THE RELATION BETWEEN MOTOR SKILL PERFORMANCE AND INHIBITORY CONTROL IN FIVE AND SIX-YEAR-OLD CHILDREN

By

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PUBLIC ABSTRACT

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Children need to learn foundational movement skills in order to successfully participate in sports, games, and leisure activities, which are important elements of development. Likewise, children must develop their cognitive skills to succeed in academics, relationships, and careers. Recent research indicates that development of locomotor and cognitive skills are related. Inhibitory control (the ability to suppress distracting information) is an important cognitive ability developing in young children.

The purpose of this study was to examine how the level of challenge impacts the relationship between inhibitory control and motor skill performance in five- and six-year old children. To assess the role of challenge, 82 normally developing kindergarten-aged children from a relatively affluent mid-Michigan school district were assessed on low- and high-challenge motor skill and inhibitory control tasks, respectively. Control variables were included for characteristics such as age, BMI, gender, and ethnic background.

The level of challenge did not appear to influence the relationship of inhibitory control with motor skill performance. Instead, motor skill and inhibitory control performance were dominated by subjects' age, despite the fairly narrow range of ages in the sample. The relation of age to performance may be due to normal maturation, or perhaps to enrichment opportunities provided by the school district's learning environment. Continued work on this topic could offer further clarity and the opportunity to extend our knowledge of young children's development.

ABSTRACT

THE RELATION BETWEEN MOTOR SKILL PERFORMANCE AND INHIBITORY CONTROL IN FIVE AND SIX-YEAR-OLD CHILDREN

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Introduction: Recent research shows a relation between motor skill performance and inhibitory control. As the current literature has not presented clarity on how these two skills relate, a need exists to further investigate this relation. Therefore, the aim of this study was to add clarity through examining the effect of challenge on this relation.

Methods: A cross-sectional design was used to assess eighty-two typically developing five- and six-year-old children on two levels of motor and inhibitory control tasks (low challenge and high challenge). The sample was composed of two groups, 49 children from a suburban mid-Michigan school and 33 children from surrounding mid-Michigan communities. Demographic information (child's birthdate, ethnicity, gender and parent education) was obtained via parent survey. Children's height and weight were directly measured to determine body mass index (BMI). Two sets of instruments were used to measure motor and cognitive performance. The motor skill set included the TGMD-2 (Ulrich, 2000) to assess low-challenge skills and the KTK (Vandorpe et al., 2011) plus an obstacle course (Niederer et al., 2011) to assess high-challenge motor skills. The second set of skills were assessed using two inhibitory control tasks, the HTKS (McClelland & Cameron, 2011) to assess response inhibition (low-challenge) and the BST (Esposito et al., 2013) to assess interference control (high-challenge).

Results: Pearson correlations showed the low challenge motor performance measures to be significantly related to the high challenge inhibitory control measures (r = .264 accuracy and .282 response time). Age was significantly related to the high challenge inhibitory control measures (r = .498 accuracy and r = .628 response time) and to the low challenge motor performance measures (r = .332). Multiple regression analyses showed age to be the strongest predictor of high challenge inhibitory control outcomes (accuracy and response time), in both low-challenge and high-challenge motor skills regressions.

Conclusions: The role of challenge in the motor skill–inhibitory control relation was not supported. The low challenge motor performance was related to the high challenge inhibitory control measures, but disappeared once age was accounted for. Age played a prominent role in the prediction of inhibitory control outcomes. Along with maturational processes, the experiences of children from enriched environments may facilitate motor skill and inhibitory control development.

This Dissertation is dedicated to my family.
To my father, who imparted to me the love of learning.
To my mother, who taught me the benefits of hard work.
To my children and grandchildren who share their talents,
passions, and knowledge with the world in hopes
of making it a better place.

To children everywhere:
that you may be free to move, have stimulating and joyful
learning experiences, and have a passion to share.

To future researchers:
that the information presented here may inspire you to keep learning
and making the world a better place for our children.

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PREFACE

This study developed from personal experience and from a personal philosophy of childhood education. Children have the right to a healthy start in life, one that enables them to develop both physical and cognitive skills, preparing them for a healthy, productive future (Center on the Developing Child, 2010). Young children generally find great joy in movement and learning, two interrelated processes, and need to participate in an environment that facilitates the development of both (Blair & Diamond, 2008). However, changing school atmospheres have altered the learning environment for young children, placing higher academic demands on children (Love, Logue, Trudeau, & Thayer, 1992) while decreasing movement opportunities in schools (Catering & Polak, 1999). Children who from the start of their academic career are given the chance to move and to be active may perform better academically than peers who have not enjoyed the same opportunities (Palmer, Miller, & Robinson, 2013; Pagani & Messier, 2012). Movement may influence learning both directly (Haapala et al., 2014; Pagani & Messier, 2012) and indirectly—indirectly by incrementally improving cognitive functioning (Hedges et al., 2013; Palmer, Miller, Robinson, 2013; Wassenberg et al., 2005). However, while we know that physical activity is beneficial to both physical and cognitive health in older children and adults, research is scarce on its effect on young children. Research is also scarce on the importance of learning motor skills. Motor skill proficiency is a prerequisite for increased participation in sport and leisure activities (Clark & Metcalfe, 2002; Stodden et al., 2008; Taylor, Legrand, & Newton, 1999). However, the process of learning such motor skills provides challenging opportunities that may also help young children to exercise and facilitate cognitive development. This study will investigate the role that challenge may play in helping children develop to their full potential, both physically and cognitively, adding to our understanding of development in this age group.

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CHAPTER 1

INTRODUCTION

"I've learned in my life that it's important to be able to step outside your comfort zone and be challenged with something you're not familiar or accustomed to. That challenge will allow you to see what you can do."

J. R. Martinez

The purpose of this study was to better understand the relation between motor skill performance and inhibitory control in young children. While recent research has taken an interest in this relation, current studies show differing results (Rosey, Keller, & Golomer, 2010; Planinsec, 2002; Roebers & Kauer, 2009). The wide variety of motor tasks, cognitive assessments, ages, and samples used in trying to understand the relation makes it difficult for researchers to draw conclusions. However, in reviewing the literature, the importance of challenge in the skills assessed continued to emerge as a critical factor linking motor skills and inhibitory control. Since both motor skills and inhibitory control are important developmental abilities to attain, clarity on how motor skill performance and inhibitory control relate could offer helpful insight into the developmental needs of young children. Therefore, the aim of this study was to investigate this relation further, specifically investigating the role of challenge as a link in the relation between these two skills.

Many children enter school at a disadvantage because they are lacking in motor skills and inhibitory control (Rimm-Kaufman, Pianta, & Cox, 2000). Motor skill performance refers to the ability to perform age-appropriate motor skills (Haibach, Reid, & Collier, 2011). Inhibitory control is the ability to suppress automatic responses and manage conflicting stimuli and is necessary for effective planning and execution of behavioral tasks (Barkley, 1997; Diamond, 2013; Miyake & Friedman, 2012). Children who have developed these skills perform better academically and adapt better socially (Allen, Hume, Allan, Farrington, & Lonigan, 2014). Along with working memory and cognitive flexibility, inhibitory control is considered a foundational executive function skill (Barkley, 1997; Diamond, 2013; Miyake et al., 2000). Although motor skill performance and inhibitory control have been linked in theory (Barkley, 1997), empirical research has not found a consistent relation between the two. This inconsistency may be explained by the failure of the studies to consider the role of challenge level in the relation. Indeed, executive function skills are needed during challenging cognitive and behavioral tasks.

Executive functions are the subset of cognitive skills that enable an individual to assert voluntary control over his or her thoughts and actions during goal-directed behavior (Barkley, 2012,1997; Banich, 2009; Diamond, Barnett, Thomas, & Munro, 2007). Executive functions, in which inhibitory control figures prominently, are needed when children are confronting novel (Rabbitt, 1997) or challenging tasks (Hughes & Graham, 2002), solving problems (Cameron et al., 2012), or mastering new skills (Tracy et al., 2003). Executive functions—and particularly inhibitory control—improve when used in repeated and challenging tasks (Diamond et al., 2007). Inhibitory control makes it possible for a child to hold automatic thinking or action in abeyance and to stop and entertain new thoughts and actions. When learning new tasks, automatic actions compete with the need to plan and carry out new actions and must be inhibited (Luft & Buitrago, 2005). For example, learning a new scale on the piano requires one to inhibit formerly learned finger patterns in order to practice the new pattern. Children with well-developed inhibitory control can better evaluate, make choices, and carry out plans (Diamond & Lee, 2011) including movement plans (Sangster, Polatajko, & Whitebread, 2013).

Inhibitory control primarily resides in the prefrontal region of the brain (Tanji & Hoshi, 2008), particularly the anterior cingulate (ACC) and the dorsolateral prefrontal cortex (DLPFC). These regions are connected to many parts of the brain including the basal ganglia and the cerebellum, which are also important in movement. The ACC and the LPFC are important to this study because they are activated during challenging motor and cognitive tasks (Bunge & Zelazo, 2006; Hikosaka et al., 1999; Morris, Dezfouli, Griffiths, & Balleine, 2014). These brain regions are activated during interference control, when children must focus their attention and distinguish between conflicting choices so they can suppress inappropriate actions. These brain regions are also rapidly developing in five- and six-year-old children. Therefore, a task's challenge level should be important in the relation between motor skill performance and inhibitory control in this age group, as difficult tasks require the use of these regions to manage the task. Learning motor skills is most cognitively challenging in the initial stage of learning.

Motor skills are learned in stages, with the first stage requiring a great deal of cognitive effort to perform (Fitts & Posner, 1967; Hikosaka et al., 1999; Luft & Buitrago, 2005). Motor skills are also learned in sequence. Conceptually, motor skill learning is acquiring individual movement sequences (Hikosako et al., 1999) that are then used to plan more complex movements (Luft & Buitrago, 2005). A child first learns to balance and then to sit, stand, walk, and run. This learning process subsequently leads to the integrating of learned skills—kicking a soccer ball while dodging opponents in a soccer game (Clark & Metcalf, 2002; Payne & Isaacs, 2012). Each new skill will initially be challenging, until the skill or skill sequence is learned and becomes automatic. This initial learning is challenging to the child and is the point where executive function skills, including inhibitory control, are most necessary (Hikosaka et al., 1999).

To assess the relation between the two domains, motor skill performance and inhibitory control, a motor task must be chosen that is challenging enough to engage inhibitory control. While a variety of motor assessments have been utilized in the research studies, they tend to assess the same skills over a large age range and do not adequately address level of challenge. Therefore, they may not be utilizing motor tasks that activate interference control. Further, since children grow, develop, and move on to new motor skills and sequences, a skill that may be challenging at one age will not necessarily be challenging at another. This could lead to further inconsistencies in the studies. For example, Rosey, Keller, & Golomer (2010) found balance was related to inhibitory control in three to four year old children but not in five year old children. The balance task may have been challenging in the younger group of children, creating a need for inhibitory control; but the five-year-olds had already mastered this balance task, and inhibitory control was no longer required, resulting in a non-significant relation between the two domains under study. Livesey, Keen, Rouse, & White (2006) did not find balance or catching bean bags to be related to inhibitory control in kindergarten children but did find fine motor skills to be related. Five- and six-year-old children are generally past the initial learning stage in balance and catching skills but spend substantial amounts of time mastering fine motor skills during the school day.

Once a motor skill is learned, different brain regions take over the management of the learned skill (Hikosaka et al., 1999; Tracy et al., 2003). Performing a motor skill will not necessarily involve inhibitory control if the motor skill under study has already been mastered, since in this case new learning is not required. Inhibitory control only comes into play when the motor task is challenging—challenging because it involves new learning. Without a task to activate the cognitive skill assessed, a relation is not likely to be found. To understand the relation between motor skill performance and inhibitory control, what may need to be assessed is not only the type of motor skill being performed but also whether or not the skill being performed is challenging.

Conceptually, the level of challenge corresponds to Vygotysky's zone of proximal development (Vygotsky, 1987). The zone represents, at the lower end, enough challenge in a task to push children beyond what they know or can do on their own and, at the upper end, a level of challenge that is beyond the child's biological and developmental ability, the middle being where children learn best (Vygotsky, 1978). When a task is challenging enough, children can extend their current learning. This zone of proximal development represents a challenge that is new, difficult, and requires the use of executive functions, specifically here inhibitory control, to complete. However, many of the tasks in the current assessments may not even reach this zone in some of the populations examined, due to the fact that these assessments are designed to identify children with motor delays. For this reason, the tasks in these assessments will challenge children who have motor delays, but will not necessarily be challenging for typically developing children.

This leads to the proposed study, which was designed to examine the relation between motor skill performance and inhibitory control in five- and six-year-old children as a function of the challenge level. To accomplish this objective, the relations between two measures of inhibitory control IH1 and IH2 and two measures of motor skill performance MS1 and MS2 were assessed in a 2x2 framework that varied the performance measures according to their level of challenge.

IH1 Inhibitory control that is at a low challenge level in this age group was assessed with Cameron-Ponitz et al.'s (2008) Head-Toes-Knees-Shoulders (HTKS) task, which focused on the subjects' abilities to suppress automatic responses in a "Simon says…" framework. Automatic response suppression is a precondition for higher-level inhibitory control and should be relatively well developed in five- and six-year-old children.

IH2 Inhibitory control at a higher challenge level in this age group was assessed with Esposito et al.'s (2013) Bivalent Shape Task (BST), which goes beyond automatic response suppression to focus on selective attention and interference control. These aspects of inhibitory control are in a transition phase in five- and six-year-old children and typically are more challenging than suppression of automatic responses.

MS1 Motor skills that present a relatively low challenge level in this age group were assessed with the Test of Gross Motor Development-2 (TGMD-2), a widely used measure of gross motor skill performance (Ulrich, 2000). A majority of five- and six-year-old children are beyond the initial learning stage in these skills.

MS2 Motor skills at a higher challenge level was assessed with two measures: (a) the motor agility tasks of the Korperkoordination Test fur Kinder (KTK; see

Kiphard and Schilling, 2000), and (b) an obstacle course challenge (Niederer et al., 2011).

OLS regressions of the motor skill measures on the inhibitory control measures allowed an assessment of the following four research questions, controlling for age, gender, and body mass (BMI).

1. Is low-challenge inhibitory control IH1 related to low-challenge motor skill MS1 performance?

2. Is high-challenge inhibitory control IH2 related to low-challenge motor skill MS1 performance?

3. Is low-challenge inhibitory control IH1 related to high-challenge motor skill MS2 performance?

4. Is high-challenge inhibitory control IH2 related to high-challenge motor skill MS2 performance?

It was expected that the relations of inhibitory control to motor skill would be statistically significant only for the higher challenge level measures, and in particular for the IH2xMS2 relation in research question #4.

The strength of the relations of inhibitory control with motor skill performance as a function of the challenge level was assessed by comparing the correlations between the motor skill and inhibitory control with Meng et al.'s (1992) test of correlated correlations. The following correlations (r) were tested for equality: $r_{IH1.MS2} = r_{IH1.MS1}$, $r_{IH2.MS1} = r_{IH1.MS1}$, $r_{IH2.MS2} = r_{IH1.MS2}$, and $r_{IH2.MS2} = r_{IH2.MS1}$. If challenge level indeed was important in these relations, then the correlations based on measures at higher challenge levels should exceed the correlations at lower challenge levels.

A statistically significant finding using either research method would be evidence that the failure of previous studies to find a relation between motor skill performance and inhibitory control was because the studies failed to appropriately challenge the students with respect to their motor skills, inhibitory control, or both.

CHAPTER 2

REVIEW OF LITERATURE

This chapter will review current research into the relation between motor skill performance and inhibitory control, a fundamental executive function. Researchers have not found a consistent relation between movement and executive functions and no longer assume a general or global link between the two. The present study hypothesizes that their inconsistent findings result from a failure to consider the role challenge plays in the relation. As part of this this review, the chapter will consider literature that seems to support the role of challenge in the relation, such as the work of L. S. Vygotsky (1962, 1978, 1987). Next, the chapter will look at the principal constructs of the present study—inhibitory control and motor development—in that order. Finally, the chapter will close with a discussion of the assessments chosen for the study and how they align with the concept of challenge.

Research into the Relation between Motor Skills and Executive Function

The relation between motor skill performance and executive function is not well understood. As early as 1950 Piaget (Piaget, 1950) posited a relation between movement and the development of cognition. More recently, with the ability to assess executive functions in young children, researchers have shown a renewed interest in movement and executive function, especially in the relation between motor skill performance and inhibitory control. A review of the current literature in the field, however, shows that different studies are reaching conclusions that are inconsistent with one another, with some studies showing a relation between motor skills performance and inhibitory control (Livesey, Keen, Rouse, & White, 2006) and others finding relations only by certain tasks, ages, or sample (Rosey et al., 2010; Roebers & Kauer, 2009). Thus the link between motor skill performance and inhibitory control remains unclear. On the whole, however, the studies may reveal an important, if unrecognized, consistency. What may be consistent in the research is the presence of some degree of challenge whenever a relation can be found between motor skills performance and inhibitory control and, conversely, the lack of challenge when a relation between the two cannot be found.

Current research has moved away from assuming a general or global link between movement and executive functions, since empirical studies using overall motor scores have not found a consistent relation between the two (e.g., Roebers & Kauer, 2009). Instead researchers have turned to the study of specific motor tasks, which are more likely to show a relation with inhibitory control. In these studies the relation is often attributed to the skill itself, such as coordination, gross motor skills, fine motor skills, or speed of movement (Planinsec, 2002; Piek et al., 2008; Rosey, Keller, & Golomer, 2010).

The Need for Challenge

Instead of attributing the relation to the motor skill itself, however, results from such studies might better be understood in terms of challenge. It may be that executive functions have a more active role to play in the learning of the skill and less of a role in its exercise once the skill has been developed. Consider the development of gross and fine motor skills. Motor development literature indicates that gross motor skills are developed prior to fine motor skills (Clark & Metcalfe, 2002; Payne & Isaacs, 2012). Infants and toddlers are rapidly developing their gross motor skills (Clark & Metcalfe, 2002; Payne & Isaacs, 2012), and such skills at this age are challenging to them. As children move into preschool and the early elementary school years, gross motors skills have been learned and fine motor skills begin to rapidly develop, which in turn are now challenging tasks to master. Rosey, Keller, & Golomer (2010) found that in three to four year old children balance and two gross motor skills (hopping, throwing) show a low to moderate relation to inhibitory control but that in five-year-olds the same gross motor skills no longer show a significant relation to inhibitory control. This is what one might expect in terms of challenge. Three- and four-year-olds still find the learning of these skills challenging, but five year olds generally do not. The older children, unsurprisingly, performed these motor skills significantly better than did the younger children. In another study of six-year-old children, Livesey, Keen, Rouse, and White (2006) assessed children on three aspects of motor performance (gross motor, fine motor, balance) and did not find balance to be associated with inhibitory control. This finding indicates that balance may develop at an earlier age, which aligns with the findings of Rosey et al. (2010), in which case, the assessment would not be challenging to a six-year-old. Although children continue to develop and master these skills, what is important here is that the foundational skill is generally present and can be performed upon request.

Kindergarten children spend from 27% to 66% of their school day involved in a variety of fine motor tasks (Marr, Cermak, & Cohn, 2003). For this age group, research has shown a strong relation between fine motor skills and inhibitory control (Becker, Miao, Duncan, & McClelland, 2014). This relation appears to be particularly true for visuo-motor integration skills, which require children to coordinate motor and visual skills (Carlson, Rowe, & Curby, 2013; Davis, Pitchford, & Limback, 2011). For children ages four to six this kind of coordination is difficult. As the children get older visual motor integration is shown to be a high predictor of academic achievement (Carlson, Rowe, & Curby, 2013), increases in coordination, and is performed more smoothly by children (Bo, Contreras-Vidal, Kagerer, & Clark, 2006; Decker at al., 2011).

To summarize, while current studies are limited, they offer insight into the possible role of challenge in the relation between motor skill performance and inhibitory control. Research suggests that the motor skills children find to be novel (Roebers & Kauer, 2009), challenging (Diamond, 2013), and complex show a strong relation to inhibitory control. Novelty, challenge, complexity—these are what children encounter in the initial stages of learning a new motor skill or building new sequences from established skills, and it is in the challenge of this new encounter that executive functions are relied upon and strongly activated. In this manner, children are able to progressively adapt to the environment in which they live. This is not to suggest that learning a new motor skill or sequence of skills is not a continuous process. There is no clear line between learning and having learned a skill. Practice leads to improvement, and each step of learning can be challenging. Executive functions themselves depend on experience, as well as repeated practice with increasingly difficult activities (Diamond, 2013; Dowsett & Livesey, 2000). The point being made here, and what this study will test, however, is that in certain circumstances inhibitory control strongly relates to motor skill performance. If one is searching for the connection between motor development and inhibitory control, there is a real possibility it will be found in the level of challenge.

The necessity of challenge in the motor/inhibitory control relation is supported by Vygotsky's social learning theory (Vygotsky, 1962, 1978). Vygotsky believed learning was facilitated through social interaction, largely through language. Social interaction was considered critical as children engaged with capable peers, teachers, and competent adults (Vygotsky, 1978, 1987). Through engaging with others who could inform, guide, allow for practice, and give feedback, children could learn best (Vygotsky, 1962, 1978). Further, through learning, children developed. This development might be a new understanding, a new skill, or an improvement in current abilities. In this way, Vygotsky believed learning came before and facilitated development (Vygotsky, 1978). Vygotsky believed that children could do more with help from others than they could do on their own. For example, a piano teacher listens to a child play a piece of music and can provide feedback on areas that need improvement, then finds just the right piece of music to practice next—a piece that is challenging enough to need practice and improve the skills, but not so challenging that the child cannot learn the new piece or becomes frustrated. Thus the piano teacher is able to find the child's optimal zone of learning. Vygotsky called this optimal zone of learning the zone of proximal development (ZPD) (Vygotsky, 1962, 1987). Vygotsky introduced the idea ZPD as a conceptual area where children learn best (Vygotsky, 1962, 1978). The ZPD represents at one end of the zone what a child can do automatically and on her own (what she has learned, a skill) and at the other end of the zone what she can do with help (what she is learning and challenged by) (Vygotsky, 1962).

Diamond (2013) emphasized this level of challenge in a recent paper, reporting that executive function skills can be improved with practice, but the level of challenge needs continually to be increased. Ericsson et al. (2009) further supported this view in stating that improvement in most anything occurs by trying to become skillful just beyond the current ability. Diamond (2013) further reports that the largest gains in executive function interventions are those with the most demanding tasks, free of floor and ceiling effects, further supporting the idea that challenging motor tasks need to be utilized in investigating a relationship between the motor and cognitive domains.

Therefore, an understanding of the ZPD and how it relates to learning is key to this study. When learning is taking place the individual is involved in problem solving, understanding, planning, or creating, and that is when inhibitory control becomes engaged. Challenging tasks require the use of inhibitory control to master. For inhibitory control to relate to motor skill performance, it may very well be that the skill must be challenging. This suggests that in an assessment of the motor skills performance/inhibitory control relation, for the relation to be found, the skills assessed must be skills that challenge the child to learn new ways of moving or to adapt movements already learned. The critical factor in the relation, often missing in the research, may well be the level of challenge.

Inhibitory Control

Inhibitory control is one of three core executive function skills (Diamond, 2013). These include inhibitory control, working memory, and cognitive flexibility (Miyake et al., 2000), with inhibitory control viewed as foundational to the other two (Barkley, 1997). While there is not one accepted definition of executive function skills, it is generally agreed upon that they are defined as a specialized set of cognitive skills that enable individuals to focus, hold information in mind, solve problems, plan, and carry out goal-directed behavior (Blair & Razza, 2007; Diamond & Lee, 2011; Hughes, 2011). This is in contrast to carrying out actions automatically (Diamond, 2013). To adapt successfully to the challenge of new and complex situations automatic learned responses are not sufficient. Executive functions, which reside primarily in the prefrontal cortex, are needed (Hughes, 2011), in particular inhibitory control. Inhibitory control restrains the impulse to react, providing space for focus and decision. Inhibitory control enables an individual to persist in problem solving and attain future goals through managing competing stimuli, and suppressing responses that are not appropriate to the task at hand (Center on the Developing Child, 2011; Diamond, 2013).

It is necessary to distinguish between two forms of inhibitory control: first, the inhibition of a prepotent response, i.e., the ability to stop an automatic response; and, second, interference control, the ability to inhibit distracting stimuli. Inhibition of a prepotent response is generally developed in children by the time they reach the age of five (Bryce, Szucs, Soltesz, & Whitebread, 2011). Interference control is a longer-developing inhibitory skill that matures in late adolescence (Diamond, 2013; Diamond, Barnett, Thomas, & Munro, 2007; Nigg, 2000). Inhibitory control begins to develop in the first year of life. By the end of year one, infants normally have begun to suppress automatic behavior, demonstrating a nascent ability to adhere to parental wishes and to regulate their own behavior (Kochanska, Murray, & Coy, 1997). Inhibitory control develops sequentially. Once children learn to inhibit an automatic response, they continue to develop this skill in relation to rules (Dowsett & Livesey, 2000; Livesey & Morgan, 1991; Zelazo, Carter, Reznick, & Frye, 1997). Once children can inhibit a response, they can hold a rule in mind, leading to more complex forms of inhibitory control, such as remembering rules, discriminating between rules, evaluating rules, suppressing an ineffective rule in favor of an appropriate rule, taking appropriate actions based on rules (Livesey & Morgan, 1991; Zelazo, Reznick, & Pinon, 1995; Zelazo & Recnick, 1991). This sequence of development takes time and practice to build. Studies have shown that inhibitory control improves with practice (Diamond, Barnett, Thomas, & Munro, 2007; Diamond & Lee, 2011). Further, through practice one is overcoming challenges, thus improving skills or learning.

Studies also show that inhibitory control greatly improves through meeting the challenges of everyday experiences such as movement experiences. Children benefit immensely from rich opportunities to improve inhibitory control that they get in scheduled activities like martial arts (Diamond & Lee, 2011) or musical training (Bialystok & DePape, 2009; Moreno et al., 2014; Moradzadeh, Blumenthal, & Wiseheart, 2015). But they also improve inhibitory control in their everyday encounters (Dowsett & Livesey, 2000), which include play and physical activities that utilize and develop motor skills. In running an obstacle course in gym class, for example, they must remember directions, must inhibit one movement to implement a change in movement, must pay attention to the environment and deal with the unexpected. Indeed, Diamond and Lee (2011) suggest simply playing a sport, which requires and challenges the executive functions, may contribute the same benefits as organized sport activities. In these types of physical activities, children are not just exercising the body; they are building the mind and developing cognitive skills, such as inhibitory control (Diamond & Lee, 2011). Unfortunately the direction of our schools is moving away from physical education and the freedom of play. For example, 20 % of schools in the U. S. have eliminated recess in favor of more sedentary academic time in the classroom (Satcher, 2005). Further, only 8% of elementary schools, 6.4% of middle schools, and 5.8% of high schools offer daily physical education (SHPPS, 2000). Inhibitory control is important for children to develop. In the short run it leads to better peer relations and improved academic performance. In the long run it leads to better life outcomes. Learning motor skills may provide important childhood experiences that help children develop both their physical and cognitive abilities.

Motor Development

Much of a child's day is spent in movement. To coordinate muscular, skeletal, neural, and cardiovascular systems in the body in order to move efficiently and effectively, children must overcome many challenges (Payne & Isaacs, 2012). The role of an informed parent, trained physical education teacher (Gallahue & Donnelly, 2003), or an experienced coach is to help children learn these skills by incrementally increasing the level of challenge. Once children have developed a skill, they are ready to move onto learning a new skill, or to using the learned skill in a new manner. In reality, there may be multiple skills that are developing simultaneously, with each at a different developmental point.

Broadly defined, motor development is the change in motor behavior throughout the lifespan (Gallahue & Ozmum 1995; Payne & Isaacs, 2012). Motor development can be viewed as both a *process*, the learning and perfecting of motor skills, and a *product*, motor performance at a specific point in time (Clark & Metcalfe, 2002; Payne & Isaacs, 2012). What is hypothesized in this study is that inhibitory control is essentially related more to the *process* of learning motor skills, rather than the *product*. Thus, in this study, assessing the *product* was to assess motor skills that late kindergarten children can perform easily, or fundamental motor skills. Although the children may not perform each skill at a fully mature stage, all the children should know how to run, jump, throw, kick, etc. and should be able do so without much thought (Clark & Metcalfe, 2002, Payne &

Isaacs, 2012; Seefeldt & Haubenstricker, 1982). Assessing the *process* skills will be to assess skills the children are developing. These skills require focus, attention, problem solving, and new patterns of coordination to perform, therefore making them more challenging. In this study these are referred to as motor agility skills, skills children use in sport and leisure activities. To determine whether or not skills that are challenging relate to inhibitory control over and above those skills that are automatic, it will be necessary to test both the relation between automatic skills and inhibitory control and the relation between challenging skills and inhibitory control. There are no assessments at hand with which to do this easily, even though there is a vast literature available on the development of motor skills (Haywood & Getchell, 2009; Haibach, Reid, & Collier, 2011; Payne & Isaacs, 2012; Thelen & Smith, 2002). Nor is there an established vocabulary to refer to skills that are *automatic* and those that are *challenging*. Related terms may include similar categories such as *learned* and *learning* or *developed* and *developing*. The point is, children learn when faced with new challenges, and through conquering the challenges they develop more complex skills and move on to new challenges, thus moving development forward.

Literature shows that the learning of a motor skill occurs in stages (Fitts & Posner, 1967; Gallahue & Ozmun, 1995; Haibach, Reid, & Collier; 2011; Payne & Isaacs, 2012). The first stage, according to Fitts and Posner (1967) requires the most cognitive effort, as the individual struggles to coordinate body parts and motor sequences to create the new movement (Haibach, Reid, & Collier, 2011). This learning stage requires much trial and error as well as feedback and guidance from the teacher or coach, resulting in a great deal of learning about how to position the body, which body parts to move, the amount of force to exert, the order of movements, and so on. While this learning is going on, the movements appear to look clumsy and uncoordinated. During this time, coordination of underlying neural mechanisms is also occurring in order to create new neural patterns. In this initial learning, cortical regions of the brain that facilitate this process are the supplementary motor cortex (SMC), the dorsolateral prefrontal cortex (DLPFC), the motor cortex (MC), the anterior cingulate cortex (ACC), and the parietal cortex (PC) (Floyer-Lea & Matthews, 2005; Hanakawa, 2011, Puttermans, Wenderoth, & Swinnen, 2005). Many of these same regions are also activated when inhibitory control is needed (Hummel et al., 2002), indicating inhibitory control may be active during initial learning stages when learning is difficult and new patterns of movement are selected and initiated. Once initial learning has occurred, new neural patterns have formed. After this initial learning takes place, different brain regions take over so the prefrontal cortex can be freed up to manage new learning (Floyer-Lea & Matthews, 2003).

Doya (2000) suggests that different stages of learning are designated to different brain regions. Learning new motor sequences is managed by the prefrontal cortex and the presupplementary motor area. The frontal lobes are needed to process sensory information, focus on the correct movement, inhibit prelearned movement patterns, and plan and carry out new motor sequences (Doya, 2000; Hikosaka et al., 1999; Tanji & Hoshi, 2008). Once these new motor sequences are repeatedly practiced, the motor sequence forms a new neural pathway and a motor memory is established (Hikosaka et al, 1999). After repeated practice, the motor sequence becomes an automatic movement, the cognitive load is reduced, and the maintenance of the movement is taken over by different brain regions (Dayan & Cohen, 2011; Diamond, 2000; Fitts & Possner, 1967). Hikosaka et al. (1999) suggests a loop circuit from the motor cortices to the anterior cerebellum facilitates this task, which then fine-tunes movement through timing adjustments. These studies support the idea that inhibitory control is needed most during the initial stages of learning.

The dorsolateral prefrontal cortex (DLPFC) is also related to the two domains, inhibitory control and motor skills. The DLPFC is activated when a decision needs to be made as to which motor movement to choose in a given situation (Stephan et al., 2002; Willingham, 1999). Further support comes from work by Diamond (2000) showing the DLPFC is activated when a motor skill is new, difficult, and unlearned. Luft and Buitrago (2005) supported this understanding and showed the DLPFC was also active in observation of movements, particularly important in early learning stages. Tanji & Hoshi (2008) suggest this region is involved in the cognitive control of movement through connections between the DLPFC and the premotor cortex, the pre-supplementary motor area and the supplementary eye field. While this study is focused on behavioral observations, it is important to briefly understand these underlying cortical functions, so that appropriate motor skills can be identified for assessment purposes.

For the proposed study, it is necessary to know which motor skills are challenging (developing) in kindergarten children, and which skills are automatic. Clark & Metcalfe's (2002) *Mountain of Motor Development* (Appendix 2) is a useful tool for this task and has been helpful in determining which skills to assess in the current study. Clark and Metcalfe (2002) present motor development as a progression. Their model shows the broad, foundational skills at the bottom of the mountain, with subsequent skill periods building upon these foundational skills. The skills in each period become more complex and specific with the advance upward (Appendix 2). Two of these periods are relevant to the proposed study: the foundational period and the next period higher up the mountain, the context specific period.

Two types of gross motor skills, located at the center of Clarke and Metcalfe's (2002) model, will be included in this study: locomotor skills in which children learn to move their body from place to place (e.g., running, jumping, hopping), and object control skills in which children manipulate an object (e.g., striking, kicking, rolling a ball). By the time children reach kindergarten, these skills are typically automatic, even if not performed at the most mature level. These skills form the foundation for the context specific period (Clark & Metcalfe, 2002). During the context specific period children begin to combine the fundamental motor skills and use the skills in games of sport and leisure. For example, children will run and kick a soccer ball, run and dodge an opponent in football, or ride a bike around trees and over rough terrain. Moving in this way requires quick thinking, deep focus, the inhibiting of conflicting or prior movement patterns, and the coordination of thinking and moving. These skills are challenging to children ages five to six. The skills employed in moving in this manner can also be thought of as motor agility skills. Motor agility (MA) skills are defined as "movements utilizing rapid whole-body movements with a change in velocity or direction in response to a stimuli" (Sheppard, & Young, 2006, p. 922). Where previously the children needed much practice to coordinate and strengthen the fundamental motor skills, they now need much practice to coordinate and combine these base skills into sport specific agility skills.

A second tool is Seefeldt & Haubenstricker's (1982) 60% chart (Appendix 3). While the 60% chart was developed several years ago, it is useful in further identifying specific skills (to be used in the proposed study) that fall within the foundational category, skills that would be considered automatic for five and six years-olds. Researchers developed the chart through careful observation of over 36,000 feet of film of children performing nine different fundamental motor skills. From these observations researchers identified common patterns and elements that made up each skill, then used this criteria to determine developmental stages for each skill (Seefeldt & Haubenstricker, 1982). The skills and stages of accomplishment for the kindergarten age group can be reviewed in Appendix 3. The chart allows one to take the kindergarten age group (five to six years) and systematically identify, for each specific skill, what stage of accomplishment was reached by 60% of children in the age group. At stage one children are just learning the skill and find the skill difficult and challenging. At stage two children can perform the skill fairly fluently; they do not need to be taught the skill but do need to be taught how to improve the skill. Needed for the proposed assessment are motor skills that can be performed in a relatively automatic manner, with little deliberation. The 60% chart offers the best method available for identifying the skills five to six year-old children have learned to perform automatically. Only skills where 60% of the children can perform the skill past stage two have been chosen for this study. Once the skills are chosen through this method, the choice of available assessments is narrowed.

Assessments

Cognitive assessments.

Two categories of assessments will be used in this study: inhibitory control and motor skill performance. Each category is discussed below and includes the assessments and their rationale. In choosing the assessments for each category, the following criteria were developed: (a) the assessment must be a valid and reliable assessment; (b) it must assess the construct being examined in the current study; (c) it must be age and developmentally appropriate; and (d) it must require minimal tools and equipment, to ease the assessment of a large group of children in an ecological setting, such as a school. In the following paragraphs the inhibitory control assessments will be addressed first and the motor assessments second.

Researchers have increasingly developed cognitive assessments that are ecologically reliable and valid for use with young children (Carlson, 2005; McClelland & Cameron, 2011; Esposito, Baker-Ward, & Mueller, 2013). The availability of these assessments will solve some of the problems previously encountered in studying young children's inhibitory control. For example, while prior studies used parent and teacher reports, the development of direct assessments for use with young children has helped provide more accurate data. While teacher and parent reports are easy to use, they are subject to the observer's bias, whereby more direct, objective, and ecologically valid measures can provide more accurate data and improve study results (McClelland & Cameron, 2011). Further, tests used in clinical settings can be difficult to use with larger groups of children in school settings (Pickering & Gathercole, 2004), and they may require specialized materials (Hughes, 1998). Additional problems have included: the need for assessments with simple and concise directions that young children can understand and follow; the need for assessments that can be used with multiple language groups; and the need for assessments that can be used with children who are non-literate (McClelland & Cameron, 2011). For longitudinal research, assessments are needed that can be used with multiple age groups.

The Head, Toes, Knees, Shoulders task (HTKS, Cameron-Ponitz et al., 2008, 2009; Gestdottir et al, 2014) and the bivalent shape task (BST, Esposito, Baker-Ward, & Mueller, 2013) have best overcome these obstacles. The tasks in these assessments, furthermore, have the ability to provide valid and reliable data in relation to the sample and constructs the proposed study will examine. They therefore were chosen as the most appropriate options for the study. The HTKS provided data on suppression of a prepotent response (lower challenge) while the BST provided data on interference control (higher challenge). The outcome of the measures were then examined in the relation between two types of motor skills (fundamental motor skills and motor agility skills).

This study used the HTKS task (Cameron-Ponitz et al., 2008) to assess subjects' abilities to suppress an automatic response. The HTKS task has been thoroughly investigated in the literature (Cameron-Ponitz et al., 2009; McClelland & Cameron, 2011; Wanless et al., 2011) and has been widely adopted since its introduction. Like the BST, the HTKS task is appropriate as a measure of inhibitory control in kindergarten children. The HTKS task was developed to measure behavioral regulation in children ages three to six, with a strong component of the task being inhibitory control (McClelland & Cameron, 2011). The HTKS task has been shown to be valid and reliable in four different cultures (Wanless et al., 2011) and in the aforementioned age group (Gestsdottir et al., 2014; McClelland & Cameron, 2011; Wanless et al., 2011). The majority of studies using the HTKS task have attempted to examine the underlying constructs important in children's academic achievement, both prior and during the early years of formal education. Research shows the HTKS to reliably and significantly correlate/predict children's early reading and math achievement (Cameron Ponitz et al., 2008; 2009; Gestsdottir et al., 2014; Wanless et al., 2011). The HTKS has also been more recently used to measure self-regulation in a group of seven to nine year-old children with developmental coordination disorder (Jokic, Polatajko, & Whitebread, 2013). The HTKS task differs from the BST in that it focuses more on the child's automatic response suppression than on interference control. Children must remember the rules of the activity, pay attention to the commands, and then perform the requisite command. In phase two of the HTKS task, they must inhibit their natural tendency to perform the given command and instead are asked to give the opposite response, which requires suppressing their automatic response.

Various assessments have been used to measure inhibitory control with young children such as the go/no-go task, the day/night Stroop (Gerstadt, Hong, & Diamond, 1994; Livesey et al., 2006), and the stop signal task. These tasks either have not shown a relation between inhibitory control and motor skill performance, or have shown ceiling effects in kindergarten children (Carlson, 2005; Livesey et al., 2006). Two reasons for these results may be that the tasks are not assessing the component of inhibitory control developing in kindergarten children or the tasks are too easy for the age assessed, showing a ceiling effect (as found in the day/night Stroop) (Livesey et al., 2006). The HTKS is a direct measure that taps inhibitory control by asking children to inhibit a dominant response, and then to implement a different response (when asked to touch their head, they are to touch their toes) (Wanless et al., 2011). The HTKS has been shown to be significantly related to inhibitory control (Cameron-Ponitz et al., 2009; Lan et al., 2011; Wanless et al., 2011), is easily understood and administered, does not require extra materials, and provides reliable scores (McClelland et al., 2007; Cameron-Ponitz et al., 2008, 2009). However, the task does include some limitations. First, the HTKS is designed to measure self-regulation, and self-regulation is composed of inhibitory control, attention, and working memory (Carlson & Moses, 2001; Wanless et al., 2011). While these separate constructs were not separated out in this assessment, all the components have been shown to support interference control, and the HTKS has been shown to significantly correlate with measures of inhibitory control (Lan et al., 2011; Mahler, et al., 2012; Wanless et al., 2011). This supported its use as a measure of this construct. Furthermore, through the process of counterbalancing the congruent and incongruent trials, memory was controlled for this study. Another limitation of the HTKS is that it has been developed for ages three to six, so five- and six-year-old children are at the top end of the age group. However, current research studies have not shown a ceiling effect in this age group. A last limitation, the HTKS did not offer the capability of recording response time, as do computer assessments. The benefits of the HTKS were that it was a fun assessment for the children, reducing fatigue or boredom, was performed without the need for tools or equipment, and offered a behavioral assessment whereby the children had to not only understand the directions, but physically act upon the directions, differentiating the HTKS from tasks such as the stop signal task used in Livesey et al. (2006).

While one may argue that the HTKS task employs an interference component, the literature does not define the task as such (Cameron Ponitz et al., 2008). The HTKS task requires children to suppress an automatic response, then choose an alternative response, similar to the Day Night task (Gerstadt et al., 1994). The Day Night task was also designed to measure inhibition of a prepotent response (Diamond, Kirkham, & Amso, et al., 2002). In both tasks the children are not responding to competing stimuli at any given time. The children must respond to one stimulus, while suppressing an automatic response. Thus, the HTKS has been described primarily as a response inhibition task. The bivalent shape task (BST) is described as an interference control task, presenting bivalent stimuli, increasing inhibitory control demands through additional interfering stimuli. The BST required the children to choose between two viable perceptual stimuli and respond in one of two ways.

The bivalent shape task (BST) similarly taps interference control from children to adulthood. The BST was designed to capture the components of the Stroop task for bilingual children and use them in a task that nonliterate and young children could perform. Bilinguals show a superior advantage on conflict interference tasks, believed to be due to the continual practice using attention, flexibility, and inhibition in managing two representations of language (Adesope, Lavin, Thompson, & Ungerleider, 2010; Hilchey & Klein, 2011; Kapa & Colombo, 2013). The Stroop task has shown significant differences in interference control in bilingual adults but not in young children. As the Stroop requires the ability to read to perform the task, an improved task was needed for nonliterate children (Esposito et al., 2013). Among preschool children results have been inconsistent on this bilingual advantage, similar to results examining the relation between motor skill performance and inhibitory control. The benefit of the BST was that it presented bivalent stimuli, similar to the Stroop task, which is a greater challenge to children (Esposito et al., 2013). This increased challenge provided a larger differentiation among the children's scores, allowing the researcher to distinguish between children who had well developed interference control and children who did not. The Stroop task has been shown to activate the anterior cingulate cortex and the dorsolateral cortex (Banich et al., 2000; Milham, Banich, & Barad, 2003; Swick & Jovanovic, 2002). These regions have been implicated in conflict interference (Swick & Jovanovic, 2002) and activated in early learning (Bryden et al., 2011). Although there have not been neuroimaging studies showing the BST also activates these brain regions, the BST correlates highly with the Stroop task, presents the same conflict interference, and thus suggested logically that the same brain regions are activated. Therefore, the BST was an excellent alternative to the traditional Stroop task for young children, assessing the same underlying constructs and activating the same brain regions, without requiring the children to be literate to perform it.

In summary, the HTKS task was a helpful assessment in that it was fun, valid, reliable, and could be accomplished in a short period of time, tapping into inhibitory control in five- and six-year-old children. While bivalent stimuli were not presented, the task did offer congruent and incongruent trials, presenting a conflict the children had to overcome. Further, while tasks such as the Day/Night Stroop require a verbal response, the HTKS task also required a motor response using gross motor skills. Research shows that children will know and tell a rule before they can actually carry it out and act upon it (Dowsett & Livesey, 2000; Livesey & Morgan, 1991; Zelazo et al., 1995). Therefore the

HTKS presented a task that could overcome the ceiling effects Livesey et al., (2006) found with the Day/Night Stroop task. The BST further extended the challenge with the use of bivalent stimuli and was expected to specifically activate the ACC and the DLPC, two areas activated in interference control, the focus of this study. So, while the two tasks have some limitations, they provided the best possibilities for assessing the constructs in question in this study. As well, they did so in an ecological setting, with minimal equipment.

Motor assessments.

To date, researchers have addressed the relationship between motor skill performance and inhibitory control using a variety of assessments. Several researchers have used standardized assessments such as the Bruininks-Osteresky Test of Motor Proficiency (Bruininks & Bruininks, 2005), the Test of Gross Motor Development (TGMD-2, Ulrich, 2000), or the Movement Assessment Battery for Children (MABC-2, Henderson & Sugden, 2007). These assessments have the advantage of offering a range of skills in different movement categories (gross motor, fine motor, balance) to assess movement competency. Additionally, these assessments are standardized, and norm referenced allowing clinicians or researchers to compare the individuals being assessed with a normed group, and to administer the assessments according to standardized procedures (Montgomery & Connolly, 1987). These assessments are generally used to identify children with deficiencies or delays, evaluate motor skills in the presence of a disease or injury, or help physical education teachers identify the skills that children have, so appropriate lesson plans can be developed. Consequently, the designs of these tests place limits on their usefulness for the current study. For example, the assessments will show a wide variation of abilities in individuals who are struggling; however, they may show little variation of abilities among children who can perform the skills. Using assessments that are designed to identify atypical performance will not serve the objectives of this study, in which challenging motor skills in typically performing children is the focus. Another aspect of these assessments that makes them unsuitable for the study is that they use the same set of motor tasks over a large age range. For example, the BOT-2 (Bruininks & Bruininks, 2013, 2005) assesses fine motor and gross motor skills in children ages 4-21 years. But as children age, motor skills develop and increase in complexity (Clark & Metcalfe, 2002; Payne & Isaacs, 2012). Tasks developed in an earlier period become easier, more automatic, and become less challenging. What was needed for the current study were motor tasks that challenged typically developing five- and six-year-olds.

One assessment with more possibilities was the TGMD-2 (Ulrich, 2000). While this assessment assesses children's gross motor skills, which are generally well developed by age seven (Clark & Metcalfe, 2002), the qualitative aspect provided a way to differentiate more extensively within a skill. For example, each skill has a number of criteria that are observed for each motor skill. Each skill is performed two times. Thus, if a skill has four criteria that must be met, there is a total possible score for that skill of eight. Therefore, the assessment provided an evaluation of how well the children could perform the skill. While the TGMD-2 has the ability to differentiate between abilities in a particular skill, the skills performed did not involve difficult problem solving or did not challenge the children to the degree needed to engage interference control. Children were asked to perform the skill as they knew how to perform it; they were not taught how to perform the skill at a more advanced level. As a result, two separate assessments were used to assess two separate types of motor skills (less challenging and more challenging.)

The criteria identified to assess the fundamental motor skill/inhibitory control relation were: (1) the skill assessed must have been past the initial stage of learning; (2) it must have been automatic, to the degree that when the researcher asked the children to perform the skill, they did not need to be taught; and (3) it must have been a motor assessment established in the literature. Therefore the TGMD-2 was an appropriate choice for the first research question in this study, which examined the relation between fundamental or learned motor skills and inhibitory control in five- and six-year-old children. The TGMD-2 could be administered to a large group of children in a school setting; was easily set up in stations in the gymnasium; assessed skills children like to perform; and could be videotaped for later scoring purposes. Further, since this segment of the study focused on gross motor skills, the TGMD-2 also nicely met this criterion.

To address research questions regarding motor agility skills and inhibitory control, the task of finding an appropriate assessment was more difficult. Again, this was due to the purposes of most available motor assessments, which were designed to identify children with motor delays or difficulties. One impractical solution would have been to only assess children with delays. Some researchers have tried to overcome the problem by assessing individual skills. For example, Rosey, Keller, & Golomer (2010) chose three specific skills to assess, two gross motor skills and a balance task. They justified the choice of skills as being fundamental to later sport skills. In a second study, Roebers & Kauer (2009) assessed individual skills that would enable them to detect children with developmental disorders. Yet, this method, assessing individual skills, did not meet the criterion of using an assessment that was well established in the literature. For the current study, the criteria for selecting motor agility skills to be used in the study were: (1) that the skills were new to the children, meaning the children could not perform the skill without brief instruction; (2) that the tasks should require a problem to solve, conflict to manage, or a novel manner of moving, in order to tap into the inhibitory control mechanism; and (3) that the tasks were established in the literature.

Two different assessments fit these criteria and were used in this study. The first was the Korperkoordination Test fur Kinder (KTK, Kiphard & Schilling, 2000), developed for children five to fifteen years of age. The KTK included an assessment of four motor tasks that required attention, inhibition, focus, and flexibility, which are executive functions. The assessment is designed both for identifying children with motor delays and for distinguishing typically developing children in terms of normal and exceptional or gifted abilities (Vandorpe et al., 2011). The second assessment was a short obstacle course (Neiderer et al., 2011). In order to properly maneuver the obstacle course, the children needed to again use their executive functions, including inhibitory control, to perform the task properly. In completing the course the children had to: stop running to change movements; problem solve how they would move over and under a bench; use their motor skills in a newly prescribed manner; and manage their movements according to changing task constraints. Together, the KTK (Kiphard & Schiling, 2000) and the obstacle course (Niederer et al., 2011) were to provide the best assessments available to test the motor agility skills/inhibitory control relation, which was then compared to the fundamental motor skills/inhibitory control relation.

While current studies have offered insight into how motor skill performance and inhibitory control might relate, these studies presented several limitations. First, the use of observer rated responses increased the possibility of biased responses. Second, many studies reported motor skill performance as a total of all motor scores rather than as separate skill components (gross motor, fine motor, etc.). Third, the motor assessments utilized largely represented skills typically developing children could do, rather than skills that were novel and challenging for the children. Fourth, other factors that may influence motor performance were not always controlled for. These factors included age, body mass index, gender, and socioeconomic status.

Regarding socioeconomic status, subjects in this study came from a relatively affluent and homogeneous set of kindergarten children with normal growth patterns. Indeed, only 6 percent of the subjects received free or reduced-fee lunches. Next, regarding body mass index (BMI), research shows fundamental motor skills are a prerequisite for a physically active life (Williams et al., 2008; Wrotniak et al., 2006). At the same time research shows children who are overweight and obese have less proficient fundamental motor skills than their normal weight peers (Lopes et al., 2012; Morrison et al., 2012; Vameghi, Shams, & Dehkordi, 2013). An individual's body mass index (BMI) is commonly used to screen for overweight and obesity. BMI is determined by using the child's height and weight measurements in the formula: weight (kg)/height squared (meter squared). The Centers for Disease Control and Prevention (CDC, 2009) use BMI scores for children to find the child's placement in age and gender appropriate percentiles to identify whether children are underweight, normal, overweight, or obese. Children over the 85th percentile are classified as overweight, while children over the 95th percentile are considered obese.

Currently, results on the effect of BMI on motor skill performance are mixed, with some studies showing no effect of BMI on motor coordination (Frey & Chow, 2006), while other studies show poorer motor coordination in children with an elevated BMI (D'Hondt et al., 2013). Current statistics show one in three children or adolescents ages 6–11 in the U.S. is overweight or obese (National Institutes of Health, 2012), which could have affected the performance of some students in the sample, particularly locomotor skills such as running and hopping, which were used in this study, and the motor agility skills, which require speed and change of body positioning. Since both types of these skills were assessed in this study, it was necessary to determine if BMI was an influencing factor.

Regarding gender, some studies show gender differences. Planinsec (2002) assessed five- and six-year-old children on 28 motor skills and cognitive assessments finding gender differences with tasks that included speed and coordination. The authors attributed the differences to development whereby girls are generally better at balance and boys at explosive strength. In contrast, Piek et al. (2008) and Roebers & Kauer (2009) did not find gender differences in their studies. The vast differences in assessments used to measure the motor tasks in the studies made the effect of gender unclear. In referencing the 60% chart (Seefeldt & Haubensricker,1982), gender differences are most evident with throwing. While it was difficult to predict what the gender differences would be in this study, gender was included in the model to examine its influence on the motor/inhibitory control relation.

Conclusion

In summary, a renewed interest in the relation between inhibitory control and motor skill performance has presented limited insights into how these domains might relate. The current studies do not present results that can be explained across differing age groups, by motor skills, or by the assessment used. While the inhibitory control assessments have been more fully considered, the motor assessments used need more consideration as to why certain motor skills should be assessed and which motor skills to include in the assessments. It is argued here that challenge is a critical factor that must be considered, both with inhibitory control and motor skill performance. For, as motor skills are appropriately challenging for the age and developmental level assessed, the need for inhibitory control arises. Additionally, research indicates that inhibitory control is related to the initial stages of learning a motor skill, a point where performing the skill is challenging. While improving a current level of motor performance is challenging, this study was a cross sectional design, focused on typically developing children, and did not include an aspect of learning, or improving a motor skill. Thus, assessments needed to be used that could (a) assess children on what they knew – as in performing motor skills they knew, and (b) assess children on skills they did not know – as in performing motor skills that were new or were being performed in a novel manner. Chapter three provides the specifics on how the proposed study was carried out.

CHAPTER 3

METHODS

Research Design

This study used a cross-sectional design to examine the relation between motor skill performance and inhibitory control as a function of the challenge level in five and six-year-old children. Two sets of instruments were used to examine the relation in typically developing five and six-year-old children from a suburban mid-Michigan school.

1. Inhibitory control (IH) was assessed with two tasks that differed in challenge level.
    a. IH1: The Head, Toes, Knees, Shoulders task (HTKS; McClelland & Cameron, 2011) is an inhibitory control task (i.e., the ability to suppress an automatic or prepotent response) that is a relatively low level of challenge for most five- and six-year-old children.
    b. IH2: The Bivalent Shape Task (BST; Mueller & Esposito, 2014) is a more challenging task for five- and six-year-old children that goes beyond automatic or prepotent response suppression into the realm of interference control.
2. Motor skills (MS) were assessed with two tests that differed in challenge level.
    a. MS1: Fundamental motor skills that are automatic in this age group were measured using skills from the Test of Growth and Motor Development-2 (Ulrich, 2000).

b. MS2: Motor agility skills that are novel and challenging in this age group were assessed using the Body Coordination Test for Children (Vandorpe et al., 2011) and an obstacle course (Niederer et al., 2011).

Although both sets of skills differ on dimensions in addition to challenge level, each of the lower-level tasks is focused on a set of skills that generally are well developed in five- and six-year-old children. The higher-level challenges assess skills that typically are in a transitional stage in five- and six-year-old children. Controls for age, body mass, and gender were included, based on the researcher's measures and a parent questionnaire used to collect demographic information on the subjects.

Participants

The participants in this study were a convenience sample composed of 82 typically developing five- and six-year-old children recruited from a mid-Michigan elementary school and surrounding communities. The children in the school setting were assessed at the end of the 2014-2015 school year. The participants from the community were assessed during the summer months after the school year ended. Participants in the sample were classified as 87.7% Caucasian and 10% other ethnic background. Separately, the groups were composed of 85.4% Caucasian (school group) and 90.1% Caucasian (summer group), and 14% other (school group) and 9.1% other (summer group). The inclusion criteria was as follows: (a) children who were not identified as special needs by the school district or parents (i.e., did not attend the resource room or require a personal aide in the classroom/did not have a documented disability), (b) children who were physically able to perform the motor skills, and (c) children who returned a signed parental consent form prior to commencement of the study.

Procedures

Compliance with human research protocols.

Approval for the study was obtained from the school district and from the Institutional Review Board at Michigan State University (application completed). Written and informed consent was obtained from the parents or legal guardians of the children prior to commencement of the study (Appendix 6). A child assent form was completed on the day of the study (Appendix 7). The parents and children were informed that participation was voluntary and that the child could withdraw at any time during the study.

The classroom teacher sent the initial forms home to the children's parents (or legal guardians) in the students' weekly folders: introductory letter, approved consent forms, assent form, questionnaire (Appendices 4-7). These folders are a common vehicle for teachers to communicate with parents, and information is regularly returned to teachers in these folders. Parents/legal guardians were asked to complete and return the forms in a sealed envelope in their child's folder one week prior to data collection. The researcher or teacher followed up with a reminder letter to parents/guardians in which a consent form were received by the predetermined date, along with a reminder to return the form the following day.

Assent forms were verbally explained to the participants in small groups of up to four students in a manner that was clear and understandable. The summer group of participants completed the assent process one on one with the lead researcher. The research team answered any questions as they arose (see Appendix 7). All children were offered the choice as whether to participate or not, as well as the option to opt out at any time during the study. All research assistants were observant of any child who did not wish to participate and offer them the choice of opting out of the study. Overall, the children were happy and excited to participate in the research.

Data collection.

The research team for the individual assessments included the lead researcher and graduate and undergraduate students. Members of the research team were trained by the lead researcher on each assessment's protocols and on compliance with MSU's human research protocols. Data were collected from two sources: (a) a parent questionnaire (Appendix 5), and (b) an individual assessment of each child.

Assessments of individual children were conducted over three and a half-weeks during their physical education period or during non-instructional class time. Along with measures of body mass (i.e., height and weight), all measures took 50-60 minutes per child. The two inhibitory control assessments were counterbalanced with half the children performing the HTKS task first and half the children performing the BST first. The motor assessments were completed with participants rotating stations led by the researcher and trained graduate students. The motor assessments took approximately 45 minutes per child.

Data collection during the three and a half-week period was organized as a treasure hunt. For each station (or task) completed, children were given a sticker to place on their treasure map. At each station, a trained researcher explained and then demonstrated the procedure for the task and then gave the student an opportunity to practice the task before the assessment. Every effort was made to assure the atmosphere was positive and the children were comfortable. Upon completion of the treasure hunt, the children were able to choose an item from a treasure chest (e.g., a book, a blow-up ball, bubbles, or a Frisbee) as an incentive to complete the assessments (see Appendix 10).

Measures

Physical characteristics and demographics.

The parent questionnaire was used to collect demographic data (Appendix 5) including the child's date of birth, gender, and race/ethnicity. This data was collected as research shows these factors may be related to inhibitory control. Parents also were asked to indicate whether the child was diagnosed with any behavior disorders, learning disabilities, or physical disabilities that would impede participation and the need for inclusion of typically developing children.

Participants attended an affluent suburban school that had relatively little variation in socioeconomic status or students' IQ scores. Although these would make interesting control variables in a comparison of students from low and high-income neighborhoods, they are not included here because of the relative homogeneity of children in this sample.

Inhibitory control (IH) measures.

Inhibitory control relies on two related but distinct cognitive functions: automatic response suppression and interference control. This study used two separate measures of inhibitory control in an attempt to separately assess these processes and their relation to motor skill challenge level. Including both measures was also done to promote construct validity in the assessment of inhibitory control and hence in the reliability of the findings.

IH1: Head, Toes, Knees, Shoulders (HTKS).

This study used the HTKS task (Cameron-Ponitz et al., 2008) to assess subjects' abilities to suppress automatic responses. The HTKS task has been thoroughly investigated in the literature (Cameron-Ponitz et al., 2009, McClelland & Cameron, 2011; Wanless et al., 2011) and has been widely adopted since its introduction. The ability to suppress automatic responses to stimuli is a necessary precondition for effective interference suppression, and is developed at an earlier age than is interference control.

The HTKS task has two test phases in which children were required to touch a body part in a 'Simon Says' manner that is familiar to children. In phase 1, the child was instructed to touch the body part indicated by the researcher (e.g., "touch your head"). In phase 2, the child was instructed to touch the body part opposite to the one indicated by the researcher (e.g., touch your toes in response to "touch your head"). Scoring was on a 0-2 scale with 0 for an incorrect response, 2 for a correct response, and 1 for a response that began incorrectly but was then corrected. The assessment included 26 items for a range of scores from 0 to 52 and took about five to seven minutes to complete. The children were given two opportunities to practice before the official scoring began.

The HTKS task is appropriate as a measure of inhibitory control in five- and six-year-old children. The HTKS task focuses on the child's automatic response suppression, which is a fundamental element of inhibitory control. Children must remember the rules of the activity, pay attention to the commands, and then perform the requisite command. In phases 2 of the HTKS task, they must inhibit their natural tendency to perform the given command and instead are asked to give the opposite response, which requires suppressing their automatic response.

The HTKS task enjoys high inter-rater reliability (McClelland et al., 2014) and has been found to be a valid and reliable measure of inhibitory control in a variety of cultures (Lan et al., 2011; Mahler et al, 2012; von Suchodoletz et al., 2013; Wanless et al., 2011), and particularly in five- and six-year-old children (McClelland & Cameron, 2011).

IH2: the Bivalent Shape Task (BST).

The interference control aspect of inhibitory control was assessed with the Bivalent Shape Task (Esposito et al., 2013). Subjects were asked to identify whether a shape displayed on a computer screen was a circle or a square. The shape was presented either in red, blue, or neutral (black-and-white). Subjects were instructed to focus on the shape and to ignore the colors. Subjects identified the shape by moving the mouse to one of two response buttons at the bottom of the screen, either a red circle at the left or a blue square at the right. The BST includes congruent trials in which the stimulus color matches the response color, incongruent trials with different colors for the stimulus and response, and neutral trials based on black-and-white shapes. The BST took about five minutes to complete. Both accuracy and response time scores were recorded and used in the final analyses. Accuracy was recorded as the number of correct trials. Response time was recorded in milliseconds. Maximum response time was set at 3 seconds. Responses <200ms were omitted from the final analyses.

Success on the BST requires automatic response suppression as a pre-condition for interference control. Using the BST, Esposito et al. (2013) found that bilingual children perform better on incongruent trials than do monolingual children, which is consistent with bilingual children having advantages in selective attention and interference control. Although the BST is relatively new and has not been as thoroughly investigated in the literature as the HTKS task, the BST has been found to be a valid and reliable measure of inhibitory control in both children and adults (Mueller & Esposito, 2014).

Motor skill (MS) measures.

Two distinct periods of motor development have been identified in the literature, the fundamental movement period and the context-specific period. Motor skill and inhibitory control assessments have been chosen that focus on the element of challenge.

MS1: fundamental motor skills.

Fundamental motor skills represented skills that were less challenging for five- and six-year-old children. The main point here is that the skill mastery was not as crucial for the study purpose as much as the fact that the children could perform the skill itself without instruction or new learning.

Fundamental motor skills were assessed using the Test of Gross Motor Development-2 (TGMD-2), a widely used, validated, criterion- and norm-referenced process-oriented assessment used to evaluate gross motor skill performance in children ages three to ten (Ulrich, 2000). This assessment was chosen because it: (a) required minimal equipment, (b) provided clear criterion for each skill for ease of assessment, (c) utilized a qualitative component that allowed for variation in skill abilities, and (d) provided an accurate assessment of the six fundamental motor skills used in this study. Good intra- and inter-reliability scores have been shown with an overall gross motor quotient composite of 0.91, test-retest with coefficients at or above 0.88, and a test score reliability of 0.98. The TGMD-2 has further been shown to be reliable across demographic groups with coefficients exceeding 0.80.

While performing their motor skills, participants were videotaped with a Canon Vixia camera so that their performance could be scored at a later time. This allowed the researcher to focus on the children, making sure the process ran smoothly and without interruption. Students were allowed ample recovery time after each motor task, so that fatigue did not influence the results. The motor skill assessments were counterbalanced by starting the children in equal groups at each station then rotating the students through each station in a sequential manner. Each skill was demonstrated and the children were given a practice trial. Two trials of each skill were recorded. For the fundamental motor skills, the scores of both trials were totaled. For the agility skills (the obstacle course and the jumping task), the better of the two trials were recorded.

The study used raw scores, which provided the ability to use specific skills from the TGMD-2 for this study. Six of the twelve gross motor skills from the TGMD-2 were measured, (throw, kick, jump, catch, strike, and hop). These six skills were chosen as five- and six-year-old children typically are beyond the initial stage of learning for these skills (Seefeldt & Haubenstricker, 1982). This met the requirement for this study that the skills be somewhat automatic and not overly challenging. The TGMD-2 is assessed on a possibility of three-to-five performance criteria per skill (a score of 1 if each criterion is met and a 0 if not). Raw scores were calculated by totaling the criterion scores from each skill, then adding them together for a total raw score. Children were videotaped for later scoring. One practice trial and two performance trials were given to each child. The time allotment for assessment was approximately 25 minutes.

MS2: motor agility skills.

Motor agility skills represented skills in the 'context specific period' (Mountain of Motor Development, Clark & Metcalf, 2002) and skills that are more challenging because they require integrating different movements, positions, instruction, and speed.

The Korperkoordination Test fur Kinder (KTK). The motor agility aspect of motor skill performance was assessed with the Korperkoordination Test fur Kinder (KTK) (Vandorpe et al., 2011). The KTK is composed of four motor coordination tasks that measure dynamic balance, speed, agility, and power (Lopes, Santos, Pereira, & Lopes, 2013). These four tasks also represented skills that had to first be explained and demonstrated, suggesting they required cognitive effort to perform:

1. *Walking backward*. The children walk backwards three times on each of three beams that decrease in width (total of 9 trials). A maximum of 24 successful steps per trial/beam are counted. A successful step is one where the foot is placed and held on the beam.
2. *Move sidewise*. The children are to move across the floor by standing on a flat rubber 8" circle, placing a second circle within in stepping distance, move to that circle, then pick up the last circle. This process is repeated for 20 seconds and the number of relocations are recorded and summed over two trials.
3. *Hopping for height*. The children jump over a foam obstacle on one leg. The children must hop at least two times in front of the obstacle and at least two hops on the same foot after hopping over the obstacle. The process is repeated three times then an additional obstacle added

(foam obstacle 23.5” x 8” x 2”). This is repeated for a maximum of 13 stacked foam blocks. Each trial consists of three attempts and scoring is given as 3 points for the first attempt, 2 points for the second, and one point for the third. The task is completed with an unsuccessful attempt to jump over the obstacle without the foam sticks falling over. This process is repeated for both legs. The task has a possible of 78 points (6 points per attempt for 13 attempts).

4. *Jump sidewise*. The children jump back and forth with both feet together over a thin stick taped to the floor. The number of jumps for 15 seconds is recorded. The children have two trials that are summed for a total score.

The KTK has been used in studies of children ages 5-15 years (Kiphard & Schiling, 1974; Vandorpe et al., 2011). Each skill item has the ability to be scored relative to gender and age specific reference values (Lopes, Santos, Pereira, & Lopes, 2013, p. 13). Raw scores are used. The test-retest reliability for the raw score total is 0.97 and coefficients for individual tests range from 0.80 to 0.96.

<u>The Obstacle Course</u>. An obstacle course was used in combination with the KTK (Kiphard & Schiling, 1974) as an additional measure of a motor agility skill to increase construct validity of the motor agility measures (Niederer et al., 2011). This skill was chosen to fulfill the need for a motor skill task that was challenging, novel, and required learning to perform, meeting the need for an assessment in this study that would increase the need for inhibitory control to perform the skill. The performance of this skill requires the coordination of speed, spatial orientation, change of direction, running, balance,

coordination, and memorizing a short sequence of actions (Sheppard & Young, 2006) in a novel format. It is being suggested here that inhibitory control is needed in directional changes, visual orientation, and adaptation to new learning. This task was further selected since (a) it was designed for children ages three to six (Kunz, 1993, as stated in Niederer et al., 2011), (b) had been used in prior studies (Niederer et al., 2011), and (c) could be performed quickly with simple instructions. The participating child was instructed to run 1 meter from a marking cone to a bench placed perpendicular to the running path. The participating child had to climb over the bench, crawl under the bench and run back to the starting cone. This process was repeated three times as fast as possible. The time it took to complete the course three times was measured in seconds. Participants were allowed two trials with the faster trial used for data analysis. The test-retest reliability in the Niederer et al. (2011) study was $r = 0.82$ ($p< 0,01$).

Research Questions and Data Analysis

The objective was to estimate the relation between motor skill performance and inhibitory control in kindergarten children as a function of the challenge level. Descriptive statistics (ranges, means, standard deviations, and correlations) were calculated on all variables to obtain the characteristics of the sample and assess the integrity of the data (identify outliers or coding errors). The control variables (age, BMI and gender) were expected to be related to the motor skill and inhibitory control measures. In particular, based on the literature it was expected that motor skill performance and inhibitory control would be positively related to age (Hughes, 2011; Seefeldt & Haubenstricker, 1982) and negatively related to BMI (Morrison et al., 2012;

Pauli-Pott et al., 2010), and that females would show better inhibitory control than males (Wanless et al., 2013; Yuan et al., 2008).

The following two-by-two research design was used to identify and test associations between the measures of motor skill performance and inhibitory control.

		Inhibitory control (IH) measures	
		IH1: HTKS	IH2: BST
Motor skill	MS1: TGMD-2	1: IH1 v MS1	2: IH2 v MS1
(MS) measures	MS2: Agility	3: IH1 v MS2	4: IH2 v MS2

Each of these associations was assessed in two complementary ways; (a) with an OLS regression controlling for age, gender, and body mass, and (b) with a variant of Fisher's z-transformation) that compared correlated correlations (Meng et al, 1992).

Both of these tests assume normality, which was assessed in the data with Shapiro-Wilks' (1965) normality test. In a comparison of competing normality tests, Razali and Wah (2011) found that the Shapiro-Wilks test had the best power for a given level of significance. For comparison to the literature, the Kolmogorov-Smirnov normality test also was applied. (Note: Mardia's test of multivariate normality also could have been applied.) These tests were conducted on the motor skill performance measures and the inhibitory control measures, as well as on the control variables (age, gender, and body mass). Several OLS regressions were run, first without and then with the control variables.

$$IH1 = a + b_{IH1.MS1}\,MS1 + b_{AGE}\,AGE + b_{GEN}\,GEN + b_{BMI}\,BMI + e \tag{1}$$

$$IH2 = a + b_{IH2.MS1}\,MS1 + b_{AGE}\,AGE + b_{GEN}\,GEN + b_{BMI}\,BMI + e \tag{2}$$

$$IH1 = a + b_{IH1.MS2}\,MS2 + b_{AGE}\,AGE + b_{GEN}\,GEN + b_{BMI}\,BMI + e \tag{3}$$

$$IH2 = a + b_{IH2.MS2}\,MS2 + b_{AGE}\,AGE + b_{GEN}\,GEN + b_{BMI}\,BMI + e \tag{4}$$

Equation (1) established a baseline for comparison of the other relations. Based on the literature on inhibitory control, it was expected that the results would not show a statistically significant relation between the fundamental motor skill TGMD-2 measure and the HTKS inhibitory control measure, after controlling for subjects' demographic characteristics. That is, the $b_{IH1.MS1}$ coefficient should not be statistically different from zero. The remaining three OLS regressions provided insight into the relation between motor skill performance and inhibitory control as a function of the challenge level.

Multicollinearity among the measures may have resulted in insignificant $b_{IH-.MS-}$ coefficients, so these regressions were also run without the control variables. A comparison of the coefficients with and without the control variables allowed an assessment of the importance of the control variables as omitted variables related to the subjects' stage of development.

The issue of causality also merits a brief comment. Regression analysis suggests a causal relation between the dependent and independent variables. In fact, motor skill performance and inhibitory control are simultaneously influenced by a host of endogenous factors that develop in tandem as individuals proceed through the maturation process. Each individual's level of physical and cognitive development is influenced by their genetic and social endowments including family circumstances, their social interactions, and the local educational support system. Regression analysis is merely a convenient statistical tool for investigating the association between motor skills and inhibitory control in the presence of the control variables, and is not intended to infer causality. The choice of dependent and independent variables is in fact somewhat arbitrary.

Previous research has found conflicting evidence regarding the relation between motor skill performance and inhibitory control in five- and six-year-old children. The basic tenet of this study was that the reason for a finding of no relation was because the motor skill and inhibitory control measures may not have been at an appropriate challenge level in this age group. This called for a comparison of the slope coefficients across Equations (1) through (4); in particular, between the correlations $r_{IH1.MS1}$, $r_{IH2.MS1}$, $r_{IH1.MS2}$, and $r_{IH2.MS2}$. The testable hypothesis was that the relation between motor skill performance and inhibitory control assessed at an appropriate challenge level would exceed the relation when the challenge level is low.

$r_{IH2.MS1} > r_{IH1.MS1}$ A higher challenge level IH2 improves its relation with MS1
$r_{IH1.MS2} > r_{IH1.MS1}$ A higher challenge level MS2 improves its relation with IH1
$r_{IH2.MS2} > r_{IH2.MS1}$ A higher challenge level IH2 improves its relation with MS2
$r_{IH2.MS2} > r_{IH1.MS2}$ A higher challenge level MS2 improves its relation with IH2

These correspond to comparisons of the relative strengths of the relations in equations (1) - (4), but without the controls for demographic variables. Correlations were compared with a one-sided test of significance based on the hypothesis that challenge level matters.

These correlations were compared with Meng et al.'s (1992) comparison of correlated correlations, which is based on a z-test for the significance of the difference between two sample correlation coefficients $r_{Y,X1}$ and $r_{Y,X2}$. Meng et al's comparison is structured as follows, assuming normally distributed variables. Let $z_{r1} \equiv z_{Y,X1}$ and $z_{r2} \equiv z_{Y,X2}$ be correlations between the dependent variable Z and the predictor variables X1 and X2, and let $z_X \equiv r_{X1,X2}$ be the correlation between the two predictor variables. Next, transform the correlations into their Fisher z-transformations z_{r1}, z_{r2} and z_X in order to standardize the raw variables into unit normal variables. The following z-test comparison was then made of the transformed correlations: $Z = (z_{r1} - z_{r2})$ [(N-3) / $2h(1-r_x)$ $]^{1/2}$, for $h = (1-f\dot{r}^2)/(1-\dot{r}^2) = 1 + \dot{r}^2(1-f)/(1-\dot{r}^2)$, $\dot{r}^2 = (r_{X1}{}^2+r_{X2}{}^2)/2$ = the mean of the r-squares $r_{X1}{}^2$ and $r_{X2}{}^2$, $f = (1- r_x)/(2(1-\dot{r}^2)) \leq 1$, and N = the number of subjects. A 95 percent confidence interval for the difference in z-scores is then given by $(z_{r1} - z_{r2}) \pm 1.96$ [$2h(1-r_x)$ / (N-3) $]^{1/2}$, such that five percent of a unit normal distribution lies outside ±1.96.

CHAPTER 4

RESULTS

This study was designed to examine the relation between motor skill performance and inhibitory control in five- to six-year-old children as a function of the motor challenge level. To accomplish this objective, the correlations between two measures of inhibitory control (IH) and two measures of motor skill (MS) performance were assessed in a 2x2 framework that varied the motor skill and inhibitory control performance measures according to their level of challenge. The details of this framework appear in Table 1.

Table 1. A framework for assessing performance as a function of challenge level

		Inhibitory control	
		IH1 Low challenge HTKS Head-Toes-Knees-Shoulders	**IH2 High challenge** BST Bivalent Shape Test
Motor skills	**MS1 Low challenge** TGMD-2 Fundamentals	$r_{MS1.IH1}$	$r_{MS1.IH2}$
	MS2 High challenge KTK agility	$r_{MS2.IH1}$	$r_{MS2.IH2}$

Low-challenge motor skills for kindergarten children were assessed with a set of fundamental motor skills drawn from the TGMD-2 tests. High-challenge motor skills were assessed with KTK agility and an obstacle course measures. Low-challenge inhibitory control was assessed with the HTKS (head-toes-knees-shoulders) test. High-challenge inhibitory control was assessed with two complementary measures, accuracy and response time on the Bivalent Shape Test (BST). A higher score on each of these measures reflects a higher performance, except for BST response time where a lower score reflects a quicker response. Controls were introduced to account for potentially confounding factors such as age, gender, and BMI. A test group variable was added when data collection extended beyond the school year and into the summer months.

The strength of the relation of inhibitory control with motor skill performance as a function of the challenge level was assessed by comparing the correlations $r_{MS.IH}$ between the motor skill and inhibitory control measures in Table 1 using Meng et al.'s (1992) z-test comparison of means. The following correlations (r) were tested for equality: $r_{IH1.MS2} = r_{IH1.MS1}$, $r_{IH2.MS1} = r_{IH1.MS1}$, $r_{IH2.MS2} = r_{IH1.MS2}$, and $r_{IH2.MS2} = r_{IH2.MS1}$. If challenge level was important in these relations, then correlations based on measures at higher challenge levels should exceed correlations at lower challenge levels. Meng et al.'s test provided a comparison of the relative strength of these relations.

Lastly, a series of OLS regressions were run with inhibitory control performance as the dependent variables and the motor skill measures, age, gender, BMI, and test group as the predictor variables to determine the relation/contribution of each variable to the relation.

Participant Characteristics

The sample was composed of 82 children ages five and six, residing in the mid-Michigan geographic region. The 82 children were assessed as two separate groups, on two separate occasions beginning May 2015, and continuing through September 30, 2015. First, 65 children from the kindergarten classes of a suburban school were invited to participate in the study. A total of 49 (75%) children returned consent forms and were assessed during the month of May, 2015. The assessments took the remainder of the school year to complete. An additional 33 children were assessed over the summer, creating a final sample of 82 children. The same protocol was followed for both groups, with one difference. The "school" group was recruited through the school and assessed individually in small groups during the school day, while the "summer" participants were assessed individually in their homes and recruited from surrounding communities by word of mouth. It was common for either the physical education teacher or parent to be in close proximity during the assessments. The test group variable was coded as 1=school and 2=summer.

Preliminary Data Analyses

All data for the remaining subjects was entered twice and reviewed for accuracy. This examination revealed two likely recording errors, some missing observations, a small number of outliers, and non-normality in the data. One school participant did not have complete demographic information on the participant questionnaire, including birthdate. An attempt to contact the family was unsuccessful, as the family had moved. This participant was deleted, leaving a final sample size of 81.

Two body mass index (BMI) values were coded as missing because they likely were the result of recording errors. Each of these recorded measures was below a 3 percentile threshold for age and gender relative to the CDC pediatric BMI charts (CDC Growth Charts, 2009; Osborne, 2003). A BMI below the 3 percentile level is viewed as unhealthy (CDC, 2009). The recorded BMI values were grossly inconsistent with the physical appearance of the participants. Other measures for these two participants were retained in the subsequent analyses.

Including the two BMI observations noted above, a total of 8 missing values appeared in three of the eleven variables. There was no discernible pattern in the missing data, which were due to student absenteeism, to scheduling changes within the school, or to the recording errors noted. These missing values represented less than one percent (about 0.9 percent) of all recorded values. There were three missing scores for HTKS (IH1), three missing scores for KTK (MS2), and two missing scores for BMI. As the missing data appeared to be random, the data met the criteria to run the analyses using listwise deletion of missing data.

A visual inspection of histograms and scatterplots revealed outliers in the data. Statistical tests for outliers that were conducted but not reported (Mahalanobis Distance, Cook's Distance, Casewise Diagnostics) confirmed the existence of outliers in several of the variables. Outliers did not appear to be the result of recording errors (except for the two BMI values noted), misreporting by participants, or faulty equipment. Rather, each outlier appeared to represent a legitimate value in the sample, and so was retained in the analyses (Osborne, 2003; Osborne & Overbay, 2004). Although not reported, analyses also were conducted with the outliers removed to assess the robustness of the findings. Removing the outliers did not materially change the relative strengths of the relations in the sample, nor did it change the conclusions of the study.

Normality was assessed in the data with Shapiro-Wilk and Kolmogorov-Smirnov test statistics. At least in part because of the presence of outliers, these diagnostic statistics reject normality at p-values of less than 0.001 in several of the variables. Results for these two diagnostics were qualitatively similar, so only the Shapiro-Wilk test statistics will be reported. Normality test results are not reported for age, because age should be relatively uniformly distributed across the sample. Caution should be exercised in interpreting the results of this study because of nonnormality in some of the variables.

Characteristics of the Sample

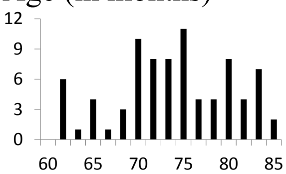
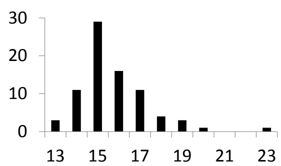
Table 2 presents the characteristics of the sample, and Table 3 presents descriptive statistics on the motor skill and inhibitory control measures. The characteristics of the sample reflect the relatively affluent, suburban, Midwest population from which it was drawn. The majority of participants were within normal BMI ranges, mostly of Caucasian decent and from families where at least one parent held a college degree. Further, nearly one third of the participants had a parent with a post-graduate degree. The group assessed in the school comprised approximately 60% of the sample.

As noted in Panel A of Table 2, the mean age of the school group (74.96 months) was significantly different from that of the summer group (70.58 months) at 1 percent based on a two-tailed Student t-test comparison of means. A t-test comparison of means is not strictly appropriate here because of age's uniform distribution across the kindergarten year. Nevertheless, several different versions of the t-test rejected the assumption of equal means. The t-statistics reported in Table 2 assumed equal variances but allowed for unequal sample sizes. Subjects' BMI measures did not show a significant difference. T-tests also were conducted on the motor skill and cognitive function variables, and the results showed differences between the school and summer groups on both of the high-challenge inhibitory control scores, but not on the low-challenge inhibitory control scores.

Panel B of Table 2 presents information on the categorical controls: gender, ethnicity, parents' education, and whether a participant was bilingual. With the exception of gender, these variables reflect the characteristics of this relatively affluent, suburban, Midwest school district.

Table 2. Characteristics of the sample

Panel A: Cardinal demographic variables

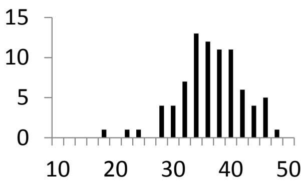
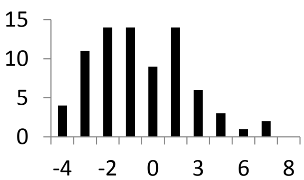
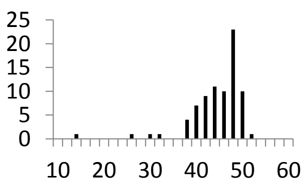
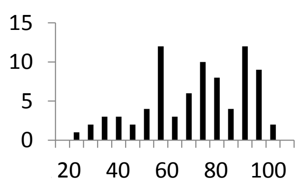
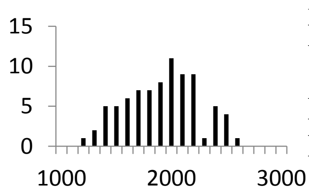
Variable		School	Summer	Total
		Sample		
Age (in months)	N	48	33	81
	Mean	74.96	70.58	73.18
	Standard deviation	4.40	7.79	6.35
	Minimum	67.6	60.1	60.1
	Maximum	83.2	83.9	83.9
	Shapiro-Wilk normality test	n/a	n/a	n/a
	T-test comparison of means			3.22‡
BMI	N	46	33	79
	Mean	16.13	16.15	16.14
	Standard deviation	1.85	1.29	1.53
	Minimum	13.5	14.3	13.5
	Maximum	23.3	20.2	23.3
	Shapiro-Wilk normality test	0.90‡	0.88‡	0.90‡
	T-test comparison of means			0.05

Panel B: Number of subjects in the categorical demographic variables

Variable	Category (code)		School	Summer	Total
			Sample		
Gender	Males(1)	22	11	33	(40.7%
	Females (2)	26	22	48	(59.3%)
Ethnicity	Caucasian (1)	41	30	71	(87.7)
	Other (2)	7	3	10	(12.3)
Parents' education	College grad (1)	47	30	72	(88.9)
	Other (2)	1	3	9	(11.1)
Native tongue	English (1)	18	19	37	(45.7)
	Bilingual (2)	4	4	8	(9.9)
	Not available (missing)	26	10	36	(44.4)

† and ‡ indicate significance at 5 percent and 1 percent significance levels, respectively. It should be noted that 44.4% of the data on Native tongue is missing. Many parents left this answer blank, possibly due to the fact that their child was not bilingual. It leaves the data results unknown for this variable.

Table 3. Descriptive information on the main variables

Variable		Sample: School	Summer	Total
MS1: FMS (Total Fundamental Motor Skills): low-challenge motor skill measure				
	N	48	33	81
	Mean	36.83	35.00	36.09
	Standard deviation	4.97	6.28	5.57
	Minimum	24	18	18
	Maximum	47	46	47
	Shapiro-Wilk normality test	0.99	0.97	0.98
	T-test comparison of means			1.465
MS2: KTK (Korperkoordinations Test fur Kinder): high-challenge motor skill measure				
	N	46	32	78
	Mean	-0.19	0.05	-0.09
	Standard deviation	2.77	2.54	2.66
	Minimum	-4.51	-4.47	-4.51
	Maximum	7.05	6.85	7.05
	Shapiro-Wilk normality test	0.96	0.98	0.97†
	T-test comparison of means			-0.40
IH1: HTKS (Head/Toes/Knees/Shoulders): low-challenge inhibitory control measure				
	N	45	33	78
	Mean	44.22	45.61	44.81
	Standard deviation	7.03	4.58	6.12
	Minimum	13	28	13
	Maximum	52	51	52
	Shapiro-Wilk normality test	0.74‡	0.85‡	0.76‡
	T-test comparison of means			-0.99
IH2acc: BST percentage accuracy: high-challenge inhibitory control measure				
	N	48	33	81
	Mean	77.71	62.29	71.43
	Standard deviation	16.7	20.3	19.7
	Minimum	21.44	27.78	21.44
	Maximum	100	98.89	100
	Shapiro-Wilk normality test	0.94†	0.96	0.95‡
	T-test comparison of means			3.74‡
IH2rt: BST response time: high-challenge inhibitory control measure				
	N	48	33	81
	Mean	1865	2114	1967
	Standard deviation	287	331	328
	Minimum	1235	1425	1235
	Maximum	2537	2623	2623
	Shapiro-Wilk normality test	0.98	0.96	0.98
	T-test comparison of means			-3.61‡

† and ‡ indicate significance at 5 percent and 1 percent significance levels, respectively.

Females outnumbered males by 48 to 33 in the sample. The probability of observing 33 or fewer males in a sample of 81 subjects assuming an equal probability of males and females in the population based on a binomial test is only 5.96 percent. This suggests that sample selection bias might have entered the study as students or their parents selectively responded to our recruitment efforts. However, gender was not significantly related to any of the other variables (except age) at 5 percent (see Table 4 below), so sample selection bias likely did not materially affect the findings.

Table 3 presents descriptive statistics on the motor skill and inhibitory control measures, including normality tests and t-test mean comparisons between the school and summer groups. As with the control variables in Table 2, nonnormalities are present in the performance measures. There also is a statistically significant difference in the performance of the school and summer groups on the BST (IH2) measures. Although this performance difference possibly is due to the different settings used to assess the two groups, evidence is presented later in this chapter that it really is variation in age that drives this finding.

Relations between Motor Skill Performance and Inhibitory Control

Table 4 presents Pearson correlations between the motor skill, inhibitory control, and control variables for the 73 subjects that had measures for all of the variables (that is, using listwise deletion of missing values). The control variables age, BMI, and gender were expected to have a significant influence on the outcome variables based on the related literature. Data on parent education and ethnicity also were collected, although these two potential controls generally were not significantly related to the other variables.

Table 4. Correlations

	MS2	IH1	IH2acc	IH2rt	Age	BMI	Ethnic	Gender	Educ	Group
MS1	0.44‡	0.22	0.26†	-0.28†	0.33†	-0.14	0.09	0.07	0.18	-0.22
MS2		0.20	0.20	-0.16	0.16	-0.05	0.05	0.24†	0.11	0.03
IH1			0.25†	-0.05	0.11	-0.01	-0.06	0.07	0.02	0.16
IH2acc				-0.73‡	0.50‡	0.04	0.17	0.02	0.15	-0.41‡
IH2rt (lower scores = better performance)					-0.63‡	-0.11	-0.28†	0.19	-0.03	0.38‡
Age						0.04	0.04	-0.27†	-0.18	-0.34‡
BMI							0.29	-0.02	-0.20	-0.03
Ethnicity								0.01	0.10	-0.11
Gender									0.04	0.12
Parent's education										-0.15

† and ‡ indicate significance at 5 percent and 1 percent significance levels, respectively.

Table 5 presents Pearson correlations between the motor skill, inhibitory control, and control variables by group. The summer group generally shows higher correlations than the school group, likely due to the fact that the summer group showed more variability in some of the control variables. Notably, age is significant in the summer, but not the school group. Age is also a factor when looking at response time, with a high correlation in the summer group versus a moderate correlation in the school group.

Table 5. Correlations by test group

	1. School test group (N = 36)					2. Summer test group (N = 29)				
	MS2	IH1	IH2acc	IH2rt	Age	MS2	IH1	IH2acc	IH2rt	Age
MS1	0.27	0.24	0.08	-0.17	0.11	0.67‡	0.36†	0.29	-0.26	0.39†
MS2		0.12	0.16	-0.15	0.11		0.36†	0.31	-0.23	0.25
IH1			0.38†	-0.07	0.18			0.33	-0.22	0.22
IH2acc				-0.61‡	0.32†				-0.74‡	0.49‡
IH2rt					-0.41†					-0.70‡

† and ‡ indicate significance at 5 percent and 1 percent significance levels, respectively.

Each of the correlations in Table 5 is in the expected direction, in that children who performed better on the motor skill tasks also performed better on the inhibitory control tasks. Statistically significant correlations were found between the low-challenge motor skill performance and the two outcomes of the high-challenge inhibitory control tasks ($r_{MS1.IH2acc} = 0.264$, $p < 0.05$; and $r_{MS1.IH2rt} = = -0.282$, $p < 0.05$) and age ($r_{MS1.Age} = 0.332$, $p < 0.05$). However, only the low-challenge MS1 (TGMD-2) measure had statistically significant correlations with the inhibitory control measures at 5 percent.

The high-challenge motor skill KTK measure had a large and statistically significant correlation with the low-challenge motor skill TGMD-2 measure ($r_{MS1.MS2} = 0.436$, $p < 0.01$), but did not have a significant correlation with any of the other variables. The correlations of the high-challenge MS2 (KTK) measure with inhibitory control were fairly strong, but the correlations didn't quite meet the 5 percent significance threshold. This raises a concern that the TGMD-2 and KTK tests used to distinguish between low- and high-challenge motor skills might not differ sufficiently in challenge level.

Test group is significantly correlated with age, MS1 (TGMD-2), and IH2acc and IH2rt (BST accuracy and response time) in Table 4. The mean age of the summer test group (coded as 2) was several months younger than the group tested during the school year (coded as school = 1). The differences in age were most likely due to the fact that the summer group included five-year-old children who had not yet attended school. If the data collection methods were equivalent for the school and summer test groups, then this would explain the negative and significant relation between the test group and age variables, and possibly also between test group and the two IH scores. Another possible explanation is the younger age of the summer sample, which included children that were entering kindergarten in the following fall. In any case, multicollinearity between age and test group could bias regression tests against finding significance. This is addressed in the last section of this chapter.

Several variables were not normally distributed, so nonparametric Spearman correlations were calculated to corroborate the parametric correlations in Table 4. In nearly all cases, the sign, magnitude, and statistical significance of the nonparametric correlations were similar to those of the parametric correlations. The parametric correlations reported in Table 4 appear to be a legitimate characterization of the relations between these variables.

The Pearson correlations were further examined to find significant relations for inclusion as controls in the regression models. BMI, gender, and parents' education were in general not significantly related to other variables, and are not included in the regression models that appear below.

Z-test of the Relative Strength of the Correlations (Meng et al., 1992)

Meng et al.'s (1992) z-test of correlated correlations is used to examine the role of challenge level on the relation of motor skill performance to inhibitory control. If challenge level is important, then correlations based on measures at higher challenge levels should exceed correlations at lower challenge levels. The following correlations are tested for equality: $r_{MS2.IH1} = r_{MS1.IH1}$, $r_{MS1.IH2} = r_{MS1.IH1}$, $r_{MS2.IH2} = r_{MS2.IH1}$, and $r_{MS2.IH2} = r_{MS1.IH2}$, where IH2 is measured with BST accuracy or with BST response time. These correlations are summarized in Table 5, along with their probability values. Although the Meng et al. test does not allow the control variables to be included, it does allow a comparison of the correlations as a function of the challenge level.

Table 6. Correlation summary on main variables

Inhibitory control performance	Motor skill performance: Low challenge MS1 (TGMD-2)		Motor skill performance: High challenge MS2 (KTK)	
Low challenge IH1 (HTKS)	0.22	(0.06)	0.20	(0.10)
High challenge IH2acc (BST accuracy)	$0.26^{\dagger}$	(0.02)	0.20	(0.10)
High challenge IH2rt (BST response time)	$-0.28^{\dagger}$	(0.02)	-0.16	(0.18)

P-values in parentheses. † indicates significance at a 5 percent significance level.

The central hypothesis of this study is that the relation between motor skill performance and inhibitory control in this age group should be stronger at higher challenge levels. Reading down the columns, this might be true for the relation of the low-challenge MS1 (TGMD-2) measure to inhibitory control, but not for the relation of the high-challenge MS2 (KTK) measure to inhibitory control. The correlation between MS1 and IH1 ($r_{MS1.IH1} = 0.22$) is lower than the correlation between MS1 and BST accuracy ($r_{MS1.IH2Acc} = 0.26$). The correlation between MS1 and BST response time ($r_{MS1.IH2Rt} = -0.28$) is the strongest, recalling that shorter BST response times correspond to better inhibitory control. Meng et al. provide a test of whether challenge level has a statistically significant impact on this relation.

The MS2 (KTK) correlations are not consistent with the hypothesis that the motor skill - inhibitory control relation increases in strength with the level of challenge. Correlations of MS2 with IH1 ($r_{MS2.IH1} = 0.20$) and with IH2Acc ($r_{MS2.IH2Acc} = 0.20$) are equal, and are not significant at 5 percent. And, the magnitude of the correlation of MS2 with IH2Rt ($r_{MS2.IH2Rt} = 0.16$) is lower than with IH1, although this correlation again lacks statistical significance. These correlations do not lend support to the hypothesis that the strength of the motor skill - inhibitory control relation increases with the challenge level.

Reading across the rows, each of the inhibitory control measures is more strongly correlated with the low-challenge MS1 measure than with the high-challenge MS2 measure. Again, this is inconsistent with the hypothesis that the motor skill - inhibitory control relation increases with the challenge level.

Meng et al.'s (1992) test is applied as outlined in the dissertation proposal, despite this preliminary evidence against the central hypothesis of this study. The results are reported in Table 7, where a critical value of 1.96 is necessary for statistical significance at 5 percent. Consistent with Table 6, the only z-score that is statistically significant at 5 percent is the comparison of the correlation MS1 to IH1 and to IH2Acc; i.e., $r_{MS1.IH1}$ = $r_{MS1.IH2rt}$ = -3.95. This is statistically significant at 1 percent, but is opposite the predicted direction. For $r_{MS1.IH1}$ and $r_{MS1.IH2rt}$, challenge level was negatively related to the motor skill - inhibitory control relation. Other comparisons are not significant at 5 percent.

Table 7. Meng et al. (1992) tests of the influence of challenge level on performance

		Inhibitory control		
		IH1 (HTKS) **Low challenge**		**IH2** (BST) **High challenge**
Motor skills	**MS1** (TGMD-2) **Low challenge**	$\mathbf{r_{MS1.IH1}}$	$r_{MS1.IH1} = r_{MS1.IH2acc}$ Z = 0.336 $r_{MS1.IH1} = r_{MS1.IH2rt}$ Z = -3.975^{fl}	$\mathbf{r_{MS1.IH2}}$
		$r_{MS1.IH1} = r_{MS2.IH1}$ Z = 0.219		$r_{MS1.IH2} = r_{MS2.IH2acc}$ Z = 0.555 $r_{MS1.IH2} = r_{MS2.IH2rt}$ Z = -0.993
	MS2 (KTK) **High challenge**	$\mathbf{r_{MS2.IH1}}$	$r_{MS2.IH1} = r_{MS2.IH2acc}$ Z = 0.000 $r_{MS2.IH1} = r_{MS2.IH2rt}$ Z = 0.000	$\mathbf{r_{MS1.IH2}}$

The z-test critical value for significance at a 5 percent significance level is 1.96.
‡ indicates significance at a 1 percent significance level.

Regression Analyses and Results

Another aim of the study was to examine the influence of the related variables (age, BMI, gender, parents' education, and test group) on the MS–IH relation using OLS regressions. This is essentially the same framework as in Table 1, but using regressions with controls for potentially related factors. The final regression model included only age and test group as control variables. BMI, gender, and parents' education were not included in the final regression models because their correlations with the motor skill and inhibitory control variables generally were not statistically significant. As noted earlier, three observations of MS2 (KTK) and three observations of IH1 (HTKS) were missing.

The results are reported in Table 8 for each of the MS–IH comparisons. Inhibitory control is chosen as the dependent variable in these regressions, although the choice of dependent variable is somewhat arbitrary because inhibitory control and motor skill performance are endogenous or codetermined in that they are related to a set of hereditary and environmental factors that impact performance.

Table 8. Regression results for IH predicting MS with controls for age and test group

Dependent variable: Low Challenge Inhibitory Control IH1 (HTKS)

Independent variables	*B*	*SE B*	*β*	*t*	*p-value*	*(Part r)*^{2}
Low challenge MS1 (TGMD-2)	0.22	0.13	0.20	1.68	0.10	0.04
Age	0.12	0.12	0.13	1.06	0.29	0.01
Test group	2.38	1.47	0.19	1.62	0.11	0.03
Note: Adjusted r-square = 0.04, F-statistic = 2.04 (N = 77, p-value = 0.12)						
High challenge MS2 (KTK)	0.37	0.27	0.16	1.34	0.18	0.02
Age	0.14	0.12	0.14	1.14	0.26	0.02
Test group	2.22	2.22	0.15	1.15	0.15	0.03
Note: Adjusted r-square = 0.03, F-statistic = 1.75 (N = 74, p-value = 0.17)						

Dependent variable: High Challenge Inhibitory Control IH2 (BST accuracy)

Independent variables	*B*	*SE B*	*β*	*t*	*p-value*	*(Part r)*^{2}
Low challenge MS1 (TGMD-2)	0.28	0.35	0.08	0.81	0.42	0.01
Age	1.20	0.32	0.39	3.71	0.00	0.12
Test group	-9.64	4.03	-0.24	-2.39	0.02	0.05
Note: Adjusted r-square = 0.28, F-statistic = 11.23 (N = 80, p-value = 0.00)						
High challenge MS2 (KTK)	1.20	0.74	0.16	1.62	0.11	0.03
Age	0.17	0.33	0.37	3.59	0.00	0.12
Test group	-10.28	4.12	-0.26	-2.50	0.02	0.06
Note: Adjusted r-square = 0.28, F-statistic = 11.20 (N = 77, p-value = 0.00)						

Dependent variable: High Challenge Inhibitory Control IH2 (BST response time)

Independent variables	*B*	*SE B*	*β*	*t*	*p-value*	*(Part r)*^{2}
Low challenge MS1 (TGMD-2)	-3.66	5.48	-0.06	-0.67	0.51	0.00
Age	-26.35	5.05	-0.51	-5.22	0.00	0.22
Test group	126.90	62.85	0.19	2.02	0.05	0.03
Note: Adjusted r-square = 0.37, F-statistic = 16.47 (N = 80, p-value = 0.00)						
High challenge MS2 (KTK)	-5.14	11.54	-0.04	-0.45	0.66	0.00
Age	-27.73	5.10	-0.53	-5.44	0.00	0.24
Test group	135.41	64.51	0.20	2.10	0.04	0.04
Note: Adjusted r-square = 0.38, F-statistic = 16.43 (N = 77, p-value = 0.00)						

Table 8 includes unstandardized parameter estimates (*B*) and standard errors for the independent variables, along with standardized betas (*β*), t-statistics, probability values, and squared semipartial correlations or (Part r)^2 for the motor skill and control variables, as well as the regression's adjusted r-square. Squared semipartial correlations (Part r)^2 for each independent (MS or control) variable indicate how much the regression's R-square will decrease if that variable were removed from the regression. Adjusted r-square (R^2) is the percentage of the variation in the IH measure that is explained by the independent variables, after adjusting for degrees of freedom. The F statistic is a test of the null hypothesis that all of the coefficients on the independent variables are zero. The F statistic is included because collinearity in the explanatory variables might result in a particular regression significantly explaining an independent variable even though none of the explanatory variables are significant. The dependent variables have different units, so standardized betas are reported to allow a comparison of the relative contribution of the dependent variables to the variance of the independent variable. Squared partial correlations indicate how much of the variance in an independent variable that is not explained by the other dependent variables is explained by a particular dependent variable.

As suggested by the correlations in Table 4, age indeed is the strongest predictor of inhibitory control performance in Table 8 with statistically significant coefficients in the expected direction and at a one percent significance level for each of the high challenge IH2 inhibitory control (i.e., BST accuracy and response time) regressions. This is evidence that students exhibit a significant increase in inhibitory control between the ages of 60 months and 84 months (the range of ages in the sample). Interestingly, the inclusion of age and test group rendered the coefficients on MS1 insignificant in the MS1–IH2 (BST accuracy and response time) regressions. Test group is statistically significant at 5 percent in each of the high challenge MS2-IH2 regressions.

Squared semipartial correlations (Part r)^2 in Table 8 indicate how much R-square will decrease if that variable is removed from the regression. For example, the square of the semipartial correlation of age in the MS2–IH2rt regression is $(-0.49)^2 = 0.24$, so the regression's R-square would decrease by 0.24 if age were removed from the regression and IH2rt was explained solely by MS2. The adjusted r-square or total explanatory power of the three independent variables combined is 0.38, or 38 percent of the variation in IH2rt. The most notable result (Table 8) is that none of the motor skill coefficients is significant after controlling for age and test group. Coefficients on age are not significant in the MS1–IH1 regressions, but are significant at 1 percent in the MS1–IH2, MS2–IH1, and MS2–IH2 regressions. In this sample of five- and six-year-old children, subjects' age is predominant in explaining performance on both motor skill and inhibitory control tasks.

Multicollinearity between age and test group is likely to bias these regression tests against finding statistical significance, so these tests were repeated with only the control for age (the strongest predictor of performance in Table 8). The results are reported in Table 9.

Table 9. Regression results for IH predicting MS with a control for age

Dependent variable: Low Challenge Inhibitory Control IH1 (HTKS)

Independent variables	B	SE B	β	t	p-value	(Part r)^2
Low challenge MS1 (TGMD-2)	0.20	0.13	0.18	1.52	0.14	0.03
Age	0.08	0.11	0.08	0.67	0.50	0.00
Note: Adjusted r-square = 0.02, F-statistic = 1.72 (N = 77, p-value = 0.19)						
High challenge MS2 (KTK)	0.40	0.27	0.17	1.48	0.14	0.03
Age	0.08	0.11	0.08	0.67	0.50	0.01
Note: Adjusted r-square = 0.01, F-statistic = 1.53 (N = 74, p-value = 0.22)						

Dependent variable: High Challenge Inhibitory Control IH2 (BST accuracy)

Independent variables	B	SE B	β	t	p-value	(Part r)^2
Low challenge MS2 (TGMD-2)	0.34	0.36	0.10	0.95	0.35	0.01
Age	1.44	0.32	0.47	4.55	0.00	0.20
Note: Adjusted r-square = 0.23, F-statistic = 13.19 (N = 80, p-value = 0.00)						
Low challenge MS2 (KTK)	0.99	0.76	0.13	1.30	0.20	0.02
Age	1.45	0.32	0.46	4.57	0.00	0.21
Note: Adjusted r-square = 0.23, F-statistic = 12.79 (N = 77, p-value = 0.00)						

Dependent variable: High Challenge Inhibitory Control IH2 (BST response time)

Independent variables	B	SE B	β	t	p-value	(Part r)^2
Low challenge MS1 (TGMD-2)	-4.43	5.58	-0.08	-0.79	0.43	0.01
Age	-29.52	5.90	-0.57	-6.03	0.00	0.30
Note: Adjusted r-square = 0.34, F-statistic = 21.80 (N = 80, p-value = 0.00)						
High challenge MS2 (KTK)	-2.39	11.73	-0.02	-0.20	0.84	0.00
Age	-31.38	4.90	-0.60	-6.40	0.00	0.35
Note: Adjusted r-square = 0.35, F-statistic = 21.46 (N = 77, p-value = 0.00)						

Table 9 presents the regressions run a second time with only age as the control variable; that is, excluding test group which is closely associated with age. The results align with the results of the prior regression model with test group included. Again, age is the strongest predictor of inhibitory control performance with statistically significant coefficients in the expected direction and at a one percent significance level for each of the high challenge inhibitory control MS–IH2 (i.e., BST accuracy and response time) regressions. In all cases the adjusted r-square for each regression was reduced, showing that removing the test group variable lowered the percentage power of the model. For example, the adjusted r-square or total explanatory power of the three combined independent variables in the MS2–IH2rt regression model is 0.38, or 38 percent of the variation in IH2rt, whereas the explanatory power of the same regression with the test group removed is 0.35, or 35 percent.

CHAPTER 5

DISCUSSION

The purpose of this study was to better understand the relation between motor skill performance (MS) and inhibitory control (IH) in young children. More specifically, it was to determine whether or not the level of challenge was a factor in the MS–IH relation. Three analyses were used to assess the influence of challenge on the MS–IH relation. The first was an assessment of the correlations among measures of motor skill performance and inhibitory control with several control variables. The second was an assessment of the correlations between motor skill performance and inhibitory control in a 2x2 design that varied MS and IH according to the level of challenge. The third was an assessment of the association of motor skill performance and inhibitory control while controlling for possible confounding variables.

The study makes the following three contributions to the literature: a) The study did not indicate that the level of challenge is an influencing factor in the MS–IH relation; b) The study found a significant relation between the TGMD-2 measure of fundamental motor skills and the Bivalent Shape Test (BST) of inhibitory control; and c) The study showed that age has a significant impact on both motor skill performance and inhibitory control.

The study first assessed the relations among inhibitory control (HTKS/IH1 and BST/IH2), motor skill performance (TGMD-2/MS1 and KTK/MS2), age, body mass, gender, and composition of the test groups. The results partially supported the hypothesis that the motor skills tested, as well as the confounding variables, would show a relation to inhibitory control. Consistent with Roebers and Kauer (2009) and Livesey et al. (2006), performance on the various motor skill and inhibitory control tasks showed a weak positive correlation using a variety of correlational analyses and controls. All results were in the expected directions, although not all correlations were significant.

The strongest relation between motor skill performance and inhibitory control in the study was between TGMD-2 (MS1) and BST (IH2). This contradicted the hypothesis that MS2 and IH2 would show the strongest relation, but it also led to the unexpected discovery of the study - the significant relation between fundamental motor skills and interference control. The weak, positive correlations between motor skill performance and inhibitory control are consistent with previous research including Roebers and Kauer (2008) and Livesey et al. (2006). However, this was the first study to show a relation between a group of fundamental motor skills (TGMD-2/MS1) and interference control in typically developing children of this age group.

An examination of the literature did not find any studies using the TGMD-2 in relation to inhibitory control in typically developing children. Though some studies have examined this relation, it is difficult to match these findings with the current study because of differences in the measures and methods used in the studies. For example, Livesey et al. (2006) assessed a small sample of 36 children ages 63-83 months and found a significant correlation (r = 0.40) between ball skills (rolling a ball and catching bean bags) and the Day/Night Stroop task. Similar to the present study the researchers also found a correlation between the composite motor score and the Day/Night Stroop task (r = .45). The current study found a lower correlation with the composite motor scores and inhibitory control (r = BST acc .26, BST rt -0.28) but used different assessments as well as a more comprehensive group of fundamental motor skills. With different motor tasks and inhibitory control tasks it is difficult to make robust comparisons between the two studies. However, together the studies may suggest that some fundamental motor skills show a positive relation to inhibitory control. Additionally, both studies show the predominant influence of age, which basically eliminated the MS-IH relations in both studies when it was included in analyses. Livesey et al. had a smaller sample of children (N = 36) than the current study but the participants may have similarities in backgrounds – Livesey et al. recruited participants from a private school and aftercare facilities. However, a comparison of the participant backgrounds between the studies is unclear as not enough background information is available from the Livesey et al. study to fully determine any similarities.

Roebers and Kauer (2009) assessed a sample of 112 children ages 79 -106 months and found a significant correlation (r = -0.29) between the jump task from the KTK (Kiphard & Schilling, 2000) and response times from the Eriksen Flanker task (Eriksen & Eriksen, 1974). Roebers and Kauer correlated performance on three gross motor tasks with cognitive measures of performance, but they did so individually for each of the motor skill measures and for a single trial. The current study consolidated two of the three measures used by Roebers and Kauer over two trials in an attempt to create a single composite measure of motor skill performance. Similarly, Livesey et al. (2006) assessed a small sample of 36 children ages 63-83 months and found a significant correlation (r = 0.40) between ball skills (rolling a ball and catching bean bags) and the Day/Night Stroop task.

The study most similar to the current research is Rosey et al. (2010), which assessed three- to five-year-old children on two (throw & hop) of the six fundamental motor skills assessed in the current research. Their study showed small to moderate correlations with several inhibitory control tasks. The dominant relations in Rosey et al. were found with the inhibitory control tasks that required a motor response versus the verbal inhibition task (Day/Night Stroop). This is in contrast to the Livesey et al. (2006) study, which showed a significant relationship between motor tasks and the DNS in slightly older children. The dominant relation in the current study was found with the interference control task (BST/high challenge) versus the response inhibition task (HTKS/low challenge). The three studies show some fundamental motor skills to be related to different aspects of inhibitory control at different ages. The three studies further suggest support for the hypothesis that specific motor skills may be related to specific executive functions (Roebers & Kauer, 2009).

Age had the strongest impact on the measures of motor and inhibitory control skills, as well as on estimates of the MS–IH relation. Motor skill and inhibitory control performance were positively correlated with age, and correlations between these and other measures in the study were greatly attenuated after controlling for age. Additionally, in the current study there was a marked difference in the age range between the summer and school groups. Larger variability within the summer group (a range of 60 months to 84 months, with a standard deviation of 7.8 months) than in the school group (68 months to 83 months, with a standard deviation of 4.4 months) resulted in stronger and more significant correlations with age, as well as stronger and more significant correlations between the other variables because of their collinearity of age. A further difference between the two groups was that the summer group included a small number of participants that had not yet entered kindergarten. These summer group participants may not have had the same motor skill training that physical education class offers children who spent a year in school and participating in physical education. It is not known whether the children who were not yet old enough for kindergarten attended young five classes however, in which case they would have participated in the same physical education opportunities as part of their school day. Because the current study did not identify children who had or had not attended either young fives or kindergarten class, it is difficult to evaluate the role of physical education experience in study outcomes.

The current study did not find a relation between gender and the motor skill or inhibitory control measures, which is consistent with some previous research on this age group (Roebers & Kauer, 2008; Stockel & Hughes, 2015). In contrast, Planinsec (2002) did find gender differences using a broader battery of 28 gross motor skills, including measures of agility, coordination, strength, speed, and balance. Gender differences in the Planinsec study may be attributed to the larger range of gross motor tasks, as well as to differences in gender growth patterns.

The current study showed a significant relation between ethnicity and the BST (high challenge, response time only), with children of other than Caucasian ethnicity performing significantly faster with their response times than their Caucasian peers (M = 1732.23, SD 301.19 vs. M = 1999.78, SD = 319.44; t (79) = 2.50, p = 0.02). However, with so few participants having an ethnicity other than Caucasian (10 vs. 71), it is difficult to make strong conclusions from the results. A few outliers could be driving this result. One study indicated that young children of Korean descent perform better on measures of inhibitory control (Oh & Lewis, 2008) whereas other research indicates that children of African American ethnic background show slower growth in inhibitory control (Moilanen et al., 2009). In the current study only one participant was identified as African American, one as Hispanic, one as Asian, and six as mixed.

The current results also did not find body mass to be related to inhibitory control, likely due to the limited variability in the body mass indices in this relatively homogeneous sample of suburban children (mean BMI = 16.14, with a standard deviation of 1.53). None of the previous studies examining the MS–IH relation included body mass as a covariate. Because gender and body mass index were not significantly related to inhibitory control, they were not included in the regression model.

The variability of scores on the various MS, IH, and control measures in the current study appears in Table 2 of Chapter 4. The sample was composed of 88% Caucasian children from homes with highly educated parents. Nearly 90% of the parents were college graduates and nearly one third had a post graduate degree. An attempt was made to determine the number of bilingual children in the sample because research shows children who are bilingual perform better on interference control tasks. However, 44% of the parents did not answer this particular question and only 8% of the children in the study were reported to be bilingual. Parents may have left the answer blank if their child was not bilingual. However, because it is not known why so many parents did not answer the question, no conclusions can be made.

Many of the prior studies examining the MS–IH relation do not discuss covariates other than age and gender, with fewer studies discussing gender differences. Generally, studies that include age as a covariate have found age to be a factor in measures of motor skill (Barnett et al., 2013; Vandorpe et al., 2011; Yang et al., 2015) and inhibitory control performance (Esposito et al., 2014; Gestsdottir et al., 2014; Wanless et al., 2011) and in the MS–IH relation (Livesey et al., 2006). In the current study, age was significantly related to the low challenge MS1 motor tasks (TGMD-2) and the high challenge inhibitory control tasks (BST accuracy and response time). The influence of age was more visible in the summer group, which had a wider variation in age than the school group.

Another broad area of difference among studies lies in their samples. The sample in this study was composed of a relatively homogeneous group of suburban children living in the northern U.S. whose parents were well-educated. Roebers and Kauer (2009) assessed a sample from rural regions of Switzerland, whereas Livesey et al. (2006) assessed a sample of children from private schools and after-school centers in Sydney, Australia. Though assessing these different samples offers insight on different groups of children, it also complicates comparison of studies. Children from different countries, cultures, and demographics may have widely differing educational, home, and leisure experiences that influence their performance outcomes, even when of the same age.

Interpretations of the Study Results Regarding the Level of Challenge

To determine whether challenge level was a factor in the MS–IH relation, a comparison of correlated correlations (Meng et al., 1992) and an OLS regression controlling for age, body mass, gender, and test group were used. The hypothesis that the function of challenge was a factor in the MS–IH relation was not supported by the current study design using either analysis. The OLS regressions indicated that motor skill performance (MS1 or MS2) was not a significant predictor in the outcome of the inhibitory control measures (IH1 or IH2) after controlling for age. As noted, age was the largest contributor to the model.

This section interprets the results of the study, beginning with the role of challenge in the MS–IH relation from the literature on cognition. Explanations for why the principal hypothesis is not supported by the study are then entertained. These explanations basically boil down to two possibilities. First, the assessments (i.e., the measures and tests) used in the study may have been unable to identify the role of challenge in the MS–IH relation. Second, it could be that motor skill performance is not related to inhibitory control after controlling for age.

Why there should be a relation to challenge.

Diamond and Lee (2011, pp. 963) state that for executive functions to improve, they need to be challenged. Research further indicates that individuals who participate in motor skill learning intervention programs improve in various executive functions (Budde et al., 2008; Lakes & Hoyt, 2004; Palmer et al., 2013). Further research shows that children who need the most improvement in executive functions improve the most with intervention help (Diamond & Lee, 2011). Together, these areas of research indicate that challenge is a factor, indeed necessary, in improving executive functions.

Moreover, prefrontal regions of the brain, including the dorsolateral prefrontal cortex, the anterior cingulate, and the premotor regions are recruited for new and challenging learning, whether the learning is motor or cognitive (Diamond, 2009). Research shows motor tasks that are more challenging also show increased brain activation in the key prefrontal cortex areas involved in motor planning, error detection, and interference control (Serrien, Ivry, & Swinnen, 2007). Motor skills that are more challenging also require more practice over time to master, because more dynamic neural changes occur with the learning of these skills (Serrien, Ivry, & Swinnen, 2007). Once a skill is learned, neural processing is reallocated to a less cognitive demanding mode (Doyon et al., 2003; Meister et al., 2005; Patel, Spring, & Turner, 2013; Puttermans et al., 2005) reducing activation in areas of the prefrontal cortex and thus preserving brain efficiency. Further, Milton, Solodkin, Hlustik, and Small (2007) state that individuals learning a new motor skill display difficulty in filtering out irrelevant information. Research also indicates interference control is needed to select an intended motor action (Tanji & Hoshi, 2008). In short, neurobiology shows that more challenging tasks recruit brain regions that regulate interference control and provide top down control to facilitate learning and mastery of the task. Further, as a task is mastered the need for interference control is reduced.

The small number of studies investigating the MS–IH relation and the lack of consistent methodologies makes comparison among studies difficult. While Roebers and Kauer (2009) found one motor coordination task to be significantly related to inhibitory control, challenge was not confirmed in their study. The researchers' focus was to investigate where relations might exist between motor skills and a variety of executive function skills. The researchers concluded that that the motor tasks activated different aspects of cognitive control and suggested that while cognitive control is mainly required for cognitive tasks, and motor control for motor tasks, there is some overlap (pp. 180). This overlap may occur when the motor tasks are cognitively challenging enough to perform, that is, when they actually require the use of executive functions to learn and execute.

What is speculated here is that when motor learning is new or challenging, it may be considered both a cognitive and a motor task. This means cognition and action must coordinate together to produce new coordinated movement patterns. It also stands to reason that if the motor task to be learned requires inhibition of prior learned movements, conflict of rules, or suppression of interference, inhibitory control would be needed. Yet the lack of empirical research on the cognitive demands of various motor skills, or motor skill groups (fine motor, gross motor, strength, etc.) limit the ability to make clear conclusions on why motor skills such as the KTK fail to show a relation with inhibitory control. Combining the motor coordination tasks with fundamental motor skills and increasing the external task constraints might have improved the assessment.

Two explanations for the findings of the study.

Two possible explanations for the findings of the study have been considered and will be discussed. These explanations cannot be confirmed by the current study but may offer insights for the design of future research. First, the assessments used in this study may not have been able to capture the level of challenge needed to confirm the hypothesis. That is, design flaws may have prevented accurate testing of the hypotheses. Second, motor skills either may not be related to inhibitory control or may covary with other variables in the MS–IH relation, particularly with age.

Inadequate assessments of motor skill performance and inhibitory control.

A possible explanation for the results of the current study may lie with the assessments themselves. In trying to determine how movement and cognition are related, researchers have held to the idea that specific motor skills can be related to specific executive functions. This may well be true, but, if we are to advance our understanding of the relation, future studies need to be more specific in demonstrating how it is true. It may be that you only find those specific relations when challenge is involved. This is in line with Diamond and Lee (2011) who claim that executive functions are improved when tasks performed place a high demand upon the executive functions. New or different assessments may be needed to clarify this thought.

In general, the current motor assessments have been designed to identify children who do not perform motor skills at age norms. Typically developing children, therefore, may not find them necessarily challenging. This does appear to be the case for the low-challenge inhibitory control HTKS measure, which appears to have a ceiling effect at a score of around 50 in Table 3. Available motor assessments test a broad range of motor skills, without a specific focus on the kinds of skills tested (gross motor, fine motor, balance). For example, a motor assessment may assess a small number of fine motor, gross motor, or balance skills in order to identify children who clearly have trouble executing the skill at age norms. The current study tried to improve upon this by assessing an array of fundamental motor skills and an array of coordination skills, rather than one or two such skills in each category. For example, the current study used the TGMD-2 (Ulrich, 2000), which is a qualitative measure that focuses specifically on fundamental motor skills. An examination of the TGMD-2 scores (appendix 11) showed sufficient variability among the low-challenge motor scores and no evidence of floor or ceiling effects. Current motor assessments also test a wide range of ages, from children to adults, again often not accounting for age by increasing the motor task challenge by age. Children’s motor abilities improve with age and practice, so a motor skill that is challenging for a typically developing five-year-old will not be as challenging for a twelve-year-old to perform. In summary, current assessments do not incrementally increase the challenge level of each task in the assessment by age or ability, meaning the tasks would not be challenging for all ages covered in their assessment.

The tasks for this study were carefully chosen from the current available assessments. What was needed for the study was a way to separately test low and high challenge motor tasks against low and high-challenge executive function tasks. The tasks selected for use in the study were chosen both to match the age and development of the children in the sample and also to distinguish between high and low-challenge levels as best as possible. Six fundamental motor skills, selected from TGMD-2 (Ulrich, 2000) were used as the low-challenge motor assessment. These six skills, according to the 60% chart, are skills that five and six-year–old children have been shown to perform well (Seefeldt & Haubenstricker, 1982). Finding a high-challenge motor task presented more of a problem as the majority of motor tasks are designed to identify underperforming children. The KTK has been used to identify children who do not perform at age norms, but it also has been used to identify children who are more advanced in their motor coordination skills. The KTK, which has been used as a sports recruitment tool, is described as a motor coordination task, with motor coordination being defined as "precise, balanced movements performed quickly through the smooth and efficient combination of the neural and muscular systems" (Cunha et al., 2015; Kiphard & Schilling, 2000). This would seem to make a strong case for the KTK as a high-challenge motor task. Further, an examination of possible floor and ceiling effects (appendix 11) showed the KTK to be challenging for the children but without floor effects. Yet, as discussed above, the KTK (MS2) showed only a weak relation to inhibitory control measures (IH2). This may be due to the fact that the KTK presented more of a physical challenge than a cognitive challenge. Future research will need to address this issue.

The distributions of the individual components of the motor skill tasks indicate that the low-challenge (TGMD-2) and high-challenge (KTK) motor skill assessments indeed were capturing at least some element of challenge (Appendix 11). There was a fairly wide variation of scores and there were no apparent ceiling or floor effects for each sub-measure of motor skill performance. Each of the individual components seemed to be capturing some element of variability in the subjects' performances, and contributed to the composite low- and high-challenge measures.

A possible explanation for the finding that there is little impact of challenge on the MS–IH relation is that the low- and high-challenge motor skill measures in this study should have been constructed to capture the acquisition of motor skills, rather than to merely measure the level of motor skills at different challenge levels. Cognitive function should be most engaged during skill acquisition, and might not be as engaged when performing already-acquired motor skills such as in the TGMD-2 measure. With this in mind, it would have been interesting to examine the relation between cognitive function and improvement in newly learned motor skills over subsequent trials. That is, do higher levels of inhibitory control allow children to more quickly master motor skill tasks during acquisition? This question is left to future research.

To better understand the MS–IH relation, greater attention needs to be paid to the tasks that make up future assessments. Tasks selected for future assessments need to be age-appropriate, meaning they need to be motor tasks children of a specific age are in the process of learning. This aligns with Fitts and Posner's (1967) cognitive stage of learning and neuro research indicating that inhibitory control is needed to reduce interference as new neural networks are formed. The tasks also need to match each child's level of motor development. Such tasks might first be identified through examining Clark and Metcalf's model (2002), the *Mountain of Motor Development*. A challenging task for a five-year-old child most likely will not be a challenging task for a ten-year-old child. Indeed, these ages differ in the motor development periods they align with on Clark & Metcalf's model, indicating that children engage in more complex movements as they age. Additionally, a child who has had many enriching opportunities may find a specific motor task less challenging to perform than would a child who has had fewer enrichment opportunities and is performing at a lower developmental level. To test for the MS–IH relation, tasks selected for future assessments also need to require the use of executive functions (Diamond & Lee, 2011). This means there may be a need for a cognitive component in performing the task, suggesting a relation between the two skill sets. This concept of a needed cognitive component in motor learning is similar to the same need in cognitive based learning. Executive functions are needed to stop what one is doing in order to do something else, to ignore distractions so one can focus on new learning or problem solving, to remember rules, and to change perspectives when evaluating or problem solving. Specific to this study, motor assessments would need to require children to stop an automatic learned motor execution (response inhibition), be confronted with conflicting rules or choices, or involve additional conflicting stimuli (interference control) to execute a new movement. Unless executive functions are engaged, there may not be a relation with motor skill performance. Future motor assessments will need to involve activities that require executive functions and not just assess whether or not a child can perform a motor task.

More recent studies are beginning to recognize the importance of building the need for executive functions into their assessments. Marchetti et al. (2015), examined whether motor and physical fitness and sport skills are separately predictive of executive function. The researchers based their study upon the premise that sport activities involve cognitively demanding motor actions requiring the use of executive functions. Other researchers have examined martial arts and yoga with assessments that test for executive functions (Gothe, Kramer, & McAuley, 2014; Gothe, Pontifex, Hillman, & McAuley, 2013; Lakes & Hoyt, 2004; Luu & Hall, 2016). One difference between these types of activities and the assessments in the current study is the increased task demands, or increased cognitive challenge needed to perform the movements. Indeed, sport and activity coaches gradually increase the difficulty of the tasks as students improve, resulting in increased learning and development. Diamond (2011) claims that to see improvements in executive functions, executive functions must be continually challenged, with the strongest improvements evident in activities that place high demands upon executive function abilities. This idea parallels Vygotsky's (1978, 1962) zone of proximal development. Stephan et al. (2002) suggest individuals must be fully conscious of a task to engage the prefrontal regions implicated in this study. This suggests a demand for full attention during performance, which aligns with the initial stage of learning a motor skill (Fitts & Posner, 1967). Diamond and Lee (2011) suggest bimanual training may also improve executive functions. The researchers further suggest sports may improve executive functions through increased demands for attention, working memory, and disciplined action (suggesting inhibitory control is also needed). As Diamond states, “researchers must begin to look at activities that are more interesting than running in place” (Diamond, 2015, pp. 2). These tasks must also provide incremental cognitive challenges as children increase in age and ability.

In light of Diamond & Lee’s (2011) points, the results might have shown stronger correlations if the cognitive challenge had been increased, that is, if more cognitively challenging motor tasks for this age group had been included. The high challenge motor task needed to require a higher demand for executive function, in particular for inhibitory control, than the low challenge task. One way to address the choice of motor assessments for this age group would be to refer to the *Mountain of Motor Development* (Clark & Metcalf, 2002, appendix 3). As the figure of the mountain shows, children ages five- and six are moving up the mountain from the fundamental motor patterns period to the context specific period. This means children are moving from learning their fundamental motor skills to now using these skills in a specific context. This context might be a game of soccer, or baseball, for example. The fundamental movement patterns should be fairly automatic by the end of kindergarten, so that the children can now focus their attention on moving in these patterns, but now with additional constraints. Additional constraints might be running and maneuvering a soccer ball around opposing teammates. Moving in this manner may require an increased demand for executive functions to attend to what is going on within the context of the game as players are continually moving. One has to inhibit kicking the ball until the opportune moment and to evaluate when that moment might be, evaluate the circumstances of the game, and make quick decisions.

Interestingly, these types of activities are what Vygotsky (1962) describes in the Zone of Proximal Development.

Cognitive skills need to be engaged to participate in the game, and with practice and feedback the children continue to improve. A better assessment in the current study might have imitated the components of game participation, doing so for short periods so as not to confound the results with aerobic activity. One possibility would have been to include some of the game drills coaches have their athletes do to prepare for a game. Another possibility would be to be more specific in the components of motor skills used for assessments. For example, Marchetti et al. (2015) assessed ability to finely control motor ability with a kinesthetic discrimination and response task that is needed to fine-tune the force output of a movement. The researchers then examined the ability of participants to adapt the force output in relation to perceived environmental changes. The researchers further assessed the participant's ability to make appropriate decisions.

Other possibilities would have been to include movements that involved bimanual control (Serrien, Ivry, & Swinnen, 2007), crossing the midline, or fine motor manipulation (ping pong, throwing, kicking) with increased external constraints. Rhythm and visual integration also have been hypothesized to increase the challenge level of motor tasks (Diamond, 2015). While an example of a specific assessment may not be available, the executive function components addressed earlier and the *Mountain of Motor Development* (Clark & Metcalf, 2002) taken together may help to guide future research in creating more specific assessments. A benefit of the current study may be to call attention to the need for better assessments. While this study did not show that challenge significantly impacted the MS–IH relation, it is possible that improved assessments could in future come up with a different finding. Indeed, support for new assessments also comes from researchers such as Sheppard and Young (2006) who also suggest a need for new tests that combine physical and cognitive measures.

Additional variables may be more prominent in the MS-IH relation.

While motor skill performance failed to predict either of the inhibitory control outcomes, age predominantly predicted the interference control measures (response time and accuracy). Test group also was a significant predictor of the interference control measures, but to a lesser degree. Age was more strongly correlated to interference control in the summer versus the school group. However, the summer group had a wider age variation than the school group (summer = 60.1 - 83.9 months vs. school = 67.6 - 83.2 months) with a mean difference between groups of 4.4 months. Thus, the inclusion of the summer group of children in the sample may have strengthened the relation of age to interference control. In reviewing studies that used the same assessments as the present research, age was controlled for more often in the studies on inhibitory control versus the studies on motor skill. Consistent with the present research, studies controlling for age on inhibitory control measures found age to be a significant factor in the results. Age being a strong factor in study outcomes follows research that indicates there is a marked growth in neural cells, their complexity, myelination, and the growth of synapse development, all of which facilitate improvement in interference control (Carver, Livesey, & Charles, 2001). In general, the prefrontal cortex shows an overall improvement in processing speed with development (Kail, 1988; Tamm, Menon, & Reiss, 2002). Diamond partially attributes improvements in the Day Night Stroop task to such changes in the prefrontal cortex (Diamond, Kirkham, & Amso, 2002). The results of this study are also in line with Livesey et al. (2006) who found the MS–IH relation to be substantially reduced when age was controlled for. In the current study, age-related changes appear to be the driving force behind the inhibitory control scores. Together, the results of the current study and prior research suggest that another variable, age, may be driving performance of motor and inhibitory control. This finding adds to the small body of literature on the MS–IH relation suggesting age related changes are prominent in this age group.

Yet, while age related changes are largely composed of growth and maturational changes, these changes do not occur in a vacuum. Indeed, Diamond, Kirkham, and Amso (2002) suggested improvements in the Day Night Stroop task may have been partially due to the maturational changes in the prefrontal cortex. Blair and Diamond (2008) describe development as a delicate dynamic interaction between genes and environment. This leaves a question. What other factors may be responsible for IH task improvements? Though the current study cannot answer this question, research suggests inhibitory control is malleable, and dependent upon environmental experiences (Bryce, Szucs, Soltesz, Whitebread, 2011; Diamond & Lee, 2011). Research has also shown that parenting can have a positive or negative effect upon the development of inhibitory control (Carlson & Meltzoff, 2008; Davidov & Grusec, 2006), as can learning two or more languages (Carlson & Meltzoff, 2008) or music training (Seinfeld et al., 2013). Intervention studies have shown children who participate in challenging motor tasks have significantly improved attention and inhibitory control skills when compared to control groups. Further, studies show children who participate in motor skill instruction and practice along with physical activity, improve in executive function skills (Apache, 2005;

Budde et al., 2008; Marchetti et al., 2015; Palmer et al., 2013. This suggests that the development of inhibitory control is facilitated through challenging learning experiences interacting with individual biology. Further, several experiences interacting together may facilitate such development in children (Diamond, 2009). The children in the current study appear to have had a wide variety of enriching and challenging experiences in their lives as shown by the parent surveys. Additional research might explore the effect of participation in enriching experiences and see if they mediate the age related changes.

While growth and maturity are important factors in facilitating development, research indicates the environmental context in which a child is raised also asserts a strong influence (Gallahue & Donnelly, 2003; Shonkoff & Phillips, 2000; Venetsanou & Kambas, 2010). An enriching environment helps to facilitate the child's development on many levels, and possibly could even override the need for motor skill development to foster cognitive development. Many of the children in this sample came from middle to upper class homes and had well-educated parents who could afford to provide them with enriching extracurricular activities. Conversely, research shows an increased risk of both motor and neurodevelopmental and academic delays in children living in disadvantaged environments (Hackman & Farah, 2009; McPhillips & Jordan-Black, 2007). While age was predominant in the current study, what was not accounted for was how these other factors may have influenced or mediated the age related outcomes. It may be that children need a variety of experiences in their early years, and together these experiences may facilitate and foster normal development. For example, while young children are learning their motor skills, they are also improving their physical fitness, their social skills, and so on. The influence of the individual domains on cognitive development has not been parsed out in research. Yet two studies indicate that physical fitness and motor skill learning together are related to attention and/or to inhibitory control (Marchetti et al., 2015; Palmer, Miller, & Robinson, 2013). The present research suggests what inhibitory control looks like in children who receive many enriching experiences, but does not tell us what inhibitory control looks like in children who do not receive these experiences. Further research can improve upon the current study to address this issue.

A further consideration regarding the MS–IH relation may be whether motor skill performance ties to executive functions other than inhibitory control. Research does not provide clear and consistent findings. However, research suggests that inhibitory control is a precursor to higher-level executive function skills (Macdonald et al., 2014). There has been some research on the relation of working memory and motor skills performance, yet findings are mixed (Piek et al., 2004; Rigoli, Piek, Kane, & Oosterlaan, 2012; Roebers & Kauer, 2009; Wassenberg et al., 2005). Studies have also found some indication that speed of performance (Piek et al., 2004, Planinsec, 2002; Roebers & Kauer, 2009) or task switching (Rigoli et al., 2012) tie to motor performance. This is an area of research beyond the scope of this study, yet one that warrants more investigation.

The process of learning and performing motor skills is a dynamically changing process. Roebers and Kaurer (2009) assert that several executive function components may be activated in the process of performing motor skills, with differing emphases. It may be that inhibitory control works in a coordinated way with other executive functions. The various executive function skills may come on and offline as needed to execute motor tasks. This may be further complicated by age and development.

Limitations

This study presents some limitations. First, as the study was correlational, the results cannot be interpreted as causal. The study was observational and did address possible confounding variables, but the results indicate associations only. Correlational findings cannot authoritatively direct clinical or academic interventions or curriculum development.

Second, the present study employed a convenience sample that is not representative of all typically developing children. Neither is the sample representative of all the children of this age group in one school, presenting selection bias. The parents had the option of whether to have their child participate or not and the children had the same option. Therefore, the final sample may differ from the larger possible sample in various ways.

A third limitation is one of generalizing the results of this study to a larger or broader population. From the homogenous sample assessed in this study it is not possible to generalize to children with disabilities, children from lower socioeconomic populations, children from more diverse ethnic backgrounds, or even to children with high body mass indices/health issues. A more diverse sample may yield different results. Moreover, it is not possible to generalize to a broader age range. The study was limited to five and six-year-olds.

The assessments currently available also limited the study. Few available assessments provide ways of testing typically developing children or ways of measuring challenge to test the hypothesis of the study. Research has not shown how cognitive demanding it is to learn motor skills, such as the fundamental motor tasks in the TGMD-2 or the coordination tasks in the KTK. Further, the cognitive challenge may change with age, development, or experience. Future research will have to address this lack of knowledge. The cognitive assessments in the study included both a behavioral assessment (HTKS) and a computerized assessment (BST). The BST is a fairly new assessment, and the children's familiarity with technology could further influence results.

The current study was designed to include children ages five and six, however this age group includes children who may or may not have attended a year of kindergarten. Attending a year of kindergarten is determined both by the state cut off date for age and then by parental choice (often determined by age, maturity, or parents' view on the child's readiness). Children who had attended a year of kindergarten were able to participate in weekly school physical education classes. Curriculum for the kindergarten year includes fundamental motor skills such as those assessed on the low-challenge motor task in this study. Therefore, children who had a year of kindergarten may have had more instruction and practice on learning these motor skills than the children who had not yet entered kindergarten, presenting a limitation on the study.

The inclusion of low-challenging tasks increased the risk of skewing the data. If the task is less challenging, then the probability arises that most of the children will do well, particularly in a narrow age range. This clearly was at play in the low-challenge HTKS inhibitory control measure, which was left skewed and had a ceiling effect at a score of around 50. It is less obvious in the other variables of the study, which while often not normal, at least were somewhat symmetrically distributed around their medians (see Table 3). The results must be interpreted with caution because the analyses are sensitive to normality.

Finally, it must be remembered that two types of gross motor skills were assessed in this study. Motor development includes many motor skills (e.g., fine motor skills) that were not addressed here. Furthermore, executive function is an umbrella term that includes several distinct but interrelated skills. Only one of these skills, inhibitory control, was addressed here. Therefore the results cannot be interpreted in a broader sense that includes all motor and executive function skills. Again, development is complex, and current theory suggests it is a dynamic process (Diamond, 2009; Shonkoff & Phillips, 2000). Being a dynamic process, development can progress or regress and can be influenced by a multitude of variables. This means that children can vary in their performance greatly from day to day, and even a slight change in any variable can impact the performance of a skill at a particular moment in time. This might encourage researchers to conduct a more comprehensive, larger scale longitudinal study.

Strengths of the Study and Future Research

While the homogeneity of the sample poses limitations, it also is one of the strengths of the study. The sample presents a model of the types of enriching experiences that might help typically developing children reach optimal development with their motor and inhibitory control skills. The children in the study had access to quality instruction, came from homes with educated parents, had a variety of enjoyable extracurricular experiences, and participated in a well-rounded school curriculum that included physical education, art, music, and recess. These experiences may be ones that work together to fulfill the developmental needs of young children.

Another strength of the study was increased validity of the results through the use of the TGMD-2 (Ulrich, 2000) and the KTK (Kiphard & Schilling, 2000) with the obstacle course (Niederer et al., 2011). These assessments focused upon a specific group of skills rather than a broader range of skills such as used in previous studies. For example, in specifically examining fundamental motor skills (TGMD-2), several motor skills of the same group were assessed rather than one or two from the group. This increases validity by assuring results are due to the fundamental motor skills, rather than a single skill such as hopping or throwing.

Another contribution of the study was controlling for variables that might be related to the MS–IH relation. The correlation results indicated a significant relation between the low challenge motor skill and the high challenge inhibitory control measures. However, the significance of the relation nearly disappeared when age was included as a control in the regression model. Age was the predominant factor in measures of motor skill and inhibitory control, as well as in the MS–IH relation. Future research should assess and statistically test for potentially important covariates, particularly age.

The use of the BST (Esposito et al., 2013) was an additional strength of the study. The BST offered the ability to put additional demands on inhibitory control through the use multiple stimuli in a form that young children who do not yet read can perform. Secondly, the assessment was a computerized and thus could provide results both for accuracy and response time. Thirdly, being a computerized assessment, the task was able to capture the cognitive aspect of inhibitory control rather than the motor aspect. In all, the BST provided a means to assess younger children on a more advanced component of inhibitory control without the ceiling effects found in previous assessments.

An additional strength of the study was the strong indication that age needs to be considered in future studies on the MS–IH relation. However, since this study was composed of a very homogeneous group, it would be interesting to control for age in more diverse samples. While the findings of the current study included a sample of children raised in enriching environments, researchers might build upon this research to broader age ranges and other executive function skills.

Researchers might also consider studies that capture the change in the MS–IH relation over time (longitudinal) or through an intervention study. As the motor assessments in the current study may have limited the ability to adequately assess the study hypothesis, alternative methods of capturing the idea of challenge should be considered in future research. Because research suggests that learning (including motor learning) occurs with practice over time, longitudinal studies must be conducted. Longitudinal studies could be designed to account for the types and amounts of experiences children engage in with the use of more detailed surveys. This may clarify the types of experiences children with increased MS and IH abilities engage in that may facilitate age-related changes. A short, intense motor skill intervention study with a control group would be appropriate and allow for assessing children's motor and inhibitory control before, during, and after the skill learning.

Another method may be to assess individuals during the motor acquisition phase when motor tasks are most challenging. This could be accomplished through teaching a motor skill that is new and meets criteria for increased cognitive demand (attention, motor planning, spatial orientation, bimanual tasks, inhibition, etc.). Examples might include juggling, overhand striking, or line dancing. These tasks are not generally taught at the five and six-year-old level, but are skills that could be learned in this age group. While the current study was behavioral, researchers might also consider using EEG assessments to capture brain activity during motor skill learning to identify brain regions that are activated during the period of motor skill learning. The results could be compared across different motor skills or before, during, and after motor skill learning.

Another question to consider in future research surrounds motor skill and inhibitory control abilities for individuals who participate in different activities. Do those who engage in soccer versus weight training have higher inhibitory control scores? What might be the changes in inhibitory control and motor skill scores after a weight training, soccer, or TV watching intervention? Clearly, many questions can be asked in considering the role of challenge in the MS–IH relation.

In addition to examining the effects of an intervention or change over time, researchers might continue to explore the MS–IH relation with more challenging motor skills. It is not known if the low-challenge motor skills were more cognitively challenging than the high-challenge motor skills used in this study. If the more cognitively challenging motor skills were the low-challenge tasks, researchers might investigate whether using even more challenging fundamental motor skills would result in stronger correlations yet (based upon work by Diamond, 2015; Diamond & Lee, 2011). While some of the low-challenge motor skills were challenging for a number of the children in the study, the scores for all the low-challenge motor skills were combined for a composite score in the current study. Thus, the composite score included motor skills at a variety of challenge levels. It would be interesting to see what the results might look like when all the motor skills may be more challenging or in the initial stages of learning.

Skipping and the overarm strike were not examined in this study, yet may be quite challenging for five and six-year-old children yet appropriate skills for this age group. Both skills are examples of additional fundamental motor skills that could be considered in future research. These two skills include motor planning, bilateral and bimanual coordination, and coordinated rhythm to perform. Though the current study examined six skills from the TGMD-2, the full battery of skills from the TGMD-3 might be assessed. Further, assessing children prior to a year of kindergarten, or late fall of the start of the kindergarten year, may offer further insight into the MS–IH relation. During the kindergarten year children receive intentional instruction and practice on these skills, so assessing them in the fall may provide a period of assessment when these skills are more challenging for this age group.

Likewise, exploring motor coordination skills that have a stronger cognitive component may also provide different results.

As a small correlation between the low-challenge motor and the high-challenge inhibitory control tasks was found in this study, investigating the MS–IH relation with more challenging fundamental motor skills may be warranted.

Future research might also explore the relations of other executive functions with motor skills. While the current study examined two types of inhibitory control, other components of inhibitory control such as delay of gratification were not examined. Moreover, other executive function skills such as working memory and cognitive flexibility were not examined in this study and may be areas to investigate in future studies. It may be that other executive functions may be more strongly related to motor skill performance. Future studies can further investigate these topics.

Conclusions

Recently, research has shown a renewed interest in the relation between motor skills and executive functioning, yet studies present inconsistent findings and conclusions. The current study found age to be a prominent factor in this relation and a strong predictor of interference control. The maturational changes children go through may explain the age relation. The sample of children assessed in this study may also have been a factor as many of the children came from advantaged homes with plentiful enrichment experiences. Future research may wish to examine how these experiences interact with age or see if a more diverse sample of children produces findings similar to the current study.

A small, significant relation between the low challenge motor skill measure and the high challenge inhibitory control measure was identified but disappeared once age and the test group were accounted for. The MS–IH correlations did not support challenge as an influential factor in this relation. What is interesting about the findings is that they contradict what theory and research present on learning. This may simply suggest a need for new or improved motor or cognitive assessments. Alternatively, future work may point to a need to rethink theory on the connection of motor functioning and cognition.

APPENDICES

APPENDIX A

Definitions and Terms

Behavioral regulation - the integration of attention, inhibitory control, and attention to manage behavior (McClelland et al., 2007).

Body mass index (BMI) – a measure of body fat derived using measures of height and weight (Payne & Isaacs, 2012).

Challenging motor skills – the concept of challenge for this study is defined as a motor task that is more difficult than the ability of the children assessed, yet not so difficult that the children cannot cognitively or physically perform. Thus the motor skill will not be a learned, automatic skill, but new and optimally challenging to the children. This conceptualization is derived from Vygotsky's Zone of Proximal Development (Vygotsky. 1978).

Development – "Refers to the intellectual, social, physical, and emotional changes one experiences as they go through life" (Payne & Isaacs, 2012, pp. 6) and involves qualitative transitions from a set of less effective to more effective strategies" (Adolph & Tamis-LeMonda, 2014, p. 187).

Executive function skills – a set of mental skills important in learning and involved in control and coordination of information. Executive function skills are generally viewed as skills used to flexibly monitor and control behavior in novel, changing, or demanding situations (Anderson, 2002; Bryce, Szucs, Soltesz, & Whitebread, 2011) and include inhibitory control, working memory, and attention shifting (Hughes, Ensor, & Wilson, 2010).

Inhibitory control – the ability to voluntarily stop a strong or dominant response in favor of a weaker, or more adaptive response (Dowsett & Livesey, 2000). Inhibitory control can be seen in the ability to suppress information that is distracting or unnecessary for performance success (Blair & Razza, 2007).

Interference control – involves suppressing irrelevant stimuli in order to focus or attend to other stimuli based upon a goal or intention providing control over attention and action (Davidson et al., 2006; Diamond, 2013).

Motor Agility – movements that utilize "rapid whole-body movements with a change of velocity or direction in response to a stimulus" (Sheppard & Young, 2006, pp. 922).

Motor Proficiency – the ability to perform complex movement patterns with motor control utilizing fine and gross motor skills (Bruininks & Bruininks, 2005).

Motor skills – for this study are referred to as fundamental motor skills that form the foundation for more complex sport skills in later childhood. Fundamental motor skills include locomotor skills (e.g., running, hopping, skipping, jumping) and object control skills (e.g., throwing, catching, kicking, striking). Motor skills can further be divided into fine motor skills that involve the use of small muscles of the body, or gross motor skills that involve the use of large muscles of the body (Gallahue & Ozmun, 1995, Payne & Isaacs, 2012).

Readiness – readiness is a complex concept, varies by individual schools, and by parent or teacher input. Generally, readiness refers to attributes and attitudes children need to succeed in kindergarten (West, 1995).

Self-regulation - the interaction of inhibitory control, attentional control, and working memory to regulate thoughts and behavior (Becker, McClelland, Loprinzi, & Trost, 2014) in a self-controlled manner (Blair & Diamond, 2008).

Sport skills – a combination of fundamental movement skills needed to perform sport-related activities. Learning these skills requires increased precise alterations in movement and control of the basic motor skills to achieve higher levels of skill (Gallahue & Ozmun, 1995).

APPENDIX B

The Mountain of Motor Development Explanation

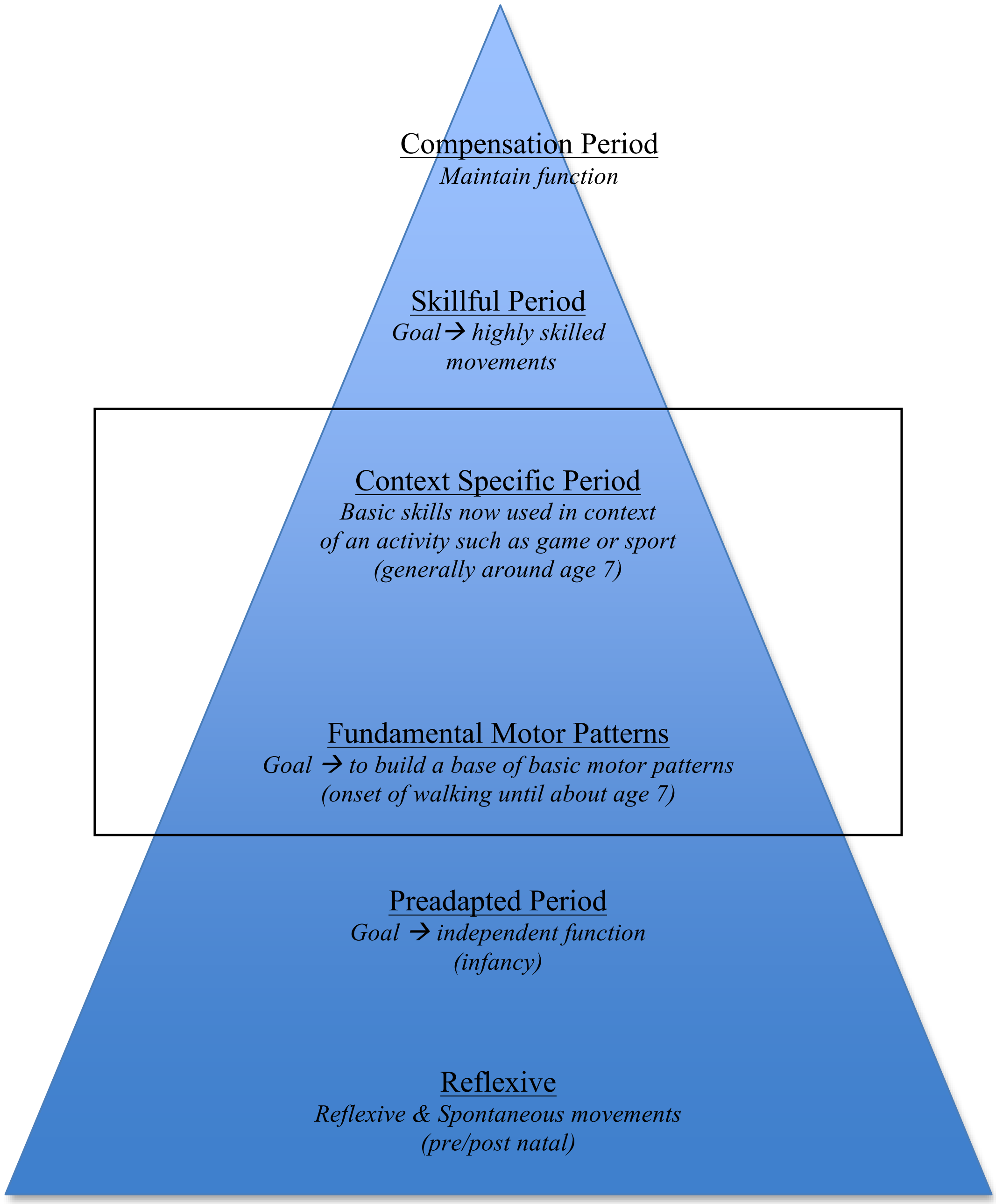
(The Model is on the next page)

The Mountain of Motor Development is a pictorial model of the periods children pass through in learning their movement patterns. The first period is the reflexive period, noted at the base of the model. From here, children move through the movement periods as shown in the model by moving up the pyramid. For example, children move from the reflexive period to the preadapted period.

The two periods of focus for the current study are identified within the rectangle in the middle of the pyramid (fundamental and context specific). Five and six-year-old children are the latter stages of learning their fundamental motor skills. By age six or seven, most children have a good base of these foundational motor skills and are ready to use them in context of a game or play activities (Clark & Metcalf, 2002; Seefeldt & Haubenstricker, 1982). As the fundamental motor skills have become more automatic, the children can now focus on combining skills, or using the skills to achieve a goal such as to make a goal and a sport game, tag someone in a game of tag, to play hopscotch, or jump rope. This illustrates children's transition to the context specific period. This transition is important for this study as it begins to occur for many children during the kindergarten year as they participate in recess, physical education, and after school physical activities and represents new learning.

This period is also an important time of transition, or a period of instability, as motor skills are being challenged and used in new ways. Thus, once again children are facing motor challenges, requiring new learning to master these new skills.

Figure 1. The Mountain of Motor Development

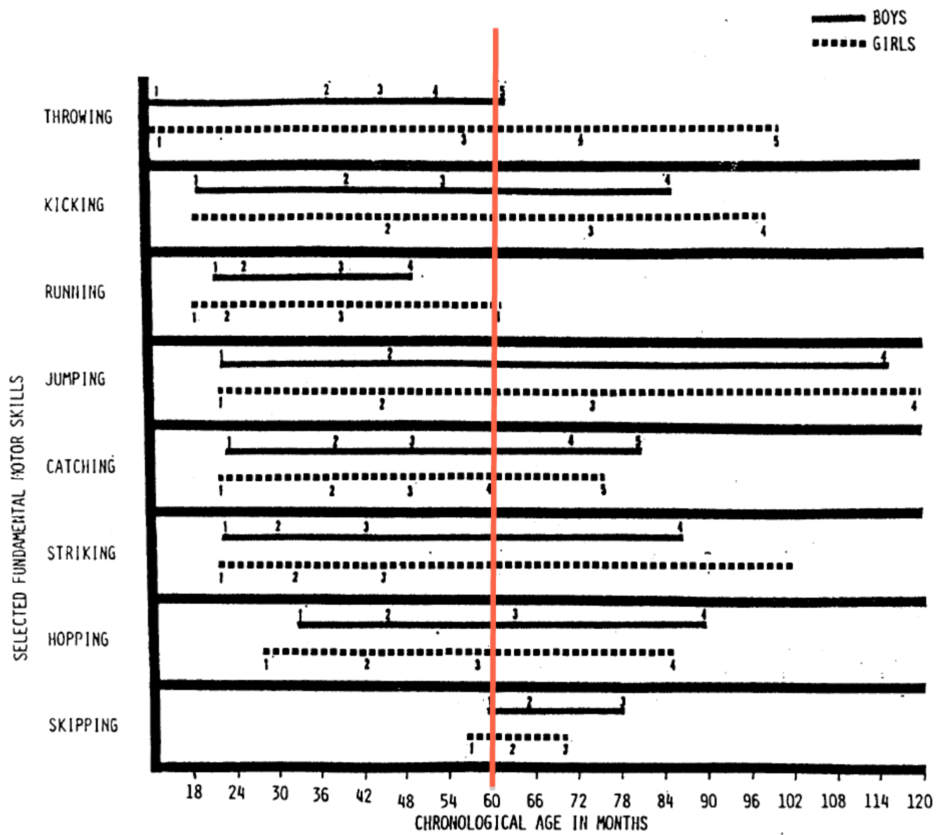


The Mountain of Motor Development (Clark & Metcalfe, 2002)

APPENDIX C

60% Chart

Figure 2. 60% Chart



AGE AT WHICH SIXTY (60) PERCENT OF THE BOYS AND GIRLS WERE ABLE TO PERFORM A SPECIFIC DEVELOPMENTAL LEVEL FOR SELECTED FUNDAMENTAL MOTOR SKILLS

Taken from: Seefeldt, V. & Haubenstricker, J. Patterns, phases, or stages: An analytical model for the study of developmental movement. In J.A.S. Kelso & J.E. Clark (Eds.), The Development of Movement Control and Coordination. New York: Wiley, 1982.

The 60% chart on the following page was created to show where 60% of children at a specific age perform their motor skills at a specific level. The chart was used to identify the skills that 60% of the children could perform past level 2 by age five. By performing a motor skill beyond level two, the children were no longer at the initial stage of learning the motor skill, theoretically reducing the cognitive resources needed to perform the motor skill.

- The column on the left identifies the motor skill.
- The most bottom row identifies the age in months.

- The horizontal lines (solid and dotted) represent each gender. The solid line represents boys, while the dotted line represents girls of the same age for the same skill. Thus differences in performance of the same skill by gender can be viewed.
- On top of each horizontal line is a number (1-5). This number represents the level of performance for each skill. This helps the viewer note the age at which a specific performance level is achieved for a particular skill by gender.
- The solid vertical line in the center represents age five, the bottom age range for the children in the current study.

APPENDIX D

Introductory Letter to Parents

Dear Parents/Legal Guardians

You and your child are invited to participate in a research study so we can learn more about how children's motor skills relate to their executive functioning. Executive function skills are very important for learning. This study will help us better understand developmental needs in the kindergarten age group. For this reason I will be assessing the motor skills, an executive function skill, and height and weight of the kindergarten children at Thornapple Elementary School. All children will be able to participate in the activities but information will only be kept for the children whose parents and the children would like to participate. I hope you will consider participating in this important study.

To complete the study, I will need parents/legal guardians to do the following:

- Read the information in the packet carefully

If you and your child would like to participate:

- Sign the consent form and return in a sealed envelope to the child's teacher
- Complete the parent/legal guardian questionnaire and also return it in the envelope to your child's teacher.
- *An envelope is provided for your convenience*

I look forward to working with your children over the next couple of weeks. I am also a former kindergarten teacher and will love to be working with kindergarten children again.

The 60% chart was created to show where 60% of children at a specific age perform their motor skills at a specific level.
The column on the left identifies the motor skill.
The most bottom row identifies the age in months.
The horizontal lines (solid and dotted) represent each gender. The solid line represents boys, while the dotted line represents girls of the same age for the same skill. Thus differences in performance of the same skill by gender can be viewed.
On top of each horizontal line is a number (1-5). This number represents the level of performance for each skill. This helps the viewer note the age at which a specific performance level is achieved for a particular skill by gender.
The solid vertical line in the center represents age five, the bottom age range for the children in the current study. The chart was used to identify the skills that 60% of the children could perform past level 2 by age five. By performing a motor skill beyond level two, the children were no longer at the initial stage of learning the motor skill, theoretically reducing the cognitive resources needed to perform the motor skill.

This study is for the completion of my PhD work at Michigan State University, thus I very much appreciate your participation and help. Please call, write, or email if you have any questions. The activities should be fun for the children – they will be moving and playing!

Thank you!
Ginny Witte
PhD Candidate
Department of Kinesiology
Michigan State University
East Lansing, Mi. 48824
wittevir@msu.edu

APPENDIX E

Parent/Legal Guardian Questionnaire

<table>
<tr><th colspan="4">Parent/Legal Guardian Questionnaire</th></tr>
<tr><td>Child's name</td><td colspan="3"></td></tr>
<tr><td>Child's birthdate</td><td>/ /</td><td>Child's gender</td><td>M F</td></tr>
<tr><td>Child's ethnicity</td><td colspan="3">African American, Asian, Caucasian, Hispanic, Other (Circle one)</td></tr>
<tr><td>Mother's education level (Circle one)</td><td colspan="3">some high school high school graduate
vocational certification 2 yrs. College
college graduate graduate degree</td></tr>
<tr><td>Father's education level (Circle one)</td><td colspan="3">some high school high school graduate
vocational certification 2 yrs. College
college graduate graduate degree</td></tr>
<tr><td>Parent contact information (please choose your preferred method of contact)</td><td colspan="3">Phone:
email:
address:
(You will only be contacted if need arises. Your information will not be shared)</td></tr>
<tr><td colspan="4">Please indicate if your child has any documented disabilities that would impede their participation in the study.</td></tr>
<tr><td>Physical limitations (ex. cerebral palsy, broken leg)</td><td>Cognitive limitations</td><td>Behavioral limitations</td><td>Emotional limitations</td></tr>
<tr><td colspan="4">Does your child have documented vision problems? Yes No</td></tr>
<tr><td colspan="4">Does your child have documented hearing problems? Yes No</td></tr>
<tr><td colspan="4">Your child's hand preference Left Right</td></tr>
<tr><td colspan="4">Does your child participate in any extracurricular activities? Yes No
If so how many hours per week? 1 2 3 4 or more
Types of extracurricular activities? ________________________________</td></tr>
<tr><td colspan="4">Concerns or questions:</td></tr>
</table>

Thank you for answering. Please return the questionnaire and the signed consent form in the sealed envelope to your child's teacher by ______. Your answers will help us know if your child will be able to perform the activities as well as concerns you may have.

APPENDIX F

Parental Consent Form

Project Title: The Relation Between Motor Skill Performance and Cognitive Function in Kindergarten Children

You and your child are invited to take part in a research study being conducted by Ginny Witte, a doctoral student from the Department of Kinesiology at Michigan State University, under the supervision of Dr. Kirt Butler. This form is to inform you of the policies and your rights in participating in research.

Purpose of the Research
This is a study focused on young children, with a goal to understand how motor skills, or our basic moving skills such as running, hopping, and throwing, relate with cognitive skills, to help children learn. Cognitive skills are skills such as focusing attention, remembering instructions, and regulating one's behavior. Children who are not capable of performing fundamental motor skills will not be able to participate.

What you and your child will do
Parent participation will involve completing a short questionnaire and signing this consent form. Children will be assessed on fundamental movement skills, two short cognitive skills, and height and weight measurements. These assessments will take place in the child's home at your convenience. The computer game and height and weight measurements will take approximately 10-15 minutes per child. The fundamental motor skill assessments will take approximately 30 minutes per child. This motor skill assessments may be videotaped so that the skills can be scored at a later time. During the cognitive assessment your child will be asked to play a game similar to 'Simon Says' and complete a short computer game.

Risk and Benefit
Research studies have both benefits and risks of participation. The benefits of this research study include: gaining a better understanding the relation between motor skills and cognitive functioning, or skills that facilitate learning, to provide data that will improve and support physical activity at home, in physical education class in your child's elementary school, or through extra curricular activities. The research will also provide data on critical cognitive skills that can be enhanced through classroom instruction. A general, overall review of the results of the study will be given to your school's principal and any interested parents. Also detailed information cannot be shared, general information about motor skills and cognition can be shared with interested parents.

The risks of participation are minimal and no greater than activities performed during a child's normal play or scheduled activities. Possible risks might be slipping while running or jumping. These risks are reduced through supervision and a positive and a fun, non-competitive atmosphere. The activities will be conducted as a treasure hunt, with the children choosing a small treasure (Frisbee, ball, jump rope) after the activities are completed. All assessments have been used in previous studies with many children without experiencing any of these risks and are perceived as fun and enjoyable activities by the children.

Participation and Confidentiality
All the information collected will be treated with confidence. No one except members of the research team and Michigan State University's Human Research Protection Program may have access to any research data. Your child's name will not be used in any reports or presentations. The study results will be based on the answers from all participants together as a group to ensure confidentiality of individual responses and assessments. Videotape material will only be shown for purposes of presentations or instruction if I have your permission. Your child's confidentiality will be protected to the maximum extent allowable by law. All records, both written and electronic, will be locked in the researcher's file cabinet and on a password protected computer file for at least three years after the completion of the study. Then records will be destroyed. You may restrict the use of different information on your child at any time. Please ask any questions about the study or activities that you are not sure about.
-It should be noted that if there is suspicion of child abuse or similar types of situations in which the safety of your child is at risk, MSU employees are required to report the information to the proper authorities.

Your Rights to Participate
Participation is voluntary. You or your child may choose not to answer specific questions or may discontinue participation at any time.

Cost and Compensation
There are no costs to participate. At the end of the second session with the children, each child may choose a toy or book to encourage physical activity, valued at approximately $5.00.

The right to get help if injured
The motor skill activities are common childhood activities. These include hopping, throwing, jumping, a short obstacle course, etc. However, as with all activities, there is a possibility of injury. If this occurs, please be aware of Michigan State University's policy. If your child is injured as a result of their participation in the research study, Michigan State University will assist parents or legal guardians in obtaining emergency care if needed. Your insurance carrier will be billed in a normal manner. Costs not covered by insurance, including deductibles, will be the parent or legal guardian's responsibility. The University does not provide compensation for injury related expenses such as pain or discomfort, lost wages, or disability, unless required by law.

Contact Information
If you have any concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher, Ginny Witte by phone at 616-648-5550, or by e-mail at wittevir@msu.edu. You may also contact the primary investigator, Dr. Kirt Butler by phone at 517-432-0035, or by e-mail at butler@msu.edu.

If you should have any questions regarding the study, the role of a research participant, or would like to share input or concerns, or register a complaint about this research study, you may anonymously contact the Michigan State University Human Research Protection Program at: 408 W. Circle Dr., Room 207, Olds Hall
East Lansing, Mi. 48824; Phone: 517-355-2180; FAX: 517-432-4503 or
email irb@msu.edu Thank you for your time with this study.

Documentation of Informed Consent
Your signature below means that you voluntarily agree to participate in this research study.

____

Parent Signature Date

Your signature below means that you voluntarily agree to allow your child to participate in this research study.

____

Parent Signature Date

____
Child's name (please print)

Please check
_____I grant permission for my child to be videotaped during the motor skills testing.
_____I do not want my child videotaped during the motor skills testing.

_____ I grant permission for videotapes to be used for educational purposes.
_____ I do not grant permission for videotapes to be used for educational purposes.

APPENDIX G

Child Assent Form

(Page one is to be read to the children, page two is the signature page)

We are doing some research on how children play, think, and exercise.
I asked your parents if it was OK to talk with you today and they said "yes."
What I would like to do is watch you 2 times in your gym class, measure how tall you are, and who much you weigh. I also want to watch you play a game on the computer. You don't have to help if you do not want to. No one will be mad or upset.

I will pass out a piece of paper with a place for your name at the top. The paper also has pictures of 2 faces, a smiley face, and a face without a smile.

Please write your name on the line at the top of the paper.
Then circle the smiley face that tells me if you want to help. Circle a smile if you want to help, and the face without a smile if you do not want to help.

Thank you!

Name:

I know my mom and/or dad (legal guardian) have said it is OK for me to do these activities.

I am doing the activities because I want to. I know I can stop at any time that I wish

Yes, I would like to do these activities.

No, I would not like to do these activities.

APPENDIX H

MSU Initial IRB Application Approval

MICHIGAN STATE
UNIVERSITY

Initial IRB Application Approval

May 1, 2015

To: Kirt Butler
645 N. Shaw Lane Room 318

Re: **IRB#** 15-437 Category: EXPEDITED 6,7
Approval Date: May 1, 2015
Expiration Date: April 30, 2016

Title: Exploring Motor Skill Performance and Cognitive Function in Kindergarten Children

The Institutional Review Board has completed their review of your project. I am pleased to advise you that **your project has been approved**.

The committee has found that your research project is appropriate in design, protects the rights and welfare of human subjects, and meets the requirements of MSU's Federal Wide Assurance and the Federal Guidelines (45 CFR 46 and 21 CFR Part 50). The protection of human subjects in research is a partnership between the IRB and the investigators. We look forward to working with you as we both fulfill our responsibilities.

Renewals: IRB approval is valid until the expiration date listed above. If you are continuing your project, you must submit an ***Application for Renewal*** application at least one month before expiration. If the project is completed, please submit an ***Application for Permanent Closure***.

Revisions: The IRB must review any changes in the project, prior to initiation of the change. Please submit an ***Application for Revision*** to have your changes reviewed. If changes are made at the time of renewal, please include an ***Application for Revision*** with the renewal application.

Problems: If issues should arise during the conduct of the research, such as unanticipated problems, adverse events, or any problem that may increase the risk to the human subjects, notify the IRB office promptly. Forms are available to report these issues.

Please use the IRB number listed above on any forms submitted which relate to this project, or on any correspondence with the IRB office.

Office of Regulatory Affairs
Human Research Protection Programs

Biomedical & Health Institutional Review Board (BIRB)

Community Research Institutional Review Board (CRIRB)

Social Science Behavioral/Education Institutional Review Board (SIRB)

Olds Hall
408 West Circle Drive, #207
East Lansing, MI 48824
(517) 355-2180
Fax: (517) 432-4503
Email: irb@msu.edu
www.humanresearch.msu.edu

Good luck in your research. If we can be of further assistance, please contact us at 517-355-2180 or via email at IRB@msu.edu. Thank you for your cooperation.

Sincerely,

Ashir Kumar

Ashir Kumar, M.D.

Chair, Biomedical and Health Institution Review Board (BIRB)
Human Research Protection Program

c: Virginia Witte

APPENDIX I

School Acceptance Letter to Perform the Study

THORNAPPLE ELEMENTARY SCHOOL

Greg Shubel, Principal

6932 Bridgewater SE, Grand Rapids, MI 49546   PH 616.493.8920   FAX 616.493.8929

February 2, 2015

To the Michigan State University Instructional Review Board,

The purpose of this letter is notify the MSU Instructional Review Board of the approval for Mrs. Ginny Witte to conduct the research necessary for her study on the relationship between motor skill performance and the inhibitory control in kindergarten-aged lower and middle socioeconomic status students.

She is currently in contact with the necessary Thornapple staff to complete this research and it is my hope that the assessments she has chosen will provide relevant insight into factors that influence a child's physical and cognitive development.

Sincerely,

Gregory W. Shubel

Greg Shubel
Principal, Thornapple Elementary School

Forest Hills

Forest Hills Public Schools

Daniel Behm, Superintendent

APPENDIX J

Physical activity treasure hunt

TREASURE HUNT

----------- activity ------------ -------------- treasure ----------------

RUN

THROW

KICK

HOP

JUMP

STRIKE

CATCH

WALK BACKWARDS

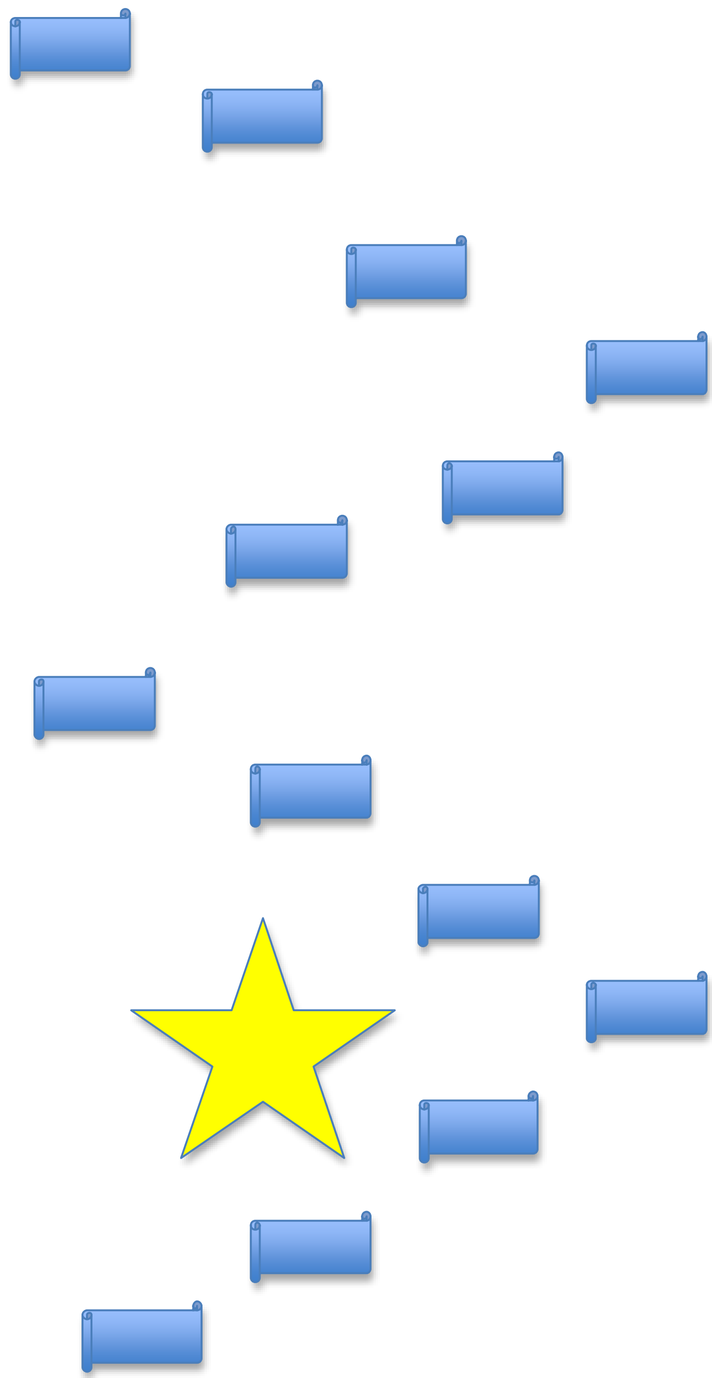
MOVE ACROSS FLOOR

JUMP OVER OBSTACLE

JUMP OVER TAPE

TOUCH YOUR HEAD

COMPUTER GAME



APPENDIX K

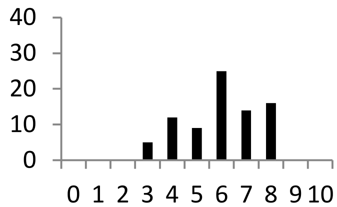
Descriptive information on the low-challenge motor skill (MS) sub-measures

Table 10. Descriptive information on the motor skill (MS) sub-measures

Low-challenge motor skill measure MS1 (TGMD-2)

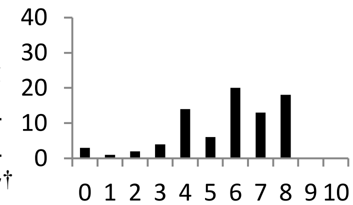
Jump

N	81
Mean	5.98
Stdev	1.49
Skew	$0.8^{\dagger}$
Kurtosis	1.2



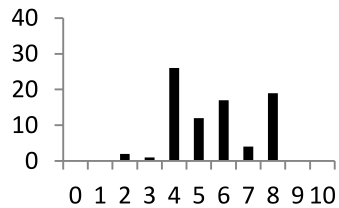
Hop

N	81
Mean	5.65
Stdev	2.04
Skew	0.4
Kurtosis	$-1.7^{\dagger}$



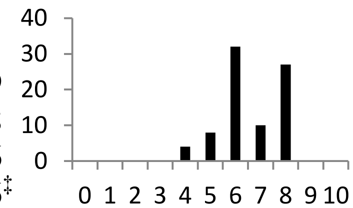
Kick

N	81
Mean	5.59
Stdev	1.66
Skew	0.3
Kurtosis	$-1.5^{\dagger}$



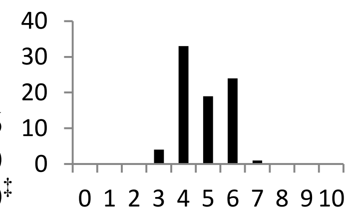
Throw

N	81
Mean	6.59
Stdev	1.18
Skew	0.6
Kurtosis	$-2.6^{\ddagger}$



Catch

N	81
Mean	4.81
Stdev	0.96
Skew	0.0
Kurtosis	$-2.0^{\ddagger}$



Strike

N	81
Mean	6.40
Stdev	1.77
Skew	0.6
Kurtosis	-0.6

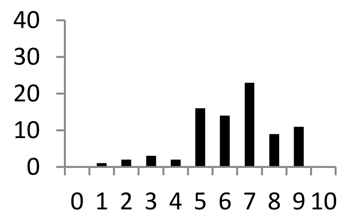
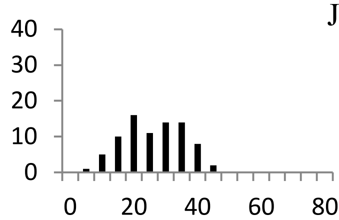


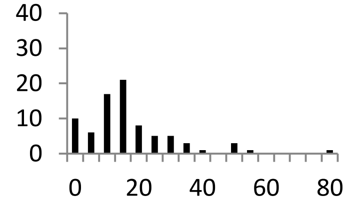
Table 10. (cont'd)

High-challenge motor skill measure MS2 (Korperkoordinations Test fur Kinder, or KTK)

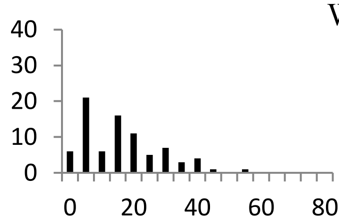
Moving sideways	
N	81
Mean	26.2
Stdev	9.4
Skew	-0.3
Kurtosis	-1.3



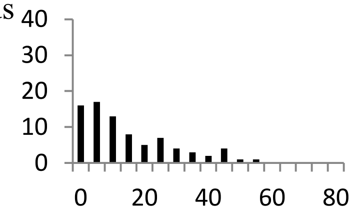
Jumping sideways	
N	81
Mean	17.0
Stdev	14.1
Skew	1.4‡
Kurtosis	1.3



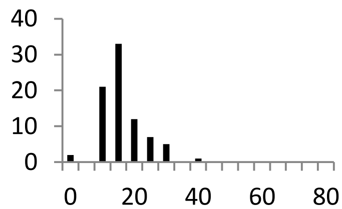
Hopping for height	
N	81
Mean	16.4
Stdev	12.2
Skew	1.3‡
Kurtosis	1.0



Walking backwards	
N	81
Mean	14.8
Stdev	14.2
Skew	0.9‡
Kurtosis	-0.5



Obstacle course	
N	81
Mean	16.2
Stdev	6.7
Skew	1.2‡
Kurtosis	0.7



† and ‡ indicate significance at 5 percent and 1 percent significance levels, respectively.

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