THE EFFECTS OF UNSTRUCTURED, OUTDOOR PLAY ON MUSCULAR STRENGTH AND NEUROMUSCULAR CONTROL IN CHILDREN

by

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ABSTRACT

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Inactivity levels among children are climbing at alarming rates, leading to research focused on cardiovascular health. However, a less known but severely dangerous childhood inactivity effect is the lack of activities that produce muscular strength (MusS) development. Appropriate MusS during childhood decreases the chances of diabetes, obesity, cardiovascular disease, and cancer while increasing bone mineral density, healthy blood lipid profiles, insulin sensitivity, mental health and quality of life dimensions. Increases in MusS also create efficient neuromuscular control (NC), allowing the child to exhibit more powerful and efficient movements. Developing appropriate MusS during childhood leads to physical, neurological, physiological, and cognitive advantage, leading to healthier, active future adults. Therefore, this dissertation explored movements beneficial for MusS and NC development in childhood, testing measures for assessing MusS and NC among children, and exploring outdoor, unstructured play as a means of promoting healthy MusS and NC development naturally for all children.

Chapter 1: Introduction

1.1 Foundation of Limb Movements

An eight-week-old fetus moves with distinct limb movement patterns that are easily recognizable and continue after birth (Einspieler et al., 2016). These movements, or lack thereof, aid in deciphering between the typical developing infants and those who may need early occupational and physical therapy interventions (Aizawa et al., 2021). Mastery of these limb movement patterns continues to advance through adulthood and is necessary for the correct brain network development to emerge (Cebolla & Cheron, 2019; Einspieler et al., 2016). Piaget's theory of cognitive development reinforces this idea that the more a body moves and interacts with the world around it, the better one can understand and synthesize new information (Babakr et al., 2019; Piaget, 1952). This new information is compared to existing information to create new physical or cognitive milestones. These milestones, or schemas, are the social, emotional, psychological, and physical building blocks required for the next stage of development (Piaget, 1952). The more schemas a child has to reference, the better they understand the world around them as they compare new experiences to stored references (Wynberg, 2021).

The physical schema foundation can be seen in Bartenieff Fundamentals (BF). BF is a theoretical framework adopted by disciplines such as dance to describe these fundamental body movements derived from all other bodily movements (Berardi, 2004). BF framework has determined movements begin in utero and continue as varying forms throughout the lifecycle, emphasizing the importance of making connections within our bodies through these movements (Berardi, 2004; Patterson-Price, 2020). By utilizing BF patterns throughout life, individuals can achieve more advanced, comfortable, efficient, pain-free, and enjoyable movements (Basso et al., 2021). BF confirms unilateral (one limb moved at a time), bilateral (both arms or both legs moving in unison), and contralateral (moving opposite and opposing limbs, often crossing the anatomical midline) movements as fundamental human body limb movements throughout the lifecycle and necessary for the proper development of muscular strength (MusS) and neuromuscular control (NC) (Basso et al., 2021; Cebolla & Cheren, 2019; Kobayashi et al., 2014).

Appropriate MusS development is essential for the developing child in both present and future movement skills and overall health. Childhood MusS decreases the chances of diabetes, obesity, cardiovascular disease while increasing bone mineral density, healthy blood lipid profiles, insulin sensitivity (Fraser e al., 2021; Garcia-Hermoso et al., 2018; Jung et al., 2019; Torres-Costoso et al., 2020), as well as increased mental health and quality of life dimensions such as positive peer and family relationships (Bermejo-Cantarero et al., 2021). Additionally, appropriate MusS in children protects the joints from injury and the bones from fracture by acting as an insulation-type tissue (Torres-Costoso, 2020). Appropriate limb use strengthens both the dominant and non-dominant limbs, creating functional limbs on both sides of the body for proper development and motor skill acquisition (Cho & Kim, 2017; Musalek et al., 2020). This proper limb development increases a child's physical performance and core stability, decreasing stumbling, injury, and fractures during movement (Kobayashi et al., 2014; Laurson et al., 2017; Stricker et al., 2020). In addition to increased stability and fewer injuries, appropriate MusS development leads to increased NC of the participating limbs.

NC consists of information processing within the brain and the appropriate voluntary movement response that follows (Stricker et al., 2020). These movements represent the brain-body connection that allows coordinated and purposeful movements, which are displayed as increased functional movement skills (FMS) (Williams et al., 2021). These FMS include a child’s ability to kick, run, jump, throw, leap, dodge, and catch and are the foundation of all future and more advanced movement skills. These movements are considered low-magnitude limb movements, which naturally increase NC in children (DiGirolamo, 2013).

Traditionally, childhood is characterized by high amounts of these low-magnitude limb movements through PA, which creates extensive brain structure, function, and connectivity changes (Hillman et al., 2014). These limb movements enable cross-education between muscles and the brain, creating new neural pathways within the brain and strengthening muscles on the loaded side and the opposite correlating muscles of the non-worked side (Andrushko et al., 2023; Pedersen, 2019; Voskuil et al., 2023). The more limb movements a child participates in, the more efficiently the MusS in the limbs will respond when summoned by the brain to perform a task, increasing NC, thereby increasing movement skill performance (Munn et al., 2005; Musalek et al., 2020; Pedersen, 2019).

Foundational Movement Skills (FMS) encompass traditional functional movement skills as well as combined skills such as resistance training movements, riding a bicycle, or using various swimming strokes (i.e., breast stroke or freestyle) (Hulteen et al., 2018). Successful FMS advancement during childhood is associated with higher physical activity levels and increased MusS throughout the lifecycle (Barnet et al., 2016). Therefore, the active child builds MusS, increases NC, further increasing movement opportunities and overall health both now and for years to come. Although research establishes the MusS and NC benefits associated with childhood PA, most American children are not reaping these benefits due to inactive lifestyles.

1.2 Inactivity of American Children

Inactivity levels among American children are climbing at alarming rates, as only 24% participate in the recommended daily 60-minutes of physical activity (CDC, 2022). Much research is focused on childhood inactivity adverse effects which impacts cardiovascular health (Lloyd-Jones et al., 2022; Tomkinson et al., 2019). However, a less known but severely dangerous childhood inactivity effect is the lack of MusS development activities produced. Both cardiovascular health and MusS components are intertwined, as inappropriate development of either is associated with an increased chance of high-risk cardiometabolic health disorders (high blood pressure, heart attack, or stroke) (Petersen et al., 2016). The CDC has prescribed 60-minutes of daily moderate to vigorous physical activity (PA) since 2008; however, due to declining activity levels and its effects on the musculoskeletal system, they updated their recommendations by additionally prescribing another 90 minutes a week of bone and muscle-strengthening activities (CDC, 2022). Despite these guidelines, childhood inactivity is still prevalent, presenting significant MusS development deficits among American children (Kann et al., 2018; Tomkinson et al., 2020; Wahl-Alexander & Camic, 2021). This inactivity is problematic not only for children's future health but also for future movement proficiencies. As appropriate PA in childhood develops MusS and increases NC, the body is prepared for safe, efficient, and advanced FMS. Contrarily, inactivity during childhood yields quite the opposite.

Childhood inactivity hinders proper musculoskeletal strength as bones and muscles weaken through decreased limb use (Barnett et al., 2016). Decreased PA levels have left American children with less bone mass and consequently less MusS than children four decades ago, preventing a means for lifetime activity (CDC, 2017; Rosengren, 2021). Without the MusS foundation, NC is greatly hindered as well, and the ability to advance in movement skills is stifled (Munn et al., 2005; Musalek et al., 2020; Pedersen, 2019). Sadly, screen time and school policy are two primary reasons for the childhood inactivity crisis (Rhea, 2021; Walsh et al., 2020).

American children's mean daily recreational screen time is 3.8 hours, not including screen time for educational learning (Walsh et at, 2020). Evidence suggests, at present, the American school day is primarily sedentary and may encourage long periods of uninterrupted sedentary behavior (Saunders et al., 2022). The International Sedentary Behavior Research Network (SBRN) states a healthy school day involves providing an activity break at least every 90 minutes in order to break up the sedentary time children experience presently (Saunders et al., 2022). Four (Singapore, Japan, Finland, and Turkey) of at least ten countries who participate in the Program for International Student Assessment (PISA, 2023), continue to rank higher across Reading, Math, and Science, while allowing two to four daily outdoor recess breaks, an extended lunch break, and often afternoon supplemental activity time (sports, music, art, or free choice) (Jarrett, 2019). However, this is different for American children throughout the school day. In America, ever-increasing testing standards have led many schools to all but remove recess opportunities from the school day and replace them with longer school days focused on classroom content and sedentary behaviors (Rhea, 2021).

To intensify the issue, as children age, PA time begins to decline naturally, and therefore, the body and limb movements become minimal. Children show a six-minute decline in moderate to vigorous physical activity (MVPA) per year, beginning at age six for girls and nine for boys (Farooq et al., 2020). As movement opportunities decline, longitudinal studies show it is replaced with sedentary time (Janssen et al., 2016). Removing daily movement opportunities, especially in schools, seems relatively harmless until the time is compounded over several years. With roughly four hours daily of sedentary screen time outside of school and longer school days with increased seat time, American children have a significant physical and cognitive disadvantage. Therefore, finding opportunities to increase PA among children is pivotal.

1.3 PA Opportunities for American Children

PA for American children currently exists as either structured or unstructured play. *Structured play* is adult-directed and intended for a specific purpose or pre-set goal. *Unstructured PA* comprises four behavioral dispositions while a child plays freely: being highly involved, intrinsically motivated, deriving pleasure, and having the freedom to modify the rules; or frankly, whatever the child wants it to be (Gray, 2017).

The most predominantly used structured PA outside of the school day is sport participation, as an estimated 40% of American children participate in sport programs (Eime et al., 2016). Most of the time, coaches for youth sports begin as parent volunteers who are not coaches by trade (Vierimaa et al., 2022). Although most coaches should ensure children have enjoyable, positive sport experiences and quality skill development, this is not always the case (Vierimaa et al., 2017). Children drop out of sports fairly often due to: overemphasis on winning, pressure to perform at higher skill levels than age appropriate, parents exposing them to sports too early, and specializing in one sport over multiple sport participation (Witt & Dangi, 2018). In line with these reasons, the number one cause for childhood attrition in sports is simply due to, “not having fun.” (Visek et al., 2022). Decreases in the perception of “fun” has caused 70% of children to drop from sport participation by the age of 13 (Ladwig et al., 2023). For children who do remain in specialized sports, research shows they are at risk for imbalanced MusS, higher injury rates, and decreased physical performance as they age (Puzzitiello et al., 2021; Rugg et al., 2021; Stricker et al., 2020). Sport participation is also limited to those who have the money, time, and transportation required for participation; eliminating the opportunity for a large percentage of children to participate (Somerset & Hoare, 2018). Therefore, sports participation is greatly hindered in its access to children of all demographic backgrounds and in its ability to maintain high participation levels as children age.

Structured and unstructured PA opportunities have been implemented in elementary school settings over time in efforts to increase overall health and classroom focus among children. In-school structured PA is in the form of physical education (PE) classes or classroom indoor structured activity breaks. PE classes are common structured PA content periods offered within the school day. PE is focused on cognitive, affective, and motor skill development, but studies have shown when motor skills and limb movements are not established first through fluid and repetitive play opportunities, then the role of PE becomes ineffective (Campbell-Pierre & Rhea, 2023; Kobayashi et al., 2014).

Classroom breaks are the other form of structured activity used during the school day. These breaks have been shown to improve children's attention and concentration for short periods of time, but are limited in implementation and amount of time studied and may require additional time, money, equipment, and specialty teacher training (Buchele-Harris, 2018; Angel Latorre-Roman et al., 2021). These classroom breaks include two to three minute movement breaks (i.e., Go Noodle, jumping jacks, running in place) when a teacher feels the children are losing focus (Liu et al., 2019; Nally et al., 2021; Watson et al., 2017; Yuksel et al., 2020). However, most of these in-class breaks only report minimal PA level improvement, as well as no lasting effect on increasing PA levels due to the limited time given per break (Errisuriz et al., 2018; Jones et al., 2020; Watson et al., 2017; Yuksel et al., 2020).

Unstructured school PA opportunities within the school day consist of outdoor play breaks, called recess, where PA can naturally be accumulated. Recess during the school day, provides access to meaningful PA as it can be integrated into the daily school routine. Recess provides an outdoor environment stimulus where children can be creative through play, master their domain, be physically active, and socialize with their peers (Rhea, 2021). The choice, creativity, and exploration recess allows may be the most influential cognitive and physical development factors (Rhea, 2021; Vidya, 2018). During the school day, recess provides children with a perfect space to be physically active and develop coordinated limb movements naturally (Dankiw et al., 2020; Webb & Rhea, 2023). Movement, in the form of discovery and play, allows for the recruitment of all four body limbs in various patterns essential to proper body and brain development. This limb utilization during play, especially contralateral movements, profoundly impacts children's physiological development (Basso et al., 2021). Research shows increasing PA within the school day can improve musculoskeletal traits for up to four years after physical activities in school have ended (Rosengren, 2021). Recess may aid in increasing PA opportunities across various demographic barriers (Ball et al., 2015; Gray, 2017; Musalek et al., 2020; Rhea 2021)

1.4 *Recess as an Equitable PA Opportunity*

Recess within the school day provides movement opportunities for children regardless of demographics, income, or local extracurricular opportunities offered. The US Department of Education (2024) states all American children should have access to free and appropriate public education, regardless of demographics, ability, or disability. Recess is considered equitable for PA opportunities as most children in America attend public education, regardless of demographic status, and therefore have access to this offering within public education. This is so necessary, as outside of the school day, PA disparities among children exist across various demographic populations, affecting MusS, NC, and whole child development (Wilson & Bopp, 2023).

These PA disparities exist due to socio-economic and cultural influences, where those who are more advantaged tend to be more physically active, less sedentary, and therefore, less likely to suffer adverse health conditions (Ball et al., 2015; Wilson & Bopp, 2023). Children in lower-income households appear to have less opportunity for PA participation outside of the school day, creating more significant developmental gaps in fine and gross motor, cognitive, language, and socio-emotional skills as they mature (Fink, 2021; Kuhn et al., 2021). The American Heart Association's "2022 Life Essential 8" assessed the cardiovascular health (CVH) of 74,435 American children ages 2-19 through a survey consisting of eight measures: diet, sleep, PA, nicotine exposure, body mass index, blood lipids, blood glucose, and blood pressure

(Lloyd-Jones et al., 2022). The study revealed white children (77.2%) participated in more PA and muscle-strengthening activities and were less overweight/obese than Black (75%) and Hispanic (71.1%) children. The study also revealed 78% of the boys, on average, participated in healthy PA while 71.8% of the girls, on average, participated in healthy PA, and girls had a 1.6% higher average BMI than boys (Lloyd-Jones et al., 2022).

Race/ethnicity, sex, and socio-economic status (SES) influence PA and MusS development and may lead to or widen PA child disparities classified as obese or overweight. Currently, 21% of American children ages 6 to 11 are considered obese (CDC, 2022). This accumulation of weight gain in childhood creates a decrease in overall MusS and NC compared to normal-weight non-obese counterparts (Avigo et al., 2019; Cho & Kim, 2017; Heo, 2014; Musálek et al., 2018). When considering PA accessibility for those who are overweight or obese and socio-economically disadvantaged, equitable recess opportunities and the freedom of choice movement are essential for the developing child.

Several recess interventions have been studied as a means of increasing cognitive, social, physical, and emotional wellbeing, and are observed anywhere from two days- to twelve weeks (Al-Yateem & Rossiter, 2017; Hyndman et al., 2014; Lee et al. 2020; Razak et al., 2018). Although these recess interventions yield significant child benefits, the long-term effects are not established. One highly successful longitudinal recess intervention, The LiiNK Project® (Let's inspire innovation 'N Kids), focuses on whole child development in elementary and middle school settings which addresses many gaps identified in other short-term unstructured or structured PA interventions (Campbell-Pierre & Rhea, 2023; Farbo & Rhea, 2022; Farbo et al., 2020; Rhea & Rivchun, 2018; Webb & Rhea, 2023). The LiiNK intervention is a multi-year, routinely scheduled, teacher embraced model that includes four 15-minute recesses (outdoor, child-directed play breaks) and 15-minute character lessons (Positive Action®) daily. LiiNK children have been found to have decreased stress levels (Kirby & Rhea, 2022), improved happiness and positive emotions (Clark & Rhea, 2017), decreased off-task behaviors (Rhea & Rivchun, 2018), and greater attentional focus when returning to the classroom (Lund et al., 2017). Though PA is not the primary goal of the LiiNK intervention, the LiiNK research team has also found children with 60-minutes of recess exhibit exponentially more MVPA (Farbo & Rhea, 2021; Farbo et al., 2020) and have significant gains in postural balance and movement skills compared to those who receive 30-minutes or less of recess (Campbell-Pierre & Rhea, 2023). The increased MVPA, balance, and movement skills within this group may lead to increased MusS and NC among LiiNK intervention children as well.

1.5 *MusS and NC Assessment in Children*

As a result of the decline in children's PA levels combined with fewer opportunities for MusS and NC development (Barnett et al., 2016; CDC, 2022; Cho & Kim, 2017; Heo, 2014; Musálek et al., 2018; Naqvi et al., 2022; Smith et al., 2019; Whal-Alexander & Camic, 2021), regular MusS testing during childhood should be considered a public health priority (Bogataj, 2020; Niessner et al., 2020; Fawcett & DeBeliso, 2014). As elementary school provides an equitable place for increased PA through recess, it also provides an equitable platform for children to participate in MusS and NC testing through PE classes. Although PE is not consistent in attendance or literacy from state to state, it has been established in America as a platform for National health and physical testing batteries such as The FitnessGram (Clennin et al., 2018; Pennington, 2023).

Therefore, monitoring MusS of all limbs, and on a child-based level within PE, is pivotal to understanding where MusS and NC development may be lacking, and for understanding the impact of school-based PA interventions on MusS and NC development. MusS and NC tests are performed on children for various reasons, predominantly in the sport performance industry.

Nevertheless, these tests have not been used to determine if there is a connection between various recess amounts and MusS and NC gains.

As established previously, BF is the foundation of all limb movements. Increased use of BF limb movements in childhood produces increased MusS, NC, leading to more advancement in FMS. Muscular strength testing can occur with single limb (unilateral) or double limb (bilateral) assessments on both the upper and lower extremities. The following compilation of tests support this body of work. The Digital Dynamometer Single-Hand Grip Test (Baptista et al., 2021; Cho & Kim, 2017) has been shown to assess unilateral upper-body MusS strength, the Single-Leg Three Hop Test (Booher et al., 1993; Hammami et al., 2022) has been shown to assess unilateral lower-body MusS, the Push-Up Test (Plowman & Meredith, 2013) has been shown to assess bilateral upper body strength, and the Two-Foot Vertical Jump Test (Bogataj et al., 2020; Cho & Kim, 2017) has been shown to assess bilateral lower-body MusS.

Contralateral limb movements require recruitment across all four limbs, core stability, and advanced sensory functions such as reaction time (the time between the brain stimulus and the movement response) (Goethel et al., 2023). Therefore, contralateral movements require vast and multiple MusS and NC responses and connections between the body and the brain. A NC test is needed to assess the potential MusS and NC benefits of children who participate in contralateral movements. The Side-Step Test (Cho & Kim, 2017), has been shown to test NC of the lower body, therefore is also needed when focusing on the relationship between MusS and NC. These five tests have been assimilated to identify MusS and NC differences in children participating in varying amounts of recess. As inactivity trends continue to rise during childhood, testing MusS and NC differences may help explain this gap in the literature.

1.6 Research Questions and Hypotheses

Therefore, the purpose of the first of three studies was to explore whether varying amounts of daily recess impacted limb movement patterns or use among grades K through 2 children. The first hypothesis stated children with 60-minutes of recess would accumulate more total limb movements than children with 20-minutes of recess. The second hypothesis stated grade-level differences would be found between the two groups. The third hypothesis stated the 60-minute daily recess group would show more contralateral limb movements as they advanced in grade than the 20-minute daily recess group. This study was foundational to the second and third studies, as it was essential to understand how children move their limbs naturally during recess.

The second study, exploratory in nature, focused on identifying the most valid and reliable MusS and NC tests for elementary-aged children, followed by a preliminary administration of these tests with grades 2-4 children. Variables influencing MusS and NC, such as sex, grade, race, and SES were explored with this population. Positive results from this study would help support the MusS and NC tools chosen for this population and a means for monitoring MusS and NC interventions such as additional recess breaks throughout the day. With this established, the next step was to use these tools to explore the LiiNK recess intervention as a viable intervention to increase MusS and NC development in elementary-aged children.

The purpose of the third study was to examine MusS and NC factors in the Fall and Spring (Time 1 to Time 2) of one school year in a predominately Hispanic sample of second grade children who received 60-minutes (LiiNK intervention) or 20-minutes (control) of daily recess. It was hypothesized children in the intervention group would demonstrate greater MusS and NC score improvements compared to children in the control group. A second hypothesis was the intervention's positive effects on MusS and NC would be consistent even when controlling for body fat percentages between groups. The independent variable for this study was the recess group and the dependent variables were the mean scores for each of the six tests administered (single hand grip, single leg three-hop, push-up, vertical jump, side-step, and body fat analysis). Exploring factors that influence MusS and NC development and viable PA interventions focused on MusS and NC development, is essential to current and future children's health and movement opportunities. This dissertation hopes to advance this narrative.

Chapter 2: The Impact of Multiple Recesses on Limb Movement Patterns in Children: An Exploratory Study

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Keywords: Unilateral, bilateral, contralateral, limb movements, unstructured play, recess.

Abstract: *Background*: Inactivity levels among elementary-aged children are climbing at alarming rates, as only 24% participate in the recommended 60 minutes of daily physical activity. Limb movements during children's active time are essential for heart, bone, and muscle health, setting the stage for an overall active and healthy life. School recess, defined as child-directed, outdoor play, is optimal for children to accumulate many types and repetitions of limb movements. Therefore, the purpose of this study was to use the Movement Pattern Observation Tool (MPOT) to determine the impact of varying amounts of daily recess on elementary-aged children's limb movement patterns. It was hypothesized that children who participate in 60 minutes of daily recess would accumulate significantly more limb movements and specifically, contralateral movements as they advance in grades. *Methods*: This cross-sectional, observational study used the MPOT to observe grades K-2 children from two schools offering one twenty-minute recess daily and two schools offering four 15-minute recesses daily. The researchers observed 3,023 children's limb movements during recess across the schools. There were 36 total observation scans completed for the four schools observed. *Results*: Children who received 60 minutes of recess maintained significantly higher activity levels and contralateral movements as they advanced by grade. Additionally, on average 96% of all children utilized unilateral, bilateral, or contralateral limb movements when observed. *Conclusion*: When given the opportunity, most children will utilize recess in a way that is beneficial for off-setting inactivity trends and is instrumental for a healthy mind-body connection as they age.

2.1 Introduction

Inactivity levels among elementary-aged children are climbing at alarming rates, as only 24% participate in the recommended 60-minutes of daily physical activity (PA) (CDC, 2022). Limb movements (unilateral, bilateral, and contralateral) utilized during children's active periods are essential for lifelong physical activity and overall health (Angel Latorre-Roman, et al.,2021; Barnett et al., 2016; Erickson et al., 2015; Koepp & Gershoff, 2022; Lloyd & Oliver, 2012;

Pendersen, 2019). The World Health Organization (WHO) defines PA as any bodily movement produced by skeletal muscles that requires energy expenditure (WHO, 2022). Bartenieff Fundamentals (BF) describes these bodily movements as a series of six movement patterns beginning in utero and continuing throughout adulthood (Berardi, 2004). Three of the six utilize limb movements and include unilateral (one arm or leg at a time), bilateral (both arms or both legs used in unison), and contralateral (coordinating one arm and one leg from the opposite sides of the body, often crossing the anatomical midline) limb use. Utilizing and mastering these limb movements must continue throughout the lifecycle to create connections with our bodies to achieve more comfortable, efficient, pain-free movement and develop proper bone density and muscular strength (Berardi, 2004; Basso et al., 2021; Patton & Viner, 2007). Therefore, the more chances a child has to utilize limb movements through PA, the more successful they can be in all types of movement and increase strength as they develop throughout their adult years (Barnett et al., 2016; Erickson et al., 2015).

Continuation of these movements is necessary throughout the lifespan as mastery is essential for brain networking and executive function (Kim, 2018). BF framework confirms unilateral, bilateral, and contralateral movements are fundamental and necessary for proper body and brain development from birth throughout adulthood (Basso et al., 2021; Cebolla & Cheron, 2018; Einspieler, 2008). Limb movements can produce a positive compounding effect as children utilize one side of the body, or alternating use of both sides, to create new neuropathways, making light work of both simple and complex movements (Munn et al., 2005). Utilizing these basic limb movements prepares the body, brain, and nervous system to complete more complex tasks as the body matures. These complex tasks are known as Fundamental Movement Skills (FMS). FMS encompasses traditional functional movement skills (kick, run, jump, throw, leap, dodge, and catch) as well as combined skills (resistance training movements, riding a bicycle, or swimming strokes) (Hulteen et al., 2018). Successful participation in FMS during childhood is associated with higher physical activity levels throughout the lifecycle (Barnett et al., 2016).

Limb movement use while children are physically active may directly influence lean muscle mass development and movement experiences, which are essential for successfully completing FMS (Musalek et al., 2020). Limb use can also place loads upon the musculoskeletal system, which rebuilds bone and muscle fibers into a more robust form. Conversely, a lack of childhood limb movements stifles muscle and bone development, decreases the chance of life-long PA, and increases the chances of injury, fractures, and all causes of morbidity (Lloyd & Oliver, 2012; Hlteen et al., 2018; Clark et al, 2011; Rosengren et al., 2021). Childhood inactivity hinders proper growth of the musculoskeletal system as bones and muscles weaken through loss of use. Elementary- aged children are in a crucial development stage to build proper bone density and muscle strength (Patton & Viner, 2007). If children frequently fail to participate in minimum levels of PA, muscular imbalances can develop between the dominant and non-dominant limbs, further disabling proper growth and development (Cho & Kim, 2017). Once a child has a muscular imbalance, the magnitude of the imbalance intensifies as the child ages if not corrected (Atkins et al., 2016). Imbalances in the extremities affect a child's physical performance and core stability, leading to increased stumbling, injury, and fractures (Kobayashi et al, 2014). Activities that increase limb usage on both sides of the body equally will decrease asymmetry issues and increase muscular strength, bone density, and muscle control, all of which increase the chances of life-long PA with fewer injuries.

Since elementary children spend over nine months per year and up to forty hours per week at school, the school day may be the most impactful place to advocate for children’s movement and activity opportunities. School recess, defined as child-directed, outdoor play, is the optimal place for children to accumulate many types and repetitions of limb movements, especially since it is one of the few places all children can access safe outdoor spaces. Recesses can be offered within the school day for children across the U.S. regardless of demographics, income, or local extracurricular opportunities offered. Recess provides children with a perfect space to be physically active and develop coordinated limb movements naturally through play (Dankiw et al, 2020). However, over the past two decades, ever-increasing standardized testing outcomes have led many schools to decrease the time offered for recess to no more than 20 minutes daily, further alienating children from access to PA and FMS (Rhea, 2021). Inactivity levels of elementary-aged children are rising as recess within the school day is declining (Chang & Coward, 2015).

LiiNK (Let's inspire innovation 'N Kids) is a whole child development recess intervention implemented in elementary and middle schools that addresses many gaps identified in other short-term PA or recess interventions (Campbell-Pierre & Rhea, 2020; Farbo et al., 2020; Farbo & Rhea, 2022; Rhea, 2021). The LiiNK intervention includes four 15-minute recesses (outdoor, child-directed play breaks) and daily 15-minute character lessons (Positive Action). LiiNK intervention results have shown first and second grade students take 900 or more steps and achieve 25 minutes more moderate to vigorous physical activity (MVPA) daily than children with 30-minutes of recess daily (Farbo et al., 2020). These results have also shown 60-minutes of recess report greater gains in postural balance and motor competency throughout the school year than children receiving 30-minutes or less of recess (Campbell-Pierre & Rhea, 2023). These results led this intervention's researchers to question whether recess supports the use of limb movements and, if so, to what degree. Recently, a tool was developed to observe limb movements on the playground (Webb & Rhea, 2023).

The Movement Pattern Observation Tool (MPOT) is used to observe and quantify limb movements (unilateral, bilateral, and contralateral) utilized by children during recess (Webb & Rhea, 2023). Though it has been shown as a reliable tool in a previous study (Webb & Rhea, 2023), this will be the first documented use of the MPOT in the field to analyze limb movement data. Therefore, the purpose of this pilot study was to use the Movement Pattern Observation Tool (MPOT) to determine the impact of varying amounts of daily recess on elementary-aged children's limb movement patterns. It was hypothesized that children with 60-minutes of recess would accumulate more total limb movements than children with 20-minutes of recess. It was also hypothesized there would be grade-level differences between the two districts due to varying amounts of daily recess. The third hypothesis was that children who participated in 60-minutes of daily recess would show more contralateral limb movements as they advanced in grade than those who participated in 20-minutes of daily recess.

2.2 Materials and Methods

Participants

This cross-sectional, observational study used the MPOT to quantify limb movements of 3,023 children who participated in varying amounts of elementary school recess. Due to the observational nature of the study, no rosters were used; only the number of children observed per grade level. The number of children included were those that were actually observed in the specific play areas during the observation. A non-randomized sampling of kindergarten, first, and second grade children throughout two North Central Texas school districts (two elementary schools per district) participated in the study. District 1 children received 60-minutes (four 15-minute segments) of daily recess. A total of 1,647 children were observed (509 kindergarteners, 542 first graders, and 596 second graders) during recess. District 2 children participated in one 20-minute daily recess. A total of 1,376 children were observed (430 kindergarteners, 553 first-graders, and 393 second- graders) during recess. All observations were completed in the Spring semester of one school year. Thirty-six total observation scans across the four schools were collected, meaning 18 observation scans per school district (2 districts), nine scans per school (4 schools), and three scans per grade (kindergarten, first, and second). On average, 2-3 observations were completed within each school day at 12 minutes per observation.

2.3 Measures

Movement Pattern Observation Tool (Webb & Rhea, 2023). The MPOT is an observational tool created to record limb movements during recess on play equipment and in open nature spaces. The MPOT was "good," approaching "excellent" in interrater reliability. The form captures the individual limb activity per child with a four-minute "snapshot" observational scan. Webb and Rhea, 2023 give a detailed description of the recording pattern used for viewing children at play on structures, swing sets, and open field areas for time efficiency. The observer used hash marks to note the child's physical activity participation (running, walking, climbing, crawling, sliding, jumping, hanging). These activities were pre-classified on the form as either unilateral, bilateral, or contralateral limb activities. Hash marks also noted the "No movement" category. "No movement" was noted by no evident use of arms or legs while observed and included standing with no other movement. Any activities not listed on the form were handwritten on the bottom for further limb movement determination.

2.4 Procedures

IRB approval for elementary observations was granted. Due to the study's observational nature, meaning no identifying factors were collected for any given child, school administrators approved this study's researcher to observe children on the playground. Therefore, parent consent and child assent were not needed. Once the researcher passed the required background check per school district, each recess observation was scheduled in advance with the participating school's principal.

Recess schedules were different for the two districts. District 1 had many more opportunities for observation since they had four 15-minute daily recesses, whereas District 2 only had one 20-minute daily recess. District 1 recesses were scheduled to capture morning and afternoon offerings on different days of the week. District 2 school recesses were scheduled at different times on the same days, but time of day by grade level varied between the two school campuses. Scheduling was much easier for District 1 (60-minutes of recess) than District 2 (20 minutes of recess) for various reasons: the number of recesses available daily was four vs. one, weather guidelines for District 1 included allowing play from 13 degrees to 103 degrees Fahrenheit, whereas District 2 was 50 to 90 degrees Fahrenheit, and their schools, at times, canceled recess because of discipline issues which meant recess was not available for observation on certain days.

Upon entering each school, the observer checked in with the administrative assistant, received a visitor pass, and proceeded to the playground. When arriving on the playground, the observer found a location to observe that would not disturb the children's natural play and had a good view of the entire playground. Once the teachers confirmed all classes for that grade were present, the MPOT observation began. Typically, observations began one to two minutes after the children were on the playground and ended within 15 minutes for all schools. Most observations were scheduled around consecutive recesses among grade levels within each school. Therefore, most grade levels were captured within one day for one observation visit, but occasionally the observer had to come back to the school to capture grades missed. This was due to reasons mentioned above or a grade level’s offered time was outside the scope of the other recess times, i.e., at least two hours before or after the other recess offerings.

Data Analysis

Descriptive statistics included the number of children by district, the count of limb movement usage, and limb movement percentage comparisons by district and grade level. The hash marks for each type of limb movement or "no movement" were counted, entered, and summed in an Excel spreadsheet. For the three hypotheses, independent variables were the district (60 vs. 20 minutes of daily recess) and grade levels (K, 1, and 2). The dependent variable was limb movement usage. For Hypotheses 1 and 3, the raw scores and percentages were reported to show the variety of movements in each category by school district and grade level. For Hypothesis 2, Chi-square tests, using $p<0.05$ as the alpha level, determined specific limb movement usage percentage differences by district and grade level. To ensure the correct alpha level was used for the significance of this sample, Bonferroni correction was calculated, which adjusted the significant alpha level to $p=0.003$ (4 movements x 3 grades x 2 groups) and $p=0.005$ (4 movements x 1 grade x 2 groups).

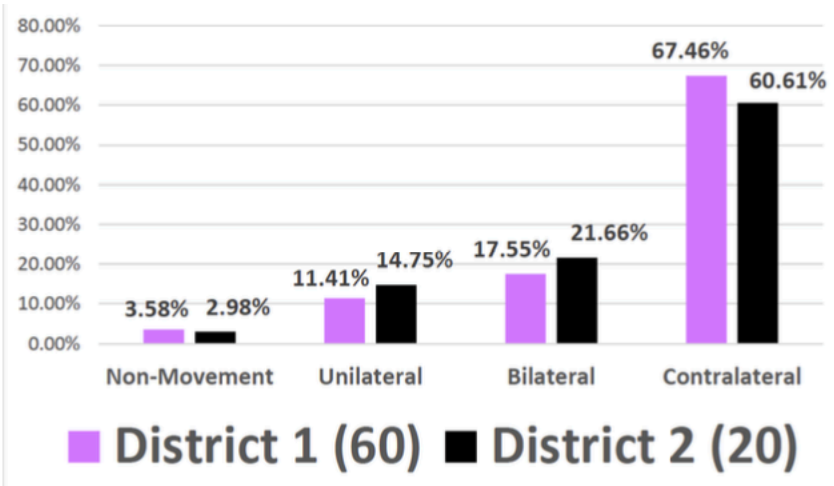
2.5 Results

Hypothesis 1

Figure 1 shows the district differences in unilateral, bilateral, contralateral, and "non-movement" limb movements during recess. It was hypothesized that children with 60-minutes of recess would accumulate more limb movements than children with 20-minutes of recess. This hypothesis was rejected as a minimum of 94% of all children across both districts participated in unilateral, bilateral, or contralateral limb movements when observed. Both groups were very similar in the number of children not participating in movements when observed as well. District 2 utilized 3.3% more unilateral and 4.1% more bilateral movements than District 1. District 1 used 6.9% more contralateral movements than District 2. When examining total movements, contralateral movements were utilized more than the other three categories (unilateral, bilateral, and non-movement) combined for Districts 1 and 2.

Figure 1

Comparison of limb movements observed



Hypothesis 2

Table 1 shows chi-square differences with Bonferroni Correction for limb movements by district within each grade level. Observations reflected grade level differences between districts due to differences in types of movements used across districts. Therefore, Hypothesis 2 was accepted. District 1 Kinders used significantly more unilateral movements, whereas District 2 Kinders used significantly more bilateral and total movements. District 2 first and second graders used unilateral movements more, while District 1 first and second graders used contralateral movements more. Figure 2 reflects raw score percentages by district and grade level to reflect non-movement. District 1 Kinders had the highest percentage of non-movers and then dropped significantly in the first and second grades. District 2 reflected just the opposite. They had lower percentages of non-movers with Kinders, first, and second graders, followed by a spike in non-moving second graders.

Table 1

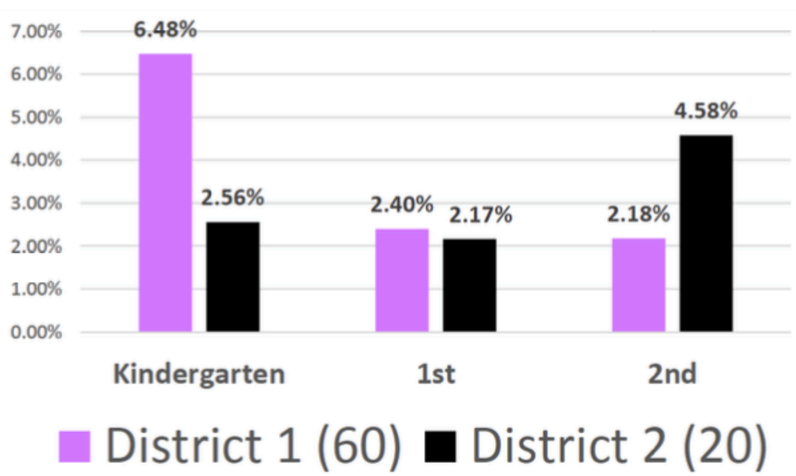
Movement usage by group and grade

Grade	Intervention	Unilateral	Bilateral	Contralateral	Total Kids in Movement	Total Kids
Kindergarten	District 1	**102 (20%)***	**83 (16%)**	291 (57%)	476 (94%)	509
	District 2	43 (10%)	105 (24%)***	271 (63%)	419 (97%)*	430
First Grade	District 1	32 **(06%)**	75 (14%)	422 (78%)**	529 (98%)	542
	District 2	60 (11%)***	88 (16%)	393 (71%)	541 (98%)	553
Second Grade	District 1	54 (09%)	131 (22%)	398 (67%)***	583 (98%)**	596
	District 2	100 (25%)***	105 (27%)	170 (43%)	375 (95%)	393

*p<0.05, **p<0.01, ***p<0.00525 (Bonferroni Correction), % calculation = limb movement count/total kids in the group, Total Kids in Movement = Unilateral + Bilateral + Contralateral.

Figure 2

Comparison of non-movements observed by group and grade level

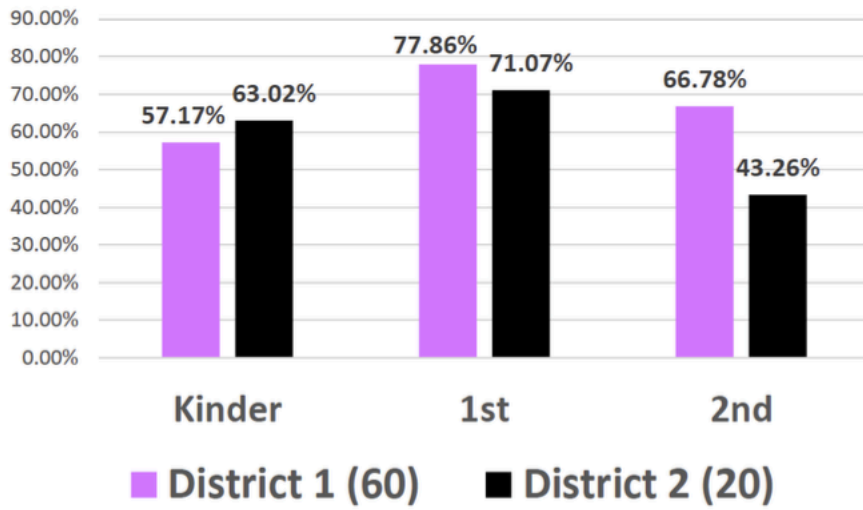


Hypothesis 3

The third hypothesis stated children who participated in 60-minutes of daily recess would show more contralateral limb movements as they advanced in grade than those who participated in 20-minutes of daily recess, which was accepted. These trends can be seen in Figure 3. Although contralateral levels remained somewhat similar for kinders and first-graders, District 1 participated in 24% more contralateral movements than District 2 by second grade, as there was a 28% decrease in contralateral movements from first to second grade for District 2.

Figure 3

Contralateral movements observed by group and grade



2.6 Discussion

District 1 children showed some significant positive patterns for limb movement and utilization. Notably, children who received 60-minutes of daily minutes of recess maintained high levels of movement participation from kindergarten through second grade. Conversely, children receiving only 20-minutes of daily recess followed the normative trends as fewer children were seen moving in the older grades either in contralateral movements or overall participation in limb movements. This data aligns with recent research that shows the more a child moves, the more likely they are to increase or maintain movement levels as they age and to develop advanced movement skills, aiding in life- long PA (Barnett et al., 2016; Hulteen et al., 2018; Farooq et al., 2020).

The root cause of limb movement differences is unclear for grade level, but the differences were evident as hypothesized. Some reasons for differences may include age, variety in playground equipment (structures, swings, slides), loose parts (balls, ropes, hoops, blocks), outdoor temperature, or time of day observed. Future studies should be conducted on which variables create grade-level differences.

Children who received 60-minutes of recess in kindergarten and first grade showed similar contralateral participation rates as the 20-minute recess group. However, by second grade, children participating in 60-minutes of recess began to reflect significantly higher contralateral use. Contralateral movements require total body participation as opposite and opposing limbs move in unison, rotating back and forth and often crossing the anatomical midline. The extensive limb-muscle recruitment and coordination required to perform a contralateral movement often place this limb movement at the top of the list for beneficial body and brain movements. Therefore, increased contralateral movements would be ideal for the elementary-aged child.

Across all groups and grades, contralateral limb movements were most commonly used, and on average, 96% of children were found to participate in limb movements when observed. Regardless of allotted daily time, recess shows to be a great opportunity for all children to develop limb movements through a variety of child-directed activities.

This study supports other research in that through limb movements, children increase muscle mass, bone density, brain health, motor skills, and life-long activity, decreasing injury rates, Type 2 diabetes, and all-cause mortality (Clark et al, 2011; Hulteen et al., 2018; Lloyd & Oliver, 2012; Rosengren et al., 2021). Due to alarmingly high childhood inactivity trends in America, recess should be included in each school day for overall health and wellness intervention and prevention.

2.7 Limitations

One limitation of this study was not capturing every student or the same student in a different recess zone. The MPOT is set up with a specific scanning order for each playground section to decrease the time spent deciding where to do the following scan. Additionally, the four-minute scan for each section was created to keep the flow of the scans moving to help prevent the overlapping of students. Even though this protocol was followed and did help prevent some overlapping of students, because this was an in-person, live observation, there is a chance some children were missed or recorded twice.

Another limitation is time of day and temperature may affect activity levels among children and possibly among specific grade levels. Some recess intervention schools have children going outside multiple times per day. Children in these intervention schools are used to participating in play with temperatures ranging from thirteen to one hundred degrees. In contrast, the other school district did not participate in weather conditions below 50 degrees Fahrenheit. In future studies, it will be wise to account for the time of day and temperature when comparing the number of limb movements between schools with varying amounts of recess.

2.8 Conclusions

The data shows, on average, 96% of all children participated in at least one of three limb movement patterns when observed. It also showed the more children participate in daily activity, the more likely they are to stay active as they age and participate in mass body movements such as contralateral activities. With this data, researchers and school officials can understand that increased recess opportunities for elementary students will increase whole-child benefits through limb-movement activity.

Chapter 3: Muscular Strength and Neuromuscular Control Differences in Elementary-Aged Children

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Key Words: Muscular Strength[1], Neuromuscular Control[2], Children[3], Demographics[4], Testing[5]

3.1 Introduction

In years past, muscular strength and neuromuscular control deficits have appeared in adults as physical activity (PA) lifestyles begin to slow. More recently, an alarming similar trend has been seen in elementary-aged children, due to sedentary lifestyles and minimal physical activity daily (CDC, 2022). Significant muscular strength (MusS) deficits, exasperated by the 2020 Coronavirus shutdown, have been one of the most alarming results seen related to childhood physical inactivity (Whal-Alexander & Camie, 2021). Childhood inactivity hinders proper growth of the musculoskeletal system as bones and muscles weaken through loss of limb use (Barnett et al, 2016; Smith et al., 2019). Lack of limb use can also create muscular weakness and imbalances between the dominant and non-dominant limbs, further disabling proper growth. Research shows a decline in MusS among youth over the past 10 years, highlighting the importance of assessing and monitoring MusS in children (Atkins et al., 2016; Laurson et al., 2017).

Although many factors influence inactivity, physical activity (PA) behavior disparities among children exist across various demographic populations including age, sex, race and socio-economic status. (Ball et al., 2015; Wilson & Bopp, 2023). Males tend to have higher PA levels and participate more in sport, thereby creating disparities in MusS development or performance

(Battaglia et al., 2021). PA participation also follows a "social gradient," where those who are more advantaged tend to be more physically active, less sedentary, and therefore, less likely to suffer adverse health conditions (Ball et al., 2015; Wilson & Bopp, 2023). Research shows developmental gaps are often the result of poverty-related factors in the home environment, as children from more affluent homes show less developmental gaps in fine and gross motor skills, cognitive skills, language skills, and socio-emotional skills than children who are in lower-income cultures or households (Fink, 2021). Therefore, race and socio-economic status (determined by qualification of state standards for free or reduced lunch within public school) were assessed in this study as potential factors influencing MusS and NC development.

Although inactivity is a root cause of inefficient MusS development, sport specialization also exacerbates appropriate MusS development. Roughly 30% of American children are considered physically active as they compete as a "sport specialist", commonly defined as year-round participant in a single sport, often to the exclusion of other sports (Bell et al, 2018, Bell et al., 2019). Although considered physically active as sport specialists, the lack of motor skill variety may also compromise MusS development. Therefore, children who specialize in a single sport early are at risk for imbalanced MusS, leading to higher injury rates and decreased physical performance (Puzzitiello et al, 2021; Rugg et al., 2021; Smith et al., 2019; Stricker et al., 2020).

Childhood inactivity, combined with the evolution of youth sport specialization, changes children's "strength" landscape (Stricker et al., 2020). This can affect a child's physical performance and core stability, leading to increased stumbling, injury, and fractures (Kobayashi et al., 2014). Once a child has a muscular imbalance, the magnitude of the imbalance intensifies as the child ages if not corrected (Atkins et al., 2016). For the inactive and the over-specialized child, balance and appropriate MusS may account for up to 70% of the variability in a child's range of motor skills, linking MusS tightly to motor competencies (Lloyd & Oliver, 2012).

As MusS improves in children, so does neuromuscular control. Neuromuscular control is the creation of new neurological pathways, between the brain and the body, through movement of the body and limbs (Musalek et al., 2018; Pederson, 2019). Increases in neuromuscular control allow a child to exhibit more powerful and efficient movements and movement skills as they age (Musalek et al., 2018; Pederson, 2019). Therefore, MusS development is fundamental for early childhood movement skill development (Stricker et al., 2020). Simple motor skills such as walking, efficiently advance into jogging, skipping, jumping, and hopping when proper MusS development exists. If a certain level of motor competence is not achieved in early childhood, a child's future motor skill development will be hampered, leading to less lifelong activity pursuits and increased risk of all-cause mortality (Avigo et al, 2019; Hulteen et al., 2018). Consequently, proper MusS development is essential for proper neuromuscular control development, creating a platform for current and future activity pursuits among elementary-aged children. These findings suggest the need for regular MusS testing in children and PA childhood interventions should be considered a public health priority (Bogataj et al., 2020; Niessner et al., 2020). The National Institute of Health's Library of Medicine deems MusS testing as an important component to reveal neurologic deficits, strength weaknesses, endurance weaknesses, and imbalanced limbs (Naqvi, 2022). As MusS in elementary-aged children is exhibited by increased neuromuscular control (NC), the inclusion of a NC test is an appropriate addition to MusS testing (Stricker et al., 2020).

Some MusS and NC measures used in a lab setting are not necessarily appropriate in a field setting such as the physical education gymnasium, where most children would be examined. A persistent need exists for utilizing strength measurement tools that are valid, reliable, affordable, portable, and easy to use in the field, such as a physical education setting (Bogataj et al., 2020).

Muscular strength testing can occur with single limb (unilateral) or double limb (bilateral) assessments on both the upper and lower extremities. The digital Dynamometer Single-Hand Grip Test (unilateral) and the Push-Up Test (bilateral) are commonly used to assess MusS in children (Baptista et al., 2022). Testing single hand grip on both sides of the body is important as grip strength is associated with the prediction of musculoskeletal fitness, upper body strength, triglyceride levels, cardiometabolic health, cardiovascular disease, type II diabetes, and bone health during childhood and while traveling through adulthood (Baptista et al., 2022; Fraser et al., 2021; Garcia-Hermoso et al., 2019; Kunutsor et al., 2021. Grip strength also reflects on the asymmetry of right and left upper unilateral strength. The Push-Up Test recruits the muscles in the front and back of both arms (triceps brachia and biceps), the chest (pectoralis major), and both shoulders (deltoids). This upper-body mass recruitment is known as arm and shoulder girdle strength. This test is recommended for the measurement of arm and shoulder girdle strength for children in national fitness batteries like the FITNESSGRAM (Watkins et al., 2017).

Lower limb MusS assessments that have been used in other children's studies include the Single-Leg Three Hop Test (unilateral) and the Two-Foot Vertical Jump Test. The three-hop test has been used to assess MusS and power in each lower limb of pre-adolescent children (Hammami et al., 2022). This test is also used to indicate sport and physical activity readiness, as low scores in the single hop test are associated with increased injury risk in the thigh and knee (Guild et al, 2020). The distance hopped difference between limbs (limb symmetry) can help identify those who may be more prone to foot and ankle injuries (Brumitt et al., 2014). Therefore, this test is vital for identifying functional strength and power in each lower limb, and asymmetry in the two limbs**.** The Two-Foot Vertical Jump is one of the most common tests for assessing physical fitness in various populations, including elementary-aged children (Bogataj et al, 2020; Booher et al, 1993). During active play and sport, children experience explosive contractions of the muscle-tendon attachment in their lower limbs (Stricker et al., 2020). If children do not develop proper lower limb MusS, these explosive movements may increase the risk of avulsion fracture until children are closer to skeletal maturity (Stricker et al., 2020). Therefore, it is essential to assess and monitor MusS in both the lower and upper limbs. Assessment of MusS in the individual and combined limbs will help identify children needing additional MusS development opportunities. MusS gains in pre-adolescent children are displayed as neuromuscular advances rather than muscle hypertrophy, as seen in pubertal children (Stricker et al., 2020). Although one may not see the muscle physically developing, as with older children, a sign that it is developing correctly would be appropriate and efficient control of the limbs. Therefore, a lower-body NC test was added to this study to aid in understanding the functionality of the how quickly and efficiently the lower body can recruit muscles for movement. As most states within the United States set standardized physical education objectives in their curriculum, understanding the state of MusS development during elementary years may aid in physical education literacy specifically aimed toward MusS development.

Normative data exists for fitness components such as cardiovascular health, but not as much on MusS of the individual limbs and combined limbs of children. Therefore, the purpose of this preliminary study was to explore MusS and NC differences among elementary-aged children by grade, sex, race, and socioeconomic status (as determined by state issued free or reduced lunch qualifications) and preliminarily assess baseline measurements for this elementary-aged population specifically. There are no hypotheses associated with this preliminary study as it is exploratory in nature. A gap remains in research for studies solely focused on the MusS and NC of children's individual limbs (unilateral) and the combined limbs (bilateral). Descriptive data such as this may aid those in the childhood health and fitness industry to assess MusS and neuromuscular control within typically developing populations and design fitness movements to strengthen the limbs as needed.

3.2 Methods

Participants

The children in this study totaled 248 (N=121 males; N=127 females) from the second (n=90), third (n=77), and fourth (n=81) grades of two different Texas schools. The assessments were scheduled in the physical education morning classes. The study population consisted of a minimum of 24 students per grade, allowing for a minimum of 77 participants per grade total. More students participated in some schools due to how the PE teacher split the class for participation, but the minimum of 24 was met for each school. Upon the PI arriving to administer testing, the PE teachers randomly selected an equal number of females and males (minimum of 12 of each) from the general class population whose parents consented and sent them to the PI to begin testing. The inclusion criteria for participating in this study were (a) typically developing, (b) no injury that inhibited participation in the physical education class and (c) being present on the day of testing. White and Hispanic were the only races included, as the "other" category had insufficient numbers necessary to be included. This study was approved by the University Institutional Review Board (1801-65-1801), followed by Superintendents, Principals, physical educators, and parents' consent. The participating children gave assent to the PE teacher once chosen, and then again before each test was administered. Children were allowed to deny participation at any time during the MusS and NC testing.

3.3 Measures and Materials

The tests were chosen as they met all of the above requirements for administration within the physical education setting and are tools to measure unilateral and bilateral MusS and NC in children (Baptista et al., 2022; Bogataj et al., 2020; Booher et al., 1993; Cho & Kim, 2017; Hashim et al., 2018; Plowman & Meredith, 2013).

The Dynamometer Grip Test. The digital Dynamometer Single-Hand Grip Test (Baptista et al., 2022; Cho & Kim, 2017) assesses unilateral upper-body MusS. The GRIPIX Digital Dynamometer Grip Strength Instrument was used to administer this test. To start the assessment, the tool was powered on and set to the appropriate age group and sex. The children were asked to stand with both feet shoulder-width apart, and maintain an angle of 15 degrees so that the torso and the arm (to be measured) did not touch each other, held the handle of the dynamometer with the second joints of their fingers, and pulled the handle while keeping their arms from shaking. They were asked to grip the dynamometer with their choice of whichever hand to begin. Once the instrument was checked to be in the correct position, the child was asked to squeeze the device for five seconds. The child was then asked to alternate hands and repeat the method. The grip strength of both hands was measured, twice on each side, and the highest value was recorded in pounds to the first decimal place. The highest attempt for the right and the left grip was used for statistical analysis.

The Push-Up Test. The Push-Up Test, as introduced in the FITNESSGRAM (Plowman & Meredith, 2013) assesses bilateral upper body MusS and endurance in elementary-aged children (Hashim et al., 2018; Kunutsor et al., 2021). To start the assessment, children assume a prone position with hands slightly wider than shoulders, legs straight, and toes tucked under. They raise into a plank position (shoulders, hips, and ankles are in a straight line as if a plank was placed on them). A soft foam ball is placed in a circular holder under the child's chest. The children participate in one practice push-up as they are cued to extend their arms while keeping their legs and back straight in a plank position, then to drop down so the chest touches the ball at the base of the push-up (90-degree angle of the elbows), and then return to the straight-arm plank position. After the practice push-up, the children were allowed to rest for a few seconds and then return to the straight-arm plank position. They were cued to start when the 30-second timer began. The children completed as many push-ups as possible within 30-seconds. For attempted push-ups to count, the body must stay in a plank position, the push-up must start and end in the extended arm position, and the chest must touch the ball on each downward attempt. The children participated in this test only once, and the whole number of completed push-ups in 30-seconds was used for the analysis.

The Single-Leg Three-Hop Test. The Single-Leg Three Hop Test (Booher et al., 1993; Hammami et al, 2022) assesses unilateral lower-body MusS. This test is an easy, field-expedient, inexpensive test to administer and is often used for return-to-play decisions after an injury (Guild et al., 2020; Millikan et al., 2019). To set up for the assessment, a four-foot line of tape was placed on the floor. This tape line was the start line for the children. A 20-foot perpendicular line of tape was placed in the center of the start line and ran out 20 feet perpendicular to the start line. A 20-foot tape measure was then placed with the zero at the back of the start line and taped down on each end. Children were taken through the following steps: 1) stand behind the start line with toes on the edge but not over; 2) balance on one foot of choice until stable; 3) hop as far as possible three consecutive times on a single leg without losing balance and landing firmly each time; and 4) on the third hop, stabilize on the landing foot for at least 2 seconds so the distance could be recorded. Failure to stick the final hop ended in a voided test score. The distance was measured from the start line to the heel of the landing leg down the perpendicular line. The children performed this process for two attempts per leg (right/left/right/left). Each distance was recorded to the nearest foot and whole inch. The farthest attempt for each leg was used for the analysis. If the child only had one attempt due to a voided test score, that score was used.

The Double Leg Vertical Test. The Two-Foot Vertical Jump Test (Bogataj et al., 2020; Cho & Kim, 2017) assesses bilateral lower-body MusS. This test is a widely used measure of children's lower limb power and MusS. To set up for the assessment, “0” of the tape measure was secured to the wall at the gym floor base, then was secured vertically up the wall. The children followed the following protocol: 1) begin in an upright position perpendicular to the wall at the tape measure; 2) extend one hand and arm up the tape measure with feet flat on the floor (hip and armpit touching the wall) – this is the “reach” which was recorded in nearest half inch first; 3) in their perpendicular position to the wall with hand still raised from the “reach”, lower their hips until the knees bent around a 90° position; 4) finally, jump vertically with both feet as high as possible, i.e., extend the hips and reach with the fingertips. The recording in nearest half inch was based on the furthest finger touch on the tape measure. Two attempts were recorded. The vertical jump score was calculated to the nearest half-inch from the highest recorded jump minus the “reach.”

The Side-Step-Test. The Side-Step Test (Cho & Kim, 2017) assesses neuromuscular control (NC) of the lower body. To set up for the assessment, parallel lines at 24” in length were taped 27” apart on the floor. Children were asked to stand with both feet inside the two taped lines. Once the timer started, they stepped with the right foot outside of the right line and returned it as quickly as possible, then they stepped with the left foot outside of the left line and returned it as quickly as possible. Side steps must alternate between right and left and one foot must always be on the ground (no jumping). Only one attempt of total whole number taps was recorded for the analysis.

No rest time was required between repetitions of any test as single-limb test were administered by switching from right to left or left to right each attempt, and no rest was taken between vertical jump attempts.

3.4 Procedures

In September, the primary investigator (PI) scheduled an adherence training for three other researchers who would help collect the data. The three other researchers are members of the same university as the PI and consisted of one PhD candidate and two staff members who are employed at the same university as the PI.   In October, 2022 the PI and the three trained researchers, administered all of the MusS and NC testing for both school districts. The PI assigned each researcher to one of the four indoor stations set up around the perimeter of the gym. One test station consisted of two tests that took the least amount of time (Dynamometer Grip Test and Vertical Jump Test). The single leg three-hop test, the push-up test, and the side-step test each represented the other three stations. On the testing day, children wore the required physical education shoes and clothes. Since the tests were all administered indoors, there was no issue with weather changes. The time of day was consistent due to the school schedule remaining the same throughout the year.

The children were informed about the purpose and technique of each test within one large group setting. They were then separated into groups of eight and assigned one of the four stations. Once at each station, the researchers gave instructions on how to perform their test in detail and gave the opportunity for the children to ask questions before beginning the tests. Once all children had completed their station test, each group rotated to the next station as explained at the beginning of class, while the researchers remained at their assigned station. Children could stop participation at any time. If a child stopped before all five tests were completed, their data was eliminated from the analyses.

Once the testing was complete, demographic data was gathered from the participating school principals. Demographic data included socio-economic status (SES) and race. SES was determined by the Texas Education Agency free and reduced lunch standards, regardless of whether they accepted these benefits. Children's race was predominantly White or Hispanic (93.5% when combined). Other races included African American, Asian, Pacific Islander, and Native American Indian and were combined as one group due to their smaller representation percentage.

Data Security

The data management personnel from the children's schools shared their demographic data through a protective link with the PI as a result of a school district agreement with the researchers. Each child was assigned an ID number to preserve confidentiality, so names could no longer be linked with demographic information. The child's ID numbers replaced their names to analyze MusS and NC testing, and all demographic data. Data was collected, processed, and complied with general data regulation procedures.

Data Analysis

All data was cleaned and coded in Microsoft Excel and then analyzed using JASP Team (2023), JASP (version 17.3) computer software. Means and standard deviations were calculated for each MusS and NC test by grade, sex, race, and free/reduced lunch. All three races were included in the descriptive analysis, but "Other" race was eliminated from any further analyses. MusS and NC test differences by grade, sex, race, and free/reduced lunch were tested using a multivariate analysis of variance (MANOVA) with a significance value set at $p<.05$. Follow up one-way ANOVAs were then run to determine any interactions and main effect differences from the MANOVA, also with a significance value set at $p<.05$. Overall effect sizes reported from moderate to high, minus sex and race with the grip test, which reported .03 and .02. All others fell between .04 and .26.

3.5 Results

Descriptive statistics were used to determine the means and standard deviations of all strength and neuromuscular control tests by grade, sex, race, and free or reduced lunch qualifications. Table 1 provides upper body MusS test means and standard deviations and Table 2 provides the lower body MusS and NC test means and standard deviations.

Table 1 reflected right and left individual hand grip strength and average grip strength increases as the grades advanced, while the push-up test scores decreased slightly as the grades advanced. Males and females showed higher right grip strength than left grip strength, while males scored higher on push-ups than females. The “Other” group, comprising only 6% of the race sample, showed the highest average scores for all upper body strength tests, followed by White, then Hispanic. Caution should be used when interpreting the “other” results due to the low representation of this group. Children who qualified for free/reduced lunch scored lower on all upper-body MusS tests than those who did not qualify for the lunch program.

Table 1

Upper-Body Strength Averages by Grade, Sex, Race and Free/Reduced Lunch

Variables	Right Grip (lb)M(SD)	LeftGrip (lb) M (SD)	Average Grip (lb) M (SD)	Grip Difference (lb) M (SD)	Push-Up M (SD)
Grade Average	28.7 (7.9)***	27.5 (7.3)***	28.4 (7.2)***	3.2 (3.0)	18.6 (9.3)
2 (n=92)	24.5 (5.7)	24.0 (5.6)	24.2 (5.3)	2.8 (2.3)	19.2 (9.3)
3 (n=81)	28.3 (7.6)	26.9 (7.0)	27.6 (7.0)	3.5 (2.9)	18.1 (8.7)
4 (n=90)	34.0 (7.9)	32.9 (7.3)	33.4 (7.0)	3.7 (4.4)	18.3 (10.0)
Sex Average	28.7 (7.9)**	27.5 (7.3)**	28.1 (7.2)**	3.2 (3.0)*	18.0 (9.0)*
Male (n=131)	30.0 (7.8)	28.7 (7.4)	29.4 (7.3)	3.1 (3.3)	19.8 (9.7)
Female (n=132)	27.5 (7.8)	26.3 (7.0)	26.9 (7.0)	3.5 (3.4)	17.3 (8.8)
Race Average	28.7 (7.9)**	27.5 (7.3)**	28.1 (7.2)**	3.2 (3.0)	18.0 (9.0)***
White (n=114)	29.7 (7.9)	28.4 (7.2)	29.0 (7.2)	3.4 (3.3)	20.4 (9.6)
Hispanic (n=132)	27.8 (7.9)	26.7 (7.3)	7.3 (7.3)	3.2 (3.2)	16.7 (8.7)
Other (n=17)	32.0(10.3)	33.3(10.2)	32.7 (9.9)	3.8 (4.2)	20.2 (9.2)
Free/Reduced Lunch Average	28.7 (7.9)	27.5 (7.3)	28.1 (7.2)	3.2 (3.0)	18.0 (9.0)
No (n=86)	29.6 (8.0)	28.8 (8.0)	29.2 (7.6)	3.8 (4.1)	20.8 (8.3)
Yes (n=177)	28.6 (8.0)	27.5 (7.4)	28.0 (7.5)	3.1 (2.9)	17.4 (9.6)

ANOVAs were run to show effects of the IV on the DV and are noted by: *p≤.05, **p≤.005, ***p≤.001.
“Other” population consisted of Black, Asian and American Indian. The number of children within these race categories were too small in number to be included as a separate category

Table 2 showed the three-hop scores increased for each individual limb, for the average three-hop scores, and the vertical jump scores as grades advanced. Males and females showed higher right leg three-hop scores than left leg three-hop score. Males outperformed females on all lower-body MusS tests. Males also showed less difference between the right and left lower limb strength than females, as seen in the “difference” column of the three-hop test. The “Other” race showed higher averages than White or Hispanic children for all lower-body MusS tests, although caution should again be used when interpreting their results. Each race reflected higher right leg three-hop test scores than left leg three-hop test scores. Children who qualified for free or reduced lunch scored lower on all individual limb three-hop scores and average three-hop scores. Neuromuscular control (side-step) mean scores also increased as the grades advanced, although there were no differences between males and females on this test. Children who qualified for free or reduced lunch showed lower mean averages on the neuromuscular control test than children who did not qualify for the program.

Table 2

Lower-Body Strength and Neuromuscular Control Means and Standard Deviations for Grade, Sex, Race and Free/ Reduced Lunch

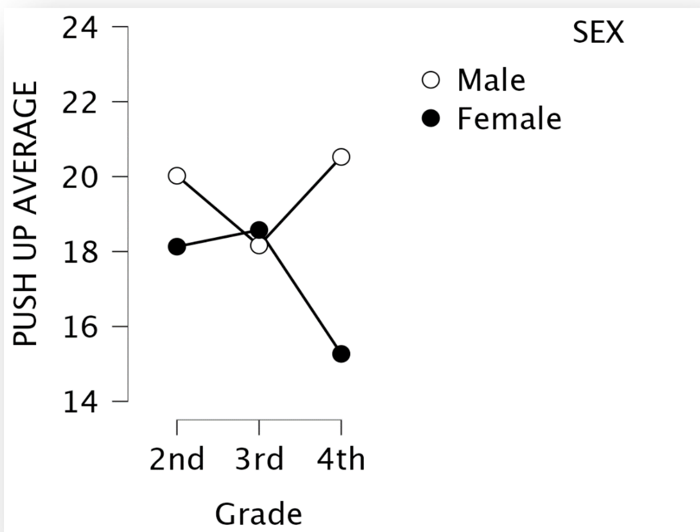
Variables	Right 3-Hop (in) M (SD)	Left 3-Hop (in) M/SD	Average 3-Hop (in) M/SD	Hop Differences (in) M/SD	Vertical Jump (in) M/SD	Side-Step Test M/SD
Grade Average	95.3 (27.3)***	91.0 (29.4)***	93.5 (26.4)***	14.4 (15.0)	8.7 (2.2)	25.1 (6.5)
2 (n=92)	82.8 (25.1)	78.1 (23.4)	80.7 (21.3)	14.8 (16.7)	8.4 (1.7)	22.0 (5.7)
3 (n=81)	94.5 (21.9)	87.3 (26.7)	91.5 (21.9)	15.3 (14.1)	8.7 (2.6)	25.3 (5.5)
4 (n=90)	108.9 (27.6)	107.7 (29.7)	108.3 (27.7)	13.1 (14.1)	9.1 (2.4)	28.2 (6.8)
Sex Average	95.0 (27.0)**	90.0 (29.0)***	92.0 (26.0)***	14.0 (15.0)*	8.6 (2.0)***	25.0 (7.0)***
Male (n=131)	100.3 (28.8)	96.4 (31.7)	99.0 (28.0)	16.2 (18.2)	9.2 (2.3)	25.0 (6.8)
Female (n=132)	90.3 (24.8)	85.6 (26.0)	88.0 (24.0)	12.5 (10.6)	8.1 (2.0)	25.2 (6.3)
Race Average	95.0 (27.0)	90.0 (29.0)	92.0 (26.0)	14 .0 (15.0)	8.6 (2.0)	25.0 (7.0)
White (n=114)	96.7 (25.5)	91.3 (28.7)	94.0 (25.5)	14.5 (12.9)	8.4 (1.9)	25.0 (6.8)
Hispanic (n=132)	92.6 (28.5)	89.8 (28.1)	91.6 (27.0)	12.6 (12.8)	8.8 (2.5)	25.3 (6.5)
Other (n=17)	106.5 (25.2)	102.1 (35.5)	104.3 (27.1)	17.1 (10.2)	9.5 (2.2)	24.7 (5.1)
Free/Reduced Lunch Average	95.0 (27.0)	90.0 (29.0)	92.0 (26.0)	14.0 (15.0)*	8.6 (2.0)	25.0 (7.0)
No (n=86)	100.2 (26.2)	96.6 (28.5)	99.0 (25.0)	15.0 (16.8)	8.7 (2.0)	26.4 (6.7)
Yes (n=177)	93.0 (27.4)	88.6 (28.9)	90.8 (26.8)	13.1 (10.2)	8.7 (2.3)	24.5 (6.4)

ANOVAs were run to show effects of the IV on the DV and are noted by: $*p \leq .05$, $**p \leq .005$, $***p \leq .001$.
"Other" population consisted of Black, Asian and American Indian. The number of children within these race categories were too small in number to be included as a separate category.

The purpose of this study was to explore MusS and NC differences by sex, grade, race, and free/reduced lunch. A MANOVA was performed to determine MusS score differences by each independent variable and an ANOVA was performed for the NC scores. Only one MusS interaction effect was found between sex and grade for the push-up test, $F(2,242)=2.88$, $p=.05$, showing second grade males performed the best of all grades by sex. Figure 1 reflects the interaction between sex and grade for the push-up test. Males showed steady progression in the push-up scores from second to fourth grade, with a slight dip between second and third grade. Females, however, showed a slight increase from second to third grade in push-up scores, but fourth grade females averaged significantly lower than both second and third grade females in push-up scores.

Figure 1

Sex by Grade Push-Up Test Interaction



Additionally, main effect differences were found for MusS scores by grade, F(2,242)=13.19, p<.001, sex, F(1,242)=6.76, p<.001, and race, F(1,242)=5.23, p<.001. No SES differences were found on any of the MusS tests (p>,05). The follow up analyses revealed children significantly improved as they advanced in grade on the average unilateral grip test, F(2,242)=42.66, p<.001, and the average unilateral hop test, F(2,242)=42.66, p<.001. Males significantly out-performed females on the average unilateral grip test, F(1,242)=9.71, p=.002, average unilateral hop test, F(1,242)=11.13, p<.001, and the vertical jump test, F(1,242)=18.74,

$p=<.001$. White children significantly out-performed Hispanic children on the average unilateral grip test, $F(1,242)=7.36$, $p=.007$ and the push-up test, $F(1,242)=12.17$, $p<.001$.

The ANOVA revealed only one NC main effect difference for grade, $F(2, 242)=23.34$, $p<.001$, showing children's side step mean scores improved as grades advanced. A strong trend was found with Free/Reduced Lunch $F(1,242)=3.22$, $p=.07$ where those who qualified for the government aid program scored lower than those who did not qualify.

3.6 Discussion

This preliminary study was designed to explore the interactions among four demographic variables with MusS and NC and preliminarily assess baseline measurements for this age group specifically. The multiple advantages of developing appropriate MusS during childhood and the declining state of muscular strength among children are established in research (Atkins et al., 2016; Avigo et al., 2019; Barnett et al., 2016; Hulteen et al., 2018; Kobayashi et al., 2014; Laurson et al., 2017; Smith et al., 2019). Much research focuses on adult PA behaviors across age, sex, race, and socioeconomic status Fuhner et al., 2021; Ning et al., 2021; Watson et al., 2018). This study is unique as it focuses on exploring MusS and NC tests, across various demographics during childhood. This is an essential first step to improve upon previous research, as gaps remain in childhood MusS trends accounting for grade, sex, race or socioeconomic status.

Grade by sex was the only interaction found for the push-up test. Boys were found to score better on push-ups from second grade to fourth grade, although a slight decrease occurred among third graders. Girls, however, were shown to slightly increase push-up scores from second to third grade, but significantly decrease in push-up scores among fourth graders. As children age, the time spent in PA begins to decline naturally, and therefore, the movement of the body and limbs become minimal. These outcomes support previous research showing a significant MVPA decline in girls (age six) and boys (age nine) (Farooq et al., 2020) and a rise in sedentary time (Janssen et al., 2016). This outcome may explain these baseline trends in upper body strength among females. If females decrease in PA three years sooner than boys, they may be recognized as needing MusS interventions earlier within childhood years.

Grade level was not a factor on the vertical jump test outcome. This may be an alarming find, as this bilateral test centers around the child's ability to generate power in the lower body mass-muscle groups. From 1972-2015, studies showed children steadily decreased in measures of muscular power (Wahl-Alexander & Camic, 2021). During active play and sport, children experienced explosive contractions of the muscle-tendon attachment in their lower limbs similar to the vertical jump (Stricker et al., 2020). If children do not develop proper lower limb MusS, these explosive movements may increase the risk of avulsion fractures until children are closer to skeletal maturity (Stricker et al., 2020). Although more testing is needed to generate normative and predictable data, if this trend continues among larger, diverse sample sizes, it will highlight the need for increased child participation in more explosive movements, such as skipping, jumping or running.

Males significantly outperformed females on every MusS test in this study which is supported in previous literature (Battaglia et al., 2021; Farooq et al., 2020; Jansen et al., 2016; Lloyd-Jones et al., 2022). Therefore, this data shows males generating more MusS on average than females, even before the hormonal growth spurt of preadolescence. This is important for those providing PA opportunities across males and females. Although a strength focus across males and females is equally important, the load one places upon males and females during PA may need to be modified according to sex, as ability to generate absolute power in individual or combined limbs may be less in females. Although males outperformed females on MusS tests, females showed equal results on the side step test (NC), possibly indicating females can control the brain-muscle connectivity as fluidly as males, even with less MusS. This is inconsistent with recent research showing males outperforming females on motor competency skills such as jumping, balancing, lateral movements and lateral jumping for speed (Battaglia et al., 2021). Although males outperformed females in this series of MusS testing, the females showed equal ability in fast, lateral movements. More studies are needed to understand this inconsistency (Lloyd-Jones et al., 2022).

Upper body strength tests were the only MusS scores significantly impacted by race: White children outperformed Hispanic children in both the push-up and the average hand grip test. Research shows adults and children alike vary across race in PA participation, and Hispanic races are less inclined to participate in muscle strengthening PA (Battaglia et al., 2021). Disparities in youth sport participation due to socio-economic status and ethnic minority membership also pose a barrier for movement opportunities among the Hispanic population (Brumitt et al., 2013; Kuhn et al., 2021; Ning et al., 2021; Watson et al., 2018). Although increased upper-body MusS should be the goal of any childhood PA program, heightened priority for Hispanic children and female children should be considered. Physical activities through physical education classes focused on upper body MusS for these two groups may need to be introduced more intentionally as early as second grade and emphasized for the duration of elementary school to maintain developmentally appropriate upper body strength.

Although not significant, the results from this smaller sample size are trending toward children who qualify for free or reduced lunch might have more issues with MusS and NC development than those who do not qualify. Children from lower income families may have less after school physical activity opportunities due to income, transportation deficits, or safety issues (Ball et al., 2015; Wilson & Bopp, 2023). Although more research is needed including larger diverse sample sizes, these trends support the idea that elementary physical educators in lower-income areas may need to focus on activities that aid in upper body MusS, single-leg MusS, and neuromuscular control development to off-set any developmental MusS deficits. To the advantage of the children who qualify for this program, they had less MusS imbalances between the dominant and non-dominant limbs in the single-leg hop. Those who work with PA of children in low-income arenas may consider focusing on overall strength development for unilateral and bilateral development.

For unilateral tests, the higher a group scored on a MusS test, the more evident imbalance was between the dominant and non-dominant limbs. An underlying, silent issue with children who display greater strength may be there is greater potential for an imbalance, and therefore greater potential for injury as they mature (Atkins et al., 2016; Avigo et al., 2018; Kobayashi et al., 2014; Lloyd & Oliver, 2012; Musalek et al., 2018; Pedersen, 2019; Stricker et al., 2020). Children with less opportunity for movement need overall upper and lower strength development focus, whereas children who present with higher MusS scores may need to focus on activities that include single-leg and single-arm activation to strengthen both dominant and non-dominant limbs. Stronger children may be in greater jeopardy of injuries due to MusS imbalance issues, therefore unilateral testing is pivotal when assessing the strength of less active and highly active elementary-aged children.

Previous to the adolescent growth spurt, elementary children exhibit MusS increases through increased NC (Stricker et al., 2020). The side-step test for NC showed children are equally capable of performing coordinated lower limb movements across sex, race and free/reduced lunch qualifications, and significantly improve as grades progress. This is exciting news for those working with children in the physical education realm. The more movements children participate in, the more proficient MusS development can be, leading to better NC (Avigo et al., 2019; Musalek et al., 2018; Pedersen, 2019; Stricker et al., 2020). Children have the ability to develop appropriate MusS through movement, they just need to be given the opportunity to move throughout the day as much as possible. In elementary school physical education classes or after school activity settings, instructors should challenge the neuromuscular systems of males and females alike, regardless of the difference in strength between the two groups. Examples of this may include balancing, core strengthening, dynamic stability, and agility exercises and plyometrics. Females may be able to do the same physical activities as males but maybe not to the same power, therefore, the activities may look different when performed by males and females.

3.7 Limitations and Future Studies

Limitations include the lack of race representation other than White and Hispanic populations. Further, the population was captured based on availability, therefore, was not an equal representation sample size between the White and Hispanic children. Another limitation is the descriptive statistics are not considered normative due to the insufficient number of children tested and the lack of representation across different regions of America. However, it provides an estimated guideline for educators and coaches who may want to strength test elementary-aged children. Finally, although the PI was present at every testing site and administered most tests, research assistants also aided in the data collection. The PI trained and approved them as competent to administer the testing. However, with different test administrators, there is always a chance of variations in data recording.

Future studies should include the same series of MusS and NC tests with larger sample sizes and more diversity in race representation to better generalize the findings across different regions and demographics. Studying special populations and those with disabilities would be a good addition to the MusS and NC testing introduced in this study. It would also be advantageous for a future study to consider past or present extra-curricular participation from the population to better connect upper body MusS deficits among different demographics with a larger population. Examining PA interventions and how they influence MusS and neuromuscular control scores among this population would also be an advantageous future study. Another future study may include analyzing the correlation in scores across the different MusS and NC tests in order to examine if all five tests are needed, or if one test may obtain indirect information about the other. In addition to future studies using these five assessments, it is recommended that these assessments be used in physical education classes as a means of monitoring weakness and growth among school-aged children. For implementation purposes, it would be necessary to create implementation videos and literature appropriate for PE teachers to administer these tests. These could be marketed as state or local PE professional development credit.

3.8 Conclusions

In conclusion, with the PA decline among children, it is essential for those working with children to monitor MusS and NC development. Increased MusS and NC are pivotal for decreased fracture incidents, increased motor skill development, and overall health (Avigo et al., 2019; Battagliia et al., 2021; Musalek et al., 2018; Stricker et al., 2020). This study aids in future MusS and NC assessments among children as it gives insight into variables that may influence MusS and NC testing scores. These influential variable findings include females and Hispanic children showing deficits in MusS compared to male and white children, especially with upper body MusS measures. This study also found children with lower MusS to have more balanced strength between the left and right matching limbs, whereas those with higher MusS scores seemed to exhibit more imbalanced scores between matching right and left limbs. These findings highlight the importance of testing MusS of unilateral and bilateral limbs, as children with proficient performance in bilateral MusS may not have proficient MusS across individual matching limbs. Although not significantly different, children classified as low SES scored lower on all five measures compared to higher SES children, showing trends aligning with previous research that children with lower SES have less opportunity for PA, and therefore less opportunity for MusS and NC development in childhood. No significant differences were found between demographic variables or grade for the NC side-step test.

A secondary conclusion to this study is the MusS and NC testing measures used in this study were found to be portable, cost-efficient (roughly $120), and easily administered to children. Monitoring a child’s MusS is essential so proper interventions can begin at early developmental stages when needed. As inactivity and sport specialization are on the rise in children, PA and MusS testing should be considered a public health priority in order to improve health and increase life-long mobility (Bogataj et al., 2020; Niessner et al., 2020). These MusS and NC testing may aid in future physical education literacy and curriculum standards as MusS and NC interventions may be needed if the trends found in this preliminary study continue in future studies.

Chapter 4: The LiiNK Project: Examining the Role of Increased Recess Time in Promoting Muscular Strength and Neuromuscular Control Among Predominately Hispanic, Second-Grade Children

4.1 Introduction

Physical activity (PA) behavior disparities exist in childhood across sex, race, and body fat composition, creating more significant physical developmental gaps as children mature (Ball et al., 2015; Jurić et al., 2023; Kuhn et al., 2021; Lerner & Browning, 2016; Obita & Alkhatib, 2023; Wilson & Bopp, 2023). For many children, the varying cultural backgrounds and social health determinants play a key role in PA engagement (Marrero-Riviera et al., 2024). Unhealthy housing, unsafe neighborhoods, and fewer convenient community locations reduce PA opportunities for varied child populations (Bantham et al., 2021). Demographically, Hispanic children and children in low socioeconomic status (SES) neighborhoods are shown to have significantly fewer safe areas for PA than those with a higher SES and safer PA areas (Gu et al., 2023) These cultural determinants have led to decreased PA opportunities across various child demographics, specifically Hispanic children, in America, and therefore an increase in prediabetes and diabetes prevalence (Lloyd-Jones et al., 2022; Zhang et al., 2024). In addition to cultural determinants, sex plays an important role in a child's PA involvement. A study of over 15,000 children aged 5-18 found that boys, on average, participate in roughly 40% more moderate to vigorous PA than females (Kretschmer et al., 2023). This is a serious disadvantage to females, as MVPA is highly influential in maintaining healthy body fat percentages during childhood (Hibbing et al., 2023; Sardinha et al., 2023;)

PA disparities such as these lead to an increased childhood obesity risk (Falconer et al., 2014; Jurić et al., 2023; Obita & Alkhatib, 2023). The weight gain accumulation creates an overall PA decline compared to normal-weight non-obese counterparts (Avigo et al., 2019; Cho

& Kim, 2017; Heo, 2014; Katzmarzyk et al., 2019; Musálek et al., 2018). Obesity not only stresses children's joints, it also alters gait mechanics and increased hip pain, further limiting PA levels (Lerner & Browning, 2016). American children account for 14.7 million of the global obesity count, with roughly 35% of those being younger than 12 (CDC, 2022). This is not a hopeful diagnosis for millions of children entering what should be considered the most active time of their lives. Children among this age group who are female and Hispanic are more likely to have at-risk overweight levels and are more likely to engage in sedentary behaviors than males or non-Hispanic peers (Lee et al., 2023). Therefore, children who represent more than one of the categories (sex, race, and obesity) are at an even more significant disadvantage.

This PA discrepancy is also intensified as only 24% of American children participate in the Center for Disease Control and Prevention (CDC) recommended 60-minutes of PA (CDC, 2022). Childhood inactivity hinders proper musculoskeletal system strength as bones and muscles weaken through decreased limb use (Barnet et al., 2016; Basso et al., 2021; Cebolla & Cheren, 2019; Kobayashi et al., 2014). Inactivity is highly problematic as muscle strength (MusS) is a dominant factor in neuromuscular control (NC), which is the brain's ability to recruit muscles efficiently for increased motor and movement skills and decreased injury (Munn et al., 2005; Musalek et al., 2020; Pederson, 2019; Stricker et al., 2021). MusS is additionally essential for children due to its ability to prevent diabetes, obesity, cardiovascular disease, bone mineral density, blood lipid profiles, insulin sensitivity, cancer, and mental health (Garcia-Hermoso et al., 2018; Laurson et al., 2017; Niessner et al., 2020; Tabacchi et al., 2019 Torres-Costoso et al., 2020). Despite CDC guidelines, childhood inactivity is still prevalent, and PA inequalities still exist, presenting significant MusS development deficits among American children (Kann et al., 2018; Tomkinson et al., 2020; Whal-Alexander & Camic, 2021). Therefore, PA must be accessible and functional to all children, regardless of sex, race, and body composition, in order to swing the pendulum to healthy and active child practices.

The conditions in which people are born, live, work, and play impact their PA opportunities, but school settings can provide safe, equitable access, and developmentally appropriate PA and movement opportunities daily for all children (Ball et al., 2015; Musalek et al., 2020). There are different ways children can incorporate movement in their school day, but school recess, or unstructured, outdoor play has developmental child benefits that physical education (PE) and after school sport programs cannot match (Rhea, 2021; Vidya, 2018). Recess provides children with a perfect space to be physically active, coordinate limb movements, and move kinesthetically, meaning varying limb movement directions while engaging in single or combined motor tasks like walking, running, jumping, dodging, and climbing movements (Campbell-Pierre & Rhea, 2023; Dankiw et al., 2020). This freedom to move with low magnitude limb movements leads to increased MusS development naturally through play, which in turn, provides the foundation for motor coordination of gross and fine motor skills (Dankiw et al., 2020; Kobayashi et al., 2014; Webb & Rhea, 2023) and the confidence to engage (Campbell-Pierre & Rhea; DiGirolamo, 2013; Kobayashi et al., 2014). Therefore, time spent in recess should be considered foundational for proper physical development and natural physical activity during the critical developmental elementary years.

PA has been shown to increase MusS in children (Barnett et al., 2016; Smith et al., 2019; Stankovic et al., 2022). Although PA yields MusS benefits, the long-term effects of recess in MusS development still need to be established. One of the only successful longitudinal recess interventions showing whole child development is the LiiNK Project® (Let's inspire innovation 'N Kids). The LiiNK Project implements four 15-minute recesses and one 15-minute character lesson (Positive Action®) daily in elementary and middle schools (Rhea & Rivchun, 2018).

Though PA is not the primary goal of this recess project, the LiiNK research team has found moderate to vigorous PA (MVPA) occurs significantly more in unstructured, outdoor recess than when structured recess is implemented (Farbo & Rhea, 2021; Farbo et al., 2020). The LiiNK intervention has also shown MVPA and imaginative play increases the children's limb usage, therefore increasing physical health (Farbo & Rhea, 2021; Webb & Rhea, 2022). Other recess benefits found with LiiNK children are lower stress levels (Kirby & Rhea, 2022), decreased problematic behaviors (Clark & Rhea, 2017; Rhea et al., 2018), greater attentional focus when returning to the classroom after recess (Lund et al., 2017), and significant postural balance and motor competency gains throughout the school year (Campbell-Pierre & Rhea, 2023). Although many whole child benefits have been found through LiiNK's longitudinal intervention, the MusS and NC recess benefits have yet to be studied. Whether genetically or environmentally driven, some demographics can play a role in PA behaviors leading to MusS and NC development during childhood. Access to quality movement opportunities is essential for MusS, NC, and the overall health of any child (Avigo et al., 2019).

As Webb & Rhea (2024) established, unilateral (one limb at a time), bilateral (both arms or both legs at the same time), and contralateral (opposite and opposing limbs used at the same time) are the foundation of all limb movements which are increased through PA. This limb utilization promotes increased MusS and NC, which in turn creates more advancement in all future and advanced movement skills. Therefore, unilateral, bilateral, and contralateral limb movements are the MusS testing foundation within this study. Unilateral and bilateral MusS will be tested for the upper and lower limbs. The following compilation of tests support this body of work. The Digital Dynamometer Single-Hand Grip Test (Baptista et al., 2021; Cho & Kim, 2017) has been shown to assess unilateral upper-body MusS strength, the Single-Leg Three Hop Test (Booher et al., 1993; Hammami et al., 2022) has been shown to assess unilateral lower-body

MusS, the Push-Up Test (Plowman & Meredith, 2013) has been shown to assess bilateral upper body strength, and the Two-Foot Vertical Jump Test (Bogataj et al., 2020; Cho & Kim, 2017) has been shown to assess bilateral lower-body MusS.

Contralateral limb movements require recruitment across all four limbs, core stability, and advanced sensory functions such as reaction time (the time between the brain stimulus and the movement response) (Goethel et al., 2023). Therefore, contralateral movements require vast and multiple MusS and NC responses and connections between the body and the brain. A NC test, the side-step test (Cho & Kim, 2017) is included in this to assess the efficiency of this brain-body connection. These five tests have been assimilated to identify MusS and NC children's differences in participating in varying amounts of recess. As inactivity trends continue to rise during childhood, testing MusS and NC differences may help explain this gap in the literature.

Therefore, the purpose of this study was to examine MusS and NC factors in the Fall and Spring (Time 1 to Time 2) of one school year in a predominately Hispanic sample of second grade children who received 60-minutes (LiiNK intervention) or 20-minutes (control) of daily recess. This study's primary goal was to focus on a specific sample of predominately Hispanic second grade children with a balanced number of males and females to determine the impact of the recess intervention, not demographic influences. It was hypothesized that children in the intervention group would demonstrate greater improvements in MusS and NC scores compared to children in the control group. It was also hypothesized children in the intervention group would continue to demonstrate greater MusS and NC score improvements after controlling for body fat percentages between groups. The independent variable for this study was the recess group and the dependent variables were the mean scores for each of the six tests administered to measure MusS and NC (single hand grip, single leg three-hop, push-up, vertical jump, side-step, and body fat analysis).

4.2 Methods

Participants

This quasi-experimental pre-test/post-test study focused on second grade students from two Texas public school districts (one elementary school per district) with predominately Hispanic populations. District 1, the LiiNK intervention children (N=59) received 60-minutes (four 15-minute segments) of recess daily, while District 2, the control children (N=49) participated in one 20-minute daily recess. For this study, race is used to describe this sample due to schools reporting only race categories, not ethnicity (Hispanic, non-Hispanic). The race choices provided were White, Black, Hispanic, Asian, Native American, Pacific Islander, and Other. The child distributions for sex, race, and body fat percentages (N=108) are provided in Tables 1 and 2. Demographic data for sex and race were gathered from the participating school principals. Children's race was predominantly Hispanic in both groups, intervention (72%) and control (61%). Other races (White, Black and Asian) were combined as the "Other" group for descriptive presentation. Time 1 assessments were completed in October 2023 and Time 2 assessments were completed in February 2024. The children were tested during their regularly scheduled PE classes and all PE classes took place between 9-10:30 am CST. The inclusion criteria for participating in this study were (a) parent consent and child assent, (b) no injury that inhibited participation in the physical education class, and (c) being present on the day of testing.

A priori power sample analysis was conducted using G*Power 3.1.9.2, with alpha and beta sets ($\alpha = 0.05$; $\beta = 0.80$) and with a large effect size ($f = 0.425$) (Macak et al., 2022). The power analysis estimated 77 children for adequate statistical power. The original sample size was 80 children per group (160 total) accounting for attrition between Time 1 and Time 2. Due to attrition rates, the final sample size was 108.

4.3 Measures

Four MusS tests (single hand grip, push-up, single leg three-hop and vertical), one NC test (side-step), and Bioelectric Impedance Analysis (BIA) (body fat analysis) were administered to children in both groups at Time 1 (October) and Time 2 (February). All six assessments identified for this study were found to be affordable, portable, and easy to use in the field such as a PE setting, and showed good reliability in previous studies (Baptista et al., 2022; Bogataj et al., 2020; Hammami et al., 2022; Cho & Kim, 2017; Farbo & Rhea, 2021; Hashim et al., 2018; Kuriyan, 2018; Lemos & Gallagher, 2017; Plowman & Meredith, 2013; Webb & Rhea, 2023). In each of the MusS and NC measures, a higher score indicates a better performance.

MusS Tests

Single-Hand Grip Test (Baptista et al., 2023; Cho & Kim, 2017)

The Digital Dynamometer is a highly reliable instrument used to assess single-hand grip. This unilateral upper-body MusS test is associated with the prediction of musculoskeletal fitness, upper body strength, triglyceride levels, cardiometabolic health, cardiovascular disease, type II diabetes, and bone health during childhood and into adulthood (Baptista et al., 2023; Fraser et al., 2021; Garcia-Hermoso et al., 2019; Kunutsor et al., 2021).

Single Leg Three-Hop Test (Booher et al., 1993; Hammami et al., 2022)

The Single-Leg three-Hop Test was used to assess unilateral lower-body MusS. In research, it is used to measure MusS and power in the individual lower limbs of pre-adolescent children (Hammami et al., 2022). It is also used to indicate sport and physical activity readiness, as low scores in the single hop test are associated with increased injury risk in the thigh and knee (Guild et al., 2020). Additionally, research supports the difference in distance hopped between limbs (limb symmetry) can help identify those who may be more prone to foot and ankle injuries (Brumitt et al., 2013).

Push-Up Test (Plowman & Meredith; 2013)

The Push-Up Test was used to asses bilateral upper body MusS. During the push-up, the muscles in the front and back of the arms (triceps brachia and biceps), chest (pectoralis major), and shoulders (deltoids) are recruited Fawcett et al., 2014). The push-up test can aid in monitoring this upper-body mass recruitment, known as arm and shoulder girdle strength (Hashim et al., 2018).

Double-Leg Vertical Jump Test (Bogataj et al., 2020; Cho & Kim, 2017).

The Double Leg Vertical Jump Test was used to measure bilateral lower-body MusS. This assessment is one of the most common tests to assess bilateral, explosive movements in from elementary aged children to adults (Bogataj et al., 2020; Watkins et al., 2017). Assessing these movements is important to determine if the child is ready for the explosive contractions of the muscle-tendon attachments in the lower limbs, as these movements are utilized in many play and sport arenas as the child advances in movement skills (Stricker et al., 2020).

Side-Step Test (Cho & Kim, 2017).

The Side-Step-Test assessed neuromuscular control (NC) of the lower body. It calls for entire core and lower body recruitment to complete the task, allowing for a better understanding of the brain-body connection. American Academy of Pediatrics has noted MusS gains in pre-adolescent children are displayed as neuromuscular advances rather than muscle hypertrophy, as seen in pubertal children (Stricker et al., 2020).

Body Fat Assessment (Kuriyan, 2018)

The Bioelectric Impedance Analysis (BIA) scale was used to determine body fat percentages of the children. BIA is able to determine an estimate of fat mass, fat free mass, water weight, and bone density that shows a moderate to strong association with results provided by DXA (Kuriyan, 2018). This assessment has been recommended as an alternative body fat measure to body mass index (BMI) in children and adolescent fitness manuals such as FitnessGram to collect data in a school setting. This shift is due to reducing human error, convenience of using it in large group settings, and body fat percentage accuracy across different populations (Farbo & Rhea, 2021; Kuriyan, 2018; Lemos & Gallagher, 2017; Plowman & Meredith, 2013).

4.4 Procedures

The University Institutional Review Board approved this study (1801-65-1801). Following IRB approval, Superintendents, Principals, physical educators, and parents consented to this study and each child assented to the tasks during the physical education class. The primary investigator (PI) scheduled adherence training for three other researchers who would help collect the data. Once the PI felt the others could competently administer the five tests and the BIA, the PI assigned one of the five stations to each researcher. Each of the stations were set up around the perimeter of the gym during the regularly scheduled Physical Education classes. One station consisted of two tests that took the least time (the Dynamometer Grip Test and the Vertical Jump Test). The single-leg three-hop test, the push-up test, the side-step test and BIA were separate stations. On the testing day, children wore the required shoes and clothes for participation in the physical education class.

The children were informed about the purpose and technique of each test within one large group setting. They were then separated into eight groups and assigned one of the four stations. Once at each station, the researchers gave detailed instructions (Webb & Rhea, 2024) on how to perform their test and allowed the children to ask questions before beginning. Once all children at each station completed the test, each group rotated to the next station, while the researchers remained at their assigned station. Children could stop participation at any time. If a child stopped before all five tests were completed, their data was eliminated from the analyses.

Single Hand Grip Test

To begin the test, power was turned on and set to the appropriate age group and sex. The children were asked to stand with both feet shoulder-width apart and maintain an angle of 15 degrees so that the torso and the arm (to be measured) did not touch each other. With the hand of choice, they held the dynamometer handle with the second joints of their fingers and their thumb wrapped over the top. They were monitored to ensure they kept their arm from touching the side body and elbow from bending more than 15-degrees. Once the instrument was checked to be in the correct position, the child was asked to squeeze the device for five seconds. The grip strength of both hands was measured, twice on each side (i.e., right/left/right/left), and each attempt was recorded in pounds to the first decimal place. The highest attempt for the right and the left grip was used for statistical analysis.

Single Leg Three-Hop Test

To set up this test, a four-foot line of tape was placed on the floor. This tape line was the start line for the children. A 20-foot perpendicular line of tape was placed in the center of the start line and extended 20 feet perpendicular to the start line. A 20-foot tape measure was then placed with the zero at the back of the start line and taped down on each end. Children were taken through the following steps: (1) Stand behind the start line with toes on the edge but not over. Balance on one foot until stable; (2) Hop as far as possible three consecutive times on a single leg without losing balance and landing firmly each time; (3) On the third hop, stabilize on the landing foot for at least two seconds to record the distance—failure to stick the final hop ended in a voided test score. The distance was measured from the start line to the heel of the landing leg down the perpendicular line. The children performed this process for two attempts per leg (right/left/right/left). Each distance was recorded to the nearest foot and whole inch. The farthest attempt for each leg was used for the analysis. If the child only had one attempt due to a voided test score, that score was used.

Push-Up Test

To begin the test, children assumed a prone position with hands slightly wider than and in line with the shoulders, legs straight, and toes tucked under. The body was raised into a plank position (shoulders, hips, and ankles are in a straight line as if a plank was placed on them). A soft foam ball was placed under the child's chest in a circular holder. The children participated in one practice push-up as they were cued to extend their arms while keeping their legs and back straight in a plank position and then to drop down. Hence, the chest touched the ball at the base of the push-up (90-degree angle of the elbows) and then returned to the straight-arm plank position. After the practice push-up, the children were allowed to rest for a few seconds and then return to the straight-arm plank position. They were cued to start when the 30-second timer began. The children completed as many push-ups as possible within 30-seconds. For attempted push-ups to count, the body must stay in a plank position, the push-up must start and end in the extended arm position, and the chest must touch the ball on each downward attempt. The children participated in this test only once, and the whole number of completed push-ups in 30-seconds was used for the analysis. Only one child was assessed at a time to record the push-ups accurately.

Double Leg Vertical Test

Initially, the 0" section of the tape measure was secured to the wall at the gym floor base and then vertically up the wall. The children followed the following protocol: 1) began in an upright position perpendicular to the wall at the tape measure; 2) extended one hand and arm up the tape measure with feet flat on the floor (hip and armpit touching the wall) – this is the "reach" which was recorded in nearest half inch first; 3) in their perpendicular position to the wall with hand still raised from the "reach," lowered their hips until the knees bent around a 90° position; 4) jump vertically with both feet as high as possible, i.e., extend the hips and reach with the fingertips. The recording in the nearest half inch was based on the furthest finger touch on the tape measure. Two attempts were recorded. The vertical jump score was calculated to the nearest half-inch from the highest recorded jump minus the "reach."

Side-Step Test

To set up this test, parallel lines 24" long were taped 27" apart on the floor. Children were asked to stand with both feet inside the two taped lines. Once the timer started, they stepped with the right foot outside of the right line and returned it as quickly as possible, then they stepped with the left foot outside of the left line and returned it as quickly as possible. Side steps must alternate between right and left, and one foot must always be on the ground (no jumping). Only one attempt at the total number of taps was recorded for the analysis.

Body Fat Test

To set up this test, the scale was placed on the floor surface, turned on, and synced to the computer that would record the child's full analysis. Once the scale was ready and assent was provided, each child stood on the metal plates of the scale with their shoes and socks off when their names were called. After about 15–20s, the scale flashed a green light signifying that the measurement was complete, and students returned to the class activity. The PI then saved the data to the computer, disinfected the scale with alcohol wipes, and called the next child to stand on the scale so the process could be repeated.

Data Security

The data management director from the children's schools shared their demographic data through a protective link with the PI as a result of a school district agreement with the PI's university. Each child was assigned an ID number to preserve confidentiality, so names could no longer be linked with demographic information. The child's ID numbers replaced their names to analyze MusS and NC testing, BIA data, and all demographic data. Data was collected, processed, and complied with general data regulation procedures.

Data Analysis

All data was cleaned and coded in Microsoft Excel and then analyzed using IBM SPSS version 29. All data were examined for outliers and missing scores and children who did not complete all four MusS and the one NC test were removed from the data set. The children who attempted the push-up test, but could not complete at least one push-up, remained in the data set with a score of zero. A test administration error in push-ups occurred when one of the raters counted push-ups inaccurately in Time 1. The error was not detected until Time 2 data collection, making it impossible to fix in the appropriate time window. This error resulted in the deletion of 17 samples from the original intervention group, leaving the remaining 59 for analysis. No other outliers were detected, so no other children were deleted from the sample. The final sample included 59 intervention children, 49 control children, for a total sample size of 108.

Sex and race distributions were examined by group and chi-square was used to analyze any group differences. Descriptive statistics were determined for MusS scores, NC scores, and for body fat category percentages at Time 1, Time 2, for the average scores (Time 1 plus Time 2 divided by two), and the change scores (Time 2 minus Time 1) by group. Independent sample t-tests were run to compare group differences for the MusS and NC tests at Time 1, Time 2, for average scores, and change scores. For Hypothesis 1, which examined factors relating to MusS and NC change scores between groups, A General Liner Model (GLM) determined group differences for the MusS and NC tests at Time 2 controlling for Time 1. For Hypothesis 2, a GLM was run to determine group differences for the MusS and NC tests at Time 2 controlling for Time 1 and body fat percentage mean scores. Bonferroni adjustment was used for all analysis and significance level was set at p=.05.

4.5 Results

Descriptive Statistics

Table 1 shows sex and race distribution of the sample. A chi-square analysis determined no sex or race differences between intervention and control groups, indicating the two groups were comparable for hypotheses testing.

Table 1

Sex and Race Distribution Comparison Between Intervention and Control Groups

Demographic Groups	N	Intervention (N=59)	Control (N=49)	X^2	p
Sex					
Female	57	32 (54%)	25 (51%)	.11	.74
Male	51	27 (46%)	24 (49%)		
Race					
Hispanic	73	43 (72%)	30 (61%)	1.66	.20
Non-Hispanic	35	16 (28%)	19 (39%)		

Chi-square analyses revealed that body fat category was not an influencing factor between groups at Time 1, Time 2, and the change scores (Time 2 minus Time 1) (Table 2). Although body fat category groups did not significantly differ on the change scores, 5% of the intervention group moved into the healthy category from Time 1 to Time 2, whereas the control group decreased in the healthy category by 2%. No change occurred in or out of the obese category for the intervention group from Time 1 to Time 2, but the control group increased in the obese category by 4%. Independent sample t-tests showed that body fat percentage is significantly different in terms of change scores between groups, but
it does not differ at Time 1 and Time 2 (Table 2).

Table 2

Body Fat Category Comparisons Between Intervention and Control Groups

	Time 1		Chi-square or t-test	Time 2		Chi-square or t-test	Change Scores[A]		Chi-square or t-test
Body Fat Categories	Intervention	Control		Intervention	Control		Intervention	Control	
Healthy	34%	43%	C^2=.78, p=.38	39%	41%	C^2=.04, p=.85	+5%	-2%	C^2=2.68, p=.10
Overfat	20%	22%	C^2=.05, p=.82	25%	22%	C^2=.11, p=.74	+5%	0%	C^2=1.89, p=.17
Obese	27%	31%	C^2=.17, p=.68	27%	35%	C^2=.68, p=.41	0%	+4%	C^2=2.29, p=.13
Body Fat %	26.8 (10.7)	25.5 (8.6)	t(93)=-.60, p=.55	27.5 (11.0)	24.8 (8.9)	t(93)=-1.28, p=.20	0.77 (3.7)	-0.73 (1.9)	t(93)=-2.29, p=.02

A. Change From Time 1 to Time 2 (Time 2 scores minus Time 1 scores)

B. Intervention n=57, Control n=37.

C. *Female % body fat: Healthy (15-29), Overweight (21-33), Obese (Over 33). Male % body fat: Healthy (14-22), Overweight (18-32), Obese (Over 32).

The intervention children scored higher than control children for Time 1, Time 2, and average scores on the following MusS tests (see Table 3): right and left single hand grip, average of right and left single hand grip, push-up; and the NC side step test. Intervention children also scored higher than control children on change scores, meaning greater improvement over time, for the MusS tests: right and left single leg three-hop, average of right and left single leg three-hop, and the NC side-step test. The control group reported higher change scores on the push-up test than intervention children, but this was due to the control children scoring lower in the Fall than the intervention children. Independent Sample T-Tests determined no significant differences between groups at Time 1 for the single leg three-hop or the vertical jump. Significant differences between group were found at Time 1 for the single hand grip, the push-up, and the side-step. Significant differences were found in Time 1 between groups for three of the five tests. Due to this finding, Time 1 was not an appropriate baseline measure for change scores from Time 1 to Time 2. Therefore, a GLM was run to determine group differences at Time 2 controlling for Time 1.

Table 3

MusS and NC Test Mean and Standard Deviations by Group

	Time 1		*Time 2*		*Average Scores[A]*		*Change Scores[B]*	
	Intervention Pre-Test	Control Pre-Test	Intervention Post-Test	Control Post-Test	Intervention Average	Control Average	Intervention Change Scores[A]	Control Change Scores[A]
MusS Tests								
Right Grip[C]	23.7 (6.4)**	20.0 (5.4)	25.3 (5.7)**	22.4 (3.4)	24.5 (5.6)***	21.2 (4.0)	1.6 (4.5)	2.4 (4.4)
Left Grip[C]	22.7 (6.2)***	19.1 (5.0)	23.7 (5.5)*	21.5 (3.4)	23.2 (5.4)**	20.3 (3.7)	1.0 (4.2)	2.4 (4.4)
Average[A, C]	23.2 (6.1)***	19.6 (5.1)	24.5 (5.4)**	22.0 (3.1)	23.87 (5.5)***	21.3 (3.6)	1.3 (4.0)	2.4 (4.0)
Right Hop[D]	69.7 (30.2)	74.1 (24.0)	83.0 (30.4)	76.3 (18.0)	76.3 (29.2)	75.2 (17.8)	13.3 (16.6)**	2.2 (23.2)
Left Hop[D]	66.2 (32.7)	73.4 (22.8)	81.0 (29.0)	73.0 (17.8)	73.6 (28.8)	73.2 (17.6)	14.8 (22.6)***	-0.4 (20.7)
Average Hop[A, D]	67.9 (28.7)	73.8 (22.9)	82.0 (28.9)	74.7 (16.6)	75.2 (28.2)	75.0 (16.8)	14.1 (15.5)***	0.92 (20.6)
Push-Up	7.1 (5.5)***	0.5 (0.8)	8.3 (6.4)***	3.4 (4.9)	7.7 (5.7)***	2.0 (2.6)	1.2 (3.4)	2.9 (4.7)*
Vertical Jump[C]	6.8 (2.0)	6.6 (1.9)	7.3 (1.9)	7.3 (1.7)	7.1 (1.8)	7.0 (1.5)	0.5 (1.6)	0.7 (2.1)
NC Test								
Side-Step	23.2 (4.6)*	21.3 (5.0)	26.7 (5.2)*	24.1 (6.2)	24.9 (4.3)	22.7 (4.7)	3.5 (4.6)*	2.8 (6.5)

A. Average (Average of right and left limb scores)
B. Change Scores (Time 2 minus Time 1)
C. Recorded in pounds to the nearest tenth
D. Recorded in inches to the nearest half-inch
E. Average Scores (Time 1 plus Time 2 divided by 2)
F. Significant differences between group averages, *p=.05, **p=.01, ***p=<.001
G. Intervention n=59, Control n=49

Hypothesis 1

Hypothesis one stated children in the intervention group would demonstrate greater improvements in MusS and NC scores compared to children in the control group. GLM determined group differences at Time 2 while controlling for Time 1 (Table 4). Intervention children significantly outperformed control children on the single leg three-hop, F(1,105)=13.1, p<.001, n^2 = .11, with an observed power of 0.95 and the NC side step, F(1,105)=4.8, p=.03, n^2 = .04, with an observed power of 0.35. The other three MusS tests were not significant.

Hypothesis 2

Hypothesis two stated children in the intervention group would continue to demonstrate greater MusS and NC score improvements after controlling for body fat percentages between groups**.** GLM determined group differences at Time 2, while controlling for Time 1 and body fat percentages (Table 4). After adding body fat percentages as another control variable, the NC side-step test was no longer significantly different between groups, but the MusS single leg three-hop remained significant between groups, $F(1,91)=23.7$, $p<.001$, $n^2 = .21$, with an observed power of .72.

Table 4

Comparing Time 2 Measure of MusS and NC by Group, While Controlling for Time 1 & Body Fat Percentages

Main Effect	MusS Tests				NC Test
	Single Hand Grip	Single Leg Hop	Push-Up	Vertical Jump	Side-Step
Group	F(1,105)=2.68, p=.97, n^2=1.7	F(1,105)=13.1, p=<.001, n^2=.05	F(1,105)=2.92 p= .09, n^2=.01	F(1,105)=.26, p=.61, n2=00	F(1,105)=4.77, p=.03, n^2=.04
Group Controlling Body Fat	F(1,91)=3.32, p=.07, n^2=.02	F(1.91)=23.5, p<.001, n2=.09	F(1,91)=3.10, P=.08, n^2=.01	F(1,91)=.14 p=.71, n^2=.9.71	F(1,91)=1.61, p=.21, n2=.02

4.6 Discussion

The purpose of this study was to examine factors related to MusS and NC scores over time (Time 1, Time 2, average scores, and change scores) in a predominately Hispanic sample of second grade children who received 60-minutes (LiiNK intervention) or 20-minutes (control) of daily recess. A balanced sample across sex, race and body fat percentage was used for the sample population, as the primary goal was to determine the impact of the recess intervention on MusS and NC test scores. Notably, we found evidence for a positive association between increased time spent in daily recess with increased MusS and NC scores among this sample of predominantly Hispanic, second grade children.

The first main finding of this study showed the LiiNK intervention children continued to score significantly better in the single leg three-hop (MusS test) when controlling for Time 1. Significant improvement among the LiiNK intervention group for the single-leg three-hop test may indicate the extra time spent in recess readies both individual lower limbs for sport and PA while decreasing injury risk to the entire lower body chain (thigh, knee, ankle and foot). All MusS tests are important measures for assessing childhood fitness and MusS function, but the single leg three-hop is unique in its assessment capabilities. The single leg three-hop test is used to measure MusS and power in the individual lower limbs of pre-adolescent children; indicating sport and physical activity readiness, as low scores in the single leg three-hop test are associated with increased injury risk in the thigh and knee, and ankle and foot (Booher et al., 1993; Brumitt et al., 2013; Guild et al., 2022; Hammami et al., 2022). As second grade children are in a pivotal movement development stage, the single leg three-hop performance gives the advantage in advanced lower-body function to the LiiNK intervention children.

The 2nd main finding was the NC side step test showed significant differences by group when controlling for Time 1. LiiNK children, who are allowed 60-minutes of daily recess from early childhood on, may be more prepared cognitively and neurologically for advanced movements and sport skills by second grade. Inactivity among children is problematic for NC ability, as brain and body development advances with limb movements (DiGirolamo, 2013). This finding once again highlights the importance of these brain-body connections needed by age seven and the possible advantage to those who participate in more unstructured, outdoor free play or recess which provides increased FMS and limb movement opportunities.

The third finding, after controlling for body fat percentages, continued to show LiiNK intervention children showing greater improvement than control children on the single leg three-hop. LiiNK intervention children shifted into the healthy and overfat body fat categories by 5% between Time 1 and Time 2, but had no shifts in the obese group. Control children lost 2% from the healthy group, had no change among the overfat group, and gained 4% into the obese group from Time 1 to Time 2. Daily recess improvements may allow children regardless of body fat percentages, to recruit and utilize lower body MusS to a significantly greater degree. Obese children are typically found to have less MusS, which hinders advanced movement skills, increases injury, and decreases risk of all-cause mortality (Avigo et al., 2019; Cho & Kim, 2017; Garcia-Hermoso et al., 2018; Heo, 2014; Laurson et al., 2017; Lerner et al, 2016; Musálek et al., 2020; Niessner et al., 2020; Stricker et al., 2021; Tabacchi et al., 2019; Torres-Costoso et al., 2020). When controlling for body fat, children who participate in 60-minutes of daily recess maintained higher lower-limb MusS. This finding points to recess as a potential PA opportunity to increase limb usage in children with higher body fat compositions especially in Hispanic children.

Descriptives showed LiiNK intervention children outperformed control children in Time 1, Time 2, and the average scores in single hand grip, the push-up, and the NC side-step. This may be due to a longitudinal effect of intervention children receiving 60-minutes of daily recess since Kindergarten. Although only four months of intervention was assessed for this study, the intervention children have attended a LiiNK intervention school for two previous years. Although movement competency in early elementary years is essential for future movement skills, many studies report low levels of these skills among children (Bardid et al., 2016; Barnet et al., 2016; Basso et al., 2021; Cebolla & Cheren, 2019; Kobayashi et al., 2014; O'Brien et al., 2016). Second grade children are a critical developmental age, as by age seven they are expected to have engaged in adequate levels of movement competency such as running, jumping, kicking and throwing (Bolger et al., 2021). Without this foundation, the ability to advance into more specialized skills such as sport or PE is greatly hindered (Munn et al., 2005; Musalek et al., 2020; Pederson, 2019; Stricker et al., 2021). As most children in this age group lack movement skills, the LiiNK intervention children were found to score higher in MusS and NC than their 20-minute daily recess counterparts.

Additionally, the control children scored significantly higher push-up change scores than the intervention group. By Time 2, only 53% of the control children could complete at least one push-up, whereas 85% of the LiiNK children could complete at least one push-up (Figure 1, Figure 2). The push-up test, as it recruits the core, arms, chest and back, is used in younger children as a discriminatory predictor of the potential participation in future athletic or advanced movement endeavors (Henriques-Neto et al., 2021). As upper body MusS is linked to decreased injury and increased sport readiness, it appears LiiNK children had overall higher percentages of children capable of completing this advanced upper-body movement.

Figure 1

Percentage of Children Completing One Push-Up

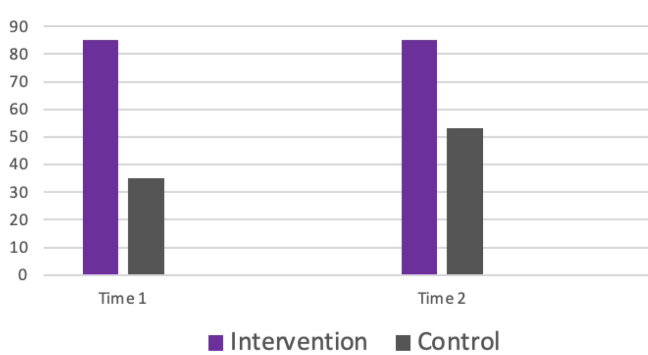
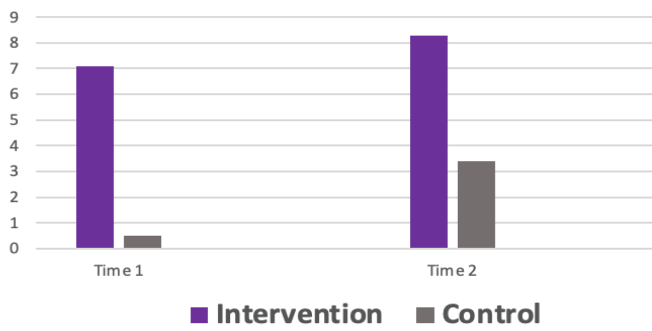


Figure 2

Average Push-Up



4.7 Limitations and Future Directions

One limitation was the sample size and geographic locations were not diverse enough to enable generalization to broader populations or to assess differences across various demographics (sex, race, SES). Another limitation was the span of four months between testing. If time allowed, the study would have benefited from an additional assessment time point following Time 2, or a longitudinal study over several years. Other limitations were found in testing administration. The PI and three trained assistants administered the test, nevertheless, an error occurred in the push-up test that caused the deletion of 17 samples from the intervention group. Additionally, for administration of the vertical jump test, the PI noticed discrepancies in the ability to administer this test properly during training. Therefore, the PI solely administered the vertical test to control the potential for error. As a result, the PI suggests the two-foot vertical jump be replaced with the two-foot broad jump for future studies. Development of a training manual and assessment protocols are needed for streamlined assessment of these tests in a larger population for future studies.

Longitudinal studies that include the effects of increased daily recess on MusS and NC are needed in future studies. Additionally, this study was intended for typically developing children in elementary school. The studies effects on non-typically developing children would be beneficial due to the numerous advantages of MusS and NC development in children, in both typically and non-typically developing children.

Environments children live and go to school in may significantly influence PA and measures of health, fitness, or wellness. Therefore, future studies may need to better control for or assess environmental factors that may influence MusS and NC testing. These include but are not limited to diet, extra-curricular activity participation, cultural norms, demographic locations, SES, green space availability during and outside of school, variances in playground equipment, and variances in PE programs or teachers perceptions on acceptable and non-acceptable play during recess.

4.8 Conclusions

PA discrepancies exist across race, sex, and body fat percentages in children. A lack of equitable PA opportunities, where children of varied race, sex, and body fat compositions can participate is evident with the inactivity epidemic in America. Unstructured, outdoor play known as school recess, can provide an equitable PA opportunity due to its accessibility across demographics and its self-directed nature that spans comfort levels, cultures, and intrinsic values of each individual child (Gray, 2017; US Department of Education, 2023). The findings showed school recess to be a preliminary positive PA influence on MusS and NC development among this sample of predominantly Hispanic, second grade children. This is an exceptional addition to the literature, as second grade students are at a pivotal developmental time in movement capabilities, where increases in MusS and NC set them up for more advanced sport and movement opportunities in the future, with less chance of injury. Whereas without this PA opportunity, typical trends within this age group point to movement deficiencies, leading to less MusS and increased injury. This study shows recess as a viable, equitable, PA opportunity across sex, race, and overweight children for MusS and NC advancement.

Chapter 5: Discussion

5.1 Overview

For the past 20+ years, MusS and NC deficits have appeared in adults as physical activity (PA) patterns began to decline (Alcazar, 2023). Over the past 10 years, this trend of physical inactivity resulting in MusS and NC decline has been seen in youth and now in children (CDC, 2022). Childhood physical inactivity hinders proper growth of the musculoskeletal system as bones and muscles weaken through the lack of limb use (Barnet et al., 2016; Smith et al., 2019). Access to quality movement opportunities accessible to all children is essential for MusS, NC, and the overall health of any child (Avigo et al., 2019). Whether genetically or environmentally driven, demographics such as race, sex, socioeconomic status (SES), and body fat play a role in PA behaviors and MusS and NC development during childhood.

The LiiNK Project (Let's inspire innovation 'N Kids) has shown over the past few years that recess, defined as unstructured, outdoor play, and character skills are very important for the developmental needs of children (Clark & Rhea, 2017; Kirby, 2022; Lund et al., 2017; Rhea & Rivchun, 2018). Though PA is not the primary goal of recess, the LiiNK research team has found MVPA occurs much more in unstructured, outdoor play than structured, outdoor play (Farbo & Rhea, 2021; Farbo et al., 2020). Moreover, increases in MVPA and imaginative play increase limb usage, postural balance, and motor competencies throughout the school year in LiiNK children, whereas children with less recess lack these developmental benefits (Campbell-Pierre & Rhea, 2023). However, a gap was still present connecting recess benefits associated with MusS and NC. This compilation of studies focused on whether MusS and NC benefits of recess could be attained.

5.2 Summary of Findings

In order to establish a link between MusS development and movements occurring during recess, Study 1 (Chapter 2) identified the body movements necessary to improve MusS among elementary-aged children. This study adopted Bartineff fundamentals to evaluate three essential limb movements fundamental to children's development: unilateral (one limb used at a time), bilateral (both upper or lower limbs activated at the same time), and contralateral (opposite and opposing limbs activated at the same time, often crossing the anatomical midline). In order to do this, the Movement Pattern Observation Tool (MPOT) was developed to allow preliminary snapshots of the limb movement variety utilized and calculate the percentage of children participating in each of these limb movements during recess (Webb & Rhea, 2023). .

Using this new and reliable measure (MPOT), limb movement usage trends were identified during recess. These trends showed kindergarten through second grade intervention children increased general limb movement percentages, whereas the 20-minute group showed a decrease in limb movements as grades progressed. Additionally, contralateral movements were the most utilized limb movement for all children. On average, 96% of all children, no matter if they had 30-minutes or 60-minutes of recess, were observed participating in the three limb movement types.

These findings led to the rationale that recess may be the catalyst for MusS development through the limb movement variety and repetitions acquired. In order to test MusS among children who participated in various amounts of recess, a preliminary study testing MusS measures matching each of the limb movement types had to be assessed. These MusS tests included the single-hand grip test for unilateral upper body MusS, the single leg three-hop for lower-body MusS, the push-up test for bilateral upper-body MusS, and the vertical jump test for bilateral lower-body MusS. As increases in NC during childhood present in childhood as increased MusS, the NC side-step test was added to the testing measures (Stricker et al., 2020). Study 2 (Chapter 3) reinforced the multiple advantages of proper MusS and NC development in children, introduced the MusS and NC testing protocol, and described other factors that may influence MusS and NC development (grade, sex, race, and socio-economic status).

Key findings among these factors included children performing significantly better as they advanced in grade across all unilateral MusS tests (single hand grip and single leg three-hop) and in the NC side-step test, which is ideal for the natural development of children as they age. Interestingly, though, this natural progression was not found in either bilateral test (push-up and vertical jump) as children advanced in grade. Males significantly outperformed females in all MusS testing, yet males and females performed similar in the NC side-step test. Hispanic children, in other studies, have shown lower PA levels than peers across other races (Lloyd-Jones et al., 2022; Zhang et al., 2024). Trends such as this were found in Study 2 as children from all other races collapsed into a Non-Hispanic race group outperformed the Hispanic race group on every MusS and NC test, and significantly outperformed Hispanic children in both upper-body MusS tests. Additionally, MusS and NC tests were successfully administered in the PE class setting efficiently and effectively. This also led to the role grade, sex, and race played with MusS and NC in elementary aged children which then supported the research focus for Study 3.

Study 3 (Chapter 4) used the same MusS and NC testing protocol to measure MusS and NC growth across two time points in intervention (60-minutes of daily recess) and control (20-minutes of daily recess) elementary school children. Grade, sex, race, and body fat were determined to be key variables in other children's PA participation studies (Avigo et al., 2019; Cho & Kim, 2017; Heo, 2014; Katzmarzyk et al., 2019; Kretschmer et al., 2023; Marrero-Riviera et al., 2024; Musálek et al., 2018; Zhang et al., 2024); therefore, a balanced sample across these demographics was used to determine the impact of the recess intervention. This study focused on a sample of predominantly Hispanic second grade children. Time 2 scores, when controlling for differences found in Time 1, showed intervention children had greater improvement in the single leg three-hop and the NC side-step test. When controlling for Time 1 and body fat, the intervention children continued to have significantly greater improvements than the control group in the single-leg three-hop.

Descriptives showed the intervention children had significantly higher right and left hand grip scores, average grip scores, push-up scores, and side-step scores than the control children (20-minutes of daily recess). A positive association was found between increased time in daily recess and increased MusS and NC scores among this sample of predominately Hispanic second grade children. A final conclusion from this study was increased recess may advance MusS and NC in elementary-aged children, leading to advanced movement skill acquisition in a pivotal stage of physical development.

***5.3* Limb Movement Assessment During Recess**

The overarching goal was to study recess as an equitable PA opportunity for advancing MusS and NC development in children. In order to do this, foundational movement theories had to be explored as well as a tool to observe these foundational movements during play. Study 1 (Chapter 2) sought to determine the theoretical base for limb movement usage among children and to develop a tool to observe and capture to what extent these movements were used among elementary children during recess. Bartineff Fundamentals became the theoretical foundation for childhood limb movements, as unilateral, bilateral, and contralateral limb movements were adopted. This theoretical base and observations of elementary children in recess confirmed that these three limb movements would be appropriate for creating the Movement Pattern Observation Tool (MPOT). This tool was developed and published due to a gap in the literature to observe limb movements during elementary school recess (Webb & Rhea, 2023) and support Study 1's purpose.

In Study 1, limb movements of 3,023 children were observed using the MPOT. This knowledge was essential in understanding recess's role in MusS development. Study 1 concluded when given the opportunity, most children will utilize limbs during recess in a way that is instrumental for healthy MusS as they age. Therefore, it was reasonable to continue researching recess for MusS development.

5.4 Assessing Muscular Strength and Neuromuscular Control

The National Institute of Health's Library of Medicine deems MusS testing as an essential component to reveal neurologic deficits, strength and endurance weaknesses, and imbalanced limbs among children (Bogatag, 2020; Naqvi et al., 2022; Niessner et al., 2020). Before researching the roles of MusS and NC development among children, Study 2 (Chapter 3) focused on determining viable testing tools for this age group and discovering which demographics (grade, race, sex, or socioeconomic) influenced these measures. Therefore, Study 2 determined and used four muscular strength testing tools to measure strength in all four limbs. These consisted of two unilateral tests measuring the individual upper and lower body limbs and two bilateral tests measuring both the upper and lower limbs working simultaneously.

Since MusS in childhood is often presented as an increase in motor neuron recruitment within the muscles, it would be rational to presume the more limb movements children utilize, the better they would perform on a NC test which was also included in Study 2's protocols (Stricker et al., 2020). This preliminary Study 2 (Chapter 3) conducted MusS and NC tests on 248 second, third, and fourth-grade children to determine how well children, in general, perform on MusS and NC assessments, and study how the limbs may be strengthened through unilateral, bilateral, and contralateral movements during recess. This study revealed that the four MusS tests and the one NC test chosen for the study were appropriate for elementary-aged children, and therefore could continue to be the measures in Study 3. The study also showed significant differences in MusS and NC scores across grade, sex, and race. Therefore, when exploring the role of recess in MusS and NC development, these demographic factors would be important to consider in Study 3.

5.5 Recess PA for MusS and NC

As American children are struggling to participate in the minimum 60-minutes of daily MVPA, those with barriers across race, sex, and body fat composition are especially in need of PA opportunities that span these barriers. The school setting has shown promise of crossing these PA discrepancy barriers (Ball et al., 2015; Gray, 2017; Musalek et al., 2020). During the school day, PA allows children to access limb movement opportunities through recess, defined unstructured, outdoor play as shown in Study 1. As a result of Study 1 demonstrating access of limb movements through PA during recess found across children in general and the preliminary MusS and NC measures and results of Study 2, Study 3 compared the MusS and NC scores between two recess groups: The LiiNK Project (intervention) children (60-minutes daily recess) and the control group (20-minutes daily recess). This study examined the role of increased recess time in promoting MusS and NC among predominately Hispanic, second grade children. As Study 2 emphasized the impact of race, grade, and sex on MusS and NC scores in children, grade was controlled by only including second grade, and a Chi-Square analysis showed race and sex to be non-significant between sampled groups. Children who were allowed 60-minutes of daily recess outperformed children with 20-minutes of daily recess in every MusS and NC test. Second grade children are a critical developmental age, as by age seven they are expected to have engaged in adequate levels of movement competency (Bolger et al., 2021). As most children in this age group lack movement skills, the LiiNK intervention children were found to be more advanced in MusS and NC than their 20-minute daily recess control group.

With significant differences between groups at baseline, Time 2 scores were assessed while controlling Time 1 scores to find the significant change between groups over this four month recess study. The LiiNK intervention group improved significantly more than the control group over the four-month intervention time period on the single-leg three-hop (MusS) test. All MusS tests are important measures for assessing childhood fitness and MusS function, but the single leg three-hop is unique as it indicates sport and physical activity readiness, with low scores associated with injury risk in the thigh and knee, ankle and foot (Booher et al., 1993; Brumitt et al., 2013; Guild et al., 2022; Hammami et al., 2022). This finding may indicate the extra time spent in recess readies both individual lower limbs for sport and PA while decreasing injury risk to the entire lower body chain (thigh, knee, ankle and foot).

The side-step test (NC) scores also significantly improved for the LiiNK children over the control children. NC is the brain's ability to recruit muscles efficiently for increased motor and movement skills and decreased injury (Munn et al., 2005; Musalek et al., 2020; Pederson, 2019; Stricker et al., 2021). This finding shows LiiNK children may be more prepared cognitively and neurologically for advanced movements and sport skills by second grade vs. the control children.

By Time 2, only 53% of the control children could complete at least one push-up, whereas 85% of the LiiNK children could complete at least one push-up. The push-up test, as it recruits the core, arms, chest and back, is used in younger children as a discriminatory predictor of the potential participation in future athletic or advanced movement endeavors (Henriques-Neto et al., 2021). As upper body MusS is linked to decreased injury and increased sport readiness, it appears LiiNK children are more prepared for advanced upper-body movement with decreased chance of injury.

When controlling for body fat, LiiNK intervention children continued to outperform control children in the single leg three-hop. Increases of daily recess may allow children regardless of body fat percentages, to recruit and utilize lower body MusS to a significantly greater degree in children. Obese children are typically found to have less MusS, which hinders advanced movement skills, increases injury and decreases risk of all-cause mortality (Avigo et al., 2019; Cho & Kim, 2017; Garcia-Hermoso et al., 2018; Heo, 2014; Laurson et al., 2017; Lerner et al, 2016; Musálek et al., 2020; Niessner et al., 2020; Stricker et al., 2021; Tabacchi et al., 2019 Torres-Costoso et al., 2020). When controlling for body fat, children who participated in 60-minutes of daily recess maintained higher lower-limb MusS, whereas the control group did not. This finding points to recess as a potential PA opportunity to increase limb usage in children with higher body fat compositions especially in younger Hispanic children.

A lack of equitable PA opportunities, where children of varied race, sex, and body fat compositions can participate is evident with the inactivity epidemic in America. Unstructured, outdoor play, or school recess, can provide an equitable PA opportunity due to its accessibility across demographics and its self-directed nature that spans comfort levels, cultures, and intrinsic values of each individual child (Gray, 2013; Gray, 2017; US Department of Education, 2023). Due to the controlled nature across sex, race, and grade, these findings showed school recess to be a strong avenue for PA, even across demographics shown by research to be limited in PA opportunities. Increased recess showed a preliminary positive influence on MusS and NC development in all three studies, but especially among Hispanic, second grade children. As most children within this age group lack movement skill development, the effects of increased daily recess seem to show the opposite.

5.6 Contribution to Knowledge Base

Activities such as school recess have been studied in the realm of MVPA, heart rate, and cardiovascular conditioning. However, until the creation of the MPOT tool (Webb & Rhea, 2023), no research existed to record the limb movements of children during recess, nor to what degree. With the development and interrater reliability of the MPOT, it is now possible to assess elementary children's unilateral, bilateral, contralateral, and "no" movements during school recess. This tool is a critical assessment, as limb movements aid in developing proper skeletal and muscular strength and neurological pathways for efficient movement and brain development. The benefits of unilateral, contralateral, and bilateral limb movements can produce a positive compounding effect as children utilize one side of the body or alternating use of the limbs to create new neuro-pathways (Munn et al., 2005), making light work of both simple and complex movements. This movement increases the child's health and wellness and stimulates the brain through nerve stimulation and oxygen consumption, prepping the children for more advanced movements.

Although fitness assessments exist in childhood to monitor health and fitness, most are centered around cardiovascular health via accelerometer data or cardiovascular fitness challenges. When MusS is assessed among children, it typically is combined with other fitness and health elements such as agility, speed, and cardiovascular elements. Since the single-hand grip test is shown in research to point to various cardiovascular disease risk factors, it is often used as the sole focus of many research studies among children (Baptista et al., 2023; Fraser et al., 2021; Garcia-Hermoso et al., 2019; Kunutsor et al., 2021).Previous to this dissertation, there was no standardized way to monitor elementary children's overall MusS and NC, nor any norm standards for these components for contemporary youth (Fraser et al., 2021). These five tests provide preliminary MusS and NC standards and aid researchers in exploring variables (recess intervention, age, sex, race, socio-economic status, body composition) that may influence MusS and NC in elementary-aged children. This dissertation highlights significant differences in MusS and NC of children across grade, sex, and race. As the inactivity epidemic continues across these demographics, this is the first step in understanding the impact this may play in MusS and NC development in children across these various sectors.

This compilation of studies provides a grouping of MusS and NC assessments specifically centered around children's fundamental limb movements (unilateral, bilateral, and contralateral). These tests were affordable, portable, and easily administered to children. Additionally, they were found to appropriately assess individual and combined limb MusS and lower limb NC of children across grade, sex, race, and body fat composition. As discrepancies exist in PA opportunities across sex, race, and body fat composition, increasing the already vast inactivity shift among American children, MusS is compromised within childhood. This series of MusS and NC tests adds to the literature an affordable, portable means for measuring MusS and NC among children for the continuation of baseline measures or influences of PA opportunities.

Recess has been studied as a means for cardiovascular health (MVPA), core stability, combination of fitness components (combination of MusS, Cardiovascular, Speed, Power, Flexibility), and for focus, retention, and behavioral changes upon returning to the classroom after play. However, recess has not been studied solely to increase limb movements during childhood, therefore increasing MusS and NC. Study 3 (Chapter 4) brings a fresh contribution to the literature about what recess may provide children regarding limb movements, and therefore MusS and NC, regardless of sex, race, and body fat composition. A need arises for children to increase limb movements throughout the day for proper brain and body development. Due to its self-directed nature, recess provides a choice of limb movement based on preference, intrinsic value, and cultural norms.

Study 3 also showed that increased time spent daily in this type of play reaps benefits for upper and lower body MusS of individual and combined limbs and lower body NC. This positive effect was shown among this second grade sample of predominantly Hispanic children. Hispanic populations are shown in research to have the least overall PA participation than other races, and therefore are less likely to develop proper MusS and NC due to inactivity levels. The LiiNK intervention seemed to have a significant influence on MusS and NC growth within a predominantly Hispanic population, as LiiNK children outperformed children with only 20-minutes of recess daily in every MusS and NC category, as well as significantly more growth over four months in lower-body MusS (single leg three-hop) and NC (side-step). For a population of students who are shown in research to reap increased detriments from inactivity compared to others, this increased MusS and NC finding among a predominately Hispanic, second grade population was very impactful.

Despite higher body fat percentages, this positive effect on lower body MusS (single leg three-hop) was displayed in children with more recess. This research provides information on a possible pathway for children with PA discrepancies (such as increased body fat) to maintain MusS and NC in childhood, increasing the ability to advance in movement skills, leading to increased activity in adulthood, and lowering the chance of all-cause mortality as they age.

5.7 Implications

Currently, most American children are categorized as having inactive daily lifestyles, leading to decreased MusS, creating a decrease in typical developmental movement capabilities. Practitioners, policymakers, and parents need to understand that in the absence of PA opportunities such as recess, the PA levels of children will continue to decline each year (Farooq et al., 2019). All children, regardless of sex, race, socio-economic status, or body fat composition, need PA interventions in order to shift the unhealthy and inactive direction our children are headed. Since recess is an equitable and accessible PA intervention across these demographics, where most children participate in limb movements, recess seems to be a strong platform for increased MusS and NC among elementary-aged children.

In summary, this compilation of studies will guide the health and fitness industry to assess children's MusS and NC across various demographics. This dissertation introduces researchers, policymakers, and school administrators to recess as an equitable PA opportunity in schools with excellent MusS and NC developmental benefits. As elementary-aged children increase sedentary lifestyles, exploring the benefits of increased daily recess time is essential. The increased daily recess may impact MusS and NC development and advanced movement skills, leading to lifetime movement opportunities and increased health as children age.

5.8 Future Research

Environments that children live and go to school in may significantly influence PA and measures of health, fitness, or wellness. Therefore, future studies may need to better control for or assess environmental factors that may influence MusS and NC testing. These include but are not limited to diet, extra-curricular activity participation, cultural norms, demographic locations, SES, green space availability during and outside of school, variances in playground equipment, and variances in PE programs or teachers perceptions on acceptable and non-acceptable play during recess.

Future studies with the MPOT may include determining the most commonly used limb movement(s) during recess, how many children utilize it, and when children begin to decrease their limb movement activities depending on grade level and sex. MPOT studies may also include observations among other PA opportunities or PA interventions to assess to what extent children participate in limb movement utilization compared to other PA.

MusS and NC tests should also be conducted with larger sample sizes and more diverse race representation to better generalize the findings across different regions and demographics. Studying special populations and those with disabilities would be an excellent addition to this study's MusS and NC testing. A future study should also consider past or present extracurricular participation from the population to better connect upper body MusS deficits among different demographics with a larger population.

An advantageous future study would also examine PA opportunities inside and outside of the school day, and how they influence MusS and NC scores among children. It is also recommended these assessments be used in physical education classes to monitor MusS weakness and MusS growth among school-aged children. For implementation purposes, it would be necessary to create videos and literature appropriate for PE teachers to administer these tests. These could be marketed as state or local PE professional development credit. An additional future protocol implementation would be to split the males and the females during the test administration. The PI noticed females were less likely to participate if males were watching their performances as they aged into third and fourth grades. Finally, this study was intended for typically-developing elementary school children. Its effects on non-typically-developing students would be beneficial to explore as a future study due to the numerous childhood advantages of MusS and NC development in both typically and non-typically-developing children.

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Webb, G.K., & Rhea, D. J. (2023). The Impact of Multiple Recesses on Limb Movement Patterns in Children: An Exploratory Study. *International Journal of Child Health and Nutrition*, 12, 99-106.

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CURRICULUM VITAE

Gemma Kate Webb
Texas Christian University, TCU Box 297730, Ft. Worth, TX 76129,
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EDUCATION

PhD in Health Sciences, Emphasis in Kinesiology, Texas Christian University, May, 2024
Principalship Certification in Educational Leadership, Dallas Baptist University, 2010
M.Ed., Physical Education, Tarleton State University, 2002
B.S., Tarleton State University, Exercise and Sport Science, 2001

PROFESSIONAL CERTIFICATIONS:

Texas Principal Certification
K-12 Physical Education
7th-12th Secondary Life Science
NASM Sport Performance Specialist
USA Track and Field Level II Coach: Heptathlete/Decathlete
Certified Fitness Instructor: YogaFit, Cooper Institute Spin, MashUp Conditioning

PREVIOUS PROFESSIONAL POSITIONS

2012-2021 Sport Performance Specialist and Fitness Instructor
2015-2018 MashUp Conditioning, Ambassador for SCW Conferences across USA Circuit
2014 Boyd High School, Boyd, TX. SPED Inclusion Teacher and Head Track and Field Coach
2005-2010 Wylie High School, Wylie, TX. PE, Biology and Aquatic Science teacher & Head Track and Field Coach
2003-2005 Education Director, Camp Eagle
2002-2003 Graduate Assistant KINE Teacher and Lab Director for Tarleton State University
2001-2003 Graduate Assistant Coach Tarleton State University Track and Field

FORMAL CONTINUING EDUCATION/PROFESSIONAL DEVELOPMENT

Texas Association for Health, Physical Education, Recreation, and Dance Conference (TAHPERD) 2005-present
National Academy of Sport Medicine 2019-present
SCW Fitness Conference, 2015-2018
Society of Health and Physical Education Conference (Shape America) 2022-present
U.S. Play Coalition Conference 2022-present
Association for Applied Sport Psychology Conference 2021-present
American College of Sports Medicine 2021-present

HONORS AND AWARDS

2023 Tarleton State University Athletic Hall of Fame Inductee

2022 Texas Association of PE, Health Recreation and Dance Graduate Research Poster 2nd Place

2022 Texas Christian University Research Symposium Award, 2nd in Quantitative Research 2022

2021, 2022, 2023, 2024 Texas Christian University Stiped to Attract Remarkable Students of Diversity (STARS-D) Fellowship Award

2021, 2022, 2023, 2024 Texas Christian University Harris College of Health Sciences Research Assistantship and Scholarship Award

2018 Azle Athletic Hall of Fame Inductee

2021 Tarleton State All-American Track and Field Heptathlete

2000, 2001 Tarleton State Academic All-American Student Athlete

2001 Verizon Academic All-American

2001 Vice President of Omicron Delta Kappa (ODK) National Leadership Society, Chartered the initiation of ODK at Tarleton State University

COURSES TAUGHT

Texas Christian University, Ft. Worth, TX:
KINE 10101 Introduction to Kinesiology
HLTH 20203 Health & Wellness Concepts
KINE 40623 PE for Secondary Youth

Tarleton State University, Stephenville, TX:
Graduate Teaching Fellow: Outdoor Education, Nutritional Science Lab Director
Graduate Assistant Track and Field Coach: Sprint & Jump Coach

Wylie High School, Wylie, TX
Physical Education, Biology & Aquatic Science

Camp Eagle, Rock Springs, TX:
Outdoor Education, Group Development, Biology

PUBLISHED MANUSCRIPTS AND ABSTRACTS

Webb, G.K.,* & Rhea, D.J. (in press, 2024). Variables that influence muscular strength and neuromuscular control in elementary-aged children.

Webb, G. K*., & Rhea, D. J. (2023). Development of the Movement Pattern Observation Tool (MPOT)—An observational tool to measure limb movements during elementary school recess. *International Journal of Environmental Research and Public Health*, *20*(8), 5589.

Webb, G. K*., & Rhea, D. J. (2023). Impact of multiple recesses on limb movement patterns in children: An exploratory study. *International Journal of Child Health and Nutrition 12*(99-106).

Caleb C. Voskuil*[1], Monique D. Dudar[1], G. Kate Webb[1], Yan Zhang[2], Joshua C. Carr[1] (2023). Influence of scanning plane and echo intensity correction on relationships between muscle size and fitness. *American College of Sport Medicine National Conference*, Denver, CO.

MANUSCRIPTS IN PROGRESS

Webb, G.K.,* and Rhea, D.J. Impact of varying amounts of recess on muscle strength and neuromuscular control among children.

RESEARCH PAPERS PRESENTED/CONFERENCE PRESENTATIONS

Webb, G.K.,* & Rhea, D.J. (April, 2024). Variables Influencing Muscular Strength and Neuromuscular Control in Elementary Children. *National Academy of Health and Physical Literacy Summit.* Baton Rouge, LA.

Webb, G.K.,* & Rhea, D.J. (Dec, 2023). Variables Influencing Muscular Strength and Neuromuscular Control in Elementary Children. *Texas Association of Health, Physical Education, Recreation, and Dance (TAHPERD) Conference*. Fort Worth, TX.

Rhea, D.J., Webb, G.K. (October, 2023). The Angle: Stressful or Playful. *US Play Coalition Regional Conference*. Fort Worth, TX.

Rhea, D.J., Campbell-Pierre, D.M.,* Webb, G.K.,* & Moore, E. (Dec, 2022). Engaging Physical Educators in Assessing Fitness Differently 2.0. *TAHPERD Conference*. Corpus Christi, TX.

Webb, G.K.,* & Rhea, D.J. (Dec, 2022). Determining Muscular Strength and Neuromuscular Control in Elementary Children Who Participate in Different Amounts of Recess. *TAHPERD Conference.* Corpus Christi, TX.

Webb, G.K.,* & Rhea, D.J. (Oct, 2022). The Impact of Multiple Recesses on Limb-Movement Patterns to Strengthen Cognition. *Association for Applied Sport Psychology (AASP) Conference.* Fort Worth, TX.

Webb, G.K.,* & Rhea, D.J. (Apr, 2022). The Impact of Multiple Recesses on Limb-Movement Patterns to Strengthen Cognition. *U.S. Play Coalition Conference*, Clemson, SC.

INTERNAL GRANTS SUBMITTED/FUNDED

2024 Harris College of Nursing and Health Sciences Research Grant Spring

2024 Texas Christian University Graduate Research Travel/Conference Grant Spring

2023 Harris College of Nursing and Health Sciences Research Grant Spring & Fall

2023 Webb, G.K. & Rhea, D.J. *TCU Open Access Fund* award.

2023 Texas Christian University Graduate Research Travel/Conference Grant Spring & Fall

2023 Harris College of Nursing and Health Sciences Travel/Conference Grant Spring & Fall

2022 Harris College of Nursing and Health Sciences Research Grant Spring & Fall

2022 Webb, G.K. & Rhea, D.J. *TCU Open Access Fund* award. $2,500.00.

2022 Texas Christian University Kinesiology Ranhoff Student Travel Grant

2022 Texas Christian University Graduate Research Travel/Conference Grant Spring & Fall

2021 Harris College of Nursing and Health Sciences Travel/Conference Grant Fall

EXTERNAL GRANTS SUBMITTED/FUNDED

2022 Webb, G. K & Rhea, D.J., Shape America: Thomas L McKenzie Research Grant (Not Funded)

COMMUNITY ACTIVITIES REALTED TO PROFESSIONAL SKILLS

2019-Present Created and direct a free community Track and Field club for K-12 Grades
2019-Present President of 401(c) Azle Athletic Hall of Fame Committee
2023-2024 Member of Student Health Advisory Council, Azle ISD
2023 US Play Coalition Play Date Speaker and Logistics Volunteer
2023-2024 TCU Harris College of Nursing and Health Sciences Dean's Student Cabinet
2024 Focus Group Member. Texas A&M Institute for Advancing School Health