MOTOR SKILL PROFICIENCY AND PHYSICAL ACTIVITY IN PEDIATRIC CARRIERS & NON-CARRIERS OF THE BDNF VAL^{66}MET POLYMORPHISM

By

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ABSTRACT

MOTOR SKILL PROFICIENCY AND PHYSICAL ACTIVITY IN PEDIATRIC CARRIERS & NON-CARRIERS OF THE BDNF VAL^{66}MET POLYMORPHISM

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Introduction: Physical activity has been established as an important health behavior. Children who are proficient performers of gross motor skills typically are more physically active and less sedentary than children with poor gross motor skill proficiency (MSP). Though physical activity (PA) is a commonly researched correlate of gross MSP, it cannot fully explain a child's level of gross MSP. Little is known about genetic influences on MSP, but evidence suggests that the brain-derived neurotrophic factor (BDNF) val^{66}met polymorphism is associated with delays in fine motor learning and retention and thus parallels may be drawn to gross MSP and the polymorphism. Physical activity (PA) is also an important factor in the secretion of BDNF. The purpose of this study was to examine the BDNF val^{66}met polymorphism in terms of gross and fine MSP, PA, and sedentary time in children.

Methods: Boys and girls (*n* = 105) between the ages of 9-10 years were recruited to participate. Demographic information (child birthdate, race, grade, and parent education) was obtained via parent survey. Height and weight were directly measured to determine body mass index (BMI). Saliva samples were collected and genotyped for the BDNF val^{66}met polymorphism. Gross MSP was assessed using locomotor, object control, and total skill scores from The Test of Gross Motor Development-2 (TGMD-2) (Ulrich, 2000). Fine MSP was assessed using scores on the pegboard and star-copying tasks from the Bruininks-Oseretsky Test of Motor Proficiency-2

(BOT-2) (Bruininks & Bruininks, 2005), and scores on the Bubbles Burst iPad application. Participants wore an Actigraph GT3X accelerometer to assess PA and sedentary time.

Results: Complete data were obtained from 82.9% (*n* = 87) of the sample. Sixty-four percent (*n* = 67) of participants were non-Met-carriers, 30% (*n* = 31) were Met-carriers, and 6% (*n* = 7) were Met-Met-carriers. Boys spent significantly less time sedentary (57.4% ± 6.3%) than girls (62.4% ± 7.0%), and greater percentages of time in moderate PA (5.1% ± 1.3%) than girls (3.5% ± 1.2%) and vigorous PA (3.0% ± 1.7%) than girls (1.7% ± 1.1%). Boys performed significantly better on the object control subtest (39.2 ± 5.1) than girls (32.1 ± 6.0), and boys also outperformed girls on the locomotor subtest (42.0 ± 2.9 versus 40.3 ± 4.5, respectively). Scores on the BOT-2 pegboard task and object control scores were weakly but significantly associated (r = .274, $p \leq .001$). Object control scores and sex significantly predicted time spent in moderate-to-vigorous PA (MVPA), $F(5, 81) = 9.470$, $p < .001$, r = .607). A significant inverse association between object control scores and sedentary time was found $F(5, 81) = 3.859$, $p < .005$, $R^2 = .192$. Discriminant function analyses explained about 27% of the variation in carrier status (R_c^2 = 26.4) and indicated that sedentary time, MVPA, locomotor skills, and fine motor skills (pegboard and star-copying scores) significantly differentiated carrier status.

Conclusions: Object control skills play an important role in the promotion of PA, particularly in girls. BDNF val^{66}met polymorphism carrier status was influenced by MVPA and sedentary time, and to some extent, fine and gross MSP. Time spent in MVPA may override deficits associated with the polymorphism.

This dissertation is dedicated to the greatest man I've ever known: S.M. True, Jr.
Poppy, for the first 28 years of my life you were my rock, my biggest fan and supporter, and the perfect example of a life well-lived. I hope that in the next 28 years and beyond, I can be a reflection of your legacy. It's good to be a True.

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CHAPTER 1: INTRODUCTION

Background and Significance

Fundamental motor skills (FMS) are acquired in childhood (Branta, Haubenstricker, & Seefeldt, 1984; Clark, 1994; Marr, Cermak, Cohn, & Henderson, 2003), and are used throughout the lifespan for activities of daily living as well as for physically demanding pursuits. FMS are classified as gross or fine. Gross motor skills are movements produced by large musculature in the arms, legs, and torso. Examples of common gross motor skills are running, jumping, kicking, throwing and other skills used in physical activity and sport settings. Fine motor skills are smaller, more precise movements produced by small muscle groups in the hands, fingers, feet, and toes. Examples of common fine motor skills are writing, typing, taping, cutting, and skills used in occupational and educational arenas. A child's level of competency for performing fundamental motor skills is called motor skill proficiency (MSP), which can lie anywhere along a continuum from very low (poor) to very high (excellent). The term MSP can be applied to both gross and fine motor skill performance. The acquisition and age-appropriate development of gross and fine FMS are important aspects of child development. Although they are moderately related, gross and fine MSP are different in nature and thus play different roles in child development (Haywood & Getchell, 2009; Logan, Robinson, & Getchell, 2011).

Gross Motor Skill Proficiency

Although the importance of attaining high levels of gross MSP in childhood has been well-documented (Stodden et al., 2008), many children demonstrate levels of gross MSP that are inadequate for their age group (LeGear et al., 2012; Morrison et al., 2012). Children with low levels of gross MSP are at greater risk for being overweight/obese throughout childhood (Cliff et al., 2012; D'Hondt et al., 2011; Logan, Scrabis-Fletcher, Modlesky, & Getchell, 2011), are less physically active as children (Cliff, Okely, Smith, & McKeen, 2009) and adolescents (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2009), demonstrate poorer health-related physical fitness as children (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008; Haga, 2009; Reeves, Broeder, Kennedy-Honeycutt, East, & Matney, 1999) and adults (Stodden, Langendorfer, & Roberton, 2009; Stodden, True, Langendorfer, & Gao, 2013), and have lower perceived physical competence (Barnett, Morgan, Van Beurden, Ball, & Lubans, 2011; Barnett, Morgan, Van Beurden, & Beard, 2008) than their more motorically-competent counterparts. Thus, children with poor gross MSP are at higher risk for certain illnesses and diseases than the motorically competent (Piek, Dawson, Smith, & Gasson, 2008; Whitt-Glover et al., 2009). The indirect effect that gross MSP has on overall health warrants a greater understanding of the relationship between gross MSP and its correlates.

Gross FMS were once thought to be acquired “naturally,” (Gesell; McGraw, 1943) but recent evidence suggests that such assertions are incorrect (Clark, 2005) and that many environmental (e.g., socioeconomic status; urban, suburban, or rural homestead; access to equipment; availability of sports programs)(Barnett, Hinkley, Okely, & Salmon, 2012), psychosocial (e.g., perceived physical competence, self-efficacy)(Goodway & Branta, 2003; Robinson, 2011), and genetic (Bishop, 2002; Francks et al., 2002; Francks et al., 2003) contributors play a role in a child’s level of MSP at any given age. Arguably, physical activity (PA) and perceived physical competence (PPC) are among the most influential contributors to gross

MSP in childhood (Stodden et al., 2008). Significant relationships between gross MSP and PA are seen at every period in childhood (early, middle, and late childhood)(Cliff et al., 2009; Fisher et al., 2005; McKenzie et al., 2002; H. Williams et al., 2008; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006), and the relationship strengthens with age. Moderate, positive relationships between gross MSP and PA are evident in middle and late childhood, and are stronger than in early childhood. Further, results from recent longitudinal studies revealed that children with better gross MSP in childhood are more physically active as adolescents than those who were not good performers of gross MSP in childhood (Barnett et al., 2011; Barnett, Morgan, et al., 2008; Barnett et al., 2009; Lopes, Rodrigues, Maia, & Malina, 2011). Despite the growing evidence that supports the relationship between gross MSP and PA, sedentary behavior has not been statistically associated with gross MSP as of yet, although it should be noted that only two known studies have examined this link (Cliff et al., 2009; Graf et al., 2004). Further research is necessary to investigate the relationship between sedentary behavior and gross MSP.

Perceived physical competence is defined as a child's personal perspective of his/her ability to perform physically demanding tasks relative to his/her peers, and plays an important mediating role between gross MSP and PA. Longitudinal evidence suggests that the relationship between gross MSP and PA is stronger when children have high perceptions of physical competence (Barnett et al., 2011; Barnett, Morgan, et al., 2008). Collectively, these findings support the notion that gross MSP is acquired through influence of a number of factors.

Seefeldt (1980) hypothesized that a motor skill "proficiency barrier" exists in which individuals who do not achieve adequate levels of gross MSP as children may likely never achieve proficiency in such skills, causing difficulty for later participation in physically-demanding, sport-related tasks. This hypothesis was recently supported by Stodden et al. (2013), who demonstrated that a motor skill proficiency barrier seems to exist, at least with respect to health-related physical fitness. Numerous factors exist that contribute to a child's propensity for breaking through the proficiency barrier and maintaining a repertoire of gross motor skills, ultimately allowing for lifelong participation in physically demanding pursuits. While the role of environmental and psychosocial correlates of gross MSP are relatively well-researched, much less is understood regarding MSP in young children from a genetic perspective, which may be a missing link to greater understanding for why some children achieve high levels of gross MSP and some children do not. Research in the gross MSP arena can benefit from studies that use a genetic approach.

Fine Motor Skill Proficiency

Fine motor skills in children are commonly associated with scholastic tasks such as handwriting, cutting, and coloring, as well as grooming and occupational tasks like buttoning a shirt and combing hair. Children who experience difficulty performing such tasks may struggle to express themselves "on paper" and may also appear untidy and unkempt because of grooming difficulties (Rose, Larkin, & Berger, 1997). These negative side effects of poor fine MSP may adversely influence peers' social perceptions (Wright & Sugden, 1996). Further, children with poor fine MSP are prone to having lower perceptions of their own scholastic ability (Piek, Baynam, & Barrett, 2006), likely due to a heightened awareness of their inability to perform school-related tasks in classroom situations, where self-comparisons to more proficient peers are readily available (Cantell, Smyth, & Ahonen, 1994). Fine MSP is necessary for activities of daily living in childhood and throughout the lifespan, but much like gross MSP, little is known with respect to why some children are more proficient performers of fine motor skills than others.

The classic perspective on fine motor skill development is that the central nervous system (CNS) is primarily responsible for the rate at which fine motor function progresses (Seitz et al., 1995). As components in the CNS mature, better control and precision over body parts is gained (Purves, 1994). If fine motor skill practice is introduced, the structural organization of the CNS is positively influenced and even greater control over body parts is gained (Zheng & Purves, 1995). Fine MSP, however, is not solely influenced by maturation and development of the CNS, as environmental factors have also been shown to play a role in fine MSP. Socioeconomic status (SES) has been identified as an important predictor of fine MSP in that children from families with low SES demonstrate poorer fine MSP than children from families with high SES (Piek et al., 2008). Attending public (versus private) school, which is an indirect indicator of SES and family income, increases a child's risk for poor fine MSP (Bobbio, Morcillo, de Azevedo Barros Filho, & GonÇalves, 2007; de Barros, Fragoso, de Oliveira, Cabral Filho, & de Castro, 2003). Regardless of the type of school a child attends, late entry into school (e.g., after the age of four) has been associated with poor fine MSP (Bobbio et al., 2007; de Barros et al., 2003). In addition to neurological and environmental factors, fine MSP is also influenced by genetic factors, which are outlined in the following section. While fine MSP is better understood from a genetic perspective than gross MSP, current research is limited to mostly adult populations. Gaps in the literature still remain in terms of pediatric populations and particularly the relationship between pediatric gross MSP and genetic factors.

Genetic Influences of Gross and Fine Motor Skills

Due in part to the recent sequencing of the human genome (Venter et al., 2001), understanding the complexity of gross and fine MSP through a genetic lens is now possible. The brain-derived neurotrophic factor (BDNF) gene has recently garnered the attention of those interested in genetic correlates of motor skill learning and acquisition, both of which are explicably related to MSP. BDNF is active in different areas of the brain that are important for learning and memory (i.e., hippocampus, motor cortex, basal forebrain), and is one of the most active neurotrophins by which neurogenesis—the brain’s ability to grow new neurons—occurs (Pencea, Bingaman, Wiegand, & Luskin, 2001). Moreover, BDNF is a key neural signal that influences synaptic plasticity and repair, processes by which the brain adapts to environmental cues and experience (e.g., movement experiences) (Lu, 2003). The BDNF gene is polymorphic, meaning that it can be expressed various ways. Different expressions of the BDNF gene have been shown to impact certain neurological conditions like Alzheimer’s , Parkinson’s, and Huntington’s diseases (Zuccato & Cattaneo, 2009), and have behavioral effects on depression and memory (Gatt et al., 2009; Kambeitz, Bhattacharyya, Ilankovic, Valli, & Collier, 2012). Roughly 70% of Americans are homozygotes with respect to the BDNF gene, resulting in two copies of the valine allele (val^{66}val); these individuals are referred to as “non-Met-carriers” of the BDNF gene (Shimizu, Hashimoto, & Iyo, 2004). The other roughly 30% of Americans are heterozygous “Met-carriers” of the BDNF gene, indicating that these individuals have a single-nucleotide polymorphism in the BDNF gene present in one of the alleles at codon 66, resulting in a $val^{66}met$ gene expression. In Met-carriers, one of the valine alleles is substituted with a methionine nucleotide, which results in the $val^{66}met$ genotype. While the effects of the $val^{66}met$ polymorphism have been studied quite extensively on memory and depression, recent research in this area has turned to the effects of the $val^{66}met$ polymorphism on motor skill learning.

The two expressions of the BDNF gene indicate different propensities for motor skill learning and retention. Met-carriers have demonstrated reduced brain motor system function, altered short-term plasticity, and greater error in short- and long-term motor learning relative to non-Met-carriers (Bueller et al., 2006; Fritsch et al., 2010; McHughen et al., 2010). Negative motoric effects of the $val^{66}met$ polymorphism are thought to occur because BDNF is not secreted following movement—called activity-dependent secretion—which may hinder a Met-carrier's ability to learn and execute motor tasks (Egan et al., 2003). Activity-dependent secretion of BDNF seems to occur normally in non-Met carriers; thus, motoric deficits are not thought to be related to BDNF polymorphism status in non-Met carriers. However, these findings can only be generalized to adults, and mostly Caucasian samples.

Studies that have examined the effects of the $val^{66}met$ polymorphism on motor learning have mostly utilized laboratory-based fine motor tasks such as tapping, pinching, and relocating pegs on a pegboard (McHughen, Pearson-Fuhrhop, Ngo, & Cramer, 2011; McHughen et al., 2010). Though studies examining the val^{66}met polymorphism have not tested gross motor skills in a child population, gross and fine MSP are moderately correlated in children (*r* = .46-.63) (Haywood & Getchell, 2009; Logan, Robinson, et al., 2011), which gives reasonable cause to posit that the val^{66}met polymorphism may influence gross MSP as well as fine MSP in children.

Although empirical evidence on the correlation between gross and fine MSP in typically-developing children is scant, gross and fine motor skills are similar developmental milestones that have been shown to follow a relatively linear path (e.g., gross and fine motor skills improve with age). Gross and fine skills—though different in nature—are acquired in a relatively similar manner. Additionally, both types of skills are influenced by a number of factors (e.g., environmental, psychosocial, and genetic). Thus, there is reason to believe that the val^{66}met polymorphism could affect both gross and fine MSP. The established relationships among gross MSP, PA, and PPC likely indirectly influence PA and PPC in a pediatric population.

Currently, gross MSP is explored primarily with respect to its underlying environmental and psychosocial factors. Most research in the field is conducted on the basis of Stodden's model (Stodden et al., 2008), which posits that gross MSP is a primary underlying factor that encourages PA in children and that the relationship between gross MSP and PA is mediated by PPC. While we support Stodden's model (Stodden et al., 2008) for its empirical support for the importance of gross MSP, the model fails to consider genetic influences on gross MSP. Thus, there remains a lack of research investigating genetic mechanisms that influence gross MSP—

and ultimately PA and PPC—in pediatric populations. The importance of fine MSP in child populations should not be overlooked as it is a key contributor to children's social and emotional development, and fine MSP delays can be detrimental in childhood. Recent evidence linking the BDNF val^{66}met polymorphism to fine motor learning and retention allows for a genetic approach to be taken with respect to children's gross MSP, ultimately providing more insight into Stodden's model (Stodden et al., 2008) as well as a more robust understanding of why some children struggle to acquire developmentally proficient levels of MSP.

Specific Aims and Hypotheses

This study considered children's gross and fine MSP from a genetic perspective while also accounting for the roles of PA, sedentary time, and PPC. Thus, the purpose of this dissertation was to examine the BDNF val^{66}met polymorphism in terms of four movement-related constructs (gross MSP, fine MSP, PA, and sedentary time) in children via the following Specific Aims:

Specific Aim #1: Describe the participant sample in terms of age, race, sex, SES, BMI, carrier status, fine and gross MSP level, PA, sedentary time, and PPC score.

Specific Aim #2: Determine the relationship between gross and fine MSP, controlling for and without controlling for BMI, SES, race, and sex.

Hypothesis 2: Gross and fine MSP would be moderately, positively related (approximately r= .30 - .39).

Specific Aim #3: Determine the relationship between gross MSP and MVPA, controlling for BMI, race, sex, and SES. A sub-aim was to determine the relationship between gross MSP and sedentary time, controlling for BMI, race, sex, and SES.

Hypothesis 3: Gross MSP and MVPA would be moderately, positively related (approximately r= .30 - .39).Gross MSP and sedentary time would be moderately, inversely related (approximately r=.30-.39).

Specific Aim #4: Determine which predictor variables predict Met-carriers and which predictor variables predict non-Met-carriers. Predictor variables included in the first model were gross MSP, fine MSP, MVPA, PPC, race, sex, SES, and BMI. In a subsequent model, sedentary time was substituted for MVPA as a predictor variable.

Hypothesis 4: The analysis would discriminate moderately between groups and gross and fine MSP, PA, sedentary time, and BMI would be identified as significant predictors of group membership. PPC, race, sex, and SES would not significantly predict group membership.

Significance of the Dissertation

Gross MSP, and especially its relation to PA in child populations, is a complex variable that is influenced by a number of factors. It was expected that this dissertation would provide new understanding of the role that the BDNF val^{66}met polymorphism has with respect to gross MSP and two of its main correlates, PA and sedentary time. Because poor gross MSP indirectly affects overall health status of children, and children who demonstrate poor gross MSP may also have lower PA levels, it is important to identify salient factors that may influence a child's ability to perform gross motor skills. This dissertation could add to the literature in terms of fine MSP and presence of the BDNF val^{66}met polymorphism. If it were to be determined that the presence of the BDNF val^{66}met polymorphism is related to gross and fine MSP in children, this understanding may allow for innovative and successful interventions to improve motor skills that consider the genetic limitations of carriers of the polymorphism. Thus, the results of this study may identify an important genetic mechanism of gross MSP and determine potential directions for motor skill interventions.

CHAPTER 2: REVIEW OF LITERATURE

Introduction

This review of literature examines the research of several areas related to the current study including: motor skill proficiency (MSP), physical activity (PA), sedentary time, perceived physical competence (PPC), and the brain-derived neurotrophic factor (BDNF) val^{66}met polymorphism. The overall purpose of this literature review was to discuss well-known and commonly researched correlates of MSP, as well as introduce a new correlate (the BDNF val^{66}met polymorphism) that is hypothesized to impact gross and fine MSP in children. An overview of the history of motor skill research is first introduced, followed by a description of gross and fine MSP and a synopsis of the theories that currently drive this research. Then each of the remaining variables of interest is discussed independently as well as in the context of their relation to MSP. Finally, a summary of the interrelationships among all four main variables of interest is given.

Fundamental Motor Skills and Motor Skill Proficiency — A Clarification of Terms

It is important to clarify some of the terminology used in this literature review. “Motor skills” is a blanket phrase that encompasses fine and gross movements and is used broadly and classically in the literature as such. “Fundamental motor skills” (FMS) is a somewhat more specific term that typically has been used to describe *gross* movements that are acquired in childhood and used throughout the lifespan. Though “FMS” is used more commonly to describe gross movement, in this dissertation it is used as a broad term to describe fine movement. However, a distinction is made between the two (i.e., gross FMS or fine FMS). “Motor skill proficiency” is essentially a term that indicates how well or how poorly a child performs gross or fine FMS. Fine MSP and gross MSP are the terms that will be used to describe the main variables of interest in this study. When the term “MSP” is used without being preceded by gross or fine, that indicates broadly that both gross and fine MSP are being discussed together. Other terminology to describe a child’s level of performance of gross FMS has been used, such as motor skill performance and motor skill competence, but the term “gross motor skill proficiency” (gross MSP) is used in this dissertation.

The distinction between fine FMS (precise movements produced by small musculature primarily in the hands and fingers) and gross FMS (large, total body movements produced by large muscle groups in the arm, legs, and torso) is important. Although fine MSP and gross MSP are moderately correlated (Haywood & Getchell, 2009; Logan, Robinson, et al., 2011), the patterns and type of movements produced under each specification are quite different, as are the specific correlates of both. Thus, fine motor skills and gross motor skills should be treated as separate entities in a review of literature, and are presented in two separate sections that follow.

History of Motor Skill Research

The general term “motor skills” encompasses both fine and gross movement and describes an important skill set of movements that children acquire at young ages and continue to use in some capacity throughout the lifespan. This skill set was once theorized to develop naturally, relying solely on the simple linear progression of brain development (Gesell & Thompson, 1938; McGraw, 1943). Motor developmentalists in the mid-20th century hypothesized that all movement followed a sequence and a pattern that was primarily influenced by brain development (Gesell & Thompson, 1938; McGraw, 1943). Essentially, the thought was that as long as the brain developed normally, movement would also develop normally. While there certainly is some merit to the hypothesis that brain development constrains movement, researchers such as Bernstein (1967) and later, Kugler and Turvey (1987) proposed that movement does not emerge solely as the results of neural codes in the brain firing in a predictable pattern; rather, movement is organized in a "soft assembly" based on cues from the task at hand and the environment in which the task is being performed. In other words, movement is adaptable and unique to the individual. These views were among the first in a shift from the "nature" perspective of motor development to a "constraints" perspective, whereby researchers began investigating movement with respect to environmental, task, and unique organismic development (Newell, 1986; Thelen, 1995). This shift in perspective was important in that it led to the study of motor skills in the context of other important child health behaviors.

In the early 1990s, as childhood obesity rates were on the rise (Anderson & Butcher, 2006), pediatric research began to focus on the many complex correlates of childhood obesity. Subsequently physical inactivity among children became a popular topic, as obesity and physical inactivity are explicably related (Ebbeling, Pawlak, & Ludwig, 2002; Marshall, Biddle, Gorely, Cameron, & Murdey, 2004; Mark S Tremblay & Willms, 2003; Trost, Kerr, Ward, & Pate, 2001). Thus, many motor development researchers began investigating motor skills in the context of PA, ultimately finding a positive link between the two (Cliff et al., 2009; Jaakkola et al., 2009; Lopes et al., 2011; Robinson, Wadsworth, & Peoples, 2012; H. Williams et al., 2008); this relationship will be discussed in more detail in later sections of this review. This progression of research has since revealed that relationships between MSP and PA, and MSP and sedentary time are not a clear-cut as once thought, and the emergence of environmental and psychosocial factors as mediators between MSP and PA is reflective of the classic views of motor skill research—movement is produced as the result of the changing relationships among the organism (human performer), the task, and the environment. Much current research, including this dissertation, strives to reflect that view. As the importance of developing age-appropriate motor skills becomes increasingly evident, more schools, practitioners, and interventionists are focusing on development of motor skills at young ages, and essentially an entire genre of research is now being dedicated to the study of motor skills and their correlates.

Gross Motor Skills

At very young ages, children begin to develop a set of skills known as gross FMS, which include skills like running, jumping, and throwing. Gross FMS are classified two ways: object control skills and locomotor skills. Object control skills are ballistic in nature and involve a child using some part of his or her body to project an object from one point to another, such as throwing, kicking, striking, catching, bouncing, and rolling (Haywood & Getchell, 2009). Locomotor skills are used to move the body through space and involve a child using some form of movement to get from one point to another, such as running, sliding, leaping, hopping, jumping, skipping, and galloping (Haywood & Getchell, 2009). These skills are important because, according to Clark and Metcalfe (2002), children who can successfully build a diverse repertoire of gross FMS will be afforded the later learning of more skillful actions that can be used in a diverse array of movement contexts (e.g., sports, games, hobbies). As such, these gross FMS are often termed the “building blocks” to more advanced movements and skills required specifically for sports (Gabbard, 2000; Haywood & Getchell, 2009; Payne & Isaacs, 2012; Seefeldt, 1980). Children who do not develop these prerequisite skills will have limited opportunities to be physically active later in life (Stodden et al., 2008), and are hypothesized to be susceptible to a gross FMS “proficiency barrier” in which poor gross MSP at a young age will result in an inability to successfully take part in physically-demanding activities such as sports, games, and fitness pursuits later in life (Seefeldt, 1980). Because of the hypothesized proficiency barrier, popular belief among motor development researchers is that gross FMS should be purposefully developed in the early childhood years because this skill set will not naturally emerge (Gabbard, 2000; Haywood & Getchell, 2009; Payne & Isaacs, 2012). Early experiences with gross FMS ultimately allow children in middle and late childhood to hone and improve skills to a point that physically-demanding pursuits become less of a challenge and more of an enjoyable experience.

The literature on expected levels of gross MSP at different points in childhood is well-established: During early childhood (4-5 year-olds), children should begin to demonstrate basic, rudimentary competence for many gross FMS (Haubenstricker & Seefeldt, 1986). In middle childhood (7-8 year-olds), most children should show intermediate to advanced levels of locomotor skills, but will still demonstrate basic to intermediate object control skills (Langendorfer & Roberton, 2002; Ulrich, 2000). By late childhood (10-11 year-olds), most children should perform the majority of gross FMS at an intermediate or advanced level (Ulrich, 2000). It is reasonable to infer that by adolescence, individuals should exhibit at least intermediate or, ideally, advanced levels of gross FMS, a trend which should continue into adulthood. These time frames, though age-related and not age-determined, are important markers for assessment of gross MSP to insure that children are performing skills at a developmentally-appropriate level. These time frames also provide a guide for researchers to compare gross MSP to other health-related factors at different points in childhood. A brief review of correlates of gross MSP follows.

Correlates of Gross Motor Skill Proficiency

In addition to being essential to performing many basic human tasks and highly-skilled movements, gross MSP is an important element of children's cognitive, social, and physical development (Cools, DeMartelaer, Samaey, & Andries, 2008; Lubans, Morgan, Cliff, Barnett, & Okely, 2010; Payne & Isaacs, 2012). Correlates of gross MSP have been classified in terms of psychological, physiological, and behavioral benefits (Lubans et al., 2010). The most well-established psychological correlate of gross MSP is PPC (Barnett, Morgan, et al., 2008; Robinson, 2011; Rudisill, Mahar, & Meaney, 1993; Southall, Okely, & Steele, 2004), though global self-concept has also been weakly correlated with gross MSP (Martinek, Cheffers, & Zaichkowsky, 1978). A detailed review of the relationship between PPC and gross MSP is given in a later section of this literature review. Briefly, children with more positive perceptions of physical competence are typically more proficient performers of gross FMS than those with negative perceptions of competence.

Two principal physiological correlates of gross MSP exist: weight status and cardiorespiratory fitness. An in-depth discussion of the gross MSP/cardiorespiratory fitness association is not appropriate for this literature review, but it is worth noting that several studies have indicated a positive relationship between gross MSP and cardiorespiratory fitness in children (Barnett, Van Beurden, et al., 2008; Okely, Booth, & Patterson, 2001; Reeves et al., 1999) as well as young adults (Stodden et al., 2009; Stodden et al., 2013).

Given the current childhood obesity epidemic (Biro & Wien, 2010; Han, Lawlor, & Kimm, 2010), the association between gross MSP and weight status is noteworthy. In general, among studies that examine the gross MSP/weight status relation, body mass index (BMI; kg/m^2) is the most common method for estimating body composition. This measure is frequently included as a variable in studies that examine associations between gross MSP and other health-related variables as it is relatively easy, non-invasive, and inexpensive to assess. A small handful of studies failed to find a significant association between gross MSP and weight status (Castelli & Valley, 2007; Hume et al., 2008; H. Williams et al., 2008). However, two of those studies used a narrow range of skills to assess gross MSP (3 skills – Hume et al., 2008; 5 skills – Castelli & Valley, 2007). The mean age (4.2 yrs) of the sample in the H. Williams et al. (2008) study may have played a role in the lack of significance, as BMI and gross MSP are highly variable at that age. Conversely, the number of studies that have found a significant inverse association between weight status and gross MSP doubles the number of studies that found no association

(6-3, respectively) (Cliff et al., 2009; D'Hondt, Deforche, De Bourdeaudhuij, & Lenoir, 2009; Graf et al., 2004; McKenzie et al., 2002; Okely, Booth, & Chey, 2004; Southall et al., 2004). Among the studies that provided correlation coefficients for the gross MSP/weight status association, weak but significant (and similar) correlations were found that ranged from r=0.20 – 0.34 ($p < .01$). It is commonly hypothesized that many factors such as physical activity, perceived competence, and health-related physical fitness mediate the relationship between gross MSP and weight status (D'Hondt et al., 2009; Stodden et al., 2008), and this relationship becomes more pronounced in older age groups (D'Hondt et al., 2011). Given the relative ease of measuring weight status and its confirmed inverse relation to gross MSP, it is important that future studies examining gross MSP also measure weight status, if for no other reason than to use it as a control variable.

The most salient behavioral correlate of gross MSP is PA (Barnett, Morgan, et al., 2008; Barnett et al., 2009; Castelli & Valley, 2007; Cliff et al., 2009; D'Hondt et al., 2009; Fisher et al., 2005; Graf et al., 2004; Hume et al., 2008; Okely et al., 2001; H. Williams et al., 2008). Numerous cross-sectional studies and one longitudinal study have confirmed the positive association between gross MSP and PA at different points in childhood. An overview of these studies is given in a later section of this literature review. In their meta-analysis of associated benefits of gross MSP, Lubans and colleagues (2010) confirmed this relationship and noted that all reviewed studies comparing gross MSP and PA using a gross MSP testing battery of >3 skills and an objective measure of PA (e.g., pedometer, accelerometer) indicated a positive, significant relationship. Many of the reviewed cross-sectional studies found significant relationships between self-reported PA and gross MSP, but the association was stronger in studies that used objective measures of PA. One longitudinal study (McKenzie et al., 2002) indicated that gross MSP among 4-6 year-olds did not predict PA at age 12. Of the 13 studies reviewed that compared children's gross MSP and PA, this was the only study that did not find a significant association between gross MSP and PA, a finding that Lubans and colleagues (2010) as well as McKenzie et al. (2002), the study authors, attributed to the limited number of gross motor skills (3) that were assessed, the broad scoring protocol, the small sample size, and the self-reported PA levels.

Despite the growing evidence that supports the relationship between gross MSP and PA, sedentary behavior has not been statistically associated with gross MSP as of yet, although it should be noted that only two known studies have examined this link (Cliff et al., 2009; Graf et al., 2004). Cliff et al. (2009) found a significant association between preschool boys' percent of time spent in moderate, moderate-to-vigorous, and vigorous PA and their locomotor and total gross MSP score, but correlations between percent of time spent in sedentary behaviors and locomotor and total gross MSP score did not near significance (r=-0.152, p=0.469; r=-0.194, p=0.352, respectively). No significant associations between percent time in sedentary behaviors and gross MSP were found among girls in the sample either. Given the established association between gross MSP and PA in this age group (Fisher et al., 2005; H. Williams et al., 2008), one could infer that a similar but inverse association would be seen for sedentary behavior and gross MSP.

Graf and colleagues (2004) used self-reported television viewing (days/week) as a representative measure of sedentary time in 6-7 year-old children and found trends indicating that children who watched the least TV weekly (1-3 days/week) scored higher on a gross MSP assessment that children who watched TV 4-6 days/week, but no significant differences were found between the groups, indicating that sedentary behavior (as measured by how many days/week a child spends watching TV) was not related to gross MSP in their sample. An obvious criticism of this study is the highly subjective and inferential nature of the measure of sedentary behavior. It is likely that 6-7 year-old children are not able to accurately report the number of days/week they watch TV, and thus results from this study may have been underestimated.

Though neither author offered an explanation for the lack of association between gross MSP and sedentary time, one possible explanation could be that children at this age have yet to participate in structured physical education and sport programs that are intended to develop gross FMS, and thus sedentary behavior has little impact on their skills, which are underdeveloped due to their age. Just as weak correlations between PA and gross MSP at this age are common (Fisher et al., 2005; H. Williams et al., 2008), likely because of underdeveloped gross FMS, young children's level of skill could also confound the relationship between gross MSP and sedentary behavior. Further research is necessary to investigate the relationship between sedentary behavior and gross MSP, but appropriately representative measures should be used to examine sedentary time (e.g., accelerometers). Additionally, as the relationship between gross MSP and PA strengthens over developmental time (Stodden et al., 2008), the relationship between sedentary behavior and gross MSP may be more salient in older groups of children.

Evidence for the association between gross MSP and other health-related variables continues to mount, as does the underlying importance of proficient development of gross FMS in children. More work is necessary to determine the causal pathways of such relationships, and great care should be taken to ensure that appropriate methodology is being used when conducting studies examining such relationships (e.g., objective measures of PA, motor skill assessment batteries with an assortment of tasks). Continued research would benefit from exploratory examinations of variables that have yet to be researched in the context of gross MSP—namely genetic factors—that are hypothesized to be associated with gross MSP.

Fine Motor Skills

The development of fine FMS, or precise movements predominantly produced by small muscle groups in the hands and fingers, begins in infancy when babies begin to use the hands to hold and manipulate objects through movements like grasping, pinching, and reaching. These behaviors spurred early research on fine motor skill development (Halverson, 1931) and eventually contributed to the belief that movement occurs as the result of interactions between the task, organism, and environment because infants' grip patterns and stages of grasping were altered when different task constraints (e.g., object sizes) and individual constraints (e.g., body size) were introduced (Newell, McDonald, & Baillargeon, 1993; Newell, Scully, McDonald, & Baillargeon, 1989). Though it may seem simple, this research was among the first in the field of motor development to determine that while neurological maturation certainly influences and constrains fine movement, environmental and task-related factors also influence and constrain movement (Newell et al., 1993; Newell et al., 1989).

As children grow and mature, fine motor skills used in infancy are translated into more mature movements and developmental milestones like handwriting, typing, cutting, dressing and undressing, utilizing eating utensils, turning pages in a book, and combing hair, which are important for grooming and occupational tasks both in childhood and adulthood. Poor fine MSP has negative consequences. Children who cannot proficiently perform such tasks at the same level and rate as their peers may struggle scholastically, as expression through writing is challenging (Rose et al., 1997). These children may also struggle with self-grooming, as fine motor tasks like combing hair and buttoning clothes is challenging (Rose et al., 1997). Poor self-grooming behaviors may cause peers to develop negative perceptions of such children (Wright & Sugden, 1996). As children are able to recognize their inability to proficiently perform certain fine motor tasks, they develop a heightened awareness of their skill level as they make peer comparisons (Cantell et al., 1994), which can ultimately cause children to develop low self-perceptions of their scholastic ability (Piek et al., 2006). As such, poor fine MSP may indirectly impair scholastic achievement. In sum, though much research on fine MSP focuses on infant behavior, poor fine MSP in childhood can be detrimental to a child's overall development, particularly in the scholastic and psychosocial realms. Therefore, a strong understanding of the mechanisms that contribute to fine MSP is valuable.

Fine MSP is typically examined through a neurological, rather than behavioral, lens. Lab-based experiments allow researchers to examine brain function simultaneously with precise finger/arm movements, which provide neurological insight into the control of fine movement. Such studies provide insight into brain regions that may be responsible for certain types of movement, and how factors within the brain may promote or demote movement efficiency. While the correlates of fine MSP and detrimental outcomes of poor fine MSP are important, the focus of this dissertation with respect to fine MSP are the pathways or mechanisms that influence learning and performance of fine motor skills. One such mechanism, brain-derived neurotrophic factor, is discussed with respect to fine motor skill in depth in a later section.

Measurement of Motor Skill Proficiency

Several testing batteries exist that attempt to assess MSP or identify motor delays in children. Many are designed for clinical use and particularly for children with motor coordination difficulties; nevertheless, many are used for general populations in studies that are not examining delays in motor development (Cools et al., 2008). Generally, the tests are concerned with movement control, body stabilization control, and object manipulation, but often tests only focus on one of those general areas. Thus, some tests examine only gross MSP, some only examine fine MSP, and some examine both gross MSP and fine MSP. Many tests are implemented to identify developmental coordination disorders, evaluate populations, assess changes and improvements, and take steps toward prescribing treatment and interventions (Guyatt, Kirshner, & Jaeschke, 1992).

Assessments of MSP can be either norm- or criterion-referenced. Norm-referenced tests compare a child’s results to the results of other populations who are thought to have “normal,” or average, scores. An element of time is attached to such tests (i.e., on average, a child will achieve a given task at a certain age). Criterion-referenced rubrics compare a child's results to a previously defined standard or set of criteria that qualitatively and quantitatively assess aspects of a skill or movement that the child attempts.

Measurement of Gross Motor Skill Proficiency

Over the past decade, many assessments that were created with the intention of diagnosing movement delay have been used in research settings to examine the association between gross MSP and other health-related variables. Testing batteries can assess gross MSP from a product- (Kiphard & Schilling, 2007; Schulz, Henderson, Sugden, & Barnett, 2011) or process-oriented (New South Wales Department of Education and Training, 2005; Ulrich, 2000) perspective, and some batteries use a combination of both (Bruininks & Bruininks, 2005). Product-oriented measures, often called product scores, are a quantitative measure of the outcome of skill performance and can be assessed several different ways (e.g., miles per hour, velocity, time to complete, distance). For instance, a product score for throwing could be distance thrown, throwing velocity, or accuracy. Process-oriented measures examine qualitative aspects of a skill based on an expert model; skills are often broken down into components and individual components are scored. Process aspects of throwing, for example, would include the presence of a contralateral step and proper hip rotation during skill performance. In addition to the product/process approach, testing batteries often examine skills in terms of fine or gross MSP, and many assessments examine both types of skill.

Popular assessment tools of MSP commonly used in North America include component developmental sequences (Roberton & Langendorfer, 1980; Seefeldt, Reuschlein, & Vogel, 1972), the Test of Gross Motor Development-2 (TGMD-2) (Ulrich, 2000), the Movement Assessment Battery for Children-2 (MABC-2) (Schulz et al., 2011), the Peabody Development Scales-2 (PDMS-2) (Folio & Fewell, 2000), and the Bruininks-Oseretsky Test of Motor Proficiency-2 (BOT-2) (Bruininks & Bruininks, 2005). Popular European testing batteries include the Motoriktest für Vier- bis Sechjärige Kinder (Zimmer & Volkamer, 1987), Köperkoordinationtest für Kinder (Kiphard & Schilling, 2007), and the Maastrichtse Motoriek Test (Vles, Kroes, & Feron, 2004). While the goal of most of these assessments is similar, the demographic for which assessments were developed should be considered by the researcher before implementing a testing battery.

Measurement of Fine Motor Skill Proficiency

Many assessment batteries for testing MSP include a fine motor portion and gross motor portion. These batteries, such as the BOT-2 and the MABC-2, are designed in a manner that allows for the fine MSP portion of the test to be conducted and scored independently from the gross MSP portion. The BOT-2, for example, has two composites that test fine MSP: the fine manual control composite, which examines coordination and control of the hands and fingers via drawing cutting tasks; and the manual coordination composite, which examines coordination and control of the arms and hands for the purpose of manipulating objects by sorting cards and putting objects on a string. These composites can be tested independently from the gross MSP composites. Similar to the BOT-2, the MABC-2 has three subtests, one of which is a fine MSP assessment (i.e., the manual dexterity subtest) and can be tested independently from the other two subtests, which examine gross MSP. The fine motor subtests of the MABC-2 and the BOT-2 are commonly used in the literature.

In addition to standardized tests, lab-based tasks are also used to test fine MSP. These tasks can examine an assortment of fine MSP components, including motor learning, motor retention, motor control, and speed and accuracy of fine movements. These components of fine MSP are thought to replicate real-world tasks and movement behaviors in a manner that can be controlled and measured by a researcher. One component of fine MSP that is of particular relevance to this dissertation is the speed-accuracy tradeoff as defined by Fitts' Law (Fitts, 1954). Fitts' Law refers to a mathematical equation that predicts the relationship between amplitude of a movement, size of a target, and the resultant movement time. A tradeoff between speed and accuracy exists in that accuracy requirements of a movement will influence the speed demands of a task. An emphasis on accuracy negatively affects speed and an emphasis on speed negatively influences accuracy. Classically, this principle has been applied to a number of motor skills in the acquisition phase, with the goal of eventually achieving the most proficient movement pattern. Fitts' Law applies to the learning environment of many spatial skills, including reaching and grasping, typing, or moving pegs from one location to another. Recent advances in technology have allowed researchers to develop computer-based tasks that examine the speed-accuracy tradeoff with specific emphasis on fine MSP. These computer-based tasks have many advantages including precision of measurement, particularly in terms of accuracy of fine movements, ease of data collection (e.g., several trials measuring all components of Fitts' Law can be conducted in a very short amount of time), and relative interest for pediatric populations as many of the computer-based tasks are disguised as child-friendly games. Though the assessment of fine MSP via computer applications is relatively novel, its propensity for accurately measuring the speed, accuracy, amplitude, and difficulty index of fine MSP is a valuable research tool for measuring components of fine MSP in young children.

Selection of Appropriate Assessments

Cultural sensitivity to differences in commonly used gross and fine FMS is imperative to the effectiveness of an assessment. For example, while it might not be appropriate to use a European assessment for studying an American population (or vice versa) depending on the selection of gross motor skills used in the testing battery (i.e., American baseball strike versus cricket strike), fine motor skill seems to be more universal and applicable across cultures (i.e., pegboard and tapping tasks). This is not to imply that European assessments would be inappropriate for an American population (or vice versa); this is a notion that must be researched and documented before making such an assertion. The underlying message it that it is important for practitioners and motor developmentalists to understand the differences, strengths, and weaknesses of the available assessments with respect to validity, reliability, ease of administration, and acceptability for the population of interest. Researchers should carefully consider the population of interest prior to selecting an assessment, and base their choice of testing battery heavily on the unique aspects of the group being studied, as well as the variables being compared to the results of the chosen assessment of MSP.

Theoretical Application

Clark and Metcalfe's (2002) "mountain of motor development" metaphor is very useful in explaining the "cumulative, sequential, and interactive" progression of gross FMS acquisitions and development of children. This metaphor asserts that children must first take steps to acquire developmentally proficient levels of gross FMS before being able to apply those skills in physically-demanding, sports-related pursuits. Using Clark's (1994) six periods of motor skill development, which hypothetically occur from infancy to adulthood in typically-developing children, the "mountain" represents an individual's non-linear, self-organizing process of gross FMS development (i.e., "climbing the mountain"). The base of the mountain represents the most rudimentary, infantile period of gross FMS development, while the top of the mountain represents the pinnacle of skill development. While climbing the mountain, an individual must acquire a repertoire of gross FMS in order to proceed up the mountain to the context-specific and skillful periods of development. Individuals who near the top of the mountain must be able to adapt their acquired gross FMS to different contexts and environments. Individuals may only reach this stage in certain skills, while other skills remain more elementary. That is, a child who primarily focuses on basketball will reach this period for dribbling, running, and jumping, but because he has never had experience with baseball may not reach this period for throwing and catching. Further, to reach the top of the mountain, an individual must be able to take those context-specific skills and apply them with "maximum certainty" to numerous, varied situations. Gross FMS performance in this final, skillful period is often compared to professional athleticism and therefore not all individuals will reach this stage.

While this metaphor is excellent in addressing an individual's gross FMS *development*, it is incomplete—at least with respect to this literature review—in explaining how gross MSP interacts with other factors to ultimately impact an individual's overall health. A conceptual model by Stodden et al. (2008), shown in Figure 2.1, expands on the work of Clark and Metcalfe (2002) by theorizing the dynamic and reciprocal nature of gross MSP in relation to PPC, PA, health-related physical fitness, and obesity risk, and how those relationships differ at different points in childhood. An important principle of the model that echoes current literature in the area is that gross MSP is paramount for promotion and sustainment of healthy PA levels in childhood, but that this relationship is mediated by other factors such as PA, PPC, and health-related physical fitness.

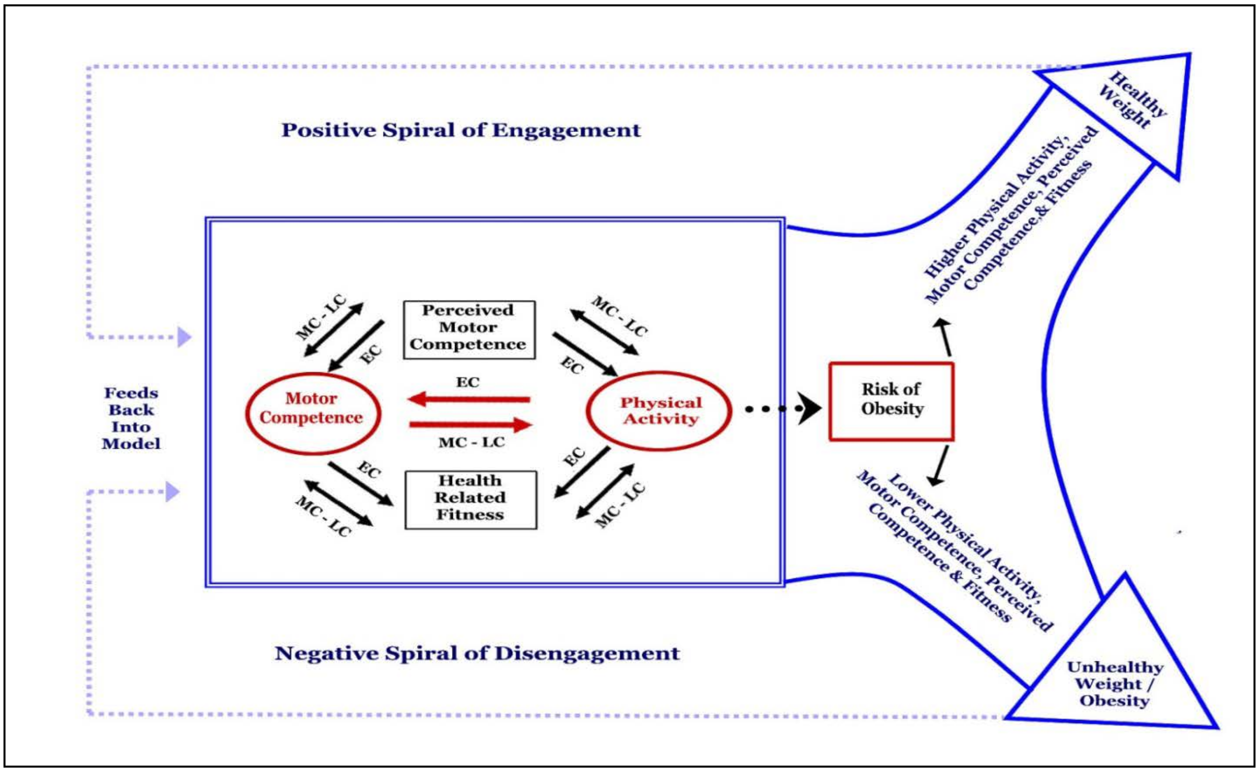


Figure 2.1. Developmental mechanisms influencing physical activity trajectories of children (Stodden et al., 2008)
Note: EC – early childhood; MC – middle childhood; LC – late childhood

The heart of the model is represented by the reciprocal and dynamic relationship between PA and gross MSP, which Stodden et al. (2008) hypothesize will strengthen over developmental time; there is some empirical evidence to support this hypothesis. The model suggests that in early childhood, PA drives gross MSP because PA offers the opportunity to explore the environment through movement, which ultimately promotes an elementary development of gross FMS. Stodden posits that though relationships exist at this age, they are often weak because skill and PA are highly variable. In middle and late childhood, the relationship strengthens and gross MSP becomes the driver of PA, hypothetically because as children develop their repertoire of gross FMS, they are able to apply these skills in sports, games, and other pursuits that require PA. Though this direct relationship is well-represented in the literature, it is evident that it is not clear-cut. As indicated by the model, other variables mediate the relationship between childhood gross MSP and PA.

Perceived physical competence plays an important mediating role in the relationship presented at the heart of the model. Because young children cannot accurately perceive skill, their PPC is often inflated and overestimated even when they demonstrate poor actual gross MSP, and therefore low correlations between PPC and gross MSP and PPC and PA are often seen. PPC becomes more salient in middle and late childhood, according to the model. At this point in childhood, children can more accurately perceive skill and can make peer comparisons, which can be detrimental or positive for PA levels, depending on whether their perceptions are positive or negative. Children use feedback from their actual gross MSP to develop perceptions of their skill. Highly skilled children are more likely to engage in physically-challenging activities that employ skill and promote PA. Conversely, children with poor gross MSP are more likely to develop negative perceptions and have a high tendency to self-select out of activities that require gross FMS, resulting in lower levels of PA.

This model also identifies health-related physical fitness as a mediator in the relationship between PA and gross MSP. In early childhood, gross MSP promotes health-related physical fitness because as children learn and hone skills, they are inevitably being active, which in turn increases health-related physical fitness. But just as with the other relationships presented in the model, Stodden et al. (2008) hypothesize that health-related physical fitness is highly variable in early childhood and weak relationships are likely to be seen; however, to date no empirical evidence exists to support this notion. Once children reach a developmental point where high levels of gross MSP can be demonstrated (e.g., middle/late childhood), gross MSP begins to more strongly correlate with facets of health-related physical fitness like aerobic capacity, muscular strength and endurance, cardiovascular fitness, and flexibility. PA inherently promotes health-related physical fitness, and thus the three (PA, gross MSP, and health-related physical fitness) work in concert with one another.

According to the model, all of the proposed developmental pathways work to promote or demote obesity through a "positive spiral of engagement" or a "negative spiral of disengagement," respectively. In essence, children with high levels of gross MSP, PPC, health-related physical fitness, and ultimately PA, will enter in the positive spiral of engagement and be more likely to maintain a healthy weight status over time. Conversely, children with poor levels of gross MSP, PPC, health-related physical fitness, and PA will enter in the negative spiral of disengagement and be more likely to maintain an unhealthy weight status over time. The model is dynamic and reciprocal because weight status, be it healthy or unhealthy, feeds back into the model and further promotes entrance into either the positive or negative spiral. The overarching goal of the model is to promote a focus on developmental trajectories, which can be positive or negative depending on the factors presented in the model, that foster engagement in and adherence to physical activity throughout the lifespan. Further, the model is unique in that it is presented with an empirical backbone that allows researchers to test the proposed pathways.

Stodden et al. (2008) acknowledge that the issue of obesity, especially when examined through a physical activity lens, is multi-faceted and complex, and note there may be missing pieces to the model. In fact, the authors explicitly state: “We recognize these relationships are embedded in and influenced by other contextual factors (environment, family, peers, socioeconomic status, culture, nutrition, self-efficacy, etc.) that affect an individual’s opportunity to be active” (p. 303). Interestingly, one factor that is not listed as being influential in those relationships is a genetic component. A body of literature indicates that skill is genetically driven (Bueller et al., 2006; P. W. Fox, Hershberger, & Bouchard, 1996; Fritsch et al., 2010; Maes et al., 1996; Marisi, 1977; McHughen et al., 2010; McNemar, 1933; L. Williams & Gross, 1980) and thus it is possible that genetic factors also drive MSP and ultimately drive the developmental trajectories implicated in Stodden’s model. However, more research is necessary to confirm this assumption.

In review, Stodden and colleagues’ (2008) conceptual model highlights important and salient correlates of gross MSP and their interactions with one another throughout childhood. While this model offers an in-depth and empirically-based illustration of the contribution of gross MSP to obesity risk through PA, PCC, and health-related physical fitness, it fails to consider one important factor that may impact gross MSP: genetics. Regardless, this model is a representation of the vast amount of research that has been conducted in the past two decades on gross MSP. Two correlates of gross MSP presented in the model that pertain directly to this dissertation and are commonly discussed in the literature are PA and PPC, both of which are reviewed in the following two sections.

Pediatric Physical Activity

Physical activity is defined by Caspersen, Powell, and Christenson (1985) as “any body movement produced by muscle action that increases energy expenditure” (p. 2), and is an important marker of health across the lifespan. Positive effects of adequate PA include improved aerobic fitness, blood pressure control, balanced body composition, and psychological health, among others (Sallis, Prochaska, & Taylor, 2000). Physical inactivity is one of the leading determinants of childhood overweight and obesity (Kruger, Kruger, & Macintyre, 2006; Ortega, Ruiz, Castillo, & Sjöström, 2008). Research has shown that childhood PA habits, whether positive or negative, tend to track into adolescence (Kristensen et al., 2008), and individuals who are consistently and continuously physically active during their youth are much more likely to be active adults than those who were less persistent participants in PA as children (Telama et al., 2005). Telama et al. (2005) also found that children who participated in multiple forms of PA (e.g., various sports, ball games, cycling, swimming) during childhood were more active than children who were involved in only one kind of physical activity, a finding that gives rise to the necessity of developing a repertoire of FMS during the childhood years.

Recently, and for the first time in American history, the U.S. Federal Government issued PA guidelines for Americans (USDHHS, 2008). These guidelines were created with respect to the amount and specific types of PA that impart considerable health benefits to American children, adolescents, and adults. According to the guidelines, children should accrue at least 60 minutes of moderate-to-vigorous PA per day, and activities that promote muscle- and bone-strengthening should be done at least three days a week (USDHHS, 2008). The most recent data from the National Health and Nutrition Examination (NHANES) indicate that 58% of children ages 6-11 years do not meet the USDHHS PA recommendations and declines in PA are seen across increasing age groups (Troiano et al., 2008). In addition to promoting PA in children, recent attention has also been given to the reduction of sedentary time (Salmon, Tremblay, Marshall, & Hume, 2011) as sedentary behaviors increase with age and are associated with negative health outcomes over time (Mark Stephen Tremblay, Colley, Saunders, Healy, & Owen, 2010). Because a majority of young children and an even greater amount of adolescents are not meeting PA recommendations and are spending more time sedentary, there is a need to determine why some children are more active than others.

Measurement of Physical Activity and Sedentary Time

The definition of "physical activity" is a somewhat vague concept, and measuring any muscle action that causes bodily energy expenditure is not a clear-cut process. Malina, Bouchard, and Bar-Or (2004) suggest that no individual measure can evaluate every complicated aspect of physical activity. Although researchers are working to improve methods of PA analysis, primitive methods of analysis are still being used in current studies that compare PA to MSP. In fact, Cliff et al. (2009) assert that conflicting strength differences in reported associations between MSP and PA may be attributable to the methods in which PA is being assessed (although one could make the same argument for assessment of MSP). Researchers should give careful consideration to the specific aspects of PA that they want to measure and the population being assessed in order to select the most appropriate method of assessment.

Numerous methods exist for measuring PA in pediatric populations. Some methods are highly precise and reliable, but lack the feasibility to be used in naturally occurring field settings. Other methods can be used in a variety of settings, but lack reliability and feasibility. PA is commonly assessed using any combination of these four dimensions: frequency, intensity, duration, and type. Different measures of PA capture these dimensions differently, with some capturing all four and some capturing only one or two. Sirard and Pate (2001) categorize PA measurement techniques in three ways: primary measures (e.g., doubly-labeled water, indirect calorimetry, direct observation), secondary measures (e.g., pedometers, heart rate monitors, accelerometers), and subjective measures (e.g., surveys, diaries). Primary measures are most commonly used as a way to validate other PA measurement tools, and are considered the "gold standard" for PA assessment. Secondary measures can be used to validate other forms of PA measurement when the use of a primary-level measure is not available or feasible. Secondary measures are objective in nature, and many have high reliability and validity, as discussed in the following paragraph. Subjective measures of PA should be validated against a primary level or secondary level criterion measure before being implemented. Each class of PA measurement (e.g., primary, secondary, and subjective) has advantages and disadvantages. Primary measures are typically the most precise method of measuring PA, but can be cumbersome and costly. Secondary measures have the advantage of objectivity, but can also be costly and difficult to maintain participant compliance. Subjective measures are inexpensive and have low participant burden, but can be less reliable when used in pediatric populations. However, subjective measures that have been validated against primary and secondary measures are widely used and accepted in the literature (Sirard & Pate, 2001).

Objective data collection measures of PA are hypothesized to reduce measurement bias (Cliff et al., 2009), despite being more complex to administer than subjective methods (Okely et al., 2001). Perhaps the simplest method of objectively measured PA is in the form of pedometers, which are electronic devices worn on the hip that measure steps taken or distance walked. A participant's or group of participants' steps/day can be compared to the step recommendations (i.e., 13000/day for boys, 11000/day for girls; (Tudor-Locke et al., 2011). Participants are typically asked to record the amount of accrued steps at the end of the day for a period of one week. Pedometers are especially useful for very large subject pools because they are inexpensive and easy to use, but are also highly susceptible to participant tampering, especially in children, and they do not capture all four domains of physical activity. They provide information regarding total volume of steps taken. Heart rate monitors provide a measure of the physiological response to PA by relying on the linear relationship between heart rate and oxygen consumption. The FLEX heart rate method is an individually determined heart rate that distinguishes between resting energy expenditure and activity energy (Livingstone et al., 1992) and has been validated in a pediatric population (Emons, Groenenboom, Westerterp, & Saris, 1992). Heart rate monitoring is cost-effective, places low burden on the participant, and is a good tool for estimating patterns of activity, but heart rate is easily affected by external variables (e.g., heat, caffeine, stress) (Sirard & Pate, 2001). Heart rate monitoring cannot provide information about the type of activity being performed, but does provide information about frequency, intensity, and duration.

Accelerometers are small, electronic devices typically worn around the hip—but can be worn around the lower back, wrist, or ankle—that measure PA by recording accelerations of movement. Recorded accelerations are converted into counts, which are placed into regression equations to determine energy expenditure. Regression analyses can also be used to create cutpoints, which reflect different intensities of exercise (e.g., sedentary, light, moderate, vigorous). Accelerometers can be uniaxial, biaxial, or triaxial, meaning that they measure accelerations along one to three planes. The CSA/Actigraph is arguably the most common accelerometer used in child PA studies (de Vries, Bakker, Hopman-Rock, Hirasing, & van Mechelen, 2006) and has been validated using direct calorimetry in 6-16 year-old children (r=0.73) (Puyau, Adolph, Vohra, & Butte, 2002), and using indirect calorimetry in 5-8 year-old children (r=0.83-0.85) (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008)

Accelerometers can store data for a long period of time (beyond three weeks depending on epoch level; the shorter the epoch level, the less data can be stored), and provide a measure of frequency, intensity, duration, and an estimate of total energy expenditure. However, accelerometers cannot assess a wide range of activities including water-based activity (although some models are now water-proof), upper-body movement, biking, walking on an incline, or carrying a load. Proper placement of the device cannot be assured once the participant leaves the physical presence of the researcher, which can result in inconsistent and inaccurate data.

Choosing a method of PA measurement requires careful evaluation of the population being assessed and the environment in which that population is being assessed. Because children typically exhibit sporadic, short bursts of activity (as opposed to exercising at a gym for an hour a day, like some adults), some methods are more salient than others in capturing a true assessment of physical activity. Heart rate monitoring, for example, is susceptible to lags, meaning that the device cannot capture quick, short-duration changes in heart rate. Though heart rate monitors would likely provide good information about a child's activity changes throughout the day, some of those short bursts of high-intensity activity might be missed. Doubly-labeled water is not feasible because of cost and participant burden (parents needing to drive children to have blood work and urine analyses done every few days); this method also gives no indication of frequency, duration, time or type of activity, which is highly important in children. Though pedometers are a cost effective, objective method for assessing PA in children, the monitors are highly susceptible to participant tampering, and asking children to write down step counts at the end of a day can decrease the objectivity of the measure (Sirard & Pate, 2001). The subjective nature of questionnaires warrants caution, and if children are very young, their answers will likely be unreliable. Using direct observation would be an ideal method for capture of the short, spontaneous bursts and varying intensities of activity in which children typically engage, but this method would require intensive training and availability of several researchers to quantify the activity of the population being assessed and is not feasible for studies with a large sample size. In pediatric studies with a large sample size, the use of accelerometers is recommended because these devices provide information on three dimensions of activity: frequency, intensity, and duration. Though the cost of multiple accelerometers is somewhat high, even with a limited number of devices, several children can be assessed over the course of a few weeks by rotating the devices through the subject pool after downloading data. In addition to measuring PA, accelerometers are recommended for measuring sedentary time in children because many children may exhibit measurement bias by over- or underestimating time spent being inactive (Atkin et al., 2013; Bryant, Lucove, Evenson, & Marshall, 2007; Reilly et al., 2008). However, because accelerometers can only capture frequency and duration of sedentary time, the type of sedentary activities in which children engage can only be captured by subjective methods, like surveys and questionnaires. Thus, if the focus of the researcher is on the type of sedentary activity (e.g., screen time), accelerometry would not be the most appropriate tool for measurement. Because PA and sedentary time, particularly in pediatric populations, are highly variable, the tool to measure PA must be carefully chosen and implementation of the measurement tool must be closely monitored by the research team to ensure proper use of the device.

Relationship between Physical Activity and Gross Motor Skill Proficiency

There is a great need to understand the developmental mechanisms that promote adherence to PA in children. PA is highly variable, both among individuals and across groups, likely because a multitude of factors contribute to a person's PA level. Factors such as socioeconomic status, opportunity, genetics, motivation, perceived competence, and weight status all play a role in children's PA levels. In recent years, gross MSP has been identified as an important contributor to children's PA levels. Cross-sectional research suggests there is a significant reciprocal relationship between gross MSP and PA. Stodden et al. (2008) hypothesize that this relationship strengthens over developmental time, and that the causal direction of the relationship changes with age. While it is assumed that children who develop higher levels of gross MSP will have a greater tendency to engage in PA as children, adolescents, and adults, longitudinal evidence that supports this assumption is limited.

The relationship between PA and gross MSP in early childhood (ages 4-6) is somewhat unclear in the literature. Clark and Metcalfe (2002) suggest that at very young ages, children's PA levels can either constrain or broaden their development of gross MSP. That is, children who are not physically active will have fewer opportunities to develop gross MSP, and children who are physically active can begin to develop skill by physically exploring their environment through movement. Stodden et al. (2008) echo this view with their hypothesis that PA promotes neuromotor development, ultimately promoting development of gross FMS at very young ages, and thus gross MSP is driven by PA during early childhood. However, this relationship is less understood than in middle- and late-childhood because gross MSP is highly variable in early years and weak relationships between gross MSP and PA are often found. For example, Fisher et al. (2005) found that among 3-5 year-old children, only 1% of the variance in objectively-measured total PA was significantly explained by gross MSP, despite the gross MSP variable being derived from performance on 15 different movement skills. When only time spent in moderate-to-vigorous PA (MVPA) was considered, slightly larger variance (3.2%) was explained by gross MSP, but time spent in light-intensity PA was not significantly explained by gross MSP. Results from a study by H. Williams et al. (2008) indicated a stronger relationship between gross MSP and PA among 4-5 year-old preschoolers: those who were in the highest tertile of gross MSP spent significantly more time in MVPA (13.4%) than children in the intermediate tertile (12.8%) and lowest tertile (11.4%). When gross MSP was considered separately from an object control and locomotor perspective, no significant differences among tertiles for object control scores and PA were found, but children in the highest tertile for locomotor scores spent significantly less time being sedentary (53.1%) than children in the intermediate (55.6%) and lowest (55.7%) tertiles. Though H. Williams et al. (2008) found no sex differences among the gross MSP/PA relationship and also found no significant relationship between object control skills and PA in preschoolers, Cliff et al. (2009) found dissimilar results in a similar study of 3-5 year-old boys and girls. Though boys and girls were equally proficient at object control skill performance, boys' object control skills were more positively associated with time spent in MVPA than those of girls', and girls' locomotor skills were actually inversely related to PA, a finding that the authors contribute to large variation in skill level among the young study sample as well as the small sample size (Cliff et al., 2009). Collectively, these three studies demonstrate that at least in early childhood, differences in the relationship between gross MSP and PA may be due to differing levels of performance among boys and girls in subdomains of skill (e.g., object control and locomotor).

In middle (7-9 years old) and late (10-11 years old) childhood, the relationship between PA and gross MSP strengthens and is better understood in the literature because correlations are stronger and findings are more consistent across studies (Fisher et al., 2005; McKenzie et al., 2002; Okely et al., 2001; Sääkslahti et al., 1999). Children with poor gross MSP levels will likely be susceptible to a hypothesized "proficiency barrier," in which participation in physically demanding activities will be difficult and unlikely because these children will not have the requisite skills to move proficiently in such activities (Seefeldt, 1980). Though these hypotheses are widely accepted as correct, longitudinal data supporting these notions do not currently exist. Nonetheless, relationships among gross MSP and PA are evident in middle and late childhood, and are stronger than in early childhood. Castelli and Valley (2007) offer one example of the strengthening relationship between gross MSP and PA over developmental time, as evidenced by a simple comparison of the gross MSP/PA correlations in their sample of children in middle and late childhood to those of H. Williams et al. (2008) and Fisher et al. (2005), who examined children in early childhood and found correlations between gross MSP and MVPA of r=0.20 (p<.001) and r=0.18 (p<.001), respectively. When Castelli and Valley (2007) examined the same relationship among 7-12 year-old children using only three skills to represent total gross MSP, correlations of r=0.52-0.55 (p<.01) were seen. Further, an examination of 8-10 year-old children by Wrotniak et al. (2006) revealed correlations between PA and gross MSP (as measured by a standardized motor assessment battery) ranging from r=0.29-0.33 (p<.05) depending on the classification of PA (i.e., MVPA/MSP=0.29; moderate PA/MSP=0.33; accelerometer counts per minute/MSP=0.32). Evidence that this relationship strengthens over developmental time is important in justifying the significance of the development of gross FMS at early ages.

Differences in object control and locomotor performance among boys and girls in middle and late childhood seem to play a role in the relationship between gross MSP and PA. Using only five skills to characterize gross MSP, Hume et al. (2008) found significant, moderate correlations between objectively-measured PA and total gross MSP among 9-12 year-old boys (r=.21-.24, p<.05) and girls (r=.21, p<.05), but found that neither gross MSP nor PA were significantly related to weight status. Three object control skills (overhand throw, two-handed strike, and kick) and two locomotor skills (sprint run and vertical jump) were assessed. Boys were significantly more physically active and better performers of object control skills, but no significant differences were seen in locomotor skill performance among boys and girls. As a result, boys' object control scores were significantly related to PA (r=.24, p<.01), but girls' object control scores were not. Significant correlations between locomotor scores and PA were seen for both boys (r=.22, p<.05) and girls (r=.29, p<.01). Morgan, Okely, Cliff, Jones, and Baur (2008) echoed these findings in an obese population. In their sample of obese 5-9 year-olds (mean age = 8.3 ± 1.1), boys' and girls' PA levels did not vary significantly, but boys were better performers of object control skills, while girls outperformed boys at locomotor skills. Thus, boys' PA, as objectively measured by accelerometer counts per minute, was significantly predicted by object control skill proficiency (R^2=0.50, p=.000), but girls' PA was not. Significant associations between girls' locomotor skills and PA were only found when MVPA was considered instead of accelerometer counts per minute (r=0.24, p<.05). When examining the relationship between gross MSP and PA in middle and late childhood, it is important to consider boys' and girls' gross MSP separately, and also to examine gross MSP from both an object control and locomotor perspective, as these two aspects of skill performance seem to differentially influence PA in this age group. Likewise, the impact of sedentary time on gross MSP should not be ignored. Despite the growing evidence that supports the relationship between gross MSP and PA, sedentary behavior has not been statistically associated with gross MSP as of yet, although it should be noted that only two known studies have examined this link

(Cliff et al., 2009; Graf et al., 2004). A more expansive review of the relationship between gross MSP and sedentary time has already been discussed (see section "Correlates of Gross MSP").

Physical activity is a complex factor to study in pediatric populations, particularly because precise and sensitive methods of measurement are challenging to conduct in large populations and because children's PA levels are highly variable. However, its importance to overall health makes it a worthwhile variable to study, particularly in the context of other common behaviors of childhood—namely, gross MSP. In general, the relationship between gross MSP and PA strengthens from early childhood to late childhood and into adolescence. Children of all ages with better gross MSP routinely spend more time being physically active than individuals with poor gross MSP, who have a greater tendency to be sedentary. Though this relationship is now well-established, correlations are often low-to-moderate, and further exploration of other factors thought to contribute to the relationship between gross MSP and PA is warranted.

Perceived Physical Competence

Over the past few decades, perceived competence has garnered interest in the field of motor development. Perceived competence, defined by K. R. Fox (1997), is a subjective statement of personal ability along a domain, such as sport, scholarship, work, or artistry. Perceived *physical* competence (PPC), a sub-domain of perceived competence that is a known contributor to MSP, is defined as an individual's personal perception of their physical strength, movement capability, capacity for sport, and fitness (Harter, 1985). In general, children with low PPC are typically less proficient at performing motor skills (Goodway & Rudisill, 1997;

Robinson, 2011), less physically fit (Barnett, Van Beurden, et al., 2008), and less physically active (Bois, Sarrazin, Brustad, Trouilloud, & Cury, 2005; Morgan et al., 2008; Raudsepp & Liblik, 2002) than children with high PPC. Further, low PPC is often seen as a barrier to participation in activities that require motor skills (Carroll & Loumidis, 2001; Sallis et al., 2000) add Ulrich 1987.

Theoretical Overview of Perceived Competence

White (1959) first introduced the concept of "competence" as a way to reconsider theories of motivation. At the time, theories of motivation did not take into consideration environmental or biological factors and as a result, a child's desire and willingness to explore and learn from the environment was not a factor. Theories at that time were based on primary, instinctual drive. White proposed the term "competence" to explain the process by which children effectively interact with their environment. These effective interactions resulted in feelings of self-efficacy, which in turn motivated the child to explore more. Thus, the phrase "effectance motivation" was born.

Harter (1978) revised and refined White's (1959) model into a researchable format based on White's empirical suggestions as well as her own. Harter (1978) expanded on many concepts introduced by White and essentially created measurable variables, one of which was perceived competence. Harter (1978) explains that individuals with high perceptions of competence are more likely to persist at certain activities than individuals with low perceptions of competence. Additionally, children are more likely to attempt activities that result in high perceptions of competence than activities that likely result in failure. Harter proposed four psychological constructs that contribute to an individual's development of competence perceptions: (1) past experiences; (2) difficulty or challenge associated with outcome; (3) reinforcement or approval from significant others; and (4) intrinsic motivation. Individuals use information from these constructs to subjectively determine competence for different tasks.

Harter (1978) and Shavelson, Hubner, and Stanton (1976) both proposed the concept of subdomains of perceived competence by suggesting that global self-worth is the result of self-perceptions of domain-specific competencies, one of which is the physical domain (others include social, emotional, behavioral, and cognitive). Individuals who view competencies as personally important are more likely to persist at activities of high perceived competence, which may contribute to an individual's overall self-worth or global self-esteem. Klint and Weiss (1987) were among the first to test Harter's (1978) competence motivation theory using different subdomains in the context of sport participation. Young gymnasts with high perceived *physical* competence felt that skill development was the primary driver for their participation in the sport, whereas other gymnasts with high perceived *social* competence felt that affiliation-related motives were more salient in their participation in gymnastics. This study arguably spurred PPC research, and much attention has subsequently been given to the relationship between PPC and gross MSP with regard to how the relationship changes as children age and develop skills, as well as how the relationship differs for boys and girls.

Relationship between Perceived Physical Competence and Gross Motor Skill Proficiency

The relationship between gross MSP and PPC is not stable throughout childhood, but there is some evidence that a very young child's PPC remains stable into late childhood (Rudisill et al., 1993). Typically, very young children demonstrate inflated perceptions of physical competence in comparison to actual competence, and older children demonstrate less inflated PPC in comparison to actual gross MSP. Though no age group has ever demonstrated perfect accuracy of physical competency estimations, children's estimations of their gross MSP seem to become more accurate with age. Sex differences also exist with respect to the gross MSP/PPC relationship. In general, girls tend to have lower PPC than boys, and girls also typically demonstrate poorer actual gross MSP in comparison with boys and most points during childhood.

In their examination of at-risk preschool children, Goodway and Rudisill (1997) found that children in their sample were unable to accurately estimate their actual gross MSP, as indicated by very low correlations between PPC and actual gross MSP. The boys in their sample demonstrated better actual gross MSP and had higher PPC than girls, but regression analyses indicated that no differences between the accuracy of either sexes' perceptions existed (i.e., neither sex over- or underestimated their actual gross MSP more than the other sex). Children as a whole in this study, regardless of sex, overestimated their actual level of gross MSP.

In Robinson's (2011) replication of Goodway and Rudisill's (1997) study, at-risk preschool boys demonstrated better gross MSP and had higher perceptions of their physical competence than girls. Girls, however, showed stronger correlations between PPC and gross MSP than boys. As a whole, children demonstrated moderate, positive correlations between PPC and actual gross MSP. Robinson (2011) attributed the difference in correlation strengths between the studies to the lower-than-typically-reported PPC in her study as compared to the Goodway and Rudisill (1997) study. Though preschool children typically greatly over-estimate their actual gross MSP, as in the Goodway and Rudisill (1997) study, children in the Robinson (2011) study reported low PPC, which more closely aligned with their low levels of actual gross MSP. Children in the Robinson (2011) study seem to have already identified themselves as having low competence for skills commonly used in sports and games, a trait that likely will prove detrimental for subsequent sport participation and participation in physically demanding activities.

Rudisill and colleagues (1993) offer some insight as to why the relationship between PPC and MSP is stronger in middle and late childhood compared to the weak relationships seen in early childhood, as the findings of Robinson (2011) and Goodway and Rudisill (1997) suggest. Rudisill et al. (1993) found that while the actual gross MSP of 9, 10, and 11-year-old children increased with age group (e.g., in their sample, older children had better gross MSP than the younger children), there were no significant differences in PPC among any of the age groups, suggesting that PPC may level off or hit a ceiling once children enter late childhood. Boys and girls in the sample both overestimated their actual competence (i.e., boys and girls perceived that they were more competent than they actually were). Rudisill et al. (1993) suggested that most very young children will overestimate their actual gross MSP, but for the most part the point at which children estimate their level of skill at a young age stays the same throughout middle- and late-childhood. Thus, as children’s actual gross MSP improves with age but their perceptions of competence remains the same throughout childhood, the gap between actual and perceived motor skill competency begins to close and stronger relationships between PPC and MSP are seen in older children (Rudisill et al., 1993).

Trends in sex differences with respect to PPC and gross MSP continue into middle school, and weight status seems to play a role in children's perceptions of competence at this age. In a sample of 11-14 year-old children, overweight and obese participants demonstrated lower actual gross MSP and PPC than normal-weight peers, suggesting that childhood obesity is likely to have adverse effects on PPC and MSP (Morano, Colella, Robazza, Bortoli, & Capranica, 2011). When sex differences were considered, boys demonstrated higher perceptions of coordination, higher sport competence, and better motor skill competence than girls, regardless of weight status. Further, when weight status was again considered, overweight and obese boys had higher perceptions of competence in comparison to normal-weight girls, even though other studies have determined that overweight and obese children—regardless of gender—typically have lower perceptions of physical competence than normal-weight peers (Southall et al., 2004). At least with respect to middle school children, it may be important to consider the implications of weight status on PPC.

Though longitudinal data on the gross MSP/PPC relationship is scarce, a handful of studies exist that introduced PPC as a mediating variable between childhood gross MSP and adolescent PA. Barnett and colleagues (2008) used structural equation modeling techniques to determine if PPC mediated the relationship between childhood object control proficiency (a measure of MSP) and subsequent adolescent PA. Analyses revealed a direct relationship between childhood MSP and adolescent PA, with gross MSP predicting 8% (R^2 = .08) of adolescent PA. However, when PPC was entered in the model as a mediating variable, 18% (R^2 = .18) of the variance in adolescent PA was explained by childhood gross MSP. Though boys in the study demonstrated higher PPC, higher actual gross MSP, and were more active than girls, sex did not mediate the relationship between any of the variable. Given the vast number of other known factors that play a role in predicting PA in adolescents, the strength of the association in this study gives rise to the importance of developing high perceptions of competence at young ages, as gross MSP and PPC seem to combine to promote positive PA outcomes in adolescents.

In a separate study by the same author (Barnett et al., 2011), the relationship between object control proficiency and moderate-to-vigorous physical activity (MVPA) in adolescents increased significantly when PPC was added as a mediating variable. Additionally, a reciprocal predictive relationship was found between gross MSP and MVPA, but only when PPC was entered as a mediating variable. Interestingly, in this adolescent population, the direct relationship between object control proficiency and PPC was stronger than the relationship between locomotor skill proficiency and PPC, suggesting that adolescents may not be able to assess locomotor skill proficiency as accurately as object control proficiency, likely because success or failure during performance of skills like catching, kicking, and throwing may be more obvious in sport situations than the success or failure of locomotor skills like running, jumping, and leaping. The reciprocity of the relationship between gross MSP and PA mediated by PPC lends itself to the importance of developing high perceptions of competence in children in concert with developing proficiency in gross MSP.

Typically, very young children have inflated perceptions of physical competence (Goodway & Rudisill, 1997) and as children get older and begin to make peer comparisons, PPC becomes more closely aligned with actual gross MSP (Rudisill et al., 1993), and the composite effect of PPC and gross MSP in childhood seems to encourage persistence at PA into adolescence (Barnett et al., 2011; Barnett, Morgan, et al., 2008). With respect to sex, a trend exists in that girls have lower perceptions of PPC than boys at every age group in childhood (Goodway & Rudisill, 1997; Morano et al., 2011; Robinson, 2011; Rudisill et al., 1993; Southall et al., 2004) and even into adolescence (Barnett, Morgan, et al., 2008). In addition to having lower levels of PPC, girls also demonstrated poorer motor skills than boys regardless of skill type (e.g., locomotor or object control) (Barnett et al., 2011; Barnett, Morgan, et al., 2008; Robinson, 2011; Rudisill et al., 1993). Because individuals of all ages with low PPC and poor gross MSP are less likely to be physically active, the importance of motor skill development and the improvement of PPC in youth cannot be overlooked. Though the combination of these two factors has proven salient in promoting adolescent PA (Barnett et al., 2011; Barnett, Morgan, et al., 2008), more research is necessary to determine their composite role in promoting PA in younger age groups.

It is worth noting that as of yet, no empirical evidence exists that links PPC to fine MSP in children. However, a study by Piek et al. (2006) found that in comparison to children with good fine MSP, 7-11 year-old children with poor fine MSP had lower perceptions of scholastic competence. Given the importance of fine MSP in the successful completion of classroom tasks (e.g., handwriting, cutting, crafts), these findings were expected. Conversely, when Piek and colleagues (2006) examined the relationship between fine MSP and perceived athletic competence, no significant associations were found even though the authors found that gross MSP deficits were significantly related to poor perceived athletic competence. These findings were echoed in an adolescent sample in the same study. While it is not beyond the realm of possibility for a child to develop perceptions of physical competence—whether good or bad—as a result of their fine MSP, only one study has examined such a link and did not return significant findings. The Piek study (2006) analyzed fine and gross MSP separately and found a significant association between gross MSP and perceived athletic competence, but not between fine MSP and perceived athletic competence in two different samples (children and adolescents). These findings further emphasize the importance of analyzing fine and gross MSP as separate variables.

Genetics and Motor Skill Proficiency

Genetics undeniably play a role in human MSP, as anecdotally shown by sport talent that "runs in the family," or sibling pairs who both excel at certain sports. The vast majority of genetic research in the motor skill arena is driven by heritability studies using twins or sibling pairs. Monozygotic (genetically identical) twins' performance has been compared to dizygotic (non-genetically identical) twins' performance in an effort to separate environmentally-influenced traits from genetically-inherited traits. These heritability studies highlight the significant genetic contribution to motor skills acquisition, learning, and performance by comparing differences between twins to differences between other individuals.

Evidence on the genetic contribution to gross MSP is more limited than that of fine MSP, but it is possible to draw some parallels to studies that have examined genetic contributions of "motor fitness" and "physiological fitness," as many of the skills examined in these studies were gross motor skills. L. Williams and Gross (1980) compared performance on a stabilometer balance task, which the authors specifically coined a “gross motor skill,” between monozygotic and dizygotic twin pairs. The stabilometer balance task is essentially a wooden platform built in a seesaw-like fashion that requires the participant to constantly adapt his or her standing state to keep the board perfectly horizontal. Their hypothesis that interindividual differences in monozygotic twins would be less than for dizygotic twins was supported, and this heritability factor actually increased through the duration of the practice attempts. In a seminal study on the contribution of genetic factors to physical fitness, Maes et al. (1996) examined performance on nine gross motor tasks, which were divided into two categories: “performance-related” tasks (static strength, explosive strength, running speed, speed of limb movement, and balance) and “health-related” tasks (trunk strength, functional strength, maximum oxygen uptake, and flexibility). Participants were 10-year-old males and females from five twin groups (male monozygotic, female monozygotic, male dizygotic, female dizygotic, and male/female dizygotic). Of particular interest to this review are the results from twin performance on the performance-related tasks, which most closely mirror the gross motor skills discussed in this literature review. Relative environmental and genetic contribution to the performance-related tasks was determined via path analysis. The analysis revealed that 23% (running speed) to 72% (static strength) of scores on the performance-related tasks were accounted for by genetic factors, with the remainder of the variance attributed to environmental factors. These results indicated that some skills, like the measure of static strength (static arm pull-up), are almost entirely genetically driven (72%). The vertical jump task, balance task, and limb-movement speed task (plate tapping with toes) are divided almost equally in terms of genetic/environment contribution (47%, 46%, and 56% genetic contribution, respectively). Running speed, however, seems to have a much greater environmental contribution than genetic, as only 23% of the variance in the shuttle run task was explained by genetic components. Much like performance on fine motor tasks, these studies indicate that performance on gross motor tasks is largely driven by genetic factors.

McNemar (1933) found that monozygotic twin pairs demonstrated a higher degree of resemblance to one another on five different fine motor tasks (pursuit rotor task, card sorting, spool packing, Miles speed drill, and Whipple steadiness task) than matched dizygotic twin pairs, indicating a heritable basis for fine MSP. Similarly, Marisi (1977) compared fine MSP as measured by a pursuit rotor tracking device between monozygotic and dizygotic twin pairs. Without practicing the task, the monozygotic twin pairs performed more similarly than the dizygotic twin pairs, indicating that genetic factors seemed to account for individual differences in skill performance, as the twin pairs had all been reared in the same environment. The assumption that there is a genetic basis for fine MSP was further confirmed by P. W. Fox et al. (1996) who replicated the Marisi (1977) study with monozygotic and dizygotic twins who were reared apart to test the hypothesis that an individual's environment has higher or at least equal relative influence on motor performance. As in the two previously described experiments, monozygotic twin pairs shower greater resemblance to one another than dizygotic twin pairs, despite being reared apart, on three different conditions of the pursuit rotor task: percent time on target, changes in performance over time, and improvement after a period of rest. Collectively, these studies demonstrate a significant genetic contribution to individual differences in fine MSP.

While many of these studies acknowledge that environmental factors play an inevitable role in MSP, the underlying message is that genetic characteristics play, at the very least, a mediating role in MSP. Genetic perspectives of MSP from the standpoint of hereditability are valuable but limited for three reasons: 1) much of the research concerning heritability and MSP is outdated; 2) the literature is unspecific in providing an explanation for differences in motor skill performance (e.g., why some individuals are better performers than others); and 3) much of the work done to date only concerns fine MSP. Thanks in part to the recent sequencing of the human genome (Venter et al., 2001), it is now possible to examine and identify specific genetic variants with the potential to contribute to and impact gross and fine MSP. One hypothesized genetic contribution to MSP, the BDNF $val^{66}met$ polymorphism, is discussed in detail in the following two sections.

Brain-Derived Neurotrophic Factor

BDNF is a protein secreted in the human brain that belongs to a class of growth factors called the “neurotrophin” class (Binder & Scharfman, 2004). Growth factors consist of either proteins or steroid hormones and are primarily known for stimulating cellular growth and positively regulating many cellular processes. The neurotrophin class of growth factors, when secreted, sends signals to certain cells to grow, differentiate, or survive (Allen & Dawbarn, 2006). “Neurotrophic factors” are neurotrophins with the specific purpose of signaling cells to survive.

As the name suggests, BDNF is found primarily in the brain. BDNF specifically acts on neurons in the central and peripheral nervous systems. BDNF is active in different areas of the brain that are known for their important role in learning and memory, such as the hippocampus, cerebellum, cortex, amygdala, and limbic structures (Conner, Lauterborn, Yan, Gall, & Varon, 1997; Cowansage, LeDoux, & Monfils, 2010; Huang & Reichardt, 2001; Yan et al., 1997). BDNF is one of the most active neurotrophins by which neurogenesis—the brain's ability to grow new neurons—occurs (Pencea et al., 2001). Moreover, BDNF is a key neural signal that influences synaptic plasticity and repair (Cotman & Berchtold, 2007); that is, BDNF is the pathway by which neuronal synapses are able to change their strength. Synapse strength and plasticity are thought to play a key role in learning and memory (C. Chen & Tonegawa, 1997; Maren, 2005), two processes through which movement is heavily dependent. Further, there is evidence that BDNF can promote long-lasting changes in synaptic plasticity (Carter, Chen, Schwartz, & Segal, 2002) and long-term memory storage (Bekinschtein et al., 2008). BDNF is expressed differently among individuals because of its genetic properties. BDNF is encoded by the BDNF gene, for which a discussion follows.

BDNF val^{66}met polymorphism. The BDNF gene is polymorphic, meaning that it can be expressed in more than one way. Roughly 70% of Americans are homozygotes with respect to the BDNF gene, resulting in two copies of the valine allele (val^{66}val); these individuals are referred to as "non-Met-carriers" of the BDNF gene (Shimizu et al., 2004). The other roughly 30% of Americans are heterozygous "Met-carriers" of the BDNF gene, indicating that these individuals have a single-nucleotide polymorphism (SNP) in the BDNF gene present in one of the alleles at codon 66, resulting in a val^{66}met gene expression (Shimizu et al., 2004). In Met-carriers, one of the valine alleles is substituted with a methionine nucleotide, which results in the val^{66}met genotype. With respect to BDNF, “having the polymorphism” indicates that an individual is a heterozygous Met-carrier.

The polymorphism has been studied most extensively in the context of memory (Kambeitz et al., 2012) and depression (Ribeiro et al., 2007), but recent research indicates that the effects of the val^{66}met polymorphism may extend to other behavioral factors—namely, MSP.

As mentioned, secretion of BDNF is important for synaptic plasticity, cell repair, and neurogenesis. Also important are the means through which BDNF is secreted. A number of stimuli can provoke BDNF secretion. The release of BDNF is “activity-dependent,” meaning that its release is contingent upon neuronal activity (Egan et al., 2003; Farhadi et al., 2000; Mowla et al., 2001), which can be influenced directly, or by experience and external environmental stimuli. Direct examples of stimuli include intermittent hypoxia (Wang, Ward, Boswell, & Katz, 2006), high potassium levels (Zafra, Hengerer, Leibrock, Thoenen, & Lindholm, 1990) and electrical stimulation (Poo, 2001). The activity-dependent secretion of BDNF is a unique feature, as an important external environmental stimulant for BDNF release that has recently gained attention in the literature is PA (Cotman & Engesser-Cesar, 2002; Schmidt-Kassow et al., 2012; Seifert et al., 2010). Animal studies indicate that PA induces increases in BDNF concentration in several brain regions, but primarily the hippocampus (Berchtold, Chinn, Chou, Kesslak, &

Cotman, 2005; Cotman & Berchtold, 2002). PA, whether acute (Cotman & Berchtold, 2002; Ferris, Williams, & Shen, 2007; Seifert et al., 2010) or long-term (Berchtold et al., 2005) promotes sustained increases in BDNF secretion in the brain. High-intensity PA seems to be most influential (compared to moderate- and low-intensity PA) in terms of increasing BDNF concentration in the adult brain (Schmidt-Kassow et al., 2012). Although studies have investigated the role of PA on BDNF secretion in animal models and adult men and women, an extensive search of the literature indicates that the role of PA in BDNF secretion has not been investigated in a child population. However, we believe that because BDNF secretion plays a role in MSP, the influence of PA on MSP may be indirectly—or even directly—influenced by BDNF. Further, these effects may play out differently in Met-carriers and non-Met-carriers.

Negative motoric effects associated with the BDNF val^{66}met polymorphism are thought to occur because BDNF is not secreted at as high of concentrations in Met-carriers as in non-Met-carriers (Egan et al., 2003; Kleim et al., 2006). Met-carriers experience an 18-30% decrease in activity-dependent BDNF secretion relative to non-Met-carriers (Z.-Y. Chen et al., 2006; Egan et al., 2003). Decreased BDNF secretion may hinder a Met-carrier's ability to learn and properly execute motor tasks. BDNF secretion seems to occur normally in non-Met-carriers, and therefore if motor deficits exist in non-Met-carriers, they are not thought to be related to BDNF polymorphism status. However, as mentioned, BDNF secretion is activity-dependent and PA stimulates increases in BDNF secretion. Thus it is possible that PA may positively influence MSP in Met-carriers, and particularly Met-carriers who are highly active at vigorous intensities.

The two expressions of the BDNF gene influence an individual’s propensity for motor skill learning and retention. Met-carriers have demonstrated reduced brain motor system function, altered short-term plasticity, and greater error in short- and long-term motor learning when compared to non-Met-carriers (Bueller et al., 2006; Fritsch et al., 2010; McHughen et al., 2010). Bueller et al. (2006) compared hippocampal volume in Met-carriers and non-Met-carriers with no known brain abnormalities. The hippocampus is a brain region known for its important role in motor memory, learning, and performance (Wise & Murray, 1999). Bueller and colleagues demonstrated that Met-carriers exhibited an average hippocampal volume 11% lower than non-Met-carriers. Differences could not be attributed to sex differences, hormonal or drug effects, or active, past, or family history of neuropsychiatric pathology. Pezawas et al. (2004) confirmed this finding in a larger sample of healthy adults. This reduction in hippocampal volume has been attributed to differences in baseline fine MSP between Met-carriers and non-Met-carriers (i.e., Met-carriers demonstrate poorer baseline fine MSP that non-Met-carriers) (McHughen et al., 2010). McHughen et al. (2010) examined the effects of the val^{66}met polymorphism on short-term motor learning and retention using a driving-based motor learning task. Healthy college-aged subjects used a steering wheel connected to a computerized driving track to guide a simulated vehicle along a black line through the middle of the track with as much accuracy as possible. The software recorded the distance from the black line to the actual steered path as a measure of error. The vehicle was programmed to purposely change direction non-instantaneously, “providing a level of demand that supported a need for motor learning” (pp. 1256). At a baseline visit, subjects completed 15 laps of the track, with a

10-second rest between each lap. Short-term learning was measured from the mean tracking error of the baseline trials. Four days later, subjects returned to repeat the 15-lap circuit as a measure of retention, which was examined by comparing driving error on lap 1 of the second visit with driving error on the last lap of the baseline visit. Results indicated no significant baseline differences in driving error between Met-carriers and non-Met-carriers on lap 1. Subjects in both groups demonstrated significant short-term learning, but short-term learning was poorer in Met-carriers than non-Met-carriers. Similarly for the retention measure, non-Met-carriers showed significantly greater retention than Met-carriers between the last lap of the baseline visit and the first lap of the second visit as evidenced by the increase in within-subject change in driving error by the Met-carriers but not the non-Met-carriers. Though these results were considered preliminary and exploratory, this study was the first of its kind to determine short-term motor learning and retention deficits in Met-carriers relative to non-Met-carriers.

There is also evidence that the BDNF val^{66}met polymorphism plays a role in long-term motor skill acquisition, at least with respect to fine MSP (Fritsch et al., 2010). Over the course of 5 days, healthy young adults (n=36) completed a sequential visual isometric pinch force task, which was representative of fine motor skill acquisition. The task was complex, requiring participants to control a force transducer (a device that converts measured forces representing pressure into output signals) by squeezing and relaxing the fingers to move a cursor on a screen as quickly and as accurately as possible between a “home” location and five different “gates” located to the right of the home button. The following sequence was used as a block: home-gate 1-home-gate-2-home-gate 3-home-gate 4-home-gate 5-home. Task difficulty was increased by the addition of a logarithmic transduction of pinch force, an important addition that created the "skill acquisition" component of the experiment. When the participant squeezed the force transducer to move the cursor to the right, only 35-45% of the participant's max pinch force resulted in a rightward movement, as opposed to max pinch force resulting in a rightward movement. Thus, participants had to "acquire" the skill of squeezing at 35-45% of their max pinch force to move the cursor. "Skill" was quantified using a mathematical model based on each individual's observed movement time per block (speed) and error rate (accuracy of hitting gates) (Reis et al., 2009). Thus skill was defined as "practice-induced change in speed-accuracy tradeoff function" (Reis et al., 2009)(pp. 1591).

Participants underwent a baseline measure on day 1 and baseline skill was determined by using the aforementioned formula for an average of 10 trials (one block). Following the baseline measure, all participants underwent a training schedule whereby the pinch force task was practiced 200 times/day (approximately 90 minutes/day) for five consecutive days. Motor skill acquisition was determined by calculating the change in score from an individual's skill performance at baseline to skill performance at the end of day five. Among Met-carriers and non-Met-carriers, baseline performance was similar, but by the end of the training period, non-Met-carriers demonstrated significantly superior motor skill acquisition compared to Met-carriers (met/met Δskill = 2.56 ± 0.2; val/met Δskill = 1.48 ± 0.29). Differences in skill performance were significant after only two days of training and persisted throughout the remaining three days of training. These findings were later replicated with almost exact duplication in a mouse model, where Met-carrier mice who completed a five-day training protocol on a running task demonstrated significantly less skill acquisition than non-Met-carrier mice; differences in skill performance were evident after only two days of training (Z.-Y. Chen et al., 2006). Collectively, these studies indicate that long-term, repetitive, motor-based training seems to elicit differences in MSP among Met-carriers and non-Met-carriers of the BDNF val^{66}met polymorphism.

To summarize, evidence exists that implicates the BDNF val^{66}met polymorphism plays a role in short-term motor skill learning (McHughen et al., 2010), long-term motor skill acquisition (Z.-Y. Chen et al., 2006; Fritsch et al., 2010), and motor skill retention (McHughen et al., 2010). The findings presented in this section can only be generalized to adult populations in the context of laboratory-based fine motor tasks. Though studies examining the polymorphism have not tested gross motor skills in a child population, gross and fine MSP are moderately correlated in children (Haywood & Getchell, 2009; Logan, Robinson, et al., 2011), which gives reasonable cause to the argument that the val^{66}met polymorphism may influence gross MSP as well as fine MSP in children. Gross and fine motor skills are similar developmental milestones which have been shown to follow a relatively linear path (e.g., gross and fine motor skills improve with age) and are acquired in a similar manner—through practice, repetition, and developmental time. Further, heritability studies indicate that both fine and gross MSP are genetically driven, at least to some extent, but more information is necessary to confirm the genetic pathways through which fine and gross MSP are driven. The studies mentioned in this section that link MSP with a specific genetic variant give rise to one possible specific genetic pathway through which gross and fine MSP is achieved in children: presence or absence of the BDNF val^{66}met polymorphism.

Summary and Conclusions

Children who are proficient performers of gross motor skills are routinely more physically active and benefit from higher self-perceptions of physical competence than children who are poor performers of gross motor skills. Collectively, these three factors work together to influence a child's overall health status. While PPC and PA are arguably the most commonly-researched and empirically-determined correlates of gross MSP, these two factors do not fully explain a child's level of gross MSP at any given time in development. Heritability studies indicate that gross and fine MSP are largely driven by genetic factors, but the specific genetic pathways through which children develop and perform MSP are still unknown. An additional factor that has garnered recent attention, the BDNF val^{66}met polymorphism, has been associated with delays in fine motor learning, both in the short-term and long-term, and delays in fine motor retention. Though studies examining the effects of the BDNF val^{66}met polymorphism have exclusively used laboratory-based fine motor tasks, parallels can be drawn between some of the tasks used those studies and common gross motor skills. In some of the studies reviewed, fine motor task performance differences were seen between Met-carriers and non-Met-carriers (favoring the non-Met-carriers) only after a period of long-term, repetitious training. Similarly, gross motor skills are not acquired naturally, but rather must be learned and developed over time through experience, practice, and repetition. Though children in late childhood have had ample developmental time to become proficient in a repertoire of gross motor skills, many still exhibit poor gross MSP. It is plausible that the BDNF val^{66}met polymorphism, in conjunction with other behavioral factors and known correlates of gross MSP such as PA and PPC, has had a long-term effect on gross MSP in Met-carrier children in the late childhood period.

Because behavioral factors like PA and PPC may attenuate the motor delays thought to be caused by the BDNF val^{66}met polymorphism, it is important to examine the interrelationships among MSP, PA, sedentary time, PPC, and carrier status in a young population. Ultimately, identifying the relationship between the BDNF val^{66}met polymorphism and gross MSP in a youth population may allow for more holistic interventions to be developed that consider the genetic limitations of the carriers of the polymorphism in conjunction with PA and PPC, with an end goal of improving gross MSP in youth.

CHAPTER 3: METHODOLOGY

Study Design and Subjects

The study design was cross-sectional. Boys and girls (n = 105) between the ages of 9-10 years were recruited from the East Lansing Parks and Recreation Before and After School Childcare program (EL B&A), East Lansing Public Schools, St. Thomas Aquinas Catholic School, Windemere Park Charter School, and by word-of-mouth. Data were collected on location, where applicable. In cases where participants were recruited by word-of-mouth, data were collected at a location convenient to both the participant and the research team. All facilities had ample space and provisions to support data collection. Children with known neurological diagnoses and those with conditions that would limit the use of accelerometry (e.g., gait impairment) were excluded.

Approval from the Michigan State University Institutional Review Board was obtained. Parental written informed consent and child assent were obtained from parents of child participants and child participants, respectively.

Measures

Physical Characteristics and Demographics

Demographic variables including birthdate, race/ethnicity, sex, and parent education were determined via a parent questionnaire included with the parental consent form. Participants' standing height and weight were directly measured to determine BMI. Children's weight was measured to the nearest 0.1 kg using a portable scale (Seca, Model 770; Hamburg, Germany), and children's height was measured to the nearest 0.1 cm using a portable stadiometer (Shorr Productions; Olney, MD). Height and weight measurements were taken twice and the average of the two measurements was retained for analysis. If height or weight measurements differed by more than 0.5cm or 0.5kg, respectively, a third measurement was taken and the two closest measurements were averaged. BMI was calculated by dividing weight in kilograms by height in meters squared (kg/m^2).

BDNF val^{66}met Polymorphism Status

Saliva samples were collected to be genotyped for the BDNF val^{66}met polymorphism. Although blood samples yield the best quality DNA, saliva samples have demonstrated a high (84%) success rate with respect to DNA genotyping (Hansen, Simonsen, Nielsen, & Hundrup, 2007). Given the established difficulties associated with obtaining blood samples from children (Howie, 2011), coupled with the established validity of using saliva as a method for DNA yield in young children (Koni et al., 2011), cheek swabs (buccal cells) were chosen as a suitable method for genotyping in this study. Buccal cells were obtained using the BuccalAmp™ DNA Extraction Kit, which includes a Catch-All sample collection swab and a tube containing QuickExtract DNA extraction solution. Standard protocol for buccal cell collection provided by the manufacturer was followed (Epicentre Biotechnologies, Madison, WI). Because children in our study were too young to accurately follow instructions provided by the manufacturer, trained research personnel assisted children with the cheek swab process. Children were asked to rinse their mouths twice with plain drinking water before tissue collection. Research assistants wore latex gloves during the process, and children were instructed to wash their hands prior to and immediately following depositing their sample. Research assistants rolled the collection swab thoroughly over the inside of the child's cheek, approximately 20 times on each side. The swab was air dried for 15-20 minutes at room temperature before being placed back into its original packaging, which is designed for transportation of the swabs from the collection site to the laboratory. Immediately following collection, saliva samples were transported to a locked freezer in the Life Sciences building at Michigan State University by a member of the research team, and were stored at -40°C until all cheek swabs were collected. Individual samples were stored securely with only the participant's ID number as a label.

DNA extraction. The principal investigator (PI) transported swabs from the Life Sciences freezer to the Genomics Core Laboratory at Michigan State University, where DNA extraction and genotyping occurred under the supervision of trained lab personnel. The QuickExtract DNA Solution tubes were pre-labeled with ID numbers of all participants who deposited a cheek swab. Each tube contained an extraction solution that eliminated the need for centrifugation and ultimately shortened the handling time of the sample. The swab end of the collection swab was inserted into the appropriate tube (according to the participant ID number found on the swab packaging and the extraction tube) and was rotated a minimum of five times. Lab personnel pressed the swab firmly against the side of the tube and rotated the swab upon removal in order to leave as much liquid as possible inside the tube. Tubes were recapped and swabs were discarded in a hazardous materials bag and disposed according to Genomics Core lab policy. Tubes were incubated at 65°C for one minute, vortex mixed for 15 seconds, incubated at 68°C for two minutes, and vortex mixed a final time for 15 seconds.

DNA quantification and genotyping. A common coding variant in the BDNF gene has been previously identified in Genbank sequences and the public SNP databases (http://www.ncbi.nlm.nih.gov/). A G→A polymorphism is responsible for the val^{66}met change (Cargill et al., 1999). The val^{66}met single nucleotide polymorphism (SNP) was typed using the polymerase chain reaction (PCR). Extracted DNA was quantified and sequenced by Genomics Core lab personnel using a TaqMan SNP Genotyping Assay (Applied Biosystems, California, USA) with the rs6265 SNP ID. The TaqMan Assay allowed for polymorphism genotyping through the use of the 5’ nuclease assay for amplification and allelic discrimination. The assay contained two primers for amplification purposes and two probes for allele detection. Presence or absence of the polymorphism was determined based on the change in dye fluorescence of the probes. The TaqMan probes had a reporter dye linked to the 5’ end of the probe. VIC© dye was used for the Allele 1 probe and FAM™ dye was used for the Allele 2 probe. A VIC© signal indicated homozygosity for Allele 1, a FAM™ signal indicated homozygosity for Allele 2, and a combination of VIC© and FAM™ signals indicated heterozygosity for both alleles. The probes also had a minor groove binder (MGB) and a non-fluorescent quencher (NFQ) at the 3’ end of the probe.

The TaqMan reaction plate was set up according to the manufacturer's specific protocol (https://tools.lifetechnologies.com/content/sfs/manuals/TaqMan_SNP_Genotyping_Assays_man.pdf). DNA was entered into a reaction mixture that included TaqMan Master Mix, the forward and reverse primers, and the two MGB probes. The MGB probes annealed to a complementary sequence between the forward and reverse primer, where the proximity of the quencher dye to the reporter dye suppressed the reporter fluorescence. An increase in fluorescence only occurred when the amplified target sequence was complementary to the probe, and therefore the fluorescence signal generated by PCR amplification indicated which alleles were in the sample.

Following PCR amplification, allelic discrimination was conducted using the Applied Biosystems Real-Time PCR System's Sequence Detection Software (SDS). Genomics Core lab personnel and the PI manually reviewed all automatic allele calls made by the software for accuracy. Following the review, allele calls were converted to genotypes. Participant genotypes were entered onto a locked spreadsheet on a computer in the Physical Activity Lab. Participant names did not appear anywhere on the spreadsheet.

Physical Activity and Sedentary Time

Subjects were asked to wear the ActiGraph GT3X accelerometer (Ft. Walton Beach, FL) to assess PA as time spent in sedentary, light, moderate, and vigorous intensity levels. The ActiGraph has a test-retest reliability of r = 0.88 (Puyau et al., 2002) and has been validated for use in children of this age group (Evenson et al., 2008). This device measures accelerations in three movement planes via a triaxial accelerometer. The Actigraph was initialized to collect raw activity data at a frequency of 30 Hz. When downloaded, the raw data were aggregated to 15-sec epochs. The activity data were interpreted using empirically-based cut points (Evenson et al., 2008): sedentary (≤26 counts/15-sec), light (>26-579 counts/15-sec), moderate (>574-1002 counts/15-sec), and vigorous (≥1003 counts/15-sec). A minimum of 4 days (8 hours/day; at least 3 weekdays and 1 weekend day) of data was required for data analysis (Puyau et al., 2002). The ActiLife Wear Time Validation tool was used to determine non-wear time. The default definitions for the Wear Time Validation were derived from Oliver, Badland, Schofield, and Shepherd (2011). The default definition for non-wear time was 60 minutes of consecutive zeroes with a two-minute spike tolerance.

Members of the research team verbally instructed children on how and when to wear the accelerometer and physically placed the accelerometer belts on the participants with the accelerometer over the right hip. Children were instructed to wear the ActiGraph in the same position that the research team placed the accelerometer belt on the waistband of their clothes for seven continuous days excluding bathing, water activities, or sleeping. Participants were also given an information sheet and a reminder flyer to take home to parents with instructions on proper wear of the Actigraph. The research team collected and subsequently downloaded accelerometers at the end of the 7-day period.

Gross Motor Skill Performance

The second edition of the Test of Gross Motor Development (TGMD-2) (Ulrich, 2000) was used to determine gross MSP. Reasons that the TGMD-2 was an appropriate assessment for this study are twofold: 1) The TGMD-2 examines gross motor skills that are performed in the

PA pursuits being assessed via accelerometry; 2) the TGMD-2 is arguably the most commonly used assessment of gross MSP and has a test-retest reliability of $r = 0.91$ (Ulrich, 2000). The TGMD-2 uses both criterion- and norm-references, and provides normative data for comparison of populations subsets by age.

The test is comprised of two subscales: locomotor (run, gallop, hop, leap, jump, and slide), and object control (overhand throw, catch, kick, stationary bounce, two-hand strike, and underhand roll). A verbal and physical demonstration was provided to participants for each of the 12 skills before their attempt at performance. Children were videotaped performing two trials of each skill. Individual skills were scored according to the test's performance criteria, which takes a process-oriented approach whereby participants are scored on selected observable criteria that are based off of an expert performance. For each criterion, a child received a score of 1 or 0. If the child performed the skill correctly according to the criterion, a score of 1 was given, but if the child did not perform the criterion correctly, he or she was given a 0. The scores from two trials of the same skill were added together to make up a Skill Score. Individual Skill Scores were combined with other Skill Scores within each of the two subtests to create a Locomotor Subtest Raw Score and an Object Control Subtest Raw Score. The Locomotor Subtest Raw Score and Object Control Subtest Raw Score were added together to obtain a Total Motor Skill Score; all three scores were used for analyses. Higher scores were indicative of better gross MSP than lower scores.

Videotaped trials of skill performance were scored by three members of the research team, one of whom was the PI and expert in TGMD-2 assessment. The PI trained the other two scorers. Inter-rater reliability for scoring was determined prior to data analysis (*r* = 0.92) to avoid any discrepancies. The acceptable level of inter-rater reliability was set at 0.90 for both subscales.

Fine Motor Skill Performance

Bubbles Burst. The Bubbles Burst iPad application (Sanger Lab, University of Southern California) was used to test various dimensions of children's fine MSP. The Bubbles Burst iPad application was only recently been developed; however, the tasks that are assessed by the application are commonly used lab-based tasks that typically are conducted using pencil-and-paper methods. Essentially, the pencil-and-paper methods that measure movement time, amplitude, index of difficulty, and absolute error have been replicated within the Bubbles Burst application in the form of a child-friendly "game." The game consists of three different sized targets: small (1.01 cm), medium (2.01 cm), and large (3.02 cm). The targets appeared one at a time at random, both in size and location, on the iPad screen. When the first target appeared, the participant used one finger to touch the target. The participant held the finger on the initial target until the next target appeared, at which point the participant moved the finger as quickly and accurately as possible to the next target. One game consisting of 45 trials (i.e., 45 target appearances) was played with the right hand and one game, also consisting of 45 trials, was played with the left hand. Thus, a total of 90 trials per participant were recorded.

Children were seated at a table with the iPad. The researcher explained the game and allowed children a brief practice period before beginning the actual task. The application initially prompted the user to enter a name, a game number, and selected hand for that particular game. The researcher entered the child's unique identification number and the number "1," indicating that the child was playing the game for the first and only time with the selected hand. For consistency purposes, all children played the first game with the right hand and the second game with the left hand. Data accrued from the child's performance were stored on the iPad until the research team downloaded the data to a laboratory computer.

For each trial, the following dimensions of fine MSP were recorded:

- Target size
- Relative accuracy – hit or miss of the target
- Movement time (s) – the amount of time between the initial touch and the touch of the subsequent target
- Absolute error (cm) – the difference between the center of the target and the center of the actual hit
- Movement amplitude (cm) – distance between the center of the initial target and the subsequent target
- Index of difficulty – a logarithm of the ratio of movement amplitude and width of the target
- Total score – (2.5 x ID)/MT, where MT is movement time, ID is index of difficulty, and 2.5 is a constant term

For each game, an average of all fine MSP dimensions were taken. Thus, each participant had one value per hand for each of the aforementioned dimensions, all of which were retained for analyses.

Bruininks Oseretsky Test of Motor Proficiency-2. Children completed two measures from the Fine Manual Control Composite of the Bruininks-Oseretsky Test of Motor Proficiency-2 (BOT-2) (Bruininks & Bruininks, 2005), the pegboard task and the star-copying task. The BOT-2 is a reliable (r=0.80)(Bruininks & Bruininks, 2005) screening tool commonly used to assess developmental delay in children, but the two tasks that were chosen for this study are reflective of tasks that 9- and 10-year-old children use regularly and are appropriate for the age group being assessed. The pegboard task was chosen because it replicates a common standard fine motor task used in other studies examining the BDNF polymorphism (McHughen et al., 2011). The star-copying task was included because of its relevance to children, as it replicates a task that many children attempt on a daily basis (e.g., drawing shapes).

For the pegboard task, children were seated at a table with a box of plastic pegs and a pegboard with 25 holes (5x5). Children were instructed to lightly hold the pegboard with their non-preferred hand to prevent the board from moving during the task. The research assistant instructed children to move pegs one at a time from the box to the pegboard as quickly as possible until the research assistant said “stop.” Children moved pegs from the box to the board for 15 seconds. The research assistant recorded the number of pegs the child successfully placed in the pegboard in 15 seconds and then asked the child to repeat the assessment for a second trial. The average of the two trials was attained for analysis.

For the star-copying task, children were seated at a table with a sheet of paper and a pencil. The sheet of paper was a replicate of the assessment sheet from the Fine Motor Integration subtest of the BOT-2 and had a picture of a simple star inside of a square box. A blank box was located below the box with the star in it. Children were instructed to copy the picture of the star, being as exact as possible, into the box below the star. Only one trial was conducted and children were encouraged to take as much time as needed. Performance was recorded for the following properties: basic shape, closure, edges, orientation, and overall size. When the property was present, the child received a score of 1 for that property; if the property was not present, the child received a score of zero. The maximum score a child could receive was 5. This task was scored by a member of the research team who was trained by an expert in BOT-2 assessment. Inter-rater reliability for scoring was determined between the research assistant and the expert prior to data analysis (r=.93) to avoid discrepancies in data analysis. The acceptable level of inter-rater reliability was set at 0.90.

Perceived Physical Competence

Children completed the perceived athletic competence subscale of the Self Perception Profile for Children (SPPC) (Harter, 1982, 1985). This measure was chosen because of its wide acceptance in the literature and its developmental nature that reflects changes in children's self-perceptions (Harter, Stocker, & Robinson, 1999; Muris, Meesters, & Fijen, 2003). Additionally, the psychometric properties of the perceived athletic competence subscale of the SPPC are strong. Test-retest reliability over a 4-week period was high (ICC = 0.90)(Muris et al., 2003), and internal reliability is high (α = 0.81) (Harter, 1982, 1985; Muris et al., 2003). A number of studies have provided evidence for convergent validity of the perceived athletic competence subscale of the SPPC in the form of parent-child agreement (*r* = 0.43, *p* = <0.05)(Muris et al., 2003) and teacher-child agreement (*r* = 0.29, *p* < .001) (Boivin, Vitaro, & Gagnon, 1992). In our study, the scale had a moderate level of internal consistency, as determined by Cronbach's alpha of 0.678.

The perceived athletic competence subscale of the SPPC consists of six written statements about children performing common motor skills. A structured-alternative format is used. Children were instructed to read the first statement and choose the phrase that most closely represented their skill level; one phrase represented high competence and one phrase represented low competence (e.g., "some kids don't feel they are able to hop well *but* other kids feel they are able to hop well"). Children were then instructed to indicate whether the chosen phrase is "sort of true" or "really true" for them. Scores range from 1-4, where children who indicated the non-skill-competent statement is really true for them receive 1 point and children who indicated the skill-competent statement is really true for them receive 4 points. The SPPC was administered individually in order to protect the privacy of the child and attempt to avoid socially-desirable responses. A member of the research team explained the assessment to the child and then remained on hand to answer any questions or clarify directions.

Procedures

All members of the research team were required to attend data collection training, which covered proper protocol for collection of saliva, fine and gross MSP, PA, PPC, and human subjects training through the MSU IRB website. Data were collected over a one-week period in two visits following receipt of parental consent and child assent. Visits were conducted in the following manner:

Visit 1: Height and weight were collected. Then, accelerometer belts were distributed and placed on participants by the research team. Participants were verbally instructed on proper wear and given hardcopy instructions to take home. Research assistants conducted the SPPC with groups of children (when applicable). Fine and gross MSP were collected in random order during this visit. Saliva collection occurred in a private area. Members of the research team wore gloves during saliva collection and instructed participants to wash their hands prior to and immediately upon depositing their sample. At the end of this visit, children who returned parent consent forms and signed assent forms were given a $10 gift card.

Visit 2: Accelerometers were collected and students who returned accelerometers were given an additional $10 gift card, regardless of data status on the accelerometer.

Note: Accelerometers that were placed on participants in the afternoon hours (e.g., later than 2:00 pm) were initialized to start the following morning. Accelerometers that were placed on participants in the morning/early afternoon hours (e.g., earlier than 2:00 pm) were initialized to start the day they were placed on participants. Participants were not informed of the initialized start time.

Treatment of Data

Each child was given a unique ID number, and no other identifying information appeared on any data document or DNA equipment. A single master list of participants' names and ID numbers and all paper data remains in a locked cabinet in the PI's office. DNA samples were stored in a locked cabinet in the research laboratory. Parents were given the option to request a report of their child's MSP, PA, and PPC scores, but were not allowed to request genotyping results. Parents were given the option to have saliva samples destroyed after the project ended.

Analysis

An *a priori* power analysis was conducted to determine sample size. Approximately 100 participants were necessary to have 95% power for detecting a moderate effect ($f^2(V) = 0.2$) when employing $\alpha = 0.05$ criterion of significance. The power analysis was based off of prevalence estimates of the BDNF polymorphism; roughly 30% of Americans are carriers of the polymorphism (Shimizu et al., 2004).

The statistical analysis plan involved performing descriptive statistics, partial correlations, multiple regressions, and discriminant function analyses to examine the BDNF val^{66}met polymorphism in terms of four movement-related constructs (gross MSP, fine MSP, PA, and sedentary time) in children. For all analyses, gross MSP was treated as three separate variables (locomotor, object control, and total gross MSP). The Specific Aims and statistical analyses for this study were:

Specific Aim #1: Describe the participant sample in terms of age, race, sex, SES, BMI, carrier status, fine and gross MSP level, PA, sedentary time and PPC score.

Descriptive statistics (means and standard deviations) were used to describe the sample.

Specific Aim #2: Determine the relationship between gross and fine MSP, controlling for and without controlling for BMI, SES, race, and sex.

Hypothesis 2: Gross and fine MSP would be moderately, positively related (approximately r= .30 - .50).

Partial correlation, controlling for and without controlling for BMI, SES, race, and sex was used to examine the association between gross and fine MSP.

Specific Aim #3: Determine the relationship between gross MSP and MVPA, controlling for BMI, race, sex, and SES. A sub-aim was to determine the relationship between gross MSP and sedentary time, controlling for BMI, race, sex, and SES.

Hypothesis 3: Gross MSP and MVPA would be moderately, positively related (approximately r = .30 - .39). Gross MSP and sedentary time would be moderately, inversely related (approximately r = .30 - .39).

Multiple linear regression, controlling for and without controlling for BMI, race, sex, and SES was used to determine the relationship between gross MSP and MVPA. A subsequent multiple linear regression, controlling for and without controlling for BMI, race, sex, and SES was used to determine the relationship between gross MSP and sedentary time. In both models, gross MSP was used as the independent variable and MVPA or sedentary time was used as the dependent variable, per the hypothesized relationship in Stodden's (2008) model. MVPA was assessed as a continuous variable, using average percent of time spent in MVPA

Specific Aim #4: Determine which predictor variables predict Met-carriers and which predictor variables predict non-Met-carriers. Predictor variables included in the first model were gross MSP, fine MSP, MVPA, PPC, race, sex, SES, and BMI. In a subsequent model, sedentary time was substituted for MVPA as a predictor variable.

Hypothesis 4: The analysis would discriminate moderately between groups and gross and fine MSP, PA, sedentary time, and BMI would be identified as significant predictors of group membership. PPC, race, sex, and SES would not significantly predict group membership.

Discriminant function analysis was conducted to determine which variables predict Met-carriers and which variables predict non-Met-carriers. Eigenvalues were examined as a measure of overall model fit. Wilks' Lambda was used to indicate the significance of the discriminant function and standardized canonical discriminant function coefficients were used to determine the relative importance of each predictor.

CHAPTER 4: RESULTS

Specific Aim 1

The goal of Specific Aim 1 was to describe the sample in terms of age, race, sex, SES, BMI, carrier status, gross and fine MSP, PA, and sedentary time. Consent and assent were obtained from 105 parents and children, respectively. All participants completed all aspects of the study, and all accelerometers were returned to the research team. Of the 105 participants, 17.1% (n = 18) returned accelerometers with insufficient wear time recorded (i.e., less than eight hours per day for at least three weekdays and one weekend day). Participants with insufficient wear time were excluded from Specific Aims 3 and 4, but because all other data were successfully recorded, those participants were included in Specific Aim 1 analyses, with the exception of the PA and sedentary time section, and Specific Aim 2 analyses.

Physical Characteristics and Demographics

Physical characteristics of the total sample and boys and girls individually are presented in Table 4.1. Roughly 55% of the sample were male (n = 58). No significant differences were found between boys and girls in terms of age, height, sitting height, and BMI percentile, but boys were slightly older, taller, and had a higher BMI percentile than girls. Boys, however, had significantly lower weight than girls (36.2 ± 7.6 kg versus 37.3 ± 11.1 kg, respectively, $t(103)$ = 0.578, p = 0.011) and lower BMI than girls (18.4 ± 3.2 kg/m^2 versus 19.3 ± 4.7 kg/m^2, respectively, $t(103)$ = 1.227, p = 0.026). For the total sample, 14.3% (n = 15) were classified as overweight (BMI percentile ≥85-94.9) and 17.1% (n = 18) were classified as obese (BMI percentile ≥95). Roughly the same number of boys and girls were classified as overweight (*n* = 8, 13.8% versus *n* = 7, 14.9%); slightly fewer boys than girls were classified as obese (*n* = 8, 13.8% versus *n* = 10, 21.3%)

Table 4.1.

Physical Characteristics of Boys, Girls, and Total Sample

	Boys (*n* = 58)	Girls (*n* = 47)	Total (*n* = 105)
Age (yrs)	9.8 ± 0.6	9.7 ± 0.6	9.8 ± 0.58
Height (cm)	140.2 ± 7.0	138.2 ± 8.2	139.5 ± 7.6
Sitting height (cm)	72.7 ± 3.3	72.3 ± 4.3	72.5 ± 3.8
Weight (kg)[a]	36.2 ± 7.6	37.3 ± 11.1	37.2 ± 9.3
BMI (kg/m^2)[b]	18.4 ± 3.2	19.3 ± 4.7	19.0 ± 3.9
BMI percentile	63.2 ± 27.9	62.5 ± 30.5	63.5 ± 28.9
Percent overweight	13.8%	14.9%	14.3%
Percent obese	13.8%	21.3%	17.1%

Notes:
[a]Significant differences between boys and girls, $t(103) = 0.578$, $p = 0.011$
[b]Significant differences between boys and girls, $t(103) = 1.227$, $p = 0.026$

Demographic characteristics of boys, girls, and the total sample are presented in Table 4.2. Most of the children were fourth graders (*n* = 63; 60.0%) and white (*n* = 81; 77.1%). In general, most children's parents were well-educated, with 65.8% of mothers reporting at least having a bachelor's degree (*n* = 69) and 68.6% of fathers reporting at least having a bachelor's degree (*n* = 72). The majority of children in the sample either attended St. Thomas Aquinas Elementary school (*n* = 33; 31.4%) or Windemere Park Charter Academy (*n* = 27; 25.7%). All demographic and anthropometric data were distributed normally.

Table 4.2.

Demographic Characteristics of Boys, Girls, and Total Sample

	Boys (*n* = 58)	Girls (*n* = 47)	Total (*n* = 105)
Grade			
3	19 (32.8%)	16 (34.0%)	35 (33.3%)
4	35 (60.3%)	28 (59.6%)	63 (60.0%)
5	4 (6.9%)	3 (6.4%)	7 (6.7%)
Race			
White	44 (75.9%)	37 (78.7%)	81 (77.1%)
Black	2 (3.4%)	1 (2.1%)	3 (2.9%)
Hispanic	2 (3.4%)	2 (4.3%)	4 (3.8%)
Native American	2 (3.4%)	---	2 (1.9%)
Biracial	5 (8.6%)	4 (8.5%)	9 (8.6%)
Did not answer	3 (5.2%)	3 (6.4%)	6 (5.7%)
Mother education			
High school diploma	3 (5.2%)	---	3 (2.9%)
Some college	7 (12.1%)	6 (12.8%)	13 (12.4%)
Associate's degree	2 (3.4%)	6 (12.8%)	8 (7.6%)
Bachelor's degree	22 (37.9%)	23 (48.9%)	45 (42.9%)
Post-graduate degree	23 (39.7%)	10 (21.3%)	33 (31.4%)
Did not answer	1 (1.7%)	2 (4.3%)	3 (2.9%)
Father education			
GED	3 (5.2%)	1 (2.1%)	4 (3.8%)
High school diploma	4 (6.9%)	7 (14.9%)	11 (10.5%)
Some college	10 (17.2%)	5 (10.6%)	15 (14.3%)
Associate's degree	3 (5.2%)	4 (8.5%)	7 (6.7%)
Bachelor's degree	19 (32.8%)	16 (34.0%)	35 (33.3%)
Post-graduate degree	17 (29.3%)	13 (27.7%)	30 (28.6%)
Did not answer	2 (3.4%)	1 (2.1%)	3 (2.9%)
School[a]			
Donley	5 (8.6%)	4 (8.5%)	9 (8.6%)
Glencairn	2 (3.4%)	3 (6.4%)	5 (4.8%)
Marble	7 (12.1%)	3 (6.4%)	10 (9.5%)
Pinecrest	5 (8.6%)	2 (4.3%)	7 (6.7%)
Red Cedar	1 (1.7%)	2 (4.3%)	3 (2.9%)
St Thomas Aquinas	17 (29.3%)	16 (34.0%)	33 (31.4%)
Dansville	---	3 (6.4%)	3 (2.9%)
Windemere Park	16 (27.6%)	11 (23.4%)	27 (25.7%)
Dewitt	---	3 (6.4%)	3 (2.9%)
Holt	3 (5.2%)	---	3 (2.9%)
Williamston	2 (3.4%)	---	2 (1.9%)

Notes:

Values are *n* (%)

[a]In some cases, "school" indicates the Before and After School program the child attended.

BDNF val^{66}met Polymorphism Status

Saliva samples (cheek swabs) were analyzed to determine BDNF val^{66}met polymorphism status in children. Successful extraction, quantification, and genotyping occurred in 100% (*n* = 105) of the samples. As expected, and in line with the literature (Shimizu et al., 2004), roughly 64% (*n* = 67) of the sample were non-Met-carriers and 30% (*n* = 31) were Met-carriers. The percentage of Met-Met-carriers in the sample was higher than expected at 6% (*n* = 7), as literature indicates that less than 1% of Americans have two copies of the Met allele (Shimizu et al., 2004); thus it was expected that only one or two participants would be Met-Met -carriers. The sample is described in terms of carrier status, age, race, and sex in Table 4.3. Most non-Met-carriers were white (*n* = 47; 70.1%) and between the ages of 9.0-10.0 years (*n* = 51; 76.1%). The overwhelming majority of Met-carriers were also white (*n* = 28; 90.3%). The distribution of boys and girls in Met-carriers and non-Met-carriers was similar, but more boys were Met-Met-carriers than girls (*n* = 5; 71.4% versus *n* = 2; 28.6%). A Pearson's chi-square test of association revealed no statistically significant association between sex and carrier status, $\chi(2) = 1.390$, $p = 0.499$.

Table 4.3.

Description of Carrier Status by Age, Sex, and Race

	non-Met-carriers (*n* = 67)	Met-carriers (*n* = 31)	Met-Met-carriers (*n* = 7)
Age			
9.0-10.0	51 (76.1%)	19 (61.4%)	3 (42.8%)
10.1-10.9	16 (23.9%)	12 (38.6%)	4 (57.2%)
Sex			
Male	38 (56.7%)	15 (48.4%)	5 (71.4%)
Female	29 (43.3%)	16 (51.6%)	2 (28.6%)
Race			
White	47 (70.1%)	28 (90.3%)	6 (85.7%)
Black	3 (4.5%)	---	---
Hispanic	4 (6.0%)	---	---
Native American	2 (3.0%)	---	---
Biracial	8 (11.9%)	1 (3.2%)	---
Did not answer	3 (4.5%)	2 (6.5%)	1 (14.3%)

Notes:
Values are *n* (%).

Physical Activity

Of the 105 participants, 87 (82.9%) met the minimum wear time criteria for inclusion of at least eight hours per day for four days, one of which had to be a weekend day. More boys than girls (48 versus 39, respectively) returned accelerometers with valid data. No significant differences in terms of race, sex, age, and carrier status were observed between participants who returned accelerometers with valid data and those who did not. Accelerometer data were interpreted as percentages of time spent in sedentary, light, moderate, and vigorous activity. Average percentages of time spent in each activity category by age, sex, race, and carrier status are presented in Table 4.4.

Results from independent t-tests indicated significant differences between 9- and 10-year-olds in terms of percentage of time spent sedentary, $t(85) = 2.771$, $p = .007$, where 9-year-olds spent significantly less time sedentary (58.5% ± 6.4%) than 10-year-olds (63.2% ± 7.9%). Significant differences between 9- and 10-year-olds also existed in terms of percentage of time spent in light PA, $t(85) = -3.14$, $p = .002$; these differences also favored the 9-year-olds (34.5% ± 5.0%), who spent more time in light PA than their older counterparts (30.5% ± 5.3%). There were no significant differences found between 9- and 10-year-olds in terms of percentage of time spent in moderate and vigorous physical activity. Boys and girls differed significantly in terms of percentage of time spent sedentary, $t(85) = 3.499$, $p = .001$, percentage of time spent in moderate activity, $t(85) = -5.818$, $p = .000$, and percentage of time spent in vigorous activity, $t(85) = 4.196$, $p = .000$. Results from the t-tests indicated that boys spent less time sedentary (57.4% ± 6.3%) than girls (62.4% ± 7.0%), greater percentages of time in moderate PA (5.1% ± 1.3%) than girls (3.5% ± 1.2%), and greater percentages of time in vigorous PA (3.0% ± 1.7%) than girls (1.7% ± 1.1%). There were no significant differences between boys and girls in terms of percentage of time spent in light activity, but boys spent slightly more time in light activity than girls (34.5% ± 4.9% versus 32.4% ± 5.7%, respectively).

An ANOVA was used to examine differences in PA among the seven race categories (white, black, Hispanic, Native American, biracial, and did not answer), but no statistically significant differences were detected among any of the race groups in terms of percentage of time spent in sedentary, light, moderate, or vigorous PA, likely due to uneven distribution among race groups (see “Race – 1” row in Table 4.4). Participants were then placed into either a “white” (*n* = 70) or “non-white” (*n* = 13) group, and participants who did not indicate their race were excluded (*n* = 4). Levene’s test for equality of variances indicated equal variances among whites and non-whites for all four PA categories, and thus no adjustment was necessary. Subsequent independent t-tests indicated no statistically significant differences among whites and non-whites in terms of percentage of time spent in sedentary, light, moderate, or vigorous PA (see “Race – 2” row in Table 4.4).

The following paragraph summarizes differences in carrier status in terms of the four activity categories. With respect to percentage of time spent sedentary, an ANOVA revealed significant differences between non-Met-carriers and Met-carriers (F (2,84) = 4.222, p = 0.018). A Tukey post-hoc test was conducted to determine where the significant differences were with respect to the three carrier statuses. The post-hoc test revealed that non-Met-carriers spent significantly less time sedentary than Met-carriers (58.1% ± 7.4% versus 62.0% ± 5.8%, p = 0.034). With respect to percentage of time spent in light physical activity, significant differences existed between non-Met-carriers and Met-carriers (F (2,84) = 4.389, p = 0.015). A Tukey post-hoc test indicated that non-Met-carriers spent a significantly greater percentage of time in light physical activity compared to Met-carriers (34.8% ± 5.4% versus 31.7% ± 4.5%, p = 0.030). With respect to percentage of time spent in moderate and vigorous physical activity, no significant differences existed among any of the carrier groups, but non-Met-carriers (4.6% ± 1.6%) demonstrated more time in moderate PA than both the Met-carriers (4.1% ± 1.3%) and Met-Met-carriers (3.7% ± 1.2%) (p = 0.195), as well as more time spent in vigorous PA (2.5% ± 1.7%) than both the Met-carriers (2.2% ± 1.4%) and Met-Met-carriers (1.9% ± 1.2%) (p = 0.500).

Similarly, while no statistically significant differences were found between the non-Met-carriers and the other two groups, Met-Met-carriers spent more time sedentary (65.0% ± 2.7%) and less time in light (29.4% ± 4.6%), moderate (3.7% ± 1.2%), and vigorous PA (1.9% ± 1.2%) than both the non-Met-carriers and Met-carriers.

Table 4.4.

Mean Percentages of Time Spent in Sedentary, Light, Moderate, and Vigorous Physical Activity

	Sedentary	Light	Moderate	Vigorous
Age[a]				
9.0-10.0 (*n* = 66)	58.5% ± 6.4%	34.5% ± 5.0%	4.6% ± 1.4%	2.4% ± 1.3%
10.1-10.9 (*n* = 21)	63.2% ± 7.9%	30.5% ± 5.3%	3.9% ± 1.8%	2.3% ± 2.3%
Sex[b]				
Male (*n* = 48)	57.4% ± 6.3%	34.5% ± 4.9%	5.1% ± 1.3%	3.0% ± 1.7%
Female (*n* = 39)	62.4% ± 7.0%	32.4% ± 5.7%	3.5% ± 1.2%	1.7% ± 1.1%
Race – 1				
White (*n* = 70)	60.0% ± 7.2%	33.2% ± 5.4%	4.4% ± 1.5%	2.4% ± 1.7%
Black (*n* = 1)	54.5% ± 0%	37.7% ± 0%	5.4% ± 0%	2.4% ± 0%
Hispanic (*n* = 3)	59.7% ± 6.1%	33.4% ± 4.9%	4.3% ± 1.9%	2.6% ± 1.3%
Native American (*n* = 2)	57.7% ± 4.2%	34.5% ± 2.1%	5.8% ± 1.2%	2.1% ± 0.8%
Biracial (*n* = 7)	55.7% ± 4.4%	37.0% ± 4.3%	4.7% ± 1.0%	2.7% ± 1.1%
Did not answer (*n* = 4)	61.4% ± 10.4%	32.4% ± 7.0%	4.2% ± 2.2%	2.0% ± 1.5%
Race – 2[c]				
White (*n* = 70)	60.0% ± 7.2%	33.2% ± 5.4%	4.4% ± 1.5%	2.4% ± 1.7%
Non-white (*n* = 13)	56.8% ± 4.6%	35.8% ± 4.0%	4.8% ± 1.2%	2.5% ± 1.0%
Carrier status[d]				
non-Met-carriers (*n* = 55)	58.1 % ± 7.4%	34.8% ± 5.4%	4.6% ± 1.6%	2.5% ± 1.7%
Met-carriers (*n* = 29)	62.0% ± 5.8%	31.7% ± 4.5%	4.1% ± 1.3%	2.2% ± 1.4%
Met-Met-carriers (*n* = 3)	65.0% ± 2.7%	29.4% ± 4.6%	3.7% ± 1.2%	1.9% ± 1.2%

Notes:

[a]Significant differences were found between age groups in terms of sedentary and light physical activity ($p = 0.007$, $p = 0.002$, respectively)

[b]Significant differences were found between sexes in terms of sedentary, moderate, and vigorous physical activity ($p = 0.001$, $p = 0.000$, and $p = 0.000$, respectively)

[c]Participants who did not indicate their race were excluded from this part of the analysis; $n = 83$

[d]Significant differences were found among the three different carrier status groups in terms of sedentary and light physical activity ($p = 0.015$, $p = 0.0130$, respectively)

Table 4.5 shows mean time spent in light, moderate, vigorous, and moderate-to-vigorous PA expressed in average minutes per day by sex and carrier status. Federal guidelines suggest that children accrue at least 60 minutes of MVPA per day (USDHHS, 2008); the percentage of sub-samples who met the federal recommendation is also presented in Table 4.5. Broadly speaking, our sample was physically inactive, at least in terms of meeting the federal PA guidelines. A one-sample t-test indicated that the total sample's average MVPA minutes per day (51.8 ± 23.3) were significantly lower than the 60-minute federal recommendation, and roughly only one-third of the sample met the recommendation (35.6%, n = 31), t(86), = -3.287, p = .001. Girls averaged only 39.0 ± 17.2 minutes per day of MVPA and only 20.5% (n = 8) met or exceeded federal PA guidelines. A one-sample t-test indicated that girls' mean MVPA was significantly lower than the federal PA recommendation, t(38) = -7.631, p = .000. While boys in the sample averaged 62.2 ± 22.5 minutes of MVPA per day, less than half met PA recommendations (47.9%, n = 23). In terms of carrier status, 45.5% (n = 25) of non-Met-carriers met recommendations and accrued an average of 55.2 ± 24.4 minutes per day of MVPA. Less than 20% of Met-carriers met recommendations, and their mean MVPA per day (46.3 ± 20.8) was significantly lower than the federal recommendation, t(28) = -3.538, p = .001. Only one of the three Met-Met-carriers met the recommendation, and Met-Met-carriers accrued an average of only 42.5 ± 18.9 minutes per day of MVPA.

Table 4.5.

Mean Minutes/Day in Sedentary, Light, and Moderate-to-Vigorous Physical Activity and Percent of Participants Meeting Federal PA Recommendations

	Sedentary	Light	MVPA	% Met Rec[a]
Boys (*n* = 48)	467.3 ± 67.6	263.4 ± 40.5	62.2 ± 22.5	47.9% (23)
Girls (*n* = 39)	440.2 ± 67.1	242.6 ± 44.7	39.0 ± 17.2[b]	20.5% (8)
non-Met-carriers (*n* = 55)	446.8 ± 74.5	266.1 ± 42.2	55.2 ± 24.4	45.5% (25)
Met-carriers (*n* = 29)	457.1 ± 55.3	234.0 ± 38.6	46.3 ± 20.8[c]	17.2% (5)
Met-Met-carriers (*n* = 3)	509.5 ± 41.6	223.8 ± 36.8	42.5 ± 18.9	33.3% (1)
Total sample (*n* = 87)	452.4 ± 68.3	254.0 ± 43.5	51.8 ± 23.3[d]	35.6% (31)

Notes:

[a]Percentage of sample that met USDHHS guidelines of 60 min/day of MVPA, expressed as %(*n*)

[b]Girls' mean minutes of MVPA were significantly lower than the federal recommendation, $t(38) = -7.631$, $p = .000$

[c]Met-carriers' mean minutes of MVPA were significantly lower than the federal recommendation, $t(28) = -3.538$, $p = .001$

[d]Total sample's mean minutes of MVPA were significantly lower than the federal recommendation, $t(86)$, = -3.287, $p = .001$

Gross Motor Skill Performance

Mean object control, locomotor, and total skill scores on the Test of Gross Motor Development-2 for boys, girls, and the total sample are displayed in Table 4.6. As a whole, participants scored higher on the locomotor subtest (41.2 ± 3.8) than the object control subtest (36.0 ± 6.5). An independent samples t-test revealed that boys (39.2 ± 5.1) performed better on the object control subtest than girls (32.1 ± 6.0), $t(103) = -6.570$, $p = 0.000$. Boys also outperformed girls (42.0 ± 2.9 versus 40.3 ± 4.5, respectively) on the locomotor subtest, *t*(75.829) = -2.166, *p* = 0.033. Likewise, boys (81.2 ± 6.8) had significantly higher total skill scores than girls (72.4 ± 8.7), *t*(103) = -5.807, *p* = 0.000.

Table 4.6.

Description of TGMD-2 Results by Sex

	Boys (*n* = 58)	Girls (*n* = 47)	Total (*n* = 105)
Object control[a]	39.2 ± 5.1	32.1 ± 6.0	36.0 ± 6.5
Locomotor[b]	42.0 ± 2.9	40.3 ± 4.5	41.2 ± 3.8
Total skill score[c]	81.2 ± 6.8	72.4 ± 8.7	77.3 ± 8.8

Notes:
[a]Significant differences existed between boys and girls, *t*(103) = -6.570, *p* = 0.000
[b]Significant differences existed between boys and girls, *t*(75.829) = -2.166, *p* = 0.033
[c]Significant differences existed between boys and girls, *t*(103) = -5.807, *p* = 0.000

Mean object control, locomotor, and total skill scores on the TGMD-2 are presented in terms of carrier status in Table 4.7. Total skill scores and scores on each of the subtests were largely similar. Separate ANOVAs revealed no statistical differences among carrier groups for object control, locomotor, and total skill scores. Though not statistically different, it is interesting to note that Met-Met-carriers (38.3 ± 5.3) outscored non-Met-carriers (35.9 ± 6.8) and Met-carriers (35.8 ± 6.3) on the object control subtest of the TGMD-2. Likewise, Met-Met-carriers had non-significantly higher total skill scores (79.7 ± 8.1) than both the non-Met-carriers (76.8 ± 9.4) and Met-carriers (77.7 ± 7.7)

Table 4.7.

Description of TGMD-2 Results by Carrier Status

	non-Met-carriers (*n* = 67)	Met-carriers (*n* = 31)	Met-Met-carriers (*n* = 7)
Object control	35.9 ± 6.8	35.8 ± 6.3	38.3 ± 5.3
Locomotor	40.9 ± 3.8	41.8 ± 3.6	41.4 ± 4.1
Total skill score	76.8 ± 9.4	77.7 ± 7.7	79.7 ± 8.1

The TGMD-2 Examiner's Manual (Ulrich, 2000) provides normative data by sex and age for both subtests of the assessment. Table 4.8 provides a comparison of the sample means for object control, locomotor, and total skill scores to the normative means. Norms and sample means are first compared in terms of sex and carrier status; for the carrier status comparison, male and female normative means were averaged to provide a comparison value, as norms for carrier status are not available. Generally speaking, our sample was low-skilled in terms of object control, locomotor, and total skill scores relative to the normative means. For all sample means across both sex categories and all three carrier statuses, one-sample t-tests indicated that sample means were significantly lower than normative means ($p > .000$).

Table 4.8.

Comparison of TGMD-2 Normative Means versus Sample Means by Sex and Carrier Status

	Locomotor		Object Control		Total Skill Score	
	Normative Mean	Sample Mean	Normative Mean	Sample Mean	Normative Mean	Sample Mean
Male (*n* = 58)	43.0 ± 5.5	42.0 ± 2.9*	44.0 ± 5.5	39.2 ± 5.1*	87.0 ± 5.5	81.2 ± 6.8*
Female (*n* = 47)	43.0 ± 3.5	40.3 ± 4.5*	43.0 ± 3.5	32.1 ± 6.0*	86.0 ± 4.0	72.4 ± 8.7*
Non-Met-carriers (*n* = 67)	43.0 ± 4.5	40.9 ± 3.8*	43.5 ± 4.5	35.9 ± 6.8*	86.5 ± 4.75	76.8 ± 9.4*
Met-carriers (*n* = 31)	43.0 ± 4.5	41.8 ± 3.6*	43.5 ± 4.5	35.8 ± 6.3*	86.5 ± 4.75	77.7 ± 7.7*
Met-Met-carriers (*n* = 7)	43.0 ± 4.5	41.4 ± 4.1*	43.5 ± 4.5	38.3 ± 5.3*	86.5 ± 4.75	79.7 ± 8.1*

Notes:
For carrier status comparison, male and female normative TGMD-2 means were averaged to provide comparison value
*Means differed significantly from normative means, $p < .000$

Fine Motor Skill Performance

Bubbles Burst, BOT-2 pegboard task, and BOT-2 star-copying task. Scores from two trials of the BOT-2 pegboard task were averaged and retained for analysis. The five components of the only trial of the star-copying task were summed and retained for analysis. Mean scores for boys, girls, and the total sample are displayed in Table 4.9. Though boys scored slightly higher than girls, no significant differences were revealed for boys and girls on the pegboard task. Boys' and girls' scores on the star-copying task were essentially identical. For the Bubbles Burst game, all values presented are an average of the scores on the two games that were played. Table 4.9 displays mean total points for the game, movement time, absolute error, movement amplitude, and index of difficulty for boys, girls, and the total sample. Separate ANOVAs revealed no significant differences between boys and girls on any of the measures derived from the Bubbles Burst game.

Table 4.9.

Description of BOT-2 Pegboard Task and Bubbles Burst Results by Sex

	Boys (n = 58)	Girls (n = 47)	Total (n = 105)
BOT-2 Pegboard task[a]	7.5 ± 1.3	7.3 ± 1.3	7.4 ± 1.3
BOT-2 Star-copying task	3.8 ± 0.9	3.9 ± 0.8	3.9 ± 0.8
BB Total points	14.7 ± 4.1	13.9 ± 3.0	14.3 ± 3.7
BB Movement time (sec)	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1
BB Absolute error (cm)	0.7 ± 0.6	0.5 ± 0.1	0.6 ± 0.4
BB Movement amplitude (cm)	9.6 ± 0.3	9.6 ± 0.2	9.6 ± 0.26
BB Index of difficulty	3.3 ± 0.0	3.3 ± 0.0	3.3 ± 0.0

Notes:
[a]Measured by mean successful attempts across two 15-sec trials

Mean pegboard scores, star-copying task scores, total score on Bubbles Burst, movement time, absolute error, movement amplitude, and index of difficulty are presented by the three carrier statuses in Table 4.10. Though separate ANOVAs revealed no significant differences in carrier status for any of the fine MSP measures, non-Met-carriers scored slightly higher on the Bubbles Burst game (14.5 ± 3.5) than both the Met-carriers (14.1 ± 4.3) and the Met-Met-carriers (13.3 ± 2.8). Likewise, non-Met-carriers had slightly lower absolute error than

Met-carriers (0.6 cm ± 0.2 cm versus 0.7 cm ± 0.8 cm, respectively); Met-Met-carriers had the lowest absolute error among the three carrier status groups (0.5 cm ± 0.1 cm).

Table 4.10.

Description of BOT-2 Pegboard Task and Bubbles Burst Results by Carrier Status

	non-Met-carriers (*n* = 67)	Met-carriers (*n* = 31)	Met-Met-carriers (*n* = 7)
BOT-2 Pegboard task[a]	7.3 ± 1.4	7.6 ± 1.1	8.0 ± 1.0
BOT-2 Star-copying task	3.8 ± 0.9	3.9 ± 0.7	4.1 ± 0.9
BB Total points	14.5 ± 3.5	14.1 ± 4.3	13.3 ± 2.8
BB Movement time (sec)	0.4 ± 0.1	0.5 ± 0.1	0.5 ± 0.0
BB Absolute error (cm)	0.6 ± 0.2	0.7 ± 0.8	0.5 ± 0.1
BB Movement amplitude (cm)	9.6 ± 0.3	9.6 ± 0.2	9.7 ± 0.2
BB Index of difficulty	3.3 ± 0.0	3.3 ± 0.0	3.3 ± 0.0

Notes:
[a]Measured by mean successful attempts across two 15-sec trials

A MANOVA was conducted to determine if any changes in the Bubbles Burst dimensions (the dependent variables) were significantly affected by changes in sex or carrier status and to determine the presence of any interactions among the various dimensions measured by the Bubbles Burst game. MANOVA results indicated no statistically significant differences in Bubbles Burst performance based on sex or carrier status. The non-significance of the model indicated that there are no significant interactions among the dimensions measured in the Bubbles Burst game.

Perceived Physical Competence

Mean scores from the perceived athletic competence subscale of the Self-Perception Profile for Children (SPPC) (Harter, 1985) are presented in Table 4.11 by sex and carrier status for the total sample. An independent samples t-test revealed no significant difference between boys' and girls' scores on the SPPC. Similarly, no significant differences were found on SPPC scores among the carrier status groups, but the Met-Met-carriers scored lower (2.6 ± 0.6) than both the non-Met-carriers (3.0 ± 0.6) and Met-carriers (3.0 ± 0.6).

Table 4.11.

Mean Scores from the Perceived Athletic Competence Subscale of the SPPC by Sex and Carrier Status

	Boys (*n* = 58)	Girls (*n* = 47)	Total (*n* = 105)
Perceived athletic competence	3.1 ± 0.6	2.8 ± 0.7	3.0 ± 0.6
	non-Met-carriers (*n* = 67)	Met-carriers (*n* = 31)	Met-Met-carriers (*n* = 7)
Perceived athletic competence	3.0 ± 0.6	3.0 ± 0.6	2.6 ± 0.6

Specific Aim 2

The goal of Specific Aim 2 was to determine the relationship between gross and fine MSP. Fine MSP was captured three different ways: through the Bubbles Burst iPad game, the pegboard task, and the star-copying task from the BOT-2. Relationships were examined with and without controlling for BMI, SES, race, and sex. Pearson's bivariate correlations between gross MSP, as measured by object control, locomotor, and total skill scores on the TGMD-2, and the three fine MSP measures are presented in Table 4.12. With regard to the relationship between fine and gross MSP, weak but significant associations were found between scores on the pegboard task and object control scores (r = .274, p < .01), as well as total skill score (r = .256, p < .01). An additional weak but significant association was found between scores on the star-copying task and locomotor scores (r = .237, p = < .05).

Table 4.12.

Pearson's Bivariate Correlations between Fine and Gross MSP Variables

	1	2	3	4	5	6	7	8	9	10
1. Object control score										
2. Locomotor score	.415**									
3. Total skill score	.920**	.738**								
4. Pegboard task	.274**	.124	.256**							
5. Star-copying task	.110	.237*	.183	.103						
6. BB total points	.084	.159	.130	.039	.028					
7. BB movement time	.016	-.034	-.003	.095	-.599**	.007				
8. BB index of difficulty	.071	-.040	.035	.049	-.050	.120	.307**			
9. BB movement amplitude	.097	-.138	.013	.056	-.069	.180	.906**	.196*		
10. BB absolute error	.077	-.185	-.001	.055	-.069	.202*	.731**	.950**	.106	

Notes:

BB = Bubbles Burst

* = statistically significant at the p < .05 level

** = statistically significant at the p < .01 level

Subsequent partial correlations were conducted to examine the potential influence of BMI, SES (as estimated by parent education), race, and sex on the relationship between fine motor tasks that achieved significance in the unadjusted model (see Table 4.12; pegboard task and star-copying task) and gross MSP. A few things are of note for the control variables: SES was treated as a continuous variable using mother's education as the SES variable. Lower values indicated less education (e.g., a value of 1 indicates obtaining a GED, while a value of 6 indicates post-graduate education). BMI was also treated as a continuous variable. Sex was entered as a dummy-coded variable (e.g., females = 0, males = 1), as was race (non-white = 0, white = 1). Sex was entered as a control variable because sex differences are often seen in assessments of fine MSP (Good et al., 2001; Nalçaci, Kalaycioğlu, Çiçek, & Genç, 2001; Piek et al., 2008).

Partial correlations were run to examine the association between scores on the pegboard task and object control and total skill scores, controlling for BMI, SES, race, and sex. Results from the unadjusted model are compared with results from the adjusted models in Table 4.13. For the adjusted models, non-significant correlations following a significant correlation in the unadjusted model indicate that both correlation variables are significantly associated with the control variable, thus nullifying the relationship between the two correlation variables. Overall, when partial correlations were used to control for the confounding influence of BMI, SES, race, and sex, the magnitude of correlations between object control and total skill scores and the pegboard task remained largely unchanged. All adjusted models with control variables achieved significance of relatively the same magnitude as the unadjusted models, indicating that the relationship between scores on the pegboard task and the object control subtest and total skill scores are not explained by BMI, SES, race, and sex.

Table 4.13.

Partial Correlations between Pegboard Task Scores, Object Control, and Total Skill Scores Controlling for BMI, SES, Race, and Sex

	Object control score	Total skill score
Pegboard task[a]	.274**	.256**
Pegboard task *BMI*	.261**	.238**
Pegboard task *SES*	.280**	.268**
Pegboard task *Race*	.268**	.249**
Pegboard task *Sex*	.278**	.249**
Pegboard task *BMI, SES, sex, race*	.265**	.241**

Notes:
Control variables for each model are indicated in italics under pegboard task
[a]Results from unadjusted model
* = statistically significant at the $p < .05$ level
** = statistically significant at the $p < .01$ level

Unadjusted Pearson's bivariate correlations indicated a significant relationship between scores on the star-copying task and the locomotor subtest of the TGMD-2 (see Table 4.12). Subsequent adjusted analyses were conducted to further examine the relationship between star-copying task scores and locomotor scores while controlling for BMI, SES, race, and sex. Results of the adjusted models are presented in Table 4.14. Because no significant unadjusted correlations were found between star-copying task scores and either the object control subtest of the TGMD-2 or total skill scores, partial correlations were not conducted for those variables.

In the models presented in Table 4.14, when partial correlations were used to control for the potential confounding influence of BMI, SES, race, and sex, the magnitude of a few of the correlations was reduced; namely, the two partial correlations that controlled for BMI. When BMI was used as a control for the relationship between star-copying task scores and locomotor scores, the correlation was no longer significant (r = .158, p = .108), indicating no apparent statistically significant relationship between scores on the star-copying task and locomotor scores. The correlation between star-copying task scores and locomotor scores was also no longer significant when controlled for by BMI, sex, and race (r = .184, p = .063). Other adjusted models controlling for SES, race, and sex were largely unchanged compared to the unadjusted model, indicating that SES, race, and sex have little statistical impact on the relationship between scores on the star-copying task and locomotor scores.

Table 4.14.

Partial Correlations between Star-copying Task Scores, Object Control, and Total Skill Scores Controlling for BMI, SES, Race, and Sex

	Locomotor score
Star-copying task[a]	.237*
Star-copying task *BMI*	.158
Star-copying task *SES*	.216*
Star-copying task *Race*	.226*
Star-copying task *Sex*	.262**
Star-copying task *BMI, SES, sex, race*	.178

Notes:
Control variables for each model are indicated in italics under star-copying task
[a]Results from unadjusted model
* = statistically significant at the $p < .05$ level
** = statistically significant at the $p < .01$ level

Specific Aim 3

The goal of Specific Aim 3 was to determine the relationship between gross MSP and PA, with a sub-aim of determining the relationship between gross MSP and sedentary time. Three separate initial regressions were run to determine the relationship between PA and object control score, locomotor score, and total skill score. The gross MSP variables were used as the independent variable and PA was used as the dependent variable, per the hypothesized direction of the relationship in Stodden's (2008) model. PA was assessed as a continuous variable, using average percentage of time spent in moderate-to-vigorous PA (MVPA) as the dependent variable. Results for the unadjusted models are in Table 4.15.

For the unadjusted models, the assumptions of linearity, homoscedasticity, independence of errors, unusual points, and normality of residuals were met. In the first of the three unadjusted models, where object control scores were used as the predictor of MVPA, object control scores significantly explained 30.0% of the variance in MVPA, $F(1,85) = 37.919$, $p < .0005$. In the second of the three unadjusted models, where locomotor scores were used as the predictor of MVPA, locomotor scores significantly explained 9.9% of the variance in MVPA, $F(1,85) = 10.427$, $p < .002$. In the final unadjusted model, total skill scores significantly explained 29.7% of the variance in MVPA, $F(1,85) = 37.323$, $p < .0005$.

Table 4.15.

Results of Three Unadjusted Regressions to Predict MVPA from Three Measures of Gross MSP

	R	R^2	Adjusted R^2	F	p
1. Object control score	.555	.308	.300	37.919	.000
2. Locomotor score	.331	.109	.099	10.427	.002
3. Total skill score	.552	.305	.297	37.323	.000

A fourth unadjusted model was run to examine the variance in MVPA explained separately by object control scores and locomotor scores. Object control and locomotor scores were entered into a multiple regression as independent predictor variables and MVPA was used as the dependent variable. Results for this model appear in Table 4.16. The overall model indicated that object control and locomotor scores significantly predicted 30.2% of the variance in MVPA, $F(2,84) = 19.646$, $p = < .0001$, adj. $R^2 = .302$. Object control scores added statistical significance to the model (β = .507; $p = .000$), while locomotor scores did not (β = .112; $p = .265$). Regression coefficients and standard errors can be found in Table 4.16.

Table 4.16.

Results of Multiple Linear Regression using Object Control and Locomotor Scores to Predict MVPA

	β	SE_{β}	B	*p*
Intercept	-4.597	2.862		.112
Object control	.218	.043	.507	.000
Locomotor	.085	.076	.112	.265

Notes:
Overall model was significant $F(2,84) = 19.646$, $p = < .0001$, adj. $R^2 = .302$
β = unstandardized regression coefficient; SE_{β} = standard error of the coefficient;
β = standardized coefficient

Subsequent adjusted models to examine the relationship between gross MSP and MVPA were completed controlling for BMI, race, sex, and SES. As in the analysis in Specific Aim 2, SES was treated as a continuous variable such that mother's education was retained as the SES variable. BMI was also treated as a continuous variable. Sex was entered as a dummy-coded variable (e.g., females = 0, males = 1), as was race (non-white = 0, white = 1). Independence of residuals was verified by a Durbin-Watson statistic 0f 1.684. Variance inflation factor (VIF) statistics for each of the independent variables was around 1.2 (range = 1.1 – 1.4), indicating no existence of multicollinearity.

Similar to the previous models, object control, locomotor, and total skill score were examined in three separate models as the main independent variable, while BMI, SES, race, and sex were also entered as predictor variables; results are displayed in Table 4.17. In the first of the three adjusted models, where object control scores were used to predict MVPA while controlling for race, sex, BMI, and SES, the overall model was significant, $F(5,81) = 9.470$, $p = < .001$, adj. $R^2 = .330$, but only object control score (ß = .390; $p = .001$) and sex (ß = .277; $p = .05$) contributed significantly to the model. In the second of the three adjusted models, where locomotor scores were used as the main predictor of MVPA while controlling for race, sex, BMI, and SES, the overall model achieved significance $F(5,81) = 6.949$, $p < .001$, adj. $R^2 = .257$ but only sex (ß = .439; $p = .001$) added statistical significance to the model. In the final adjusted model, total skill scores significantly predicted MVPA, $F(5,81) = 9.610$, $p < .001$, $r = .610$, adj. $R^2 = .334$, with total skill scores (ß = .401; $p = .000$) and sex (ß = .286; $p = .008$) contributing significantly to the model . Table 4.17 shows regression coefficient and standard errors for each of the predictor variables in each of the three models, in the order they were presented in the text.

Table 4.17.

Results of Adjusted Multiple Regressions to Predict MVPA from Three Measures of Gross MSP

	β	SE_{β}	B	*p*
1.[a]				
Intercept	-.388	2.579		
Object control score	.167	.046	.390	.001**
BMI	-.007	.078	-.008	.931
SES	.141	.212	.062	.509
Sex	1.619	.623	.277	.011*
Race	-.440	.683	-.060	.521
2.[b]				
Intercept	-1.842	4.230		
Locomotor score	.155	.080	.203	.056
BMI	.017	.086	.021	.845
SES	.168	.224	.074	.455
Sex	2.565	.568	.439	.000**
Race	-.388	.721	-.053	.592
3.[c]				
Intercept	-4.876	3.432		
Total skill score	.128	.035	.401	.000**
BMI	.031	.079	.038	.695
SES	.110	.213	.049	.605
Sex	1.671	.610	.286	.008**
Race	-.375	.682	-.051	.583

Notes:
* = statistically significant at the $p < .05$ level
** = statistically significant at the $p < .01$ level
[a]Overall model was significant, $F(5,81) = 9.470$, $p < .001$, $r = .607$, adj. $R^2 = .330$
[b]Overall model was significant, $F(5,81) = 6.949$, $p < .001$, $r = .548$, adj. $R^2 = .257$
[c]Overall model was significant, $F(5,81) = 9.610$, $p < .001$, $r = .610$, adj. $R^2 = .334$

Additional correlation and regression analyses were conducted to examine the relationship between sedentary time and gross MSP. Results from Pearson's bivariate correlations indicated significant inverse associations between percentage of time spent sedentary and object control scores (*r* = -.351, $p < .01$), locomotor scores (*r* = -.220, $p < .05$), and total skill scores (*r* = -.354, $p < .01$).

Three subsequent regression analyses were conducted. Object control, locomotor, and total skill score were examined in three separate models as the main independent variable, while BMI, SES, race, and sex were also entered as predictor variables; results are displayed in Table 4.18. In the first of the three adjusted models, where object control scores were used to predict percent of time spent sedentary while controlling for race, sex, BMI, and SES, the overall model was significant, $F(5,81) = 3.859$, $p = < .005$, $R^2 = .192$, but only object control score contributed significantly to the model (β = -.213; $p = .04$). In the second of the three adjusted models, where locomotor scores were used as the main predictor of percentage of time spent sedentary while controlling for race, sex, BMI, and SES, the overall model achieved significance $F(5,81) = 3.490$, $p < .01$, $R^2 = .177$ but sex (β = -.301; $p = .005$) was the only predictor to add statistical significance to the model. In the final adjusted model, total skill scores significantly predicted percentage of time spent sedentary, $F(5,81) = 3.989$, $p < .005$, $R^2 = .198$, but only total skill score contributed significantly to the model (β = -.234; $p = .042$). Table 4.18 shows regression coefficient and standard errors for each of the predictor variables in each of the three models, in the order they were presented in the text.

Table 4.18.

Results of Adjusted Multiple Regressions to Predict Time Spent Sedentary from Three Measures of Gross MSP

	β	SE_{β}	B	*p*
1.[a]				
Intercept	7.283	7.045		
Object control score	-.221	.127	-.213	.04*
BMI	-.110	.212	-.056	.604
SES	-.782	.580	-.143	.181
Sex	-3.088	1.701	-.219	.073
Race	2.333	1.867	.132	.215
2.[b]				
Intercept	-7.591	1.075		
Locomotor score	-.256	.209	-.139	.224
BMI	-.160	.225	-.080	.480
SES	-.797	.587	-.146	.178
Sex	-4.246	1.486	-.301	.005**
Race	2.235	1.888	.126	.240
3.[c]				
Intercept	-8.142	9.371		
Total skill score	-.181	.095	-.234	.042*
BMI	-.166	.216	-.084	.444
SES	-.731	.581	-.133	.212
Sex	-3.056	1.666	-.216	.070
Race	2.239	1.862	.126	.233

Notes:
* = statistically significant at the $p < .05$ level
** = statistically significant at the $p < .01$ level
[a]Overall model was significant, $F(5,81) = 3.859$, $p < .005$, $R^2 = .192$
[b]Overall model was significant, $F(5,81) = 3.490$, $p < .01$, $R^2 = .177$
[c]Overall model was significant, $F(5,81) = 3.989$, $p < .005$, $R^2 = .198$

Specific Aim 4

The goal of Specific Aim 4 was to determine which predictor variables predict Met-carrier status and which variables predict non-Met-carrier status via a discriminant function analysis (DFA). The purpose of a DFA is to produce a model of dichotomous group membership (e.g., carriers versus non-carriers) in terms of multiple independent variables (O'Donoghue, 2013) and subsequently determine the least number of dimensions necessary to describe differences in group membership (Institute for Digital Research and Education, 2014).

Due to the importance of including PA as a predictor variable in the DFA, participants who did not meet the minimum wear time criteria for inclusion (8 hours per day for at least 3 weekdays and one weekend day) were excluded from the DFA. Because of the low sample size of Met-Met-carriers (n = 3) following the exclusion of participants with insufficient accelerometer data, these participants were also excluded from the analysis. The total number of participants included in the DFA was 84; however, the number of participants in each of the carrier groups was unequal (non-Met-carriers = 55, Met-carriers = 29) and thus probabilities are computed from the given group sizes (i.e., weighted by the existing inequality) rather than calculating under the assumption that groups were equal (Institute for Digital Research and Education, 2014).

There are four assumptions of the DFA: 1) normal distribution of predictor variables; 2) absence of outliers; 3) homogeneity of covariance matrices; 4) non-collinearity of predictor (independent) variables (O'Donoghue, 2013). Our data for the DFA did not violate assumptions 1 or 2. Assumption 3 was initially violated by the race variable, which was structured as a dummy-coded variable (white = 1, non-white = 0). The distribution of Met-carriers and non-Met-carriers was such that 100% of Met-carriers were white, and thus the covariance matrices between groups differed significantly. Because previous research has already indicated that race is a predictor of BDNF carrier status (Egan et al., 2003; Shimizu et al., 2004), this variable was dropped from all subsequent DFA analyses. For assumption 4, sedentary time and percentage of time spent in MVPA were indicative of multicollinearity (r = -.843, p ≤.001). Thus, two separate DFAs were run in an effort to parse out the separate contributions of sedentary time and MVPA on carrier status. The "physical activity DFA" included the MVPA variable but not the sedentary variable, and the "sedentary DFA" included the sedentary variable but not the MVPA variable. No other predictor variables violated the assumptions of multicollinearity and thus were included in the DFAs.

Physical Activity Discriminant Function Analysis

A DFA was conducted to uncover the dimensions of variables that differentiate carrier status (e.g., non-Met-carriers and Met-carriers). The predictor variables included in the model were: percentage of time spent in MVPA; object control score and locomotor score; average score on the pegboard task; total score on the star-copying task; total score on the Bubbles Burst game; SPPC score; BMI; SES (as estimated by mother's education); and sex. Sex was entered as a dummy-coded variable (female = 0, males = 1). A Box's M test was run to test the null hypothesis of equal population covariance matrices, and was not significant (p = 0.565), thus satisfying the assumption that the covariance matrices do not differ between groups formed by the dependent variable.

The function significantly differentiated between the groups, Wilks Lambda = .897, Chi Square (10) = 26.051, p < 0.004. An eigenvalue was calculated to indicate the proportion of variance explained in the dependent variable (Λ = 0.515); larger eigenvalues are associated with stronger function. A squared canonical correlation was calculated to determine the percent of variation in the dependent variable discriminated by the set of independent variables (canonical correlation coefficient = .521; R_c^2 = 27.1); a high correlation indicates a function that discriminates well.

The structure matrix for the PA DFA, which indicates the correlations, or “loading,” between each predictor and the function, is presented in Table 4.19. In a simultaneous discriminant analysis such as this model, where all independent variables are entered together, only relationships that have a loading (e.g., correlation coefficient in the structure matrix) of ±0.30 or higher are interpreted (O'Donoghue, 2013). Thus, according to the structure matrix in Table 4.19, locomotor score (.501), star-copying score (.405), MVPA percent (-.402), and average pegboard score (.401) were primarily representative of group membership.

Table 4.19.

Structure Matrix from Discriminant Function Analysis: Physical Activity Analysis

	Function coefficient
Locomotor score	.501
Star-copying task	.405
% time in MVPA	-.402
Pegboard task	.401
Sex	-.229
BMI	-.086
SPPC score	.071
Bubbles Burst total points	-.042
SES	.049
Object control score	-.021

Notes:
Variables ordered by absolute size of correlation within function
Overall model was significant, Wilks Lambda = .897, Chi Square (10) = 26.051, $p < 0.004$

Classification results are shown in Table 4.20 and provide a summary of the number of participants classified correctly and incorrectly. The overall percentage of grouped cases that were correctly classified was 72.6%. Sensitivity and specificity of the classifications were 94.5% and 31.0%, respectively. A highly sensitive test indicates that there are few false negatives (e.g., Type II error), and high specificity indicates that there are few false positive results (e.g., Type I error).

Table 4.20.

Classification Results from Discriminant Function Analysis: Physical Activity Analysis

		Predicted Group Membership		
	BDNF status	non-Met-carrier	Met-carrier	Total
Count	non-Met-carrier	52	3	55
	Met-carrier	20	9	29
%	non-Met-carrier	94.5	5.5	100.0
	Met-carrier	69.0	31.0	100.0

Notes:
72.6% of original grouped cases correctly classified
94.5 = sensitivity
31.0 = specificity

Functions at group centroids were calculated for non-Met-carriers (-.237) and Met-carriers (.482), and indicate the average discriminant score for each group when the variable means (rather than the individual scores from each subject) are entered into the overall discriminant equation. The scores by which cases were coded into categories (e.g., the discriminant score) are represented on the y-axis in Figure 4.1. This figure is a visual demonstration of the effectiveness of the discriminant function, whereby very minimal overlap of the histograms would indicate a substantial discrimination. In the event that the histograms were superimposed, one on top of the other, the area where the line-of-best-fit for each histogram intersected would indicate where the means on the variables for the respective groups meet.

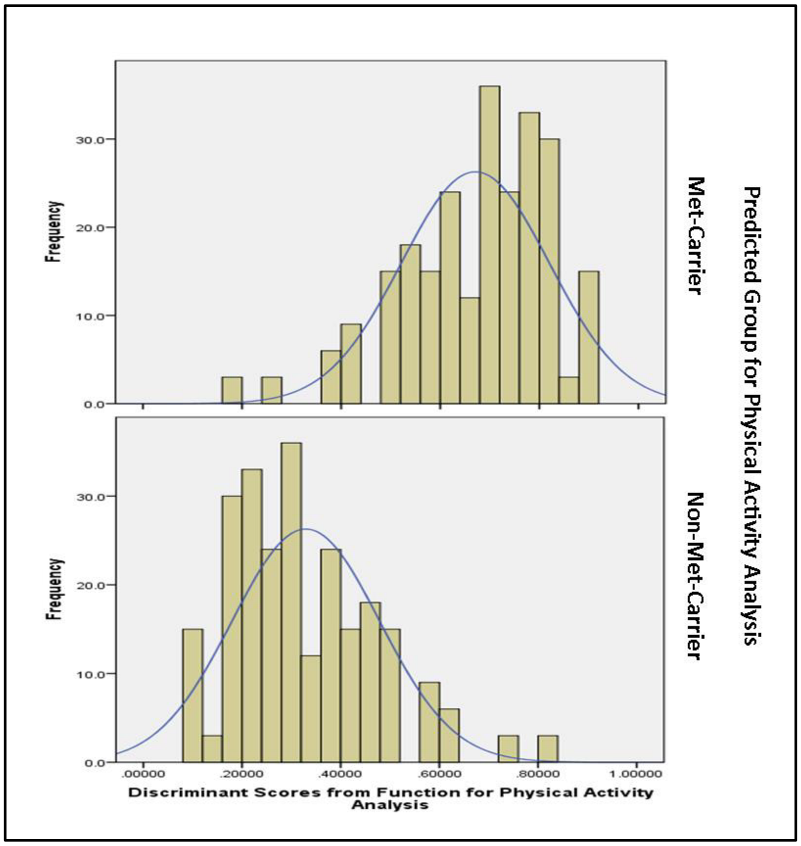


Figure 4.1. Histograms showing the distribution of discriminant scores for Met-carriers and non-Met-carriers in the physical activity analysis.

Sedentary Discriminant Function Analysis

A second DFA was conducted to uncover the dimensions of variables that differentiate carrier status (e.g., non-Met-carriers and Met-carriers), but included sedentary time as a predictor variable and excluded percentage of time spent in MVPA. The predictor variables included in the model were: sedentary time; object control score and locomotor score; average score on the pegboard task; total score on the star-copying task; total score on the Bubbles Burst game; SPPC score; BMI; SES; and sex. A Box's M test was run to test the null hypothesis of equal population covariance matrices, and was not significant (p = 0.981), thus satisfying the assumption that the covariance matrices do not differ between groups formed by the dependent variable. The function significantly differentiated between the groups, Wilks Lambda = .828, Chi Square (10) = 45.206, $p < 0.0001$. An eigenvalue was calculated to indicate the proportion of variance explained in the dependent variable ($\Lambda = 0.514$). A squared canonical correlation was calculated to determine the percent of variation in the dependent variable discriminated by the set of independent variables (canonical correlation coefficient = .514; R_c^2 = 26.4).The structure matrix for the sedentary DFA, which indicates the correlations, or "loading," between each predictor and the function, is presented in Table 4.21. Time spent sedentary (.611), locomotor score (.373), and star-copying score (.301) were primarily representative of group membership, but pegboard scores bordered on significance (.298).

Table 4.21.

Structure Matrix from Discriminant Function Analysis: Sedentary Analysis

	Function coefficient
% time sedentary	.611
Locomotor score	.373
Star-copying task	.301
Pegboard task	.298
Sex	-.170
BMI	-.121
SPPC score	.100
Bubbles Burst total points	-.059
SES	.056
Object control score	-.030

Notes:
Variables ordered by absolute size of correlation within function
Overall model was significant, Wilks Lambda = .828, Chi Square (10) = 45.206, $p < 0.0001$

Classification results are shown in Table 4.22 and provide a summary of the number of participants classified correctly and incorrectly. The overall percentage of grouped cases that were correctly classified was 71.4%. Sensitivity and specificity of the classifications were 90.9% and 34.5%, respectively.

Table 4.22.

Classification Results from Discriminant Function Analysis: Sedentary Analysis

		Predicted Group Membership		
	BDNF status	non-Met-carrier	Met-carrier	Total
Count	non-Met-carrier	50	5	55
	Met-carrier	19	10	29
%	non-Met-carrier	90.9	9.1	100.0
	Met-carrier	65.5	34.5	100.0

Notes:
71.4% of original grouped cases correctly classified
90.9 = sensitivity
34.5 = specificity

Functions at group centroids were calculated for non-Met-carriers (-.280) and Met-carriers (.531), and indicate the average discriminant score for each group when the variable means (rather than the individual scores from each subject) are entered into the overall discriminant equation. Figure 4.2 is a visual demonstration of the effectiveness of the discriminant function, whereby very minimal overlap of the histograms would indicate a substantial discrimination. In the event that the histograms were superimposed, one on top of the other, the area where the line-of-best-fit for each histogram intersected would indicate where the means on the variables for the respective groups meet.

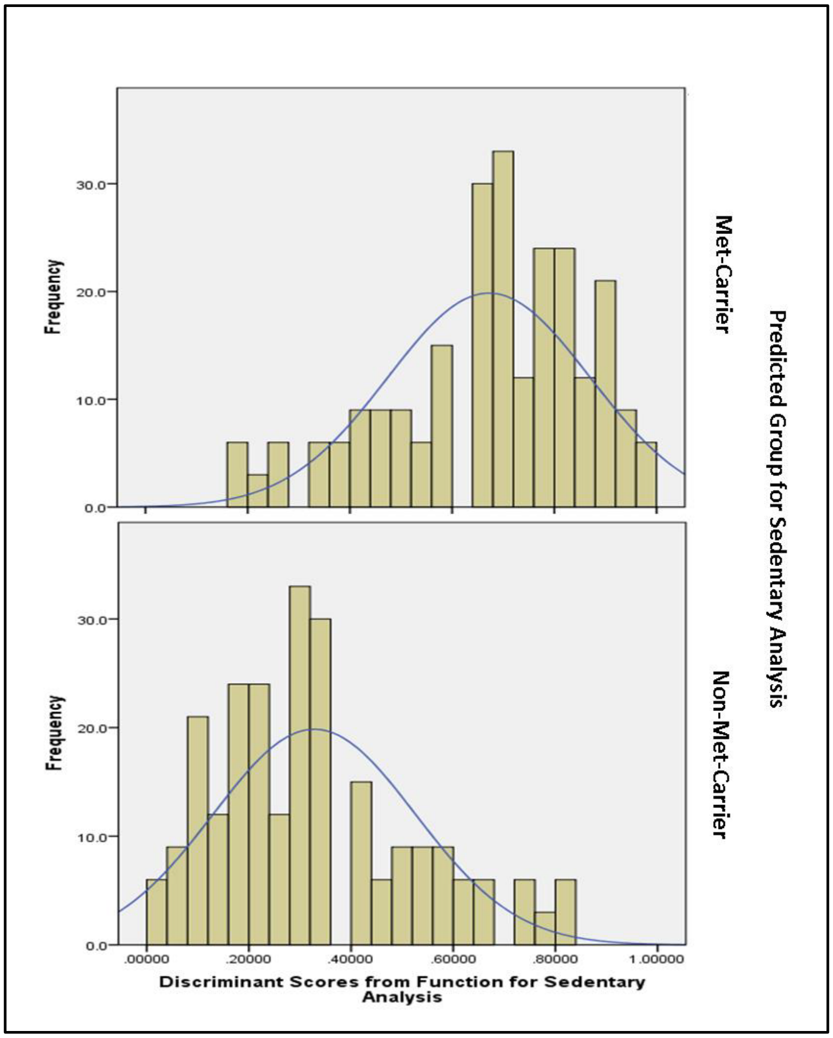


Figure 4.2. Histograms showing the distribution of discriminant scores for Met-carriers and non-Met-carriers in the sedentary analysis.

CHAPTER 5: DISCUSSION

The purpose of the experiment described in this study was to analyze children's gross and fine MSP from a genetic perspective while also considering the interactive role of PA. Thus, the purpose of this dissertation was to examine the BDNF val^{66}met polymorphism in terms of four movement-related constructs (gross MSP, fine MSP, PA, and sedentary time) in a pediatric population. A total of 105 boys (*n* = 58) and girls (*n* = 47) between the ages of 9 and 10 agreed to participate in the study. Of the 105 children, 87 (82.9%) successfully completed all aspects of the study, including gross and fine MSP, PPC, PA, sedentary time, and saliva sampling. The remaining 17.1% completed all aspects of the study except for PA and thus were included in parts of the analysis that did not involve PA. This chapter will address characteristics of the sample (Specific Aim 1), primary and secondary findings in terms of Specific Aims 2, 3, and 4, suggest explanations for the results, summarize the findings, and offer suggestions for future directions.

Specific Aim 1 – Description of the Sample

Specific Aim 1 described the sample in terms of age, race, sex, SES, BMI, carrier status, gross and fine MSP, PA, and sedentary time. Overall, our sample's demographic and anthropometric data were well-representative of the current literature. On average, children in our sample fell within the healthy weight range according to BMI percentile. Our sample fell in line with the national averages in terms of overweight and obesity. Less than 15% of our sample was classified as overweight (*n* = 15), which is slightly less than the national estimated average of 16.5% of children ages 6-11 being classified as overweight (Ogden, Carroll, Kit, & Flegal, 2014). A slightly greater portion of our sample was classified as obese (17.1%, *n* = 18), a percentage that falls in line with the national estimate of childhood obesity prevalence according to BMI (national estimate = 18.0%) (Ogden et al., 2014). Boys in our sample weighed less than girls, and also had a lower mean BMI than girls, which may be due to the stage of maturation for boys and girls at the ages of 9-10 years. Girls in our sample may have begun puberty, at which point rapid weight gain occurs; because boys typically mature later, boys may not have been at the same pubertal stage and thus were comparatively less heavy and shorter than their female peers (Haywood & Getchell, 2009). Boys, however, had a higher BMI percentile than girls (but the difference was not significant), which may also be explained by the fact that more girls than boys were classified as obese, thus skewing the data slightly.

Only slightly over 1/3 of the sample met the USDHHS (2008) recommendation of 60 minutes per day of MVPA, indicating that much of the sample was physically inactive (see Table 4.5). Boys in our sample spent significantly more time in moderate and vigorous activity than girls. Likewise, while 47.9% of boys (*n* = 23) met the recommended 60 minutes-per-day of MVPA (USDHHS, 2008) only 20.5% of girls (*n* = 8) met those recommendations. Troiano et al. (2008) indicated that the national prevalence of adherence to PA recommendations among 6-11 year-olds is 49% for boys and 35% for girls. The boys in our sample mirror this finding, but the percentage of girls meeting PA recommendations in our sample is about 15% below the national adherence prevalence. Other studies that have used objective measures of PA have returned similar findings in terms of boys accumulating more PA and less sedentary time than girls. Trost et al. (2002) examined PA behaviors of boys and girls (mean age = 10.1) and found that boys spent more minutes in MVPA when compared to girls, with an average gender difference of 11%. An even greater gender discrepancy was found in vigorous PA, with boys exhibiting 44.7% more time in VPA than girls. Likewise, boys in our sample averaged over 60 minutes-per-day in MVPA compared to only 39 minutes recorded by the girls. Boys nearly doubled the average minutes in vigorous PA (22.8 ± 13.4) of girls (12.4 ± 8.5). Discrepancies in boys' and girls' MVPA and vigorous PA are common and have also been longitudinally verified (Fuchs et al., 1988; van Mechelen, Twisk, Post, Snel, & Kemper, 2000). Girls' low participation in vigorous PA may contribute to much of the gender gap that exists in overall PA, as the gap between boys' and girls' moderate PA is not nearly as severe.

Girls in our sample were significantly more sedentary than boys (62.4% ± 7.0% versus 57.4% ± 6.3%, respectively). Some discrepancies exist in the literature regarding which sex spends more time being sedentary. For example, Fairclough, Boddy, Hackett, and Stratton (2009) found that in their sample of 9-10 year-old children, boys spent more time doing sedentary activities like watching television, playing on the computer, and playing video games than girls, but boys still accumulated more hours playing sports and games during the week. Nettlefold et al. (2011), however, found that girls accumulated more sedentary minutes throughout the overall school day, as well as during different segments of the day, including regular class time, recess time, lunch time, and scheduled physical education classes. Similar to our study, a great percentage of participants in the Nettlefold et al. (2011) study did not meet recommended MVPA guidelines of 60 minutes-per-day. In general, our sample's PA and sedentary levels were representative of the current literature.

Our sample was, in general, low-skilled when compared to the normative sample, scoring roughly 10 points below the total skill score normative mean for 9-10 year-olds on the TGMD-2 (see Table 4.8). Just as boys in our sample were more physically active than girls, boys outscored girls on both subtests of the TGMD-2. Significant differences between boys and girls existed for both the object control subtest (t(103), =-6.570, p = .000) and locomotor subtest (t(75.829), =-2.166, p = .033); however, the margin of difference in scores was much larger on the object control subtest (7.1 points) than the locomotor subtest (2.0 points). These findings echo those of Hume et al. (2008), who found that 9-12 year-old boys scored significantly higher on an object control proficiency battery involving kicking, throwing, and striking than their female counterparts ($\chi^2 = 11.79$; $p = .0001$). Hume et al. (2008) did not find statistically significant differences among boys' and girls' scores on a locomotor proficiency battery, but boys scored slightly better than girls (6.6 ± 2.37 versus 6.4 ± 2.32, respectively, $\chi^2 = 62$; $p = .53$); similarly in our sample, boys marginally outscored girls on the locomotor subtest (42.0 ± 2.9 versus 40.3 ± 4.5, respectively, $t(75.829) = -2.166$; $p = .033$). Also similar to our findings, Morgan et al. (2008) found in their sample of 5-9 year-olds that boys had significantly higher scores on the TGMD-2 object control subtest than girls (24.1 versus 20.36, respectively, $p < .05$); however, in the Morgan et al. (2008) sample, the girls were significantly better performers on the locomotor subtest of the TGMD-2 (24.8 versus 22.5, respectively, $p < .05$). The discrepancy in locomotor scores is likely due to the younger average age in the Morgan et al. (2008) sample, as girls typically outperform boys in locomotor tasks at younger ages (Haywood & Getchell, 2009). In general, our sex-specific findings on the object control and locomotor subtests of the TGMD-2 agree with the current literature for the 9-10 year-old age group. In summary, in our sample, girls were less active and less-skilled, both in terms of object control and locomotor skills, than boys. As a whole, the sample was poorly skilled compared to normative data.

Boys' and girls' scores on both of the fine MSP tasks that were pulled from the BOT-2 (pegboard and star-copying tasks) were almost identical. Relatively little empirical information is available regarding the performance of typically-developing children on items from the BOT-2, as it is most commonly used to assess motor performance in children with developmental delay. However, our sample's average score on the star-copying task (3.9 ± 0.8) echoed those of a sub-sample of healthy-weight children (3.85 ± 0.9) in a study conducted by Gentier et al. (2013). Unfortunately, Gentier et al. (2013) did not conduct the pegboard task in their sample, so no comparisons can be made between our sample's performance on that assessment. An exhaustive review of the literature returned no other studies with information on typically-developing children's scores on individual items from the BOT-2. Further, the assessment manual for the BOT-2 (Bruininks & Bruininks, 2005) does not provide normative values for individual items on the BOT-2, and instead provides norms for each composite (e.g., fine motor integration, which is made up of several items). Therefore, comparisons between our sample's scores on the pegboard and star-copying tasks cannot be made with normative data.

In terms of the distribution of carriers and non-carriers in our sample, our findings were representative of the available literature. Both Egan et al. (2003) and Shimizu et al. (2004) have estimated that in samples of American adults, roughly 30% are Met-carriers, slightly less than 70% are non-Met-carriers, and less than 1% are Met-Met-carriers. While the non-Met-carrier to Met-carrier ratio in our sample agreed with the estimates of Egan et al. (2003) and Shimizu et al. (2004), the percentage of Met-Met-carriers in our sample (*n* = 7; 6%) exceeded their estimates slightly. This finding is difficult to explain given the lack of empirical research on the prevalence of Met-Met-carriers, but further investigation is warranted. It is plausible that the val^{66}val expression was simply more commonly expressed in our population. Other studies have indicated that differences in episodic memory, fine MSP, and even mood disturbances among Met-Met-carriers and Met-carriers is not significant (Dempster et al., 2005; McHughen et al., 2011; McHughen et al., 2010), and several of these studies have included the few Met-Met-carriers in the Met-carrier group for analyses. Future research could benefit from case studies on Met-Met-carriers as a starting point for a better understanding of this type of carrier.

Few empirical studies have examined BDNF polymorphism carrier status in light of race or ethnicity. However, Applied Biosystems obtained allele frequencies on Caucasian and African American populations in order to create validated SNP genotyping assays, and these allele frequencies are commonly used to estimate statistical power for separate human populations. According to Applied Biosystems, 33% of Caucasians are Met-carriers while only 5.1% of African Americans are Met-carriers. Thus, our finding that 90.3% (*n* = 28) of the Met-carriers in our sample were white while zero black participants were Met-carriers is not surprising, especially given the low overall number of black participants (*n* = 3; 2.9%). The remaining 9.7% (*n* = 3) of the Met-carriers were either biracial or did not provide a response to the portion of the questionnaire that asked parents to indicate their child's race/ethnicity. No differences were found among males and females in terms of carrier status. Overall, the sample was reflective of empirical findings in terms of distribution of carrier status.

Non-Met-carriers spent significantly less time sedentary and more time in light PA and MVPA than Met-carriers and Met-Met-carriers. Likewise, fewer Met-carriers and Met-Met-carriers met federal PA recommendations than did non-Met-carriers. Though currently no evidence exists suggesting that BDNF polymorphism effects may encourage sedentary time and discourage PA in Met-carriers and Met-Met-carriers, our study at least confirms that a relationship between PA, sedentary time, and carrier status exists. In terms of gross MSP, no significant differences existed among carrier types for object control, locomotor, or total skill scores, though we expected that non-Met-carriers would have better gross MSP than Met-carriers and Met-Met-carriers. In fact, object control and locomotor scores were essentially identical between non-Met-carriers and Met-carriers. While it is possible that carrier status does not impact gross MSP, these findings should be interpreted with caution given that only one measure of gross MSP was used to assess overall performance and that this is the first study of its kind to examine differences in gross MSP by BDNF polymorphism status.

Specific Aim 2 – Relationship between Fine and Gross MSP

There is limited empirical information on the association between fine and gross MSP in children. However, it is reasonable to expect that a relationship would exist between children's performance on tests of fine and gross MSP because both are developmental milestones that follow a relatively linear path, and both types of skills are acquired in a similar manner, through practice, repetition, and developmental time (Haywood & Getchell, 2009). Additionally, both types of skills are influenced by a number of factors (e.g., environmental, psychosocial, and genetic). In our study, fine MSP was captured three ways: through the Bubbles Burst iPad game, the pegboard task of the BOT-2, and the star-copying task of the BOT-2. We hypothesized that gross and fine MSP would be moderately, positively related. Results differed among the fine MSP measures, such that no significant associations were found between gross MSP and any of the dimensions of fine MSP derived from the Bubbles Burst game (e.g., total points, movement time, index of difficulty, movement amplitude, or absolute error) However, weak but significant associations were found between scores on the pegboard task and object control scores (r = .274, $p < .01$) and total skill scores (r = .256, $p < .01$). An additional weak but significant association was found between scores on the star-copying task and locomotor skill scores (r = .237, $p < .05$) (see Table 4.12). To our knowledge, only one empirical study has examined the relationship between fine and gross MSP, though Haywood and Getchell (2009) mention in their textbook that fine and gross MSP are moderately related in childhood. Our findings are somewhat similar to those of Logan, Robinson, et al. (2011), who found that total skill scores on the TGMD-2 were moderately related to scores on the manual dexterity subscale of the MABC-2 assessment (r =0 .46, p = .01). However, when Logan, Robinson, et al. (2011) examined the object control and locomotor subscales of the TGMD-2 with the manual dexterity subscale of the MABC-2, only the locomotor subscale was significantly related to the manual dexterity subscale (r = 0.63, p = .01). There was no significant association between scores on the locomotor subscale and manual dexterity. The authors posited that the association between locomotor scores and manual dexterity was likely not meaningful, regardless of the statistical significance, an argument that seems plausible for the current study based on our partial correlation results for the star-copying task and locomotor scores. However, the relationship that we found between object control scores and manual dexterity may have more practical significance because many object control skills require good manual dexterity in order to achieve optimal performance on skills like throwing, catching, and striking. We had one other assessment of fine MSP (from the Bubbles Burst game) that also must be considered.

Though the Bubbles Burst game assesses commonly-researched dimensions of fine MSP, namely absolute error and movement time, the game itself is novel and has not been used as a tool for assessing fine MSP in a research setting as of yet, which may explain in part why no significant associations were found with gross MSP. In fact, an examination of the association between all six recorded dimensions on the Bubbles Burst game and the other two fine MSP assessments revealed only one significant relationship—an inverse association between movement time and scores on the star-copying task ($r = -.599$, $p < .01$), indicating that participants with faster movement times scored higher on the star-copying task. Though it was not a major focus of this Specific Aim, it was assumed that scores on the various fine MSP assessments would be related (as scores on the object control and locomotor subtests were related). However, just as scores from the Bubbles Burst game were unrelated to the other two fine MSP assessments, scores on the pegboard task and star-copying task were also unrelated, indicating that each measure assessed different, unrelated aspects of fine MSP, like fine motor integration (star-copying task) and manual dexterity (pegboard task). Though it is unclear why no associations were found between dimensions on the Bubbles Burst game and gross MSP, one possible explanation may lie in the comparison between qualitative (TGMD-2) and quantitative aspects of skill. Though the TGMD-2 scores are quantified, the instrument is a process measure that examines qualitative aspects of gross MSP. The Bubbles Burst game, on the other hand, is a fully objective, quantitative assessment of skill. Logan, Robinson, et al.

(2011) have theorized that comparisons between qualitative and quantitative assessments should be interpreted with caution because of the inherent difference in type of information yielded by each assessment: Qualitative assessments are more specific and provide information about behavioral aspects of skill while quantitative assessments are easy to score and only provide a broad overview of performance that is limited to the interpretation of success or failure of performance. Perhaps if quantitative aspects (e.g., product scores) of gross MSP were compared to the dimensions measured by the Bubbles Burst game, significant associations would have been found.

Weak but significant relationships were found between pegboard task scores and object control scores and total skill scores. Given the lack of significant association between pegboard scores and locomotor scores, it is likely that the association between pegboard scores and total skill scores was largely due to the association between pegboard scores and object control scores; thus, this discussion is focused on the specific relationship between object control scores and pegboard scores. Though the association was weak, when partial correlations were used to control for the confounding influence of BMI, SES, sex, and race, the magnitude of the correlations between object control scores and pegboard task scores remained largely unchanged, indicating that in our sample, the association between object control scores and pegboard scores was not explained by any other factor that we assessed. The pegboard task measures manual dexterity, or the ability to manipulate the hands and fingers accurately and in a coordinated manner. Many object control skills in the TGMD-2 also require manual dexterity, particularly the throw, dribble, catch, roll, and strike. The skills required to perform well on the pegboard task, such as reaching, grasping, and to some extent, bimanual control, may be requisite skills for proficient performance on object control tasks. As reaching and grasping are skills that are developed much earlier in life than many, if not all object control skills, it is reasonable to assume that children with better manual dexterity are also better performers on gross motor tasks that require aspects of manual dexterity (Haywood, Roberton, & Getchell, 2012). However, as mentioned in the previous paragraph, our results compare a qualitative (TGMD-2) assessment with a quantitative (pegboard task) assessment, and thus should be interpreted with caution.

Weak but significant associations between scores on the star-copying task and locomotor scores were found, but no such association existed for object control scores or total skill scores. The star-copying task is part of the fine motor integration composite of the BOT-2 and is thought to examine the coordination and assimilation of visual perception, otherwise known as hand-eye coordination (Bruininks & Bruininks, 2005). Given that the tasks on the object control subtest of the TGMD-2 require the ability to coordinate visual input with a motor output, much like the requirement of the star-copying task, it was surprising that no relationship was evident between object control skills and scores on the star-copying task. As for the association among locomotor skill scores and the star-copying task, this association was nullified when partial correlations were used to control for the confounding influence of BMI, SES, sex, and race (see Table 4.14). Namely, when BMI was used as a control for the relationship, the correlation was no longer significant, indicating no apparent statistically significant relationship between the two variables. Specifically, the partial correlations suggest that BMI may be more closely related to star-copying scores than are locomotor scores. Though research on BMI and fine MSP is scarce, D'Hondt, Deforche, De Bourdeaudhuij, and Lenoir

(2008) found that children with BMI classifications of overweight and obese performed worse on a visual integration task than did normal-weight children. Such deficits are likely caused by an increased inertial load on the upper-body segments of overweight/obese individuals, which in turn create difficulties in the “output” portion of the integration task (D’Hondt et al., 2008). While there may be a weak relationship between motor integration and locomotor scores in our sample, this finding is likely more attributed to the impact of BMI on fine MSP, though our results are not strong enough to suggest such a relationship.

In summary, the main finding of Specific Aim 2 was the significant relationship between manual dexterity (e.g., scores on the pegboard task) and object control and total skill scores. Children who demonstrated better manual dexterity performed better on gross motor tasks, and specifically those tasks in the object control realm. It is plausible that by encouraging the practice of fine manual dexterity tasks, such as tasks that involve reaching, grasping, and bimanual coordination, subsequent improvement may be seen on gross manual dexterity tasks like throwing, catching, and dribbling. Further, differences in the qualitative and quantitative nature of the assessments used in this analysis may be partially responsible for the weak and non-significant associations (Logan, Robinson, et al., 2011). Future examinations of the relationship between fine and gross MSP should compare performance using similar assessment techniques (e.g., quantitative fine assessment vs quantitative gross assessment).

Specific Aim 3 – Relationship between Gross MSP and PA

Correlates of gross MSP are commonly classified in terms of behavioral, physiological, and psychological benefits (Lubans et al., 2010). One well-established behavioral correlate of gross MSP is PA (Barnett, Morgan, et al., 2008; Barnett et al., 2009; Castelli & Valley, 2007; Cliff et al., 2009; D'Hondt et al., 2009; Fisher et al., 2005; Graf et al., 2004; Hume et al., 2008; Okely et al., 2001; H. Williams et al., 2008) and studies indicate a positive, reciprocal association between gross MSP and PA in 9-10 year-old boys and girls. Our sample mirrored these findings, with a few exceptions.

Despite lower-than-expected levels of gross MSP and lower-than-recommended minutes of MVPA per day, significant relationships between gross MSP and PA were found. Initial regression models examining the separate variance explained in PA by object control, locomotor, and total skill scores were all significant. When object control and locomotor scores were both entered into a model as independent variables, the overall model was still significant, but beta values indicated that only object control scores added statistical significance to the model (see Table 4.16). In this model, object control scores alone explained 30.2% of the variance in MVPA. In order to examine variance in MVPA explained separately by object control, locomotor, and total skill scores, three subsequent regression models were run with the gross MSP variable as the main predictor and sex, SES, race, and BMI entered as control variables. Though all three models were significant, the object control and total skill score models explained more variance in MVPA (R^2 = .330 and .334, respectively) than the locomotor model (R^2 = .257), and locomotor skills were not found to be a significant predictor of MVPA. Sex also added statistical significance to each of the adjusted models, while BMI, SES, and race did not (see Table 4.17). Given the discrepancies in boys' and girls' object control and locomotor skills in our sample, it is reasonable that sex would be a significant contributor to the overall model.

Though many studies in this age group have confirmed a relationship between gross MSP and PA, few have examined the discrete influence that object control and locomotor skills have on PA, especially when PA is objectively measured. Separating object control scores and locomotor scores provides a more specific interpretation for how gross MSP influences PA, and importantly, gives specific information about gross MSP that could potentially be used in intervention efforts. Wrotniak et al. (2006) and Castelli and Valley (2007) both found a significant positive association between gross MSP and MVPA in 8, 9, and 10-year-olds, but associations were low and not parsed by type of skill (i.e., object control or locomotor). Our results mirrored those of Hume et al. (2008), who found that, at least for boys, object control scores were significantly related to minutes per day of MVPA ($r = .24$, $p < .01$) but locomotor scores were not. Morgan et al. (2008) found that object control proficiency and age were the sole predictors of 32% of the variance in MVPA, while locomotor skill scores were not significant predictors of MVPA. Interestingly, Morgan et al. (2008) used a similar model of accelerometer to measure PA as was used in the present study and used the TGMD-2 to assess gross MSP, and the explained variance in MVPA was almost identical across the two studies (Morgan et al: $R^2 = .32$, present study: $R^2 = .330$). Object control proficiency has proved to be a salient predictor of PA in other studies as well, one of which was a longitudinal examination of the association between gross MSP and PA. Barnett et al. (2009) also found object control skills to be the more salient predictor of MVPA, such that children who were more object-control-proficient were more active as adolescents ($R^2 = .127$) and participated in more organized physical activity and sports ($R^2 = .182$). No such link existed between locomotor skills and adolescent PA or organized physical activity. Although PA was self-reported in the Barnett et al.

(2009) study, it is still noteworthy that object control was a salient predictor of long-term MVPA while locomotor skills were not.

There are a few possible explanations for the finding that object control skills were a salient predictor of MVPA while locomotor skills were not. Simply put, object control skills are important components of sports and games and thus children who are better performers of object control skills tend to participate in more sports and other physically-demanding activities. Further, object control skills are inherently more complex and often require elements of fitness (e.g., strength, endurance) as well as total body coordination (e.g., balance, temporal and spatial accuracy) in order to achieve success; children who have mastered these skills may be more likely to use them in physically-demanding activities, while children who do not have the prerequisite object control skills to participate in sports and games may demonstrate limited participation. Further, the ability to properly execute complex skills like throwing and kicking may improve self-esteem and overall enjoyment of activities that involve object control skills—like sports and games—thus encouraging children who are object-control-proficient to spontaneously participate in physically-demanding activities outside of regular participation (e.g., PE or organized sport), ultimately increasing overall levels of PA. Finally, object control skills may have been the more salient predictor of MVPA and sedentary time compared to locomotor skills, but most children develop locomotor skills before object control skills, and such skills are acquired earlier in childhood (Clark & Metcalfe, 2002; Haywood et al., 2012). It is possible that children in our sample had already developed their locomotor skills to the point of a "ceiling effect," whereby scores on the TGMD-2 are not sensitive or discriminating enough for a significant relationship between locomotor skills and PA to be seen. Future analyses could use a different measure of gross MSP, such as outcome measures like jump distance and/or throwing and kicking velocity, to assess locomotor skills.

An additional analysis was conducted to examine associations between gross MSP and sedentary time. Similar to the findings of MVPA and gross MSP, regression analyses indicated that object control scores (R^2 = .174) and total skill scores (R^2 = .182) significantly predicted percentage of time spent sedentary, such that higher object control scores predicted less time spent sedentary. Though both of these models controlled for race, sex, SES, and BMI, none of the other predictor variables added statistical significance to the models. Despite the growing evidence that supports the relationship between gross MSP and PA, sedentary behavior has not been statistically associated with gross MSP as of yet, although it should be noted that only two known studies have examined this link (Cliff et al., 2009; Graf et al., 2004). One would expect to see an inverse association between sedentary time and gross MSP, such that an increase in sedentary time would cause a decrease in gross MSP, much like our results revealed. However, Cliff et al. (2009) found no significance between preschool boys' and girls' percent of time spent sedentary and total gross MSP (r=-0.152, p=0.469). It is difficult to find parallels between our results and results from the Cliff et al. (2009) study because of the large discrepancies in age between the two samples (9-10 years versus 3-5 years, respectively). It is unlikely that children in preschool have begun to participate in structured physical education and sport programs that are intended to develop gross FMS, and thus sedentary behavior has little impact on their skills, which are underdeveloped due to their age. As the relationship between gross MSP and PA strengthens over developmental time (Stodden et al., 2008), the relationship between sedentary behavior and gross MSP is likely to be more salient in older groups of children, like it was in our sample.

Graf and colleagues (2004) used self-reported television viewing (days/week) as a representative measure of sedentary time in 6-7 year-old children and found trends indicating that children who watched the least TV weekly (1-3 days/week) scored higher on a gross MSP assessment that children who watched TV 4-6 days/week, but no significant differences were found between the groups, indicating that sedentary behavior (as measured by how many days/week a child spends watching TV) was not related to gross MSP in their sample. An obvious criticism of the Graf et al. (2004) study is the highly subjective and inferential nature of the measure of sedentary behavior. It is likely that 6-7 year-old children are not able to accurately report the number of days/week they watch TV, and thus results from this study may have been underestimated. Our “sedentary” variable is quite different from the variable that was used in the Graf et al. (2004) study because it is an objective measure of inactivity; though we do not have information pertaining to the specific sedentary behaviors in which children were participating, the accelerometer analysis provides an objective, concrete analysis of the average time a participant spends being inactive. Thus, our results are accurately representative of the relationship between sedentary time and gross MSP, at least with respect to object control skills. Given the significant inverse association between sedentary time and object control skills, it is important to encourage 9-10 year-old children to be active whenever possible, but a specific emphasis on the development of object control skills may be important for the promotion of activity and the reduction of physical inactivity.

In summary, in our sample, significant associations were found between object control skills and MVPA, such that object control skills, in conjunction with sex, predicted roughly 35% of the variance in time spent in MVPA. Likewise, significant inverse associations were found between time spent sedentary and object control skills. These findings highlight the important role that gross MSP—object control skills in particular—can play in promoting participation in MVPA and discouraging sedentary time among 9-10 year-olds. Girls, particularly, should be targeted for early intervention in promoting object control skills.

Specific Aim 4 – Discriminating Carrier Status

Evidence exists suggesting that the BDNF val^{66}met polymorphism plays a role in short-term motor learning (McHughen et al., 2010), long-term motor skill acquisition (Z.-Y. Chen et al., 2006; Fritsch et al., 2010) and motor skill retention (McHughen et al., 2010). We hypothesized that fine MSP, gross MSP, PA, and sedentary time would all significantly predict group membership in the carrier types. These variables, along with other variables thought to contribute indirectly to carrier status (PPC, sex, BMI, and SES) were entered into a discriminant function analysis (DFA) in an effort to characterize Met-carriers and non-Met-carriers on the basis of those predictors. Two separate DFAs were conducted; the first included percentage of time spent in MVPA as the variable representative of PA, and the second DFA included sedentary time as the PA variable. The two analyses returned similar results: Both were moderately discriminatory, as indicated by eigenvalues (O'Donoghue, 2013), and both analyses explained about 27% of the variation in carrier status. For the MVPA DFA, four predictor variables loaded significantly (locomotor score, star-copying score, percentage of time spent in

MVPA, and pegboard score). For the sedentary DFA, the same four predictor variables loaded significantly, with the substitution of sedentary time for MVPA, and with the pegboard score being borderline significant (.298). Though four predictor variables discriminated significantly between Met-carriers and non-Met-carriers, it should be noted that the overall analyses still only explained about 27% of the variation in carrier status, suggesting that other factors not included in this analysis also discriminate between carrier statuses.

For the PA DFA, group centroid for Met-carriers was 0.482 and for non-Met-carriers was -0.237). For the sedentary DFA, group centroid for Met-carriers was -0.531 and for non-Met-carriers was -0.280. Group centroids are the group means of the predictor variables; the farther apart the group means are from one another, the better the model is at discriminating group membership. For example, perfectly discriminating groups would have centroid values of -1.000 and +1.000. In our sample, group centroids in the sedentary DFA were slightly farther apart from one another, indicating that this model was better at discriminating group membership than the PA DFA. Visual interpretations of the group centroids for both models are presented in Figures 4.1 and 4.2.

For both analyses, sensitivity was above 90%, indicating the proportion of non-Met-carriers who were correctly identified; the sensitivity value also signifies a low risk for Type II error because few false negatives were identified. Unfortunately, specificity for both DFAs was around 33%, revealing a low proportion of Met-carriers who were correctly identified as such, which suggests that some false positives may have been identified in our sample. However, it should be noted that low specificity is common with unequal group sizes because there is less information to be utilized for the prediction (O'Donoghue, 2013). In our sample, carrier group distribution was unequal due to the nature of the BDNF expression—only 30% of the population are carriers of the Met allele, and thus only 30% of our total sample were carriers, leaving the other roughly 70% of the sample in the non-Met-carriers groups and creating unequal group sizes. Though the appropriate adjustments were made in our models, poor specificity was still seen, which is typical when group sizes are unequal because the smaller of the two groups suffers from the weaker classification rate, which may explain the poor specificity in both of the DFAs (Garson, 2008; O'Donoghue, 2013). At any rate, higher specificity would be better for predicting carrier status and is desirable in future analyses. Because this study is the first of its kind, it is difficult to generalize our group centroid, specificity, and sensitivity results beyond simply interpreting what the statistics indicate. An exhaustive review of the relevant literature indicated that no other studies examining the BDNF val^{66}met polymorphism have used a DFA to predict carrier status from a set of hypothetically-related independent variables. Likewise, DFA is seldom used in studies involving PA, sedentary time, or gross/fine MSP because of the continuous nature of those variables (i.e., continuous variables cannot be used as the dependent variable in a DFA because the dependent variable must be dichotomous).

Gross MSP, in terms of locomotor score, fine MSP, in terms of pegboard scores and star-copying scores, and percent of time spent in MVPA and percent of time spent sedentary all discriminated significantly between non-Met-carriers and Met-carriers, thus confirming the hypothesis that gross MSP, fine MSP, and PA are all predictive of BDNF carrier status. Scores on the pegboard task, which is a measure representative of manual dexterity, predicted group membership in the physical activity model and was borderline significant in the sedentary model. Likewise, scores on the star-tracing task, which is a measure representative of motor integration (e.g., hand-eye coordination) also predicted group membership. Fine motor tasks in other studies that have identified relationships between fine MSP and carrier status have used tasks that require both manual dexterity and motor integration, like a computerized driving task (McHughen et al., 2010), and a sequential visual pinch force task (Fritsch et al., 2010). Though the tasks used in our study did not mirror the complexity of the tasks described above, parallels can be drawn between the specific characteristics of fine MSP that can be used to predict carrier status—in our case, the characteristics of manual dexterity and motor integration.

Although the Bubbles Burst iPad game measures many specific dimensions of fine MSP that are commonly examined in studies that seek associations with the BDNF polymorphism (e.g., absolute error, movement time, index of difficulty), it was not a significant discriminator of carrier status. Scores on the Bubbles Burst game may not have been a significant discriminator because the tasks required to complete the game were not complex enough and not demonstrative of long-term learning, two facets that are typically key to predicting carrier status. In other studies that have examined performance on fine motor tasks and the BDNF polymorphism, tasks were complex in nature, requiring individuals to “learn” a new fine motor task over the period of several weeks, a parameter that was not required of participants when playing the Bubbles Burst game. However, it was hypothesized that scores on the Bubbles Burst game would discriminate carrier status because of the association between the speed-accuracy tradeoff and the BDNF polymorphism; one primary function of the Bubbles Burst game is to examine the speed-accuracy tradeoff. One explanation for the lack of significant findings is that it is possible that too few trials were completed to significantly discriminate between carriers and non-carriers. In the only other study to have used the Bubbles Burst game, 180 trials were used, where we used only 90 (Bertucco & Sanger, 2013). Perhaps if more trials were completed, enough information regarding the speed-accuracy tradeoff could be accrued to produce significant results. Finally, future analyses of this sort should consider calculating an index from all of the available fine MSP scores so that there is only one score that is representative of fine MSP. Calculating a fine MSP index score might allow for a more robust understanding of the relation between fine MSP, carrier status, and gross MSP.

One of the main findings of this Specific Aim concerns the ability of MVPA and sedentary time to discriminate between carrier groups. Though time spent in MVPA was hypothesized to discriminate, it was not expected that sedentary time would also be a key discriminating factor in a separate analysis. It is interesting that although our sample recorded low PA, at least in terms of meeting federal recommendations, time spent in MVPA and time spent sedentary were significant differentiating variables in conjunction with locomotor score and two of the fine motor tasks. Perhaps time spent in MVPA (and, likewise, less time spent sedentary) "overrides" deficits in MSP associated with the polymorphism. Physical activity is associated with gross MSP in such a way that children who are more active are better performers of gross MSP; however, there still remains variability and uncertainty about the extent to which a child's gross MSP improves as the result of PA. Kramer and Erickson (2007) hypothesized and subsequently proved (Erickson et al., 2013) that PA may attenuate the relationship between BDNF secretion and cognitive function, such that Met-carriers that are active do not experience cognitive deficit, in terms of working memory performance, in the same manner that Met-carriers who are not active experience cognitive deficit. It is reasonable then to hypothesize that, because of individual variation, genetic factors like BDNF val^{66}met polymorphism status may attenuate the relationship between PA and gross MSP, and particularly in Met-carriers.

Our population was under-skilled in terms of gross motor skills, at least with respect to the TGMD-2 norms. Both DFAs revealed that locomotor scores were significant in discriminating between carrier statuses, but object control scores did not near significance as a predictor of carrier status. This may indicate that many children haven't fully "learned" the object control tasks that were assessed. One of the underlying reasons for hypothesizing that gross MSP may be predictive of carrier status in 9-10 year-olds is because by late childhood (9-10 years), children have had several years of experience developing, practicing, and performing gross motor skills and thus children in this age range have had ample time to become proficient in a repertoire of gross motor skills. This "long-term learning" of gross motor skills was used as a parallel to the findings that polymorphic effects were most evident during tasks of long-term learning. It is plausible that in terms of object control skill performance, children are still in the developmental stages of skill acquisition (i.e., still "learning" the skills), and just like in many fine MSP studies, no carrier differences are seen during this stage of learning.

It should be acknowledged that influences other than the variables included in this study may play a role in children's gross and fine MSP, as well as their PA. These results should not be interpreted to assume that gross and fine MSP are purely genetically determined, as we contend that other genetic, biological, and environmental influences undoubtedly play a role in the movement processes examined in this study. Though a thorough review of other genetic influences on movement is beyond the scope of this discussion, Davids and Baker (2007) provide an in-depth review of genetic and environmental influences on movement performance. More specifically, other factors both within the BDNF gene and the chromosome on which the BDNF gene lies may also play a role in movement difficulties associated with the BDNF val^{66}met polymorphism. The BDNF gene has been associated with a number of other conditions and health issues. Namely, three SNPs on the BDNF gene (rs4074134, rs4923461, and rs925946) have recently been associated with obesity (Hotta et al., 2009). The BDNF gene lies on chromosome 11. Several disorders associated with genes on chromosome 11 have been identified, including Type 1 Diabetes, sickle-cell disease, muscular dystrophy, and bladder and breast cancer. It would be prudent to examine characteristics of the entire chromosome and gene in future studies regarding BDNF and MSP.

Conclusions & Future Directions

Relationship between Fine MSP and Gross MSP

In summary, a weak but significant relationship was found between a fine motor task involving manual dexterity and scores on the object control subtest of the TGMD-2. Because the association was weak, was the first of its kind, and was a comparison of one qualitative and one quantitative measure, these findings offer limited practical relevance other than to suggest that 9-10 year-old children with good manual dexterity may be at an advantage when performing object control skills. Future research should compare assessments that are on similar scales (e.g., quantitative versus quantitative) and perhaps expand the sample size, both of which might contribute to stronger associations and a better understanding of how manual dexterity contributes to object control proficiency.

In terms of the use of the Bubbles Burst iPad application, though we did not find anything of statistical significance, the game is novel and has only been used once before in a research setting (Bertucco & Sanger, 2013), but was used for a very different intent. While there may be some flaws associated with the application (e.g., frequent freezes, issues with downloading complete sets of data, images not always appearing), it should not be discounted as a tool for researching and assessing fine MSP. It has particular clinical relevance in analyzing performance according to Fitts' Law (speed-accuracy tradeoff) (Bertucco & Sanger, 2013). An anecdotal observation was that children enjoyed playing the game, were quick to grasp the directions and purpose of the game, and the game held children's attention although many other activities were typically occurring in the same area. While scores from this particular game did not discriminate between non-Met-carriers and Met-carriers, future research should focus on the development of other fun, child-friendly tablet games for analyzing fine MSP. Data processing was simple, non-time-consuming, and less cumbersome than, for example, trying to calculate absolute error on a pencil-and-paper task. Children in our sample completed only half (90) of the trials that children in the Bertucco and Sanger (2013) study completed, and therefore it is also possible that too few trials were completed to yield relationships to gross motor skills or to discriminate between carrier groups. Future studies using the Bubbles Burst iPad game should require a minimum of 180 trials, if not more.

Relationship between Gross MSP and PA

Our sample was poorly skilled and demonstrated less-than-optimal levels of physical activity, which may have had an impact on our findings, but a moderate, significant association between gross MSP was found with MVPA. Object control skills proved to be a better predictor than locomotor skills, which is not an uncommon finding as object control skills are typically the stronger predictor of PA (Barnett et al., 2011; Barnett, Van Beurden, Morgan, Brooks, & Beard, 2010). This finding could be due to the demand for more mature temporal and spatial proficiency and accuracy that is required for the performance of object control skills that is not necessarily required for many locomotor skills. Children who can perform more complex skills may find it easier and more enjoyable to participate in activities that demand the use of such skills, in turn increasing their participation in PA. Another rationale could be that children who are better at object control skills, which are commonly used in sports, exhibit greater participation in organized sports and thus engage in more PA than children without proficiency in such skills. These findings favored the boys in our study, such that girls performed significantly poorer on both the locomotor and object control subtests of the TGMD-2 and acquired less PA and more sedentary time than boys. Because object control skills are the more salient predictor of PA, both in our sample and in many other studies, interventions specific to developing and improving object control in young girls should be established with the underlying purpose of improving PA, be it through organized participation in sports or through self-selected, spontaneous activity.

Further, future research should address the relationship between time spent sedentary and gross MSP, as our findings indicated that sedentary time has a detrimental effect on gross MSP—namely on object control skills and more so for girls than boys. To our knowledge, this is the first study of its kind to examine the association between sedentary time and gross MSP using an objective measure of inactivity (versus a self-report or estimate of screen time) in 9-10 year-old children. Interventions with a specific focus on eliminating inactivity may be successful in promoting gross MSP.

Discriminating between non-Met-carriers and Met-carriers

Locomotor score, star-copying scores, pegboard scores, and physical activity, both in terms of time spent in MVPA and time spent sedentary, emerged as the main discriminators between non-Met-carriers and Met-carriers. These findings corroborate previous evidence of a relationship between fine MSP and BDNF carrier status, and partially confirm our hypothesis that a relationship between gross MSP and BDNF carrier status exists. Future research should examine the relation between MSP, be it gross or fine MSP, and the BDNF val^{66}met polymorphism through a PA lens. Because secretion of BDNF is activity-dependent, and the actual secretion of BDNF is what influences memory and learning, PA may override the MSP deficits in object control skills that were observed in our study that are associated with the val^{66}met polymorphism. Given the established relationship between fine motor skill learning and retention (McHughen et al., 2010) and long-term fine motor skill acquisition (Z.-Y. Chen et al., 2006; Fritsch et al., 2010), the suggestion to use PA as an attenuator to the MSP-BDNF interaction should be confirmed using complex fine motor tasks that require long-term learning, as carrier effects are more pronounced in those types of tasks. Examinations should use both acute and habitual PA, and provide a comparison of Met-carriers' performance on long-term fine motor tasks with and without PA. Further, similar findings on the separate DFAs for both sedentary time and MVPA may have resulted from the high, inverse relationship between sedentary time and MVPA. Pate, O'Neill, and Lobelo (2008) specifically recommend that PA researchers place an equal focus on sedentary behaviors as has traditionally been placed on active behaviors because of the inherent differences in the nature of physical activity versus inactivity. The recommendation of Pate et al. (2008) should extend to future research concerning PA and the BDNF val^{66}met polymorphism. Because highly related variables cannot be simultaneously entered into a DFA and predictor variables cannot be controlled for in a DFA, future analyses regarding the BDNF val^{66}met polymorphism should take both sedentary time and MVPA into account, and consider using a different strategy for statistical analyses.

It is interesting that 33% of participants with incomplete accelerometer data were either Met-Met-carriers (*n* = 4, 22%) or Met-carriers (*n* = 2; 11%). Typically when accelerometers are returned with incomplete data, this indicates that the participant forgot to wear his/her belt or did not wear it for the instructed period of time. Though we do not have concrete evidence of issues with memory in our sample, it is possible that Met-Met-carriers and Met-carriers have more difficulty remembering to wear their accelerometer belts than non-Met-carriers. This makes sense given the evidence of poorer episodic memory that is seen in Met-carriers and Met?-Met-carriers when compared to non-Met-carriers (Dempster et al., 2005; Kambeitz et al., 2012). Future studies using accelerometry to measure long-term PA in Met-carriers and Met-Met-carriers should take extra precautions to ensure that participants remember to wear the device or possibly explore whether these participants truly have difficulty remembering to wear the device or if our results were due to chance alone.

Strengths and Limitations

In terms of limitations, the results of this study cannot suggest causality, as this was a cross-sectional study. Additionally, there may be limited generalizability because the sample represented only one metropolitan area. The overall poor gross MSP of the sample may have had an impact on the findings. However, normative data from the TGMD-2 are nearly 30 years old, and there is no information available regarding nationally representative TGMD-2 data for the present time; thus, it is difficult to conclude with any certainty how representative our sample is in terms of gross MSP. Regarding the fine MSP measure, two games (90 trials) may not have been enough to fully capture the dimensions of fine MSP that it was intended to measure, and other iPad applications used in this context may be better used as long-term learning tasks rather than an acute measure of fine MSP. Finally, low specificity (~33%) in both of the DFAs increases the risk of spurious findings due to the possibility of Type I error.

Strengths of the study included the use of an objective measurement of PA (e.g., accelerometry). High inter-rater reliability (r = .92) was achieved for analysis of both subtests of the TGMD-2. The use of cheek swabs to collect genomic data was 100% successful in our sample. Finally, given the complexities associated with collecting objective PA data in conjunction with gross MSP data in children, along with the amount of other data that were necessary to be collected, our sample size (n = 105) was moderately large.

APPENDICES

APPENDIX A:

Parental Consent Form and Demographic Questionnaire

Parent Consent Form

Your child is being asked to participate in a research study. Researchers are required to provide a consent form to inform parents about the research study. We will also obtain assent from your child if they are interested in participating. Participation is completely voluntary. Your child may say no and it will not affect their relationship with their school, their Before and After School program (when applicable), or with Michigan State University. This consent form will explain risks and benefits of participation, and provide information to help you and your child make an informed decision. You and your child should feel free to ask the researchers any questions you may have.

Unfortunately, children with known neurological diagnoses and those with conditions that would limit the use of the activity monitor (e.g., gait impairment) cannot be included in the study.

Study Title: Motor Skill Proficiency, Physical Activity, and Perceived Competence in Pediatric Carriers and Non-Carriers of the BDNF val^{66}met polymorphism.

Purpose and Objectives

The purpose of this research study is to study children's motor skills (like running, jumping, throwing, or writing) and see how well children can perform these activities. Your child has the option of either meeting with researchers at their school or you may bring them to campus at Michigan State University.

If your child enrolls for the study at school, either during regular school hours or during their before and after school program, we would meet with your child three times within a 7 day period. Except for wearing the activity monitor at home and at school, all other research activities will take place during your child's PE class at school or at the Before and After School program.

School Visit 1: We will measure your child's height and weight, using a privacy screen. We will give your child a physical activity monitor (called an accelerometer) on a belt and show him/her how to properly wear the device for the following week. We will also send home an instruction sheet for you to read. We will conduct a short pencil-and-paper survey with your child that assesses perceptions of their physical ability. We will then ask your child to play a short game on an iPad, move pegs from a box to a pegboard, and draw a star to test their fine motor skill proficiency OR we will ask your child to do a series of gross motor skills like running, hopping, jumping, kicking, and throwing. We will videotape your child doing these skills. This session will take about 45 minutes to complete.

School Visit 2: We will make sure that your child is still wearing the accelerometer belt. Then, we will swab the inside of your child's cheek with a cotton swab. This session will take about five minutes.

School Visit 3: We will collect the accelerometer belt from your child. Then, we will ask your child to either do the fine motor skill assessments or perform the gross motor skills (whichever one they did not do on the first visit). This session will take about 15 minutes.

If you would like your child to enroll and complete research activities at MSU (in the Kinesiology Dept.), your child will complete all research activities during one visit and a second visit will be to turn in the activity monitor belt only.

MSU Visit 1: We will measure your child's height and weight. We will ask your child to wear a physical activity monitor on a belt for one week. We will show your child how to wear the belt and also send home an instruction sheet. The monitor measures how physically active your child is. We will conduct a short pencil-and-paper survey with your child that assesses perceptions of their physical ability. We will then ask your child to play a short game on an iPad, move pegs from a box to a pegboard, and draw a star to test their fine motor skill proficiency OR to perform a series of gross motor skills like running, hopping, jumping, kicking, and throwing while being videotaped. And swab the inside of your child's cheek. This session will last about 60 minutes.

MSU Visit 2: You/your child has the option of returning the activity monitor belt to us on campus or meeting with a member of the research team at a convenient location to return it. This session will take about 5 minutes.

Health status:
Your child will have their height measured to the nearest 0.1com and weight to the nearest 0.5kg using aportable height board and scale. A privacy screen will be used.

Physical Activity Assessment:
Your child will be given the small activity monitor (accelerometer) to wear around his/her waist for one week. We will show your child how to properly wear the device and send home an information sheet with detailed instructions on how to care for the monitor and place the monitor correctly. During this week your child can take the monitor off when sleeping, showering, and swimming. In addition, your child will be given flyers to help him/her remember to wear the monitor.

Perceived Physical Competence Assessment:
Your child will complete a brief questionnaire about his/her perceptions of physical ability. This questionnaire is called the Self Perception Profile for Children.

Fine Motor Skill Assessment:
Your child will play a game on an iPad called "Bubbles Burst." The game involves your child touching bubbles as they appear on the iPad screen as quickly and as accurately as s/he is able. Your child will play one game with his or her left and hand and one game with the right hand. Your child will also complete a Pegboard Task, which involves your child moving as many pegs as possible from a box to a pegboard in 15 seconds. The other fine motor skill task that your child will complete is copying a picture of a star using paper and pencil.

Genetic Marker Assessment:
We will collect a sample by swabbing the inside part of the cheek with a Q-tip-like swab. The swab has a sponge or
foam tip, which is rubbed on the inside of the cheek to collect cells. This procedure is pain-free. The swab will be used to determine if your child has a version of a gene that is related to motor skill ability (BDNF gene).

The researchers will not reveal the results of this genetic testing to you. The gene of interest in this study is only at the initial stages of research. That is, only a few studies have shown a relationship among this gene and physical activity, motor skills, and perceived competence. Thus, although the research team has some idea of this association there is no concrete evidence yet. The purpose of this study is to figure out if there is a relationship or not. The genetic samples will not be used again in any manner. Thus, the samples will not be stored and will be destroyed upon completion of the project.

Gross Motor Skill Assessment:
We will ask your child to perform 12 skills: running, jumping, leaping, hopping, sliding, galloping, throwing, kicking, catching, dribbling, rolling, and striking. We will also ask a subset of children to perform 3 more skills (underhand throw, one-handed strike, and skip). This assessment is called the Test of Gross Motor Development. We will videotape your child performing these skills so that we can code how well they do the skills at a later time.

Note: In the event that any of the following information is not clear, you/your child is encouraged to ask the research staff to explain. Or you may contact one of the researchers – information is on page 4 of this form.

Confidentiality:
All data and results will be kept confidential and protected to the maximum extent allowable by law. Subjects will

be assigned an identification code, which will appear instead of their names on research materials. A list of subjects' names and identification codes will remain in a locked cabinet in the PI's office. A key to that cabinet will be kept secure in a separate room and only the PI (Dr. Pfeiffer) and the main researcher (Larissa True) will have access to that key. All DNA information (the saliva sample) will be stored with a subject ID number. Upon completion of the study, the saliva samples will be destroyed. All other research data will be kept for at least three years after the study closes. Final aggregate results will be made available to participants upon request. It is possible that the Michigan State University Institutional Review Board will have access to the data if they deem it necessary, but the data will not be shared with others. You/your child is free to withdraw from the study at any time. Participation is completely voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. You/your child have/has the right to skip a question on the survey or refuse to do some activities if they are uncomfortable. Due to a recent addition in University policy, researchers at MSU are obligated to report any suspected child abuse or neglect to the MSU Police Department (MSUPD). If, in my position at MSU, I suspect a child may be abused or neglected, I must contact the MSUPD immediately. MSUPD will determine whether or not I am obligated to report the suspected incident to Child Protective Services.

Risks/Benefits:
The benefits of allowing your child to participate in this study are knowledge of height and weight, and the benefit of performing gross and fine motor activities. There is minimal risk associated with participating in this study. The risk is about the same as would be experienced while participating in a physical education class or playing outside. Children will be allowed and encouraged to take breaks as needed. To minimize the risk of the cheek swab technique, we will use all universal precautions as outlined in the Blood Borne Pathogen handbook (including things like wearing latex gloves and washing hands).

Cost/Compensation:
There is no cost to participate in this study. Participants will be compensated $10 (Target gift card) for returning the consent form and completing the activities associated with Visit 1. Participants will be given an additional $10
Target gift card for returning the activity monitor belt.

Injuries:
If your child is injured as a result of participation in this research project, Michigan State University will assist you in obtaining emergency medical care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or are in excess of what are paid by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Dr. Karin Pfeiffer, Principal Investigator, at (517) 353-5222 with any questions or to report an injury.

Contact Information:
If you have any questions or concerns about this study, such as scientific issues, report an injury or how to do any part of the study please contact Dr. Karin Pfeiffer at (517) 353-5222; 27 IM Sports Circle, Department of Kinesiology, Michigan State University, East Lansing, MI 48824; kap@msu.edu.

If you have questions or concerns regarding your child's rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact anonymously, if you wish the Michigan State University's Human Research Protection Program by phone: (517) 355-2180, fax: (517)
432-4503, e-mail: irb@msu.edu, or regular mail: 408 West Circle Drive, 207 Olds Hall, East Lansing, MI 48824.

Documentation of Consent:
By signing below, I voluntarily consent for my child to participate in this research study. The investigator will provide a copy of this form to me.

Printed name of parent/guardian: ______________________________

Printed name of child: ______________________________

Signature of parent/guardian: ______________________________

Date: __________

Investigator Signature: ______________________________

Child/Parent (Guardian) Information:
Child's date of birth: _________ Child's grade: _______ Child's race/ethnicity:___________

Child's sex:_____________

Is your child eligible to receive free or reduced price lunch (circle one)? YES NO

Parent contact information:

___________________________________	____________________	___________________
Street address	Phone number	Email address
___________________________________	____________________	
City, State, Zip	Alternate phone number	

Emergency/alternate contact information:

___________________________________	__________________	_____________________
Printed name	Phone number	Alternate phone number

Please indicate the highest level of education achieved by both parents/guardians (if applicable):

MOTHER:
___GED
___High school
___Some college
___Associate's degree
___Bachelor's degree
___Post-graduate degree

FATHER:
___GED
___High school
___Some college
___Associate's degree
___Bachelor's degree
___Post-graduate degree

APPENDIX B:

Participant Assent Form

Motor Skill Proficiency, Physical Activity, and Perceived Competence in Carriers and Non-Carriers of the BDNF val^{66}met Polymorphism

Dear Student,

We are doing a research study about how you move, what you think about moving, and how your genes affect the way youmove. We are trying to learn all about how kids move! You are invited to:

1) Have health and fitness measures taken on you. This will measure how tall you are, how much you weigh, how much you move, and how well you do motor skills like running, catching, throwing, drawing, playing a game on an iPad, and moving pegs around a pegboard.
2) Have one of your genes analyzed. This means that we will swab the inside of your cheek with a Q-tip-like swab.

We will either visit your school (during the Before and After Program or your PE Class) or you may have your parent(s) bring you to the gym at Michigan State University.

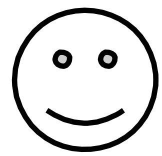
If we meet with you at school, we would like to see you three (3) times. During the first visit, we will measure how tall you are and how much you weigh. Then, we will give you a belt with a small activity monitor on it, which will tell us how much you move. We will teach you how to wear the belt and send instructions home for your parents, because we would like you to wear the belt for one week. We will ask you to answer a few questions about how you feel about doing some activities like sports and games. Then, we will ask you to play a game on an iPad called Bubbles Burst, where you use your fingers to pop bubbles on the screen, move pegs to a pegboard, and draw a star OR to do skills like running, hopping, jumping, kicking, and throwing while we videotape you. During the second visit, we will swab the inside of your cheek using the Q-tip-like swab. During the third visit, we will either have you play the iPad game, move the pegs, and draw or do the skills like running, hopping, jumping, kicking, and throwing-whichever one you did not do on the first day. At the third visit, we will have you turn in the activity monitor belt.

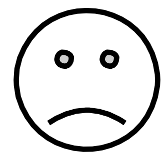
If your parent(s) bring you to MSU, we would meet with you two times. The first visit we will measure how tall you are and how much you weigh. Then, we will give you a belt with a small activity monitor on it, which will tell us how much you move. We will teach you how to wear the belt and send instructions home for your parents, because we would like you to wear the belt for one week. We will ask you to answer a few questions about how you feel about doing some activities like sports and games. Then, we will ask you to play a game on an iPad called Bubbles Burst, where you use your fingers to pop bubbles on the screen, move pegs to a pegboard, and draw a star or do skills like running, hopping, jumping, kicking, and throwing while we videotape you and swab the inside of your cheek using a Q-tip-like swab. The second visit would be to turn in the activity monitor.

The health measures are like those taken at a doctor's office or ones you do in P.E. class (gym). You may be slightly uncomfortable wearing the activity monitor, getting measured, or having your cheek swabbed, but nothing will hurt you, and we will try our best to keep all of your information private. Being in this study is your choice. You can quit the study at any time. No one will be upset with you if you decide not to participate or stop the study. If you participate, you will get a $10 Target gift card for completing the activities on the first visit, and another $10 Target gift card for wearing the activity belt for a week and returning it to us.

If you would like to be in the study, please circle the smiley face. If you do not want to be in the study, please circle the frown face.

Printed Name





This consent form was approved by a Michigan State University Institutional Review Board. Approved 03/24/2014 - valid through - 01/01/2015. This version supersedes all previous versions. IRB # 13-1167

APPENDIX C:

Main Data Collection Form

Name:__________________________ School__________________________ ID: _______________

Anthropometrics date:

Height 1:		Sitting height 1:		Weight 1:	
Height 2:		Sitting height 2:		Weight 2:	

TGMD-2 date:

Object Control	Trial 1 ☑ / Trial 2 ☑	Locomotor	Trial 1 ☑ / Trial 2 ☑	Product Score
Roll		Run		Time 1:
				Time 2:
Strike		Gallop		
Catch		Slide		
Dribble		Hop		
Throw		Leap		
Kick		Horizontal Jump		Distance 1:
				Distance 2:

Accelerometer:

Number:	
Date distributed:	
Time distributed:	
Date returned:	

SPPC:

Date completed:	

Cheek swab:

Date completed:	

BOT-2 Date:

Pegboard	Trial 1:	
	Trial 2:	
Copying a star ☑:		

Bubbles Burst (iPad) Date:

Practice ☑:	
Right hand ☑:	
Left hand ☑:	

Gift cards:

Visit 1 ☑:	
Visit 3 ☑:	

APPENDIX D:

Self-Perception Profile for Children Data Collection Form

What I Am Like

Name/ID______________________________

	Really True for me	Sort of True for me				Sort of True for me	Really True for me
			Sample Sentence				
Example	☐	☐	Some kids would rather play outdoors in their spare time	BUT	Other kids would rather watch T.V.	☐	☐
1	☐	☐	Some kids do very well at all kinds of sports	BUT	Other kids don't feel that they are very good when it comes to sports	☐	☐
2	☐	☐	Some kids wish they could be a lot better at sports	BUT	Other kids feel they are good enough at sports	☐	☐
3	☐	☐	Some kids think they could do well at just about any new sports activity they haven't tried before	BUT	Other kids are afraid they might not do well at sports they haven't ever tried	☐	☐
4	☐	☐	Some kids feel that they are better than others their age at sports	BUT	Other kids don't feel they can play as well	☐	☐
5	☐	☐	In games and sports some kids usually watch instead of play	BUT	Other kids usually play rather than watch	☐	☐
6	☐	☐	Some kids don't do well at new outdoor games	BUT	Other kids are good at new games right away	☐	☐

APPENDIX E:

BOT-2 Star-Copying Task Data Collection Form

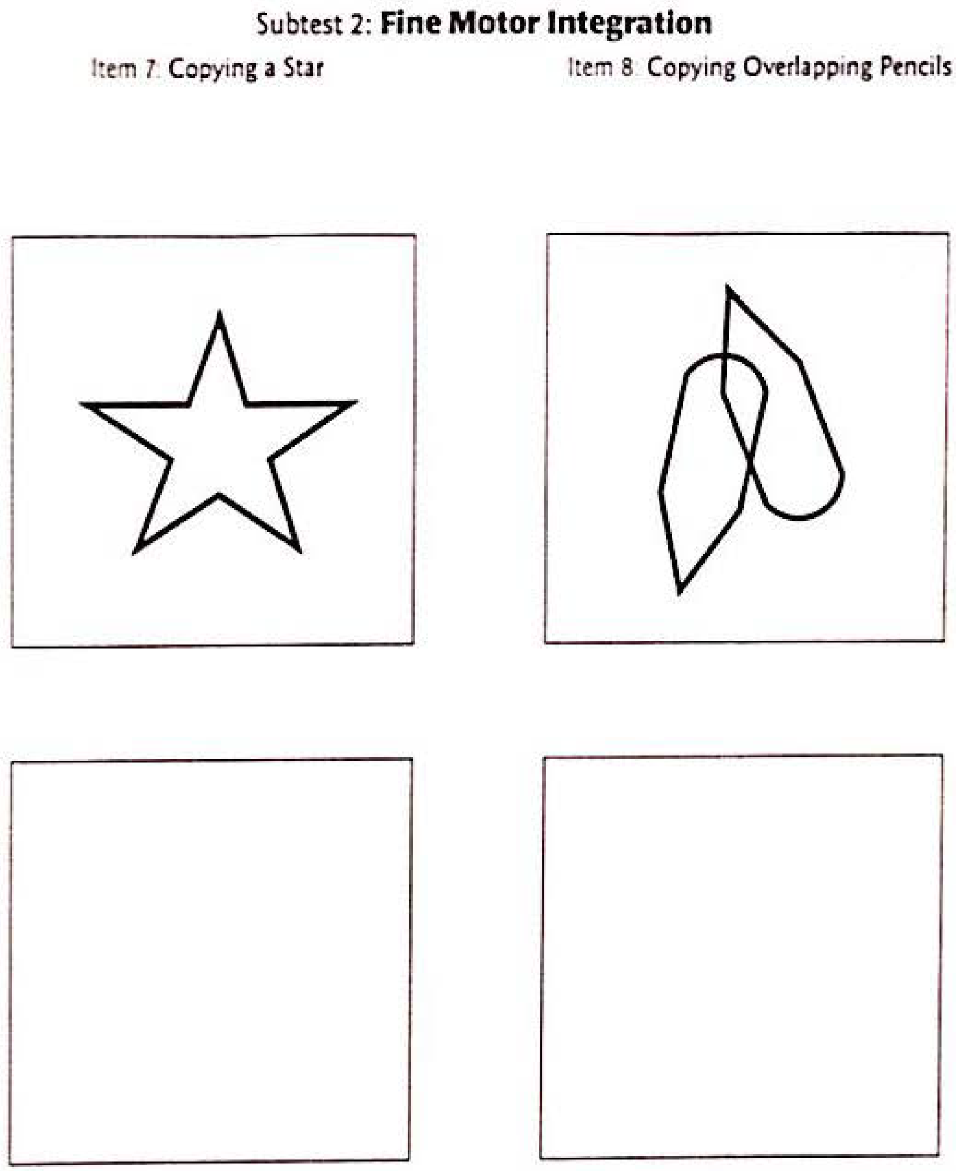


Figure A.1. Star-copying task from the BOT-2.

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