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A Preliminary Study to Explore Muscular Strength and Neuromuscular Control Differences in Elementary-aged Children

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This study explored differences in muscular strength (*MusS*) and neuromuscular control (*NC*) among elementary-age children in various demographics. Second-, third-, and fourth-grade children (n = 248; males n = 121; females n = 127) were selected from two Texas public schools. A nonrandomized cross-sectional approach was used to evaluate two unilateral strength tests (Dynamometer Grip and Single-Leg Three-Hop), two bilateral strength tests (Push-Up and Vertical Jump), and one neuromuscular control test (Side Step). The children improved as they advanced in grade on the unilateral grip test ($p < .001$), the unilateral hop test ($p < .001$), and the neuromuscular control test ($p < .001$). Males outperformed females on the unilateral grip test ($p = .002$), unilateral hop test ($p < .001$), and vertical jump test ($p < .001$). White children outperformed Hispanic children on the unilateral grip test ($p = .007$) and the push-up test ($p < .001$). The only *MusS* interaction showed that second-grade boys scored the highest on the push-up test ($p < .001$). An *NC* difference was found for grade ($p < .001$), showing that children's mean sidestep scores improved as the grades advanced. These findings suggest regular *MusS* and *NC* testing in children and a more comprehensive look at the demographic factors that influence the physical activity disparities in children's *MusS* and *NC* development.

Keywords: muscular strength, neuromuscular control, children, elementary school

Historically, deficits in muscular strength (MusS) and neuromuscular control (NC) appeared in adults as physical activity (PA) lifestyles declined. More recently, an alarming similar trend has appeared in elementary-aged children due to sedentary lifestyles and minimal daily physical activity (Centers for Disease Control and Prevention, 2022). Significant MusS deficits have been one of the most alarming results related to childhood physical inactivity (Wahl-Alexander & Camic, 2021). Childhood inactivity hinders proper musculoskeletal system growth 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. Childhood inactivity is changing children's strength landscape (Stricker et al., 2020). This is worrisome as 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 NC. NC is the creation of new neurological pathways between the brain and the body through the movement of the body and limbs. Increases in NC allow children to exhibit more powerful and efficient movements and movement skills as they age (Musálek et al., 2018; Pedersen, 2019). Suppose a certain level of motor competence is not achieved in early childhood. In that case, a child's future motor skill development will be hampered, leading to less lifelong activity pursuits and an increased risk of all-cause mortality (Avigo et al., 2019; Hulteen et al., 2018). Consequently, proper MusS development is essential for proper NC development.

Although many factors influence inactivity, physical activity (PA) behavior disparities among children exist across various demographic populations, including age, sex, race, and socioeconomic status (SES) (Ball et al., 2015; Wilson & Bopp, 2023). Males tend to have higher PA levels and

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participate more in sport, leading to greater MusS development and increased performance over females in skills such as running, jumping, and throwing (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). Research shows a decline in MusS among youth over the past 10 years, highlighting the importance of assessing and monitoring MusS in children for appropriate interventions (Atkins et al., 2016; Laurson et al., 2017).

According to the National Institute of Health's Library of Medicine, MusS testing is an important component in revealing neurologic deficits, strength weaknesses, endurance weaknesses, and imbalanced limbs (Naqvi & Al, 2023). As MusS in elementary-aged children is exhibited by increased neuromuscular control (NC) (Stricker et al., 2020), the inclusion of a NC test is an appropriate addition to MusS testing. A gap remains in research for studies solely focused on MusS and NC of children's individual (unilateral) and combined (bilateral) limbs across varied demographics. Therefore, the purpose of this preliminary study was to explore MusS and NC differences among elementary-aged children by grade, sex, race, and SES. The study also aimed to establish preliminary baseline measurements for this elementary-age population.

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. An equal number of females and males (a minimum of 12) were selected from the general class population. Participation required parental consent for data collection. Participation inclusion criteria were (a) typically developing (children who can participate in physical education class without modifications), (b) no injury inhibiting participation in the physical education class, and (c) being present on the day of testing. White and Hispanic children constituted the primary racial groups included in the analysis due to the insufficient representation of other racial categories, limiting the generalizability of findings. The University Institutional Review Board (1801-65-1801) approved this study, followed by the consent of the superintendents, principals, physical educators, and parents. The participating children gave assent and were allowed to deny participation at any time.

Measures

The National Institute of Health's Library of Medicine deems MusS testing as an important component in addressing neurologic deficits, strength and endurance weaknesses, and imbalanced limbs (Naqvi & Al, 2023). These deficits can be seen either in unilateral or bilateral strength. As MusS in elementary-aged children is exhibited by increased NC (Stricker et al., 2020), the inclusion of a neuromuscular control test is an appropriate addition to the unilateral and bilateral strength tests. Certain MusS and NC measures used in a lab setting are not necessarily appropriate in a field setting. A persistent need exists for strength measurement tools that are valid, reliable, affordable, portable, and easy to use in physical education settings (Bogataj et al., 2020). The selected tests below met the administration requirements within the physical education setting and served as tools to measure unilateral and bilateral MusS and NC in children.

Dynamometer Single-Hand Grip Test

The Digital Dynamometer Single-Hand Grip Test (Baptista et al., 2022; Kunutsor et al., 2021) assesses unilateral upper-body MusS. 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; Kunutsor et al., 2021). As a current and future indicator of health, grip strength is included in the MusS testing of children. Further, assessing right and left grip strength differences determines the asymmetry between right and left upper unilateral strength.

The Push-Up Test

The Push-Up Test (Plowman & Meredith, 2013), as introduced in the FITNESSGRAM, assesses bilateral upper body MusS and endurance in elementary-aged children (Hashim et al., 2018; Plowman & Meredith, 2013). The push-up uses upper-body mass recruitment, i.e., triceps, biceps, pectoralis major, and deltoids (Fawcett & DeBeliso, 2014). The push-up test has been found to have reasonable objectivity, reliability, and validity and is simple to administer (Hashim et al., 2018).

The Single-Leg Three-Hop Test

The Single-Leg Three (Booher et al., 1993; Hammami et al., 2022) assesses unilateral lower-body MusS and power in children (Hammami et al., 2022). This test is an easy, field-expedient, inexpensive test to administer and is often used

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for sport and physical activity readiness or return-to-play decisions after an injury (Guild et al., 2020; Millikan et al., 2019). For example, low scores in the single hop test are associated with increased injury risk in the thigh and knee (Guild et al., 2020). In contrast, limb asymmetry (limb distance differences) can help identify those who may be more prone to foot and ankle injuries (Brumitt et al., 2013).

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 (Bogataj et al., 2020; Watson et al., 2021). During active play and sports, 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, assessing lower limb MusS can help identify children needing lower limb MusS interventions to prevent injury during physical activity.

The Side-Step-Test

The Sidestep Test (Cho & Kim, 2017) was developed to assess neuromuscular control (NC) of the lower body. It should be noted this test has not had any further validity or reliability studies conducted thus far. The sidestep test 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). 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. As MusS and NC are so directly tied in elementary-aged children, a neuromuscular control step test was included in the study.

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

Procedures

The primary investigator (PI) scheduled an adherence training for three other researchers who would help collect the data. The other three researchers were affiliated with the same university as the PI, which included one PhD candidate and two staff members employed there. In October 2022, the PI and the three trained researchers, in line with previously established, research-based protocol for each test, administered all of the MusS and NC testing for both school districts. The PI assigned each researcher to one of the four indoor stations around the gym's perimeter. One test 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, and the sidestep represented the other three stations. Children wore the required physical education shoes and clothes on the testing day. Since the tests were all administered indoors, there was no issue with weather changes. The time of day was consistent because the school schedule remained 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 eight groups and assigned one of the four stations. Once at each station, the researchers gave detailed instructions on performing their test and allowed 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 stations. 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, the PI gathered demographic data from the participating school principals, including free/reduced lunch qualification information from the district database (an indicator of SES and race). Free/reduced lunch was determined by the Texas Education Agency standards based upon the primary caretaker's income, regardless of benefits acceptance. 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

School personnel provided demographic data, including free/reduced lunch program eligibility, to determine SES. Each child was assigned an ID number to preserve confidentiality. Data was collected, processed, and complied with general data regulation procedures.

Data Analysis

Data were cleaned and coded in Microsoft Excel, and analyses were performed using JASP software (version 17.3, JASP Team, 2023). Means (*M*) and standard deviations (*SD*) for each MusS and NC test were calculated by grade, sex, race, and free/reduced lunch eligibility. MusS (grip strength, single-leg three-hop, push-up, and vertical jump) and NC (side-step) differences across grade, sex, race, and free/reduced lunch status were assessed using a multivariate analysis of variance (MANOVA).

The Shapiro–Wilk test of normality was violated for the MANOVA, yet the analysis continued as the sample size was relatively large and the design was balanced. Levene's test showed homogeneity of variances for all dependent variables. Therefore, it can be assumed the variance is roughly equal across all groups being compared, which is a desirable outcome for follow-up ANOVAs. The test of multicollinearity showed a significant correlation between grip and push-up tests, and therefore, caution must be observed with that combination. Mahalanobis distance showed three multivariate outliers, which were removed accordingly. Box's test of equality of covariance matrices was statistically significant ($p < .001$), and the assumption of homogeneity of variance-covariance matrices was violated ($p = .002$). Therefore, Pillai's trace adjustment was performed for the MANOVA analysis.

Subsequent one-way ANOVAs were conducted to explore the MANOVA interactions and main effects, with a significance threshold set at $p < .05$. All ANOVA analyses are reported with Tukey's post hoc, which assessed the significance of differences between the pairs of group means.

Results

Descriptive statistics determined the means (*M*) and standard deviations (*SD*) of all MusS and NC 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. Caution should be used when interpreting the "Other" race results due to the low representation of this group. The small sample size and combining races (Black, Asian, and Native American) other than White and Hispanic into one category affects the reliability and generalizability of the findings. The "Other" category was removed from analyses and only reported as a descriptive statistic. Therefore, this study's results only generalize to White and Hispanic children.

Table 1 reflected hand grip strength increased 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" race group showed the highest average scores for all upper-body strength tests, followed by White, then Hispanic. 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 2 shows the three-hop and vertical jump scores increased as grades advanced. Males and females showed higher right-leg three-hop scores than left-leg three-hop scores. Males outperformed females on all lower-body MusS tests. Males also showed less difference between the right and left lower limb strength than females. The "Other" race averaged higher than White or Hispanic children for all lower-body MusS tests. 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 three-hop scores and the NC side-step.

NC (side-step) scores also increased as the grades advanced, while no differences were found between male and female mean scores.

Discussion

This study aimed 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 across these same independent variables. Effect sizes ranged from moderate to high, except for the grip test by sex and race, which showed minimal effects with values of .03 and .02, respectively. All other effect sizes ranged from .04 to .26. Only one MusS interaction effect was found between sex and grade for the push-up test, $F(2, 242) = 2.88$, $p = .05$ (see Figure 1). Males showed steady progression in the push-up scores as they advanced in grade, however females did not show the same trend.

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. 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

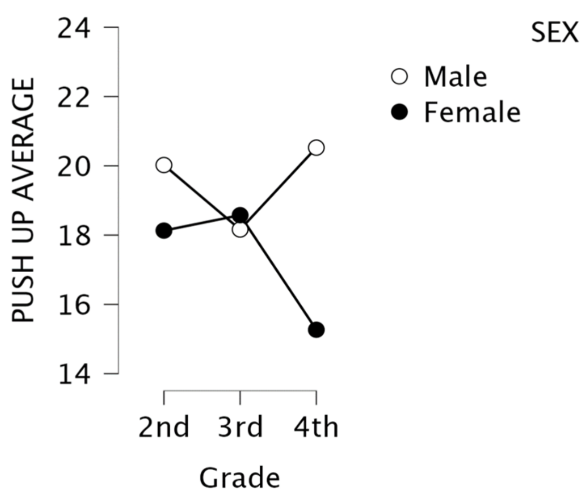

Figure 1: *Sex by Grade Push-Up test Interaction*

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Table 1: *Upper-Body Strength Means and Standard Deviations by Grade, Sex, Race, and Free/Reduced Lunch*

Variables	Right Grip (lb)	Left Grip (lb)	Average Grip (lb)	Grip Difference (lb)	Push-Up
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)	27.3 (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 Avg	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)

Note. All values are presented as mean (standard deviation). ANOVAs were run to show effects of the independent variable on the dependent variable and are noted by: $^{*}p < .05$, $^{**}p < .005$, $^{***}p < .001$.

Table 2: *Lower-Body Strength and Neuromuscular Control Means and Standard Deviations by Grade, Sex, Race, and Free/Reduced Lunch*

Variables	Right 3-Hop (in)	Left 3-Hop (in)	Average 3-Hop (in)	Hop Difference (in)	Vertical Jump (in)	Sidestep
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 Avg	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)

Note. All values are presented as mean (standard deviation). ANOVAs were run to show the effects of the independent variable on the dependent variable and are noted by: $^{*}p < .05$, $^{**}p < .005$, $^{***}p < .001$.

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 outperformed 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 outperformed 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.

Grade level was not a factor in the vertical jump test outcome. From 1972–2015, studies showed children steadily decreased in measures of muscular power (Wahl-Alexander &

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Camic, 2021). During active play and sports, children experience 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 due to inactivity, these explosive movements may increase the risk of avulsion fractures until children are closer to skeletal maturity (Stricker et al., 2020). This trend may highlight the need for increased childhood participation in more explosive movements, such as skipping, jumping, or running.

Sex played a significant role in MusS as males significantly outperformed females on every MusS test, which is supported in previous literature (Battaglia et al., 2021; Farooq et al., 2020; Janssen et al., 2016; Lloyd-Jones et al., 2022). Although a strength focus across males and females is equally important, the load placed upon the muscles during childhood may need to be modified according to sex.

Race was a significant factor in upper body strength tests, showing White children outperformed Hispanic children in the push-up and the average hand grip tests. PA participation for adults and children varies by race, and Hispanic races are less inclined to participate in muscle-strengthening PA (Battaglia et al., 2021). Disparities in youth PA due to SES and ethnic minority membership also pose a barrier to movement opportunities among the Hispanic population (Brumitt et al., 2013; Kuhn et al., 2021; Ning et al., 2021; Watson et al., 2021). 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.

For unilateral tests, the higher a group scored on a MusS test, the more evident the imbalance was between the dominant and non-dominant limbs. An underlying, silent issue with children who display greater strength may be that there is greater potential for an imbalance and, therefore, greater potential for injury as they mature (Atkins et al., 2016; Avigo et al., 2019; Kobayashi et al., 2014; Lloyd & Oliver, 2012; Musálek et al., 2018; Pedersen, 2019; Stricker et al., 2020). 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.

Increased MusS and NC are pivotal for decreased fracture incidents, increased motor skill development, and overall health (Avigo et al., 2019; Battaglia et al., 2021; Musálek et al., 2018; Stricker et al., 2020). With the PA decline among children, it is essential for those working with children to monitor MusS and NC development. This study aids in future MusS and NC assessments among children by giving insight into variables that may influence MusS and NC testing scores. Much research focuses on adult PA behaviors across age, sex, race, and socioeconomic status (Führer et al., 2021; Kuhn et al., 2021; Lloyd-Jones et al., 2022; Ning et al., 2021). This study is unique as it explores 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. This study is additionally strengthened by reporting that MusS and NC testing measures used were portable, cost-efficient (roughly $120), and easily administered to children. As childhood inactivity rises, PA and MusS testing should be considered a public health priority to improve health and increase life-long mobility (Bogataj et al., 2020; Niessner et al., 2020). This MusS testing may aid future physical education literacy and curriculum standards for MusS testing and interventions among children.

Future studies should include the same MusS and NC tests with larger sample sizes and more race diversity to better generalize the findings across different regions and demographics. Future studies would also benefit from notating the dominant hand per child to compare the dominant grip across varied demographics instead of just the right and left grip. It would also be advantageous for a future study to consider the population's past or present extracurricular participation to better connect upper-body MusS deficits among different demographics with a larger population. In addition to future studies using these five assessments, it is recommended that these assessments be used in physical education classes to monitor 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.

One limitation is the lack of race representation other than White and Hispanic due to availability in these schools. Another limitation is the lack of representation across different regions of America. However, this study 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 trained the three research assistants, there is always a chance of variations in data recording across the PI and the research assistants.

License

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