standing long jump is therefore in accord with the literature on standing long jump's impact on motor competence, as is further evident by standing long jump's relationships found with GMQ,

locomotor standard score, and object control standard score. Although standing long jump is a measure of muscular strength, to perform the movement itself requires various systems to work together for movement coordination. Standing long jump has been measured in relationship to one's static balance (Condon & Cremin, 2014), and lower motor competence has been found to correspond to poorer broad jump performance and shorter single leg balance time in children age 5-7 years (Hands, 2008). As such, coordination and balance are crucial components for the capability of performing locomotor skills including hopping, jumping, and galloping (Logan et al., 2014). These movements that require coordinated limb positioning throughout the movement may therefore be affected by combination of poor coordination and inconsistent motor control (Hands, 2008), which may be in part due to poor lower body strength. Children with low motor competence may therefore have issues with performance consistency, displaying erratic motor skill patterns that can occur with either not enough motor control, or over-rigid movements in an attempt to control movement, leading to poor performance (Hands, 2008). If a child born preterm exhibits sub-optimal performance of either balance or muscular strength, complex gross motor movements are likely to also suffer due to the limitations they invoke. Poor motor capabilities may then in turn limit opportunities for improving balance and strength through motor skill practice. Due to the prevalence of neurological injury and alterations in association with preterm birth, as well as the important role brain development plays in the development of motor capability, balance and strength may themselves be indicators of the true underlying issue being the neurological system.

5.6 Follow-Up and Intervention

Even in the neonatal period (the first 28 days of life), statistics show higher rates of re-admission and medical morbidities for children born late preterm (Morse et al., 2009). Such evidence suggests that irrespective of gestational age, all children born preterm should be monitored in terms of development (Morse et al., 2009; Shah, Kaciroti, Richards, & Lumeng, 2016). Although evidence of poor motor skills within the preterm population has been found throughout childhood (Goyen & Lui, 2002), minor motor problems may not cause enough interference to be detected until a child enters school (Forslund, 1992). The findings of this investigation support continuous follow-up throughout childhood of children born preterm regardless of health status at birth or gestational age, and particularly at age of entry to formal

schooling. Assessment of gross motor skill proficiency in later childhood is therefore warranted, as predictions of later gross motor proficiency in preterm-born children are not accurate if only assessed at very young ages (Prins et al., 2010). Such follow-up procedures should include an adequate gross motor-specific assessment, and children should be referred for intervention at the earliest indication of any motor-based issues. The results of this study support the importance of examining motor proficiency in the preterm population at later childhood ages to identify any gross motor difficulties that may exist. Such evidence is particularly important with regards to the monitoring of motor development of children born moderate to late preterm past infancy, wherein this cohort typically receives little to no developmental follow-up after birth (Pitcher et al., 2012). The age group and gross motor findings in this study support the overall need for assessing school readiness across the full range of preterm gestational ages prior to the entrance to formal schooling (Shah et al., 2016). Entrance to kindergarten or grade 1 may therefore provide a convenient landmark for the assessment of gross motor competence, since the age in British Columbia for entry to formal schooling is 5-6 years (kindergarten at age 5 and grade 1 at age 6; British Columbia's Education Program: Newcomer Welcome Letter, 2016).

5.7 Limitations and Future Directions

Limitations of this study included a small sample size (n = 18) and a lack of a term-born control group, and the results therefore cannot be used to represent the entire preterm population or to draw conclusions on comparisons of this cohort to full-term peers. These factors limit the statements that can be made regarding the relationship between gestational age and gross motor skill development. Furthermore, twins represented a marked proportion of the participant sample, which detracted from assumptions of independence when conducting analyses. As such, it is inconclusive whether twin birth had an influence on the gross motor competence exhibited by the participant sample as a whole. Children in this study were assessed with regards to their chronological age, rather than their adjusted age, in order to match realistic assessment practices in medical and school-based assessments at age 4-6. Although studies examining children born preterm sometimes use adjusted age throughout childhood (Kato et al., 2016; Van Hus et al., 2014), this practice is not recommended past 2 to 2.5 years (Dietitians of Canada & Canadian Paediatric Society, 2014). Further, this study recruited children who appear otherwise healthy with no physical disabilities or diagnosed neurological conditions; therefore it is unlikely that the

children's age would be adjusted for prematurity, particularly since children born moderate to late preterm often receive no follow-up throughout the childhood years (Pitcher et al., 2012). Accordingly, all of the normative data (e.g., growth charts, TGMD-2) utilized were not specific to a preterm population. However, it is possible that normative data sampled from the general population does include children who were born preterm, yet that information gestational age was not collected. Our recruitment strategies may also have influenced the recruitment of children with low birth weight, whereby the parents of participants who were particularly fragile at birth may have been more connected through the support groups in which recruitment posts were shared, including those for children who had stayed in neonatal intensive care units.

Future research endeavours in the preterm population are strongly recommended to include the moderate to late preterm cohort. Due to the dearth of evidence-based intervention strategies appropriate for children born preterm with minor gross motor difficulties, further investigations into such therapies is also recommended. This study offers evidence that children born preterm may show poor gross motor competence across the preterm gestational age range, including the moderate to late preterm population. The findings also suggest that difficulties with balance and/or strength in the preterm population may underlay gross motor competence and requires more in-depth investigation. Longitudinal studies of this nature with larger sample sizes are encouraged for assessing gross motor competence and its underlying contributors across the full range of preterm gestational ages, as well as with matched term-born peers.

5.8 Conclusion

This study generated information regarding the relationship of gestational age on gross motor development in children born preterm. Four to six year old children born preterm exhibited low levels of gross motor competence as measured by the TGMD-2, in addition to poor balance capabilities. Gross motor performance was not predicted by gestational age at birth but birthweight was predictive. Balance and standing long jump capabilities were predicted by gestational age and birthweight independently, holding age constant.

While gross motor proficiency of the preterm population has previously focused on children born at earlier gestational ages, the results of this study support the growing body of evidence suggesting that children born across the full range of later gestational ages also demonstrate poor gross motor skill proficiency in early childhood. The poor balance times

demonstrated by participants appeared to be related to gestational age at birth, and may play an important role in gross motor skill capability. Lower body strength as measured by standing long jump distance was also related to gestational age at birth, and demonstrated significant correlations with gross motor skill capability. Assessment of gross motor skills at age of school entry may be beneficial for children born preterm. Long-term investigations throughout childhood are required to examine the impact of gestational age on gross motor skill proficiency in the preterm population as compared to children born at term.

CHAPTER 6: Commentary on Twin Participants

6.1 Introduction

As twins were strongly represented in this study, describing this sub-population is of benefit. Detailed information such as the zygosity of twin participants was heterogeneous and not formally collected as data, therefore direct comparisons of the sets of twins to each other is not possible. However, discussing the findings of the twin participants separate from the complete data set offers a unique perspective of the data.

6.2 Descriptions of the Twin Participants

Five sets of twins participated in this study, totalling ten of the eighteen participants. Two sets of twins were 4 years of age, while three of the sets of twins were 5 years old. The five sets were a combination of identical and fraternal twins and included three sets of all female twins, one set of all male twins, and one set of mixed-sex twins.

The mean gestational age of twin participants was 31.5 ± 3.4 wks, with two sets of twins born moderate to late preterm, and three born early preterm. Twin participants had a mean birthweight of 1455.3 ± 581.0 g. The birthweight and weight of twin participants is presented in Table 7, respectively. Inter-twin height differences ranged from 0-4.1 cm, while inter-twin weight differences ranged from 0.6 to 4.8 kg. All twin participants were born as a low birthweight classification (n = 2 = low birthweight; n = 5 very low birthweight; n = 3 extremely low birthweight). Differences in inter-twin birth weight ranged from 5.0 g to 822.0 g. Four out of the five sets of twins were born by caesarean section.

Differences in balance times varied between twins, ranging from 0.4-12 s, while inter-twin grip strength differences were 0 to 3 kg and inter-twin standing long jump distances ranged from 1 to 11 cm. The twin participants had a mean GMQ of 83.5 ± 14.2, a mean locomotor standard score of 7.6 ± 2.9, and an object control standard score of 6.9 ± 1.9. The gestational age and GMQ of each set of twins can be seen in Table 7.

One set of twins outperformed the entire sample of participants. This set of twins were 4 y 6 mo old, identical females, were born at 36 weeks, and spent no days in the NICU. They demonstrated the two highest GMQ scores, two longest standing long jump distances, and both scored age-equivalencies above their age on the TGMD-2 locomotor and object control subsets.

Table 7

Descriptive Summary of Results for Twin Participants

Twin	Sex (F/M)	Age (yr)	Gestational Age (wk)	Birthweight (g)	Height (cm)	Weight (cm)	GMQ	GMQ Descriptor	Balance (s)	Grip Strength (kg)	Standing Long Jump (cm)
1A	F	4.50	36.00	2400	103.0	15.9	109	Average	17.1	6	111
1B	F	4.50	36.00	2175	103.0	15.3	106	Average	29.1	6	115
2A	M	4.17	29.86	1417	103.4	17	85	Below Average	1.9	8	75
2B	M	4.17	29.86	595	99.7	13.5	67	Very Poor	2.3	6	76
3A	F	5.58	31.29	1355	113.5	18.7	85	Below Average	5.2	10	94
3B	F	5.58	31.29	1500	114.5	19.4	76	Poor	11.6	8	86
4A	F	5.83	33.71	1503	115.1	18.1	67	Very Poor	4.3	9	83
4B	M	5.83	33.71	1843	117.9	19.8	82	Below Average	8.6	12	94
5A	F	5.50	26.57	855	114.3	23.4	82	Below Average	1.5	12	81
5B	F	5.50	26.57	860	110.2	18.6	76	Poor	2.7	10	70

6.3 Discussion

There was a high number of twin sets participating in this study. Increasing numbers of twin births are occurring as a result of the increased trend of older maternal age and technology-assisted reproduction (Blencowe et al., 2013). Multiple gestations (2 or more infants) accounted for approximately 3% of all live births in British Columbia during the years the participants were born (Public Health Agency of Canada, 2013), and have been rising steadily in BC since the millennium (British Columbia Perinatal Health Program, 2008). The risk of preterm birth is increased for multiple gestation pregnancies, with twins having much higher preterm labour and delivery rates as compared to singleton births (Chauhan, Scardo, Hayes, Abuhamad, & Berghella, 2010; Lee, Cleary-Goldman, & D'Alton, 2006; The Lancet, 2006). In 2010, there were 53.0 twin preterm births per 100 live births in Canada, as compared to 6.2 singleton preterm births per 100 live births (Public Health Agency of Canada, 2013), and multiple live births have accounted for approximately 20% of all preterm live births in BC (British Columbia Perinatal Health Program, 2008). Multiple gestation births are particularly common in the moderate to late preterm period, and more specifically, in the late preterm period (British Columbia Perinatal Health Program, 2008; Lee et al., 2006). This is evident by the average gestational age of twins at delivery being 35 weeks in Canada (CIHI, 2009). Twin participants in this study were born across the range of preterm gestational ages as were the singleton participants, as the twin participants were born between 26 and 36 weeks.

Due to intrauterine growth restrictions in the third trimester of pregnancy, it is common for twins to exhibit lower birthweight than singleton births (Hall, 2003), in addition to higher preterm rates. Preterm birth and low birthweight have been found to occur in approximately 50-60% of twin births, with 10% of twin births further classified as early preterm or very low birthweight (Blondel, Macfarlane, Gissler, Breart, & Zeitlin, 2006; Blondel et al., 2002; Chauhan et al., 2010). Due to multiple gestations' high contributions to preterm birth and reduced intrauterine space for growth, children from multiple gestations are overrepresented within the preterm and low birthweight populations (CIHI, 2009; Lee et al., 2006). This provides rationale for the high number of twins who participated in this study, and the low birthweight they were all born at. The increase in multiple gestations has led to this population accounting for a large proportion of adverse complications, neonatal outcomes as well as obstetric outcomes, many of

which are in relation to preterm birth and/or low birthweight (Blondel et al., 2002; Lee et al., 2006).

Multiple gestation births are a common reason for caesarean sections, with caesarean sections and induction of labour during the preterm period a major contributing cause of high preterm birth rates in this population (Blondel et al., 2002; British Columbia Perinatal Health Program, 2008). For example, the preterm birth rate associated with Canadian caesarean section deliveries (2009) is 13.3% as compared to vaginal deliveries 6.5-6.9% (CIHI, 2009). This trend was also consistent for our participant sample, where eight out of the ten preterm-born twins were delivered by caesarean section, whereas only four of the eight children born as single gestation preterm births were caesarean sections.

Zygosity describes whether twins arose from one egg or two (Hall, 2003), and may well be a factor in the differences seen in our twin population, as monozygotic twins have shown more neuromotor homogeneity than dizygotic twins (Lopes, Tani, Katzmarzyk, Thomis, & Maia, 2014). For example, the identical set of twins with the highest GMQ and standing long jump scores (described above) exhibited similar results to each other, measuring the same height to the tenth of a centimetre and demonstrating similar scores on the TGMD-2. Yet, they may also have been offered greater opportunities that afforded the development of such gross motor capabilities. Furthermore, as can be seen in Table 7, the twin who was born at a heavier birthweight was still heavier in most sets of twins in this study (without regard for sex, zygosity, or health conditions at birth). However, these findings bring to light complex discussions regarding the relative roles biological predisposition and environmental affordances play in a child's growth and development. Twins born at a lower birthweight did not necessarily exhibit lower GMQ scores as compared to the twin born at a higher birthweight. Furthermore, the twins with the longer balance time did not necessarily demonstrate better GMQ scores as compared to the twin with lower balance times. As this study was not specific to twins and the twins represented a small sample size, no conclusions can be drawn from examining the data of the participants who were twins, yet questions of nature versus nurture are intriguing.

6.4 Future Directions and Conclusion

As a population, twins born preterm have displayed delayed catch-up in gross motor skills past 1 year of age, and when adjusted for age, twins have shown poorer gross motor

competency in toddlerhood as compared to singletons (Nan et al., 2013). However, comparisons between preterm twins and preterm singletons have not been examined (Nan et al., 2013). Such investigations may be a research direction of interest, as are examinations of whether birth characteristics specific to preterm-born twins are predictive of later physical growth and gross motor development. The influence of preterm birth in multiple gestations are of particular interest due to the unique situation of these children and the high prevalence of preterm birth within this population. Children born preterm, who are also multiple gestation, are a sub-population of interest for future preterm research investigations and may offer informative findings when examined in further detail.

CHAPTER 7: Concluding Discussion

7.1 Summary of Study Outcomes

The overall aim of this research was to add to the body of knowledge in the discipline of motor development in general, and in the area of motor development and children born preterm specifically. This research generates empirical evidence by examining the relationship between gestational age and gross motor performance of fundamental motor skills (locomotor, object control, and balance) and muscular strength for children born preterm between the age period of 4 to 6 years. Findings showed that children born preterm exhibited poor gross motor capabilities at age 4-6 years irrespective of gestational age at birth, which is in support of the existing literature (e.g., De Jong, Verhoeven, Lasham, Meijssen, & van Baar, 2015; Foulder-Hughes & Cooke, 2003a; Odd, Lingam, Emond, & Whitelaw, 2013). Foulder-Hughes and Cooke (2003a) have also found poor motor assessments at different gestational ages and birthweights, indicating that the relationship between gestational age, birthweight, and motor proficiency is not linear, but complex in nature. The inclusion of balance-specific and muscular strength measures provides additional information regarding the gross movement capabilities of preterm children. Static balance capability and standing long jump were found to be more important to overall gross motor skill proficiency as compared to grip strength.

A major limitation of this investigation is a lack of a control group comprised of full term peers matched for chronological age. Other research has shown that children born very preterm exhibit minor motor impairments at much higher rates compared to children born at term, across multiple assessment batteries (Foulder-Hughes & Cooke, 2003a). For example, Forslund and Bjerre (1989) showed that children born <35 weeks demonstrated less skilled gross motor function versus full-term peers at 4 years of age; further, gestational age nor birthweight were considered explanatory factors (Forslund & Bjerre, 1989).

While our findings support some of the work in the literature, other studies have shown that children born moderate to late preterm exhibit better performance on gross motor skill assessments compared to early preterm cohorts. For example, Kerstjens and colleagues (2011) found preschool children born early preterm demonstrated lower gross motor function than both moderate preterm and full term peers, and no difference was shown between the moderate preterm and full term peers. Additionally, at age 5 years, micropreemies (<750 g) have demonstrated lower scores than other preterm participants (Goyen & Lui, 2002). It has been

suggested that that the combination of the brain immaturity plus the health and environmental conditions associated with preterm birth may have a larger effect on the preterm brain and maturational processes of children born at earlier gestational ages (Kerstjens et al., 2011). This is proposed to lead to subsequently higher risks of poor development in younger gestational age preterm populations (Kerstjens et al., 2011). As this study did not have a control group, statements cannot be made concerning how the children preterm population performed as compared to full-term peers. However, such inconsistencies in the literature and the finding that children born at later preterm gestational ages are demonstrating poor gross motor competence in addition to those born at early gestational ages, support the need for including children born across all gestational ages when examining the outcomes of preterm birth.

The variance in muscular strength outcomes of children born preterm in this study were explained in part by both gestational age and birthweight, indicating that the preterm contributors to gross motor competence is multi-factorial. Balance outcomes in this study are consistent with other studies of children born preterm. Gestational age and birthweight also explained some of the variance in balance scores seen, and overall the children in this study exhibited poor static balance capabilities when assessed in a balance protocol separate from the TGMD-2. Such balance deficits have also been found to be lower in children born preterm compared to full-term counterparts in early childhood (Forslund & Bjerre, 1989; Goyen & Lui, 2002; Van Hus et al., 2014), supporting our finding that poor balance capability is a negative long-term outcome of preterm birth. Due to the prevalence of neurological injury and alterations in association with preterm birth, as well as the important role brain development plays in the development of motor capability, balance and strength may themselves be indicators of the true underlying issue being the neurological system.

Due to the public nature of the recruitment strategies used, the population of participants may represent the general population of children born preterm who are not receiving follow-up care, as compared to participants in studies whose who are recruited through developmental tracking programs. The inclusion criteria used was unconventional in its inclusion of all preterm gestational ages and birthweights, as many studies limit their investigations to children born in one preterm gestational age category and/or birthweight category.

7.2 Observations

We observed certain behaviours that were not part of analysis or data recording, but were noted during the assessment or in conversations with respective parents. Although all children performed the assessment measures, due to the young age of the participants, the process was not as simple as protocols indicate, due to attentional focus, disruptive behaviour, comfort in the laboratory environment, and/or willingness to cooperate. Although efforts were made to limit distractions from the assessment, it is difficult to determine to what degree these factors can be attributed to the children's young age, or to other factors. Some participants however, exhibited prominent behavioural issues during the assessment that did not appear to be transient when discussed in conversation with parents. Level of motivation to participate appeared to increase once the TGMD-2 object control skills were introduced, but this may also be related to increased comfort level in the laboratory environment or other factors, such as the use of colourful objects, which were more enticing.

Specific observations of note during administration of the assessment protocols included the motor skills of striking and static balance, as well as observations made during the assessment of grip strength. For proper form of the strike, the TGMD-2 requires participants to position their body and hand grip to hit the ball from either the right or left side relative to the tee. However, when striking, some participants struggled to maintain a side preference; rather, many of the children attempted to alternate their side dominance during the assessment. It is unknown whether this behaviour is unique to the cohort, but research has shown that children born full term have demonstrated stronger side preference and stronger skill competence on their dominant side as compared to children born preterm (Johansson, Domellöf, & Rönnqvist, 2014).

When assessing static balance, some participants exhibited difficulty with the positioning of their hands on their hips. This could have been due to unfamiliarity with the position, or a greater focus on their lower body balance, diverting their attention from their upper body positioning. When assessing grip strength, some participants similarly struggled to maintain proper positioning while maximally squeezing the dynamometer. Examples of such deviations from proper position included lifting their feet off of the floor, abducting their elbows, twisting their trunk, or using the opposing hand to grab the tool. Although maintaining positioning is required for proper collection of data, it may have been that the children had difficulty following multiple instructions while concentrating on performing the task at hand. Alternatively, in an

attempt to perform the task better (for example, using both hands to squeeze the dynamometer produced a higher reading), the children may have been willing to ignore following certain directions. Assessments requiring fewer directions to focus on during the task are therefore optimal for young children whenever possible.

Observations were also made in relation to motor skills, which were not formally assessed in the investigation. In particular, the capability to walk up and down stairs was noted. All participants had to walk down a set of stairs to access the area used for the running assessment of the TGMD-2, and participants returned to an upper floor using the stairs. Children between the ages of 4 and 6 years are capable of walking both up and down stairs alternating one foot per step and progressing to walking up stairs while holding an object (Gerber et al., 2010; *Gross Motor Development Checklist*, 2017; Hagan, Shaw, & Duncan, 2017). However, it was observed that some of the children were still walking down and/or up stairs stepping both feet onto each step, and/or requiring the handrail. In contrast, other participants were running up and down the stairs or jumping down from a few stairs above, without concern of alternating feet. These movement observations were not recorded for data analysis; however, walking up and down stairs is an important fundamental motor skills of daily living. As such, it would be important to consider this motor task in future research.

The fine motor skills of participants were not assessed; however, the drawing samples of participants were observed. Drawing samples were used to confirm handedness of participants. As well, the children were provided the option of drawing while their respective parent completed informed consent forms and the background questionnaire. The fine motor capabilities of the children ranged widely, with participants showing both immature and mature grip holds, as well as both uncontrolled and coordinated strokes across the cohort. Such differences may simply be an outcome of age, as the fine motor expectations of a 4 year old differ from that of a 6 year old. However, the parents of multiple participants commented on the poor or above average fine motor capabilities of their children, with some participants already receiving intervention specific to the development of fine motor skills. Principles of motor development follow that gross motor skill development matures prior to fine motor skill development, as the body develops control of large muscle groups before developing control of the smaller muscles required for intricate movement. The identification of fine motor skill difficulties is often prioritized in the school setting due to its direct impact on academic work;

however, disregard for gross motor difficulty identification is worrisome. It may be beneficial to collect information in future studies regarding whether children with gross motor issues also exhibit fine motor issues, however it is important to report them distinctly as separate entities rather than grouping them together.

In conversation with participants and parents, there was a clear indication that participants received a broad range of formal opportunities for the development of fundamental movement skill development. This range included participants who were not comfortable or proficient with gross motor skills as noted by the parents, as well as participants who participated in an extensive list of organized and unorganized opportunities that encouraged gross motor skill exposure and development. For example, some participants were engaged in multiple organized sports and physical activities whereas others were involved in few or none. In future work, it may be of interest to collect such information to provide insight as to the formal movement opportunities children are being offered in early childhood and their relationships with gross motor proficiency.

7.3 Knowledge Translation

The knowledge generated through this research is of interest to a number of target audiences. Primarily, the knowledge users are other researchers involved in public health, preterm birth outcomes, and pediatric development. Parents of children born preterm are also an important audience, as are organizations offering resources and information related to preterm birth, such as the Canadian Premature Babies Foundation. These knowledge users may in turn impact health care professionals who offer care to children born preterm in areas such as physical therapy, pediatrics, and obstetrics, and those offering movement-based opportunities who recognize children with potential motor difficulties (e.g., physical education teachers, activity program leaders, and qualified exercise professionals). Delivery of knowledge was translated to these various end users through diffusion and dissemination channels due to the scope of this research, but with a multi-strategy approach.

In order to deliver knowledge to peers and researchers, findings of the empirical work will be submitted for publication in a peer-review academic journal (Chapter 5). In addition, results on a sub-population of participants have been presented at the International Society of Behavioral Nutrition and Physical Activity 2018 Annual Meeting in Hong Kong. Furthermore, a

narrative review on the literature regarding gross motor competence of children born preterm (Chapter 3) was published in the *Health & Fitness Journal of Canada* (HFJC). An infographic on how to correct for age in the preterm population when assessing gross motor milestones, was also created and published in a peer-review academic journal (HFJC), along with a summary to supplement the infographic (see Figure 11 and Chapter 2). Although this infographic was intended for knowledge users for a younger child base (i.e., children under the age of 3 years), it is relevant to the population of discussion. There are two primary benefits of a resource of this nature. First, if parents and health professionals of children born preterm understand how to properly adjust for age when assessing the gross motor skills of preterm children in the infant and toddler years, they may observe gross motor skill delays early and seek intervention to address possible difficulties. Second, if parents understand how to track gross motor capabilities of their child born preterm, they may be more attuned to continued observation of their child's gross motor skills throughout childhood.

Mobilizing knowledge is critical for the preterm population. For example, the infographic on adjusted age was created due to the lack of information currently available on gross motor milestones and adjusted age. Fletcher and colleagues (2017) have shown that 62% of parents of children born preterm were unaware of adjusting their child's age or incorrectly calculating it. Moreover, parents who can properly adjust their child's age based upon gestation are more likely to anticipate the child's growth and developmental patterns based on adjusted age (Fletcher et al., 2017). In contrast, improper or lack of adjustment of age can lead parents to believe their child's motor development is delayed, prompting unwarranted concern. This supports the need for simple informational resources on age adjustment as part of the comprehensive care approach for children born preterm (Fletcher et al., 2017). We recommend that adjusted age be used to track the growth and motor development of children born preterm by health care professionals and parents alike over the first year or two. Promoting the distribution of resources (e.g., see the associated infographic) can be a beneficial tool for parents of children born premature to refer to, as well as for use by allied health professionals and qualified exercise professionals.

In addition to academic publications and presentations, knowledge translation and mobilization of this work to the parents of the participants in this study was of primary importance. The parents or guardians of each participant will receive a set of two infographics (see Figure 12 for examples). One infographic was customized for each participant to share their

results from the study, while the other was a generalized infographic and included information on the importance of gross motor skill development and tips to improve balance, muscular strength, coordination, object control skills, and locomotor skills. By providing the supplementary infographic, parents are provided with both their child's results, as well as a simple tool to increase awareness and actively improve their child's gross motor development.

7.4 Limitations

Although this study provided informative information that can be used to direct future investigations, it had limitations. Primarily, the sample size of participants was not large (n =18), making it difficult to determine the generalizability of the results. Further, there was no control group. While there is a large cohort of children born full term, it is challenging to recruit children born full term who are matched to the children born preterm for chronological age with birth weight within a specific range of values. The lack of a matched control group means it is not possible to draw conclusions between participants born preterm and children full term, beyond comparisons to normative data. Additionally, both singleton birth and twin participants were included in this investigation, implying that the participants were not completely independent of each other. The investigation was a cross-sectional study; therefore, no statements can be made about growth and gross motor development within participants over time. Finally, use of the TGMD-2 was also limiting, as normative data is not dependent on a Canadian or preterm population, there is no distinct stability assessment, and scoring of certain skills of the assessment did not appear to accurately capture the capability of the participant. As an example, a participant may still score highly on the leap due to easily-met performance criteria, even though their form may not represent a mature leap pattern when observed.

While it is important to include both female and male participants, we did not examine sex as a variable. First, analyzing the data on sex was not appropriate due to the uneven distribution of males and females that participated in the study. In addition, the object control subtest standard scores on the TGMD-2 are determined using different charts for females and males, making sex-based comparisons potentially misinterpreted. Further, the literature to date does not consistently demonstrate sex differences in areas of gross motor skill capability, resulting in inconclusive assumptions of sex-based gross motor skill differences. For example, some studies have found no differences in motor skill capability between boys and girls in

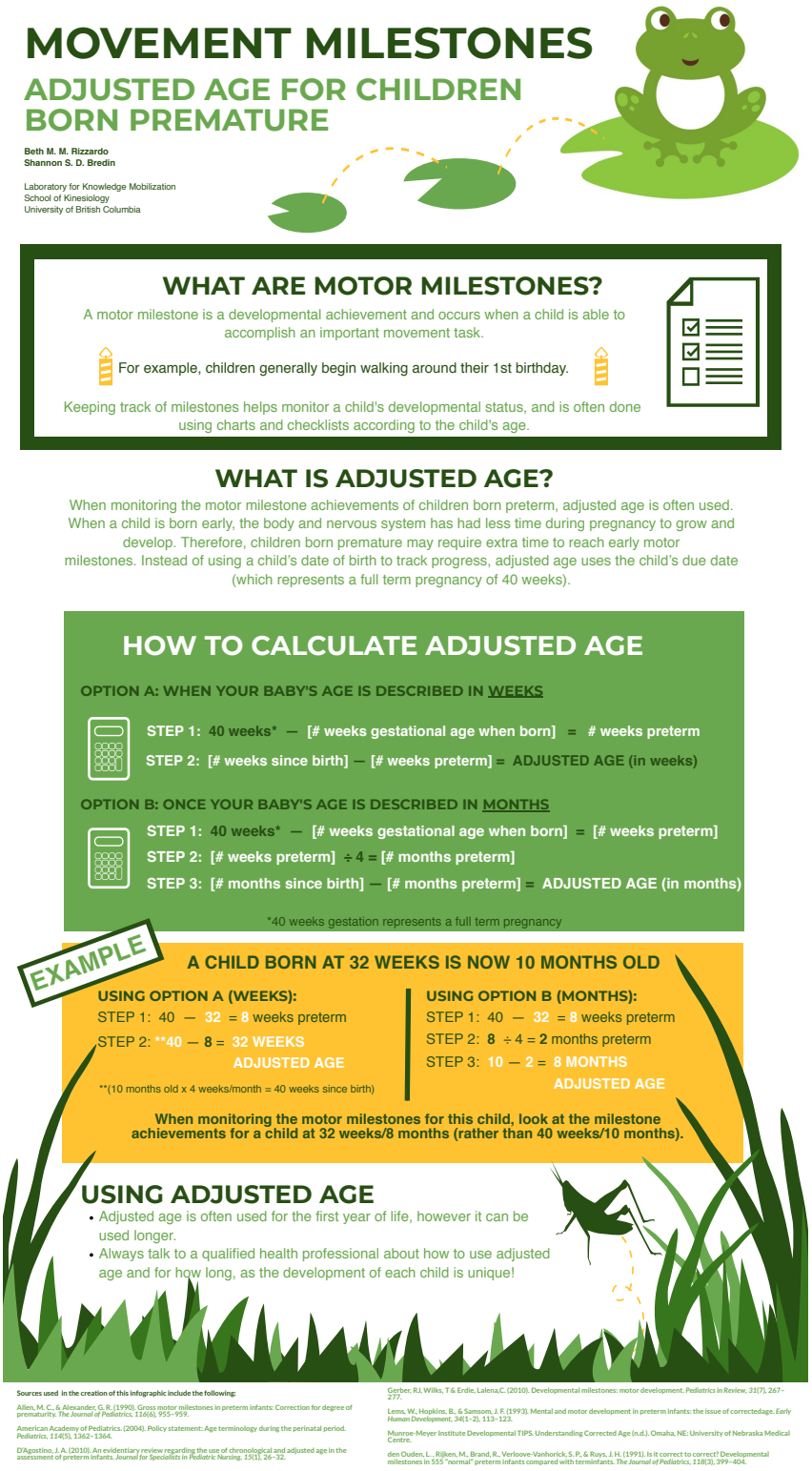


Figure 11. Age Adjustment Infographic. Reprinted with permission from Health & Fitness Journal of Canada (Rizzardo & Bredin, 2018)

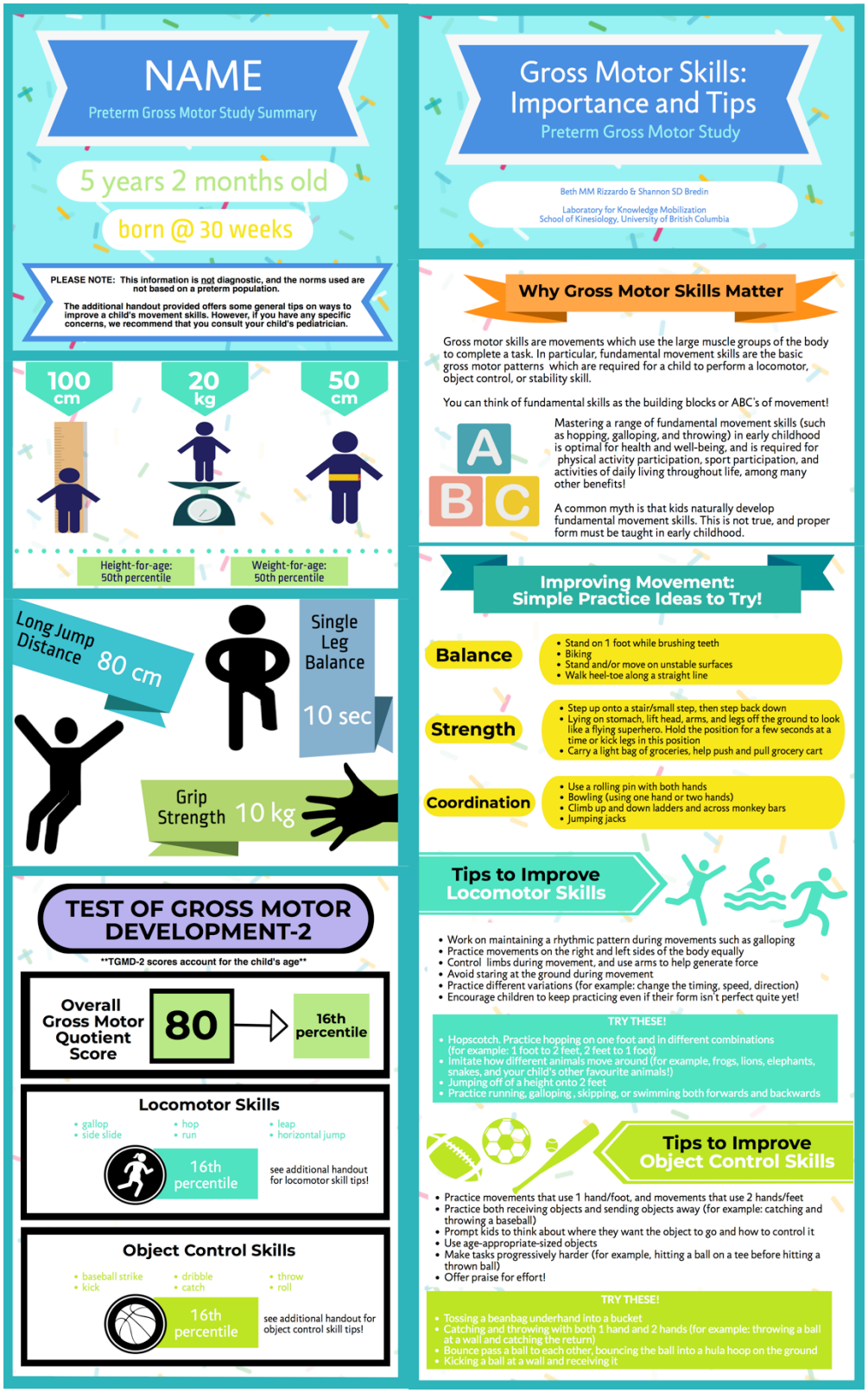


Figure 12. Sample of the Results and Resource Infographics for Parents

childhood (Foulder-Hughes & Cooke, 2003a), whereas other studies exhibit differences in some but not all gross motor subtests, such as better performance on object control subtests for males, and better static balance proficiency for females (Temple, Crane, Brown, Williams, & Bell, 2016).

7.5 Recommendations for Future Research

The results of this study offer many directions for future research, including terminology-related discussion, participant samples, and assessment tool usage. The findings of this study lead to a broader discussion regarding what constitutes gross motor competence, how it is best measured in young children, in addition to further discussions around the vague definitions and classifications of poor gross motor competence. Ambiguity and inconsistencies in the terminology used to describe various phenomena are a result of the changing meanings within motor development, that has led to multiple terms being used to describe different levels of motor functioning (Logan, Ross, Chee, Stodden, & Robinson, 2018). This is due to a lack in agreement between gross motor assessments as to what constitutes motor impairment (Wocadlo & Rieger, 2008). Similarly, there also lacks clear definitions and requirements for what classifies a child as one with poor gross motor competence, which creates a barrier for effective identification and intervention of children with gross motor difficulties. Regardless of the semantics surrounding definitions of such issues it evident that children are demonstrating motor development differences (Wocadlo & Rieger, 2008). Determining what these various gross motor differences indicate, and the neurological contributors to them, is therefore important but still yet to be fully understood (Wocadlo & Rieger, 2008). Clarifying universal terminology within the realm of gross motor competence is necessary for consistency in the research literature, creation of public health strategies, and transparency as to what difficulties are being described (Logan et al., 2018). In the meantime, for optimal screening and treatment, it is crucial that the associated issues are well-defined and recognized by health professionals, schools, and support services, alike, for the purpose of consistency.

As there remains no gold standard assessment tool for gross motor impairment in children (Brantner et al., 2009), there is opportunity for improvement of available gross motor test batteries or the creation of a new test altogether. A tool of preference would be one that provides information on gross motor capabilities separate from fine motor capabilities, and offers

information as to specific skill types or underlying issues that contribute to the overall poor gross motor competence being seen by a child. It would also be of benefit for the assessment battery to include strength and balance measures, as well as criteria that assesses both the product and process aspects of gross motor skills. Clear interpretations and recommendations for a given assessment battery score outcome are also recommended. The collection and use of preterm-specific normative data across various performance measures of gross motor competence would aid in better determining the gross motor capabilities of this population.

In addition, investigation of the long-term neurodevelopment of children born preterm in association of motor competence is highly recommended. By determining if there are subtle differences in structure or function of the nervous system of children born who suffer no major neurological complications yet exhibit poor motor competence, the true underlying constraints of the children's movement difficulties may be addressed more clearly. A better understanding of the neurological outcomes of this population and the extent to which neurodevelopment impacts gross motor skill development and associated movement skills such as strength and balance is therefore required in the preterm population. Such insight would assist in the creation of developmentally appropriate programming, prevention, and intervention strategies for these children.

Although performance was low across the TGMD-2 skills within this population, the lowest mastery was exhibited by object control skills specifically (see Figure 13). This indicates that the development of object control skills should also be of particular interest when devising such prevention and intervention strategies. For example, coincident timing is required for dribbling and catching, two of the lowest-performed skills. To perform such tasks successfully requires the coordination of an individual's motor output with the object's anticipated timing for accurate interception. Children have been found to intercept moving objects with less accuracy as compared to adults, especially at variable speeds (Haywood, Robertson, & Getchell, 2012). Therefore, it is possible that such skills were too complex in nature for successful execution at this age range. It is important to be cognizant of skills of particular concern or difficulty. Strategies for addressing poor motor competence of this population would benefit from including activities to improve coincident timing and object control tasks.

The process-oriented nature of the TGMD-2 and the performance criteria offered to score each skill may leave underlying aspects of gross motor difficulties (such as poor balance and

strength), unidentified through assessment. A child can obtain a satisfactory score on a skill due to the criteria used, even if it does not appear optimal in real-time. Furthermore, the inconsistent split of qualitative and quantitative performance criteria means that some skills are potentially not examined as comprehensively as possible. Such issues are not entirely unique to the TGMD-2, as there is still no true gold standard gross motor skill assessment in early childhood. The ambiguity in motor competence is impacted by the reporting of battery outcomes and the design of the batteries themselves. For example, the TGMD-2 is one of the only assessments that offers gross-motor specific information, as many assessments report motor issues as a general term, which does not differentiate between gross motor and fine motor skills even though such difficulties are separate. Furthermore, without reporting information of the specific skills which various pediatric populations either have difficulty in or excel in, there is little opportunity for creating effective prevention and intervention strategies to target appropriate skills and their underlying mechanisms and constraints (such as balance or low body strength). Such generalization in turn leads back to the lack of specific information available to clarify the ambiguous terminology used in the field of motor development.

This study indicates that future research studies may benefit from investigating various populations within the preterm cohort. In order to better understand the gross motor development of children born preterm, it is recommended that the moderate to late preterm cohort is included in future research, as are children born preterm at various birthweights. In addition, similar study designs would benefit from examining larger sample sizes longitudinally and including a matched control group of children born at term. Assessing the gross motor development of twins born preterm would also provide valuable information regarding the contributing factors to gross motor skill development in children born preterm.

The results of this study indicate that follow-up protocol of children born preterm should be considered until at least age of school entry, regardless of gestational age at birth or lack of severe health conditions at this age. General developmental surveillance is recommended by the American Academy of Pediatrics throughout childhood at well-child checks (Baker, Meade, & Moore, 2014; Hagan et al., 2017), however this is different than more specific developmental screening, which is the use of standardised assessments to screen for delays in development when the child may otherwise be presenting as asymptomatic (Tonelli et al., 2016). Although

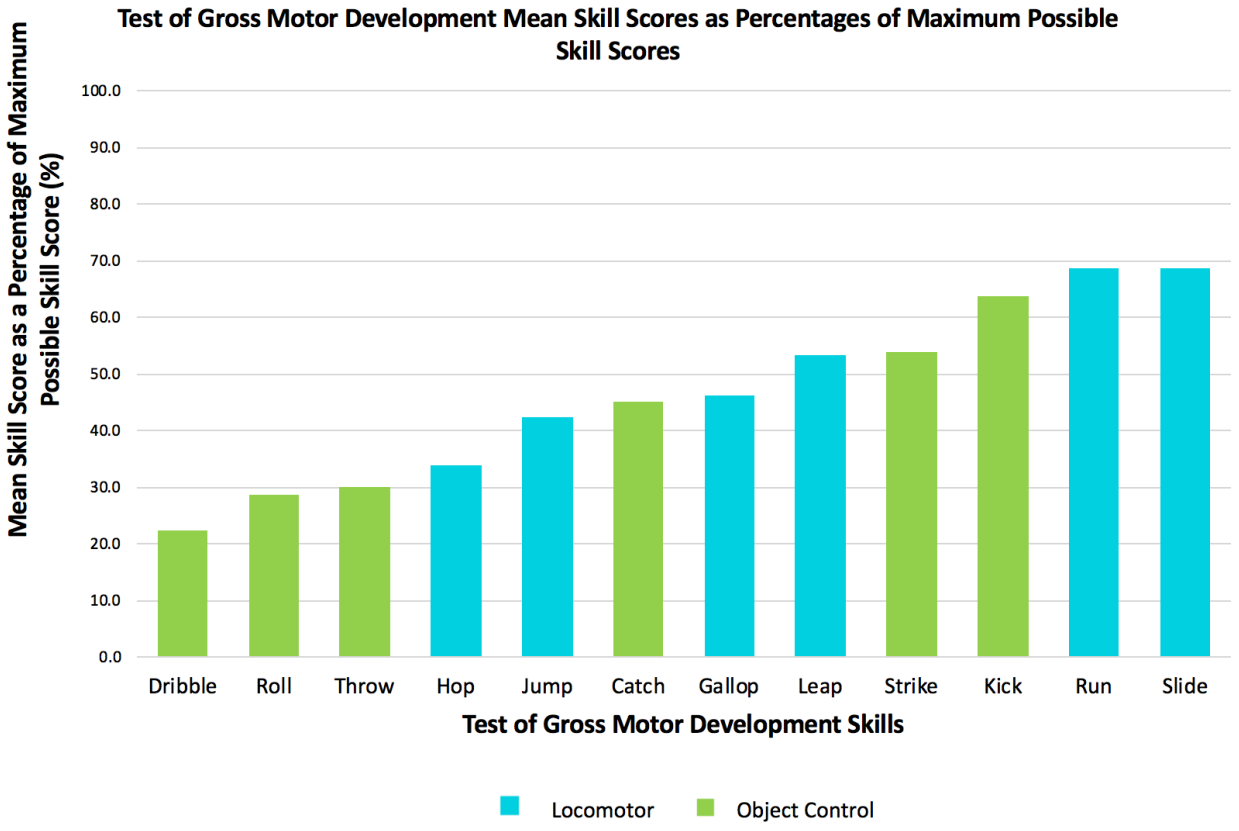


Figure 13. Test of Gross Motor Development Relative Skill Mastery

this is not recommended in Canada for children who are asymptomatic from age 1-4, the recommendation does not apply to children born preterm, whose development should be monitored through screening due to the risk factors associated with premature birth (Tonelli et al., 2016). Even so, prior to school entry most children born preterm do not receive any care regarding their development unless they also present with other high-risk characteristics (Kallioinen, Eadon, Murphy, & Baird, 2017). The follow-up care that is provided, is often only provided though neonatal services until a maximum of age 2-3 years, and is almost exclusively for children born extremely preterm (Johnson & Marlow, 2017; Kallioinen et al., 2017). This bias is due to moderate to late preterm infants having previously been identified as a group without need of motor development follow-up throughout childhood (Tavasoli, Aliabadi, & Eftekhari, 2014). However, it is now being suggested that children born late preterm also require developmental follow-up, even if the child presents as otherwise healthy (Morse et al., 2009). Given the rising rates of moderate to late preterm births and implications for the public health and educational system (Blaggan et al., 2014), examining this understudied population warrants greater attention in addition to investigations on children born early preterm.

It is incredibly important to detect deficits and support the development of children born preterm with subtle issues, in order to prevent more adverse results from occurring as a consequence (Behrman & Stith Butler, 2007). Such detection through standardized follow-up of children born preterm is needed, particularly as obstetric and neonatal intensive care are reducing mortality rates at young gestational ages (Behrman & Stith Butler, 2007). The follow-up of and detection of minor issues in gross motor proficiency in the preterm population is of particular importance, as negative outcomes such as reduced enjoyableness involved with activities at preschool and on the playground are likely to be decreased when a child has coordination or motor planning difficulties (Behrman & Stith Butler, 2007). Such evidence aligns with the outcomes of this study and supports the need for motor development follow-up until at least age 4-6 years. In a 58-participant cohort, those born extremely preterm and extremely low birthweight who appear otherwise healthy showed to progressively demonstrate poorer gross motor skill proficiency through childhood, from 13.8% scoring in the mild to significant motor deficit range at age 1 year, to 32.8% at age 3, and finally 81.1% scoring below the range of normal at age 5 years. (Goyen & Lui, 2002). Such studies support the need for continued follow-up through school age, as gross motor issues may appear more clearly as a child ages. The age

range of 4-6 years also corresponds with children's entry to formal schooling in British Columbia, making kindergarten a potential time point for implementing standardized gross motor development assessment by the child's qualified health care provider for all children born preterm. Foulder-Hughes & Cookes (2003a) suggest that when entering mainstream school, evidence-based interventions be offered to negate such motor issues in the preterm population from progressing as they age. Furthermore, at this age, children have the capability of demonstrating mature gross motor skill proficiency, however there are still a few years for the implementation of intervention strategies before the critical period for gross motor skill acquisition closes. Although kindergarten readiness tools may also be implemented by kindergarten teachers, children born preterm may benefit from gross motor-specific assessments performed by the child's primary qualified health care provider, who can also make appropriate referrals accordingly.

7.6 Conclusion

Children born early preterm show poor gross motor developmental outcomes, while moderate to late preterm infants have previously been identified as a group without need of motor development follow-up in early childhood (Tavasoli et al., 2014). The purpose of this study was to investigate the impact of gestational age at birth on gross motor skill proficiency of children born preterm with no known neurological impairment of physical disability at age 4-6 years, as well as to examine the balance and strength capability of this population. As a group, the eighteen children who participated in this study were found to have poor gross motor competence with no impact of gestational age at birth. The poor balance capabilities exhibited by this population provides indication that the motor functioning of children born preterm may have many associated factors that should be assessed when devising an optimal intervention strategy, including neurodevelopmental status. This research adds to the body of knowledge on the developmental outcomes of children born preterm in early childhood, providing gross motor-specific information across the full preterm gestational age range, and encouraging further investigation of and support for the preterm population.

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Appendices

Appendix A: UBC Qualtrics Questionnaire

Gross Motor Skills and Young-For-Date

Q2 If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

Q4 1. What is the participating child's name?

_____

Q7. What was the participating child's expected due date?

_____

Q8. What was the participating child's actual birth date?

_____

Q9. How much did your child weigh at birth?

_____

Q10. Please type in value of weight and indicate whether measurement was in lbs and oz, or g below

○ lbs and oz

○ g

Q11. How old was the participating child's mother when the child was born?

_____

Q12. Was this child the mother's:

- ○ First live birth
- ○ Second live birth
- ○ Third live birth
- ○ Fourth or higher live birth

Q13. Was your child born as a:

- ○ Single birth
- ○ Twin birth
- ○ Triplet or higher-order birth

Q14. Was the delivery:

- ○ Vaginal
- ○ Cesarean section

Q15. Was your child born:

- ○ in Vancouver
- ○ outside of Vancouver, but in British Columbia
- ○ in Canada, but outside of British Columbia
- ○ outside of Canada

Q16. Was a NICU stay required?
NICU=Neonatal Intensive Care Unit
If yes, how long?

- ○ Yes _____
- ○ No

Q18. Which hand does your child use to write or colour with?

- ○ Right
- ○ Left
- ○ Alternates

Q19. Which kind of family structure is the participating child part of?

- ○ Both biological parents
- ○ Single-parent
- ○ Same-sex parents
- ○ Blended (step-parents or divorced parents)
- ○ Foster care
- ○ Adoptive parents
- ○ Other (please specify below) _____

Q20. What is the highest education level achieved by a parent/guardian of the participating child?

- ○ Less than high school
- ○ High school graduate (includes equivalency)
- ○ Trade/technical/vocational training
- ○ Some college, no degree
- ○ Associate's degree
- ○ Bachelor's degree
- ○ Graduate or professional degree
- ○ Ph.D.

Q21. What is the total yearly household income of the home financially responsible for the child?

- ○ Less than $25,000
- ○ $25,000 to $49,999
- ○ $50,000 to $74,999
- ○ $75,000 to $99,999
- ○ $100,000 to $199,999
- ○ $200,000 to $299,999
- ○ $300,000+
- ○ Prefer not to answer

Q22. What are the three letters/number of the postal code at which your child lives the majority of his or her time: __ __ __

_____

Q23. Does your child self-identify as Aboriginal?

- ○ Yes
- ○ No

Q24. Thank you for your participation!