FITNESS ASSESSMENT IN THE HOMESCHOOLED: THE FAITH STUDY

DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
IN THE GRADUATE SCHOOL OF THE
TEXAS WOMAN'S UNIVERSITY

SCHOOL OF PHYSICAL THERAPY
COLLEGE OF HEALTH SCIENCES

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DENTON, TEXAS

DECEMBER 2016

DEDICATION

To the two best decisions I made in my life without whom
this would not be possible.

ACKNOWLEDGMENTS

I would like to express my eternal gratitude to my husband Morad and our two children Seth and Nathan for their unending love, support, and patience in all aspects of my life. I would also like to acknowledge my family and friends for their endless encouragement, understanding, and gratuitous babysitting. To my research team Aide Bravo, Naisha D’Souza, Terry Hurley, and Peggy Spivey, thank you for your enthusiasm and seamless data collection. To my committee chair Dr. Katy Mitchell and members Dr. Wayne Brewer and Dr. Alexis Ortiz, thank you for helping me materialize my dream and working at my vivacious pace to help me become the researcher I am today. I would also like to express my gratitude to Dr. Daphne Hernandez at University of Houston for mentoring me before I knew what research was. To the faculty and staff at Texas Woman’s University, thank you for the continued opportunities and guidance. To my colleagues at Houston Community College, thank you for accommodating my crazy schedule and making me feel like family. To my students, thank you for working hard right alongside me. To my fellow PhD classmates, thank you for keeping me sane. I am also incredibly grateful to the wonderful families I met through this research who allowed me the privilege of working with their precious children. Finally, thank you to my earthly father for planting the seed over 15 years ago, my mother-in-law for setting the example, and my heavenly Father for the gentle nudging, open doors, and continued blessings.

ABSTRACT

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DECEMBER 2016

The purpose of this study was to describe physical fitness, body composition, and motor skill development in elementary aged homeschool children compared to their age and gender matched peers. One hundred forty-four homeschool children aged 5-11 years were assessed for muscular fitness, cardiorespiratory fitness, height, weight, percent body fat, waist circumference, and motor skill proficiency in this cross-sectional study. Results showed homeschool children to have significantly lower upper body and abdominal strength but no significant difference in cardiorespiratory fitness compared to their public school peers. Compared to age and gender matched normative data, homeschool children had lean body composition but increased central adiposity and corresponding risk of cardiovascular disease and average overall motor skill proficiency. However, fine motor skill deficits may have been masked by composite motor skill scores. In conclusion, homeschooling may have detrimental effects on muscular fitness and central adiposity but showed no detrimental effects on cardiorespiratory fitness, body mass index, percent body fat, or overall motor skill development among the elementary school population.

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PROSPECTUS

INTRODUCTION

Regular moderate-to-vigorous physical activity is known to decrease childhood obesity, improve physical health, and enhance overall wellbeing in elementary school-aged children.[1-3] Currently, overall levels of student physical activity have increased and the number of obese school-aged children in the United States has plateaued.[4] While numerous factors contribute to a child's level of physical activity, physical fitness levels including cardiorespiratory fitness and muscle strength, body composition, and motor skills are all important correlates.[5-9] To promote these correlates, the public school system has become a popular target for physical education and activity initiatives.[10]

However, recent data indicate that 1.8 million American children receive schooling outside of the public school system.[11] This number is an increase from 1.1 million in 2003.[11] Homeschool children (HSC) are not subject to state regulations including physical education classes, physical activity initiatives, or regular fitness testing.[12] Thus, these children are at a potentially higher risk for undiagnosed deficits in physical fitness, body composition, and motor skill development. As shown in the literature, deficits in these correlates can lead not only to reduced participation in physical activity but increased levels of childhood obesity and decreased overall wellbeing.[5-9] Unfortunately, very little information is available regarding the physical fitness, body composition, or motor skill development of children educated at home. This information is necessary to assess both the health of almost 2 million American children as well as any effects of public schooling on these same constructs.

CLINICAL RELEVANCE

Physical therapists are movement system experts throughout the lifespan. Regular screening of cardiorespiratory fitness (CRF), muscle strength, body composition, and motor skill development are part of good practice. This study will identify trends among HSC and raise clinician awareness of potential deficits so that skilled interventions can be recommended. By promoting health and wellness of typically developing children, physical therapy services will be promoted and the limited perception of serving primarily children with special needs will be expanded.

REVIEW OF THE LITERATURE

Elementary school is an important time for child development. American children who are overweight as 9-13 year olds carry a 6.5 fold increased risk of becoming obese adults compared to a 2.6 fold increase if obese as preschoolers.[13] It has also been well documented that children with high levels of CRF demonstrate improved inhibitory control.[14-19] Enhanced inhibitory control allows them to better regulate their behavior, attention, and emotions as well as improve academic performance.[14-19]

Additionally, great gains in motor development are seen during the elementary school years. The Bruininks-Oseretsky Test of Motor Proficiency shows greatest gains in motor skills occur between 4 and 8 years of age.[20] Notably, improved motor skills have been associated with enhanced cognitive function in children under 13 years of age.[19] Motor skill development also improves self-efficacy, eases the transition to sports, and increases enjoyment of physical activity throughout the lifespan.[21]

Accordingly, optimal physical fitness, body composition, and motor skill development are crucial in the elementary school years. Public school physical education curriculum is designed to increase moderate-to-vigorous physical activity as well as develop motor skills within the elementary school population.[21] However, neither physical education nor fitness testing are required by the state of Texas for HSC.[22] To date, very little research has been published regarding these outcomes among HSC and what has been done fails to establish consistent trends.

In 2004, Welk et al published an article examining aerobic fitness and physical activity along with its psychosocial correlates in HSC versus public school children.[23] The Progressive Aerobic Cardiovascular Endurance Run (PACER), accelerometers, and the Children's Physical Activity Correlates scale revealed no effect of schooling type on physical activity or its correlates in a sample of 75 boys and 42 girls aged 9-16. However, they did find lower levels of aerobic fitness in older homeschool males. Notably, the criterion standards on the aerobic test used in this study have significantly changed since publication making this information no longer current.[24]

In a second study, Long et al examined physical activity and nutrition among HSC in 2010.[25] They utilized activity monitors, dual energy x-ray absorptiometry (DEXA) scans, and a 7-day food journal in 36 homeschool/public school-age and gender matched pairs. This research concluded public school children ages 7-11 had more overall physical activity and higher levels of moderate-to-vigorous physical activity than HSC, but no difference in dietary intake causing a discrepancy in energy balance.

Most recently, Cardel et al examined the body composition and dietary intake of HSC and public school children in 2014.[26] Accelerometry, DEXA scans, and two 24-hour recalls were used in 95 children age 7-12. Unlike Long et al but in agreement with Welk et al, this study concluded that there was no difference in physical activity between the two groups. This study also found public school children had increased body mass index (BMI), body fat, and intake of trans-fat, sugar, and calories.

Within the literature, additional body composition and CRF studies are needed to expand both the size and age range of the population as well as to establish consistent trends. Furthermore, there have been no published articles examining muscle strength or motor skill development within the homeschool population. In short, this research would involve a larger, more diverse sample and investigate different, more pertinent outcomes related to physical activity throughout the lifespan.

OVERVIEW OF THE STUDY

This is a descriptive exploratory study examining physical fitness, body composition, and motor skill development of HSC and comparing them to their public school counterparts and peers. Health-related physical fitness outcomes include CRF, muscle strength, and body composition as waist circumference (WC), waist circumference to height ratio (WC/HT), BMI, and percent body fat (%BF). Motor skills include fine motor, coordination, and agility components. Age and gender specific criterion referenced FITNESSGRAM® data will be used to compare physical fitness and body composition data.[27,28] Motor proficiency and %BF will be compared to age and gender normative data to identify any developmental differences and/or deficits.[20]

PURPOSE AND HYPOTHESES

The purpose of this study is to describe physical fitness, body composition, and motor skill development in HSC compared to age and gender matched peers. It is hypothesized that HSC will have significantly different physical fitness, body composition, and motor skill proficiency compared to age and gender matched peers.

PARTICIPANTS

Both male and female HSC grades K-5 of all ethnicities and socioeconomic statuses will be included in the sample. Based upon an *a priori* power analysis for the Mann-Whitney test with a medium effect size ($d = .5$), power of .9, and $p = .05$, at least 90 fourth and fifth grade HSC and 90 K-2 grade HSC will need to be enrolled for a total sample size of at least 180. Testing will occur in early summer when children have completed at least 1 year of homeschool. Children enrolled in online public schools will be excluded as their data is included in state fitness test results. Children with physical or mental impairments that their parents report will prevent them from completing study requirements and/or children with parents/guardians unable to understand the English consent form will also be excluded. Recruitment will occur by word of mouth, phone, and e-mail through homeschool support groups and co-ops.

INSTRUMENTATION

As the greatest gains in motor skills occur between ages 4-8,[20] only subjects in grades K-2 will complete the BOT-2. Due to FITNESSGRAM® reliability and validity constraints and to mirror public school data collection procedures, the 90° push-up and curl-up portions of the FITNESSGRAM® will only be evaluated in participants grades 3-5 and the PACER will be run only by subjects grades 4-5.[21] Standing long jump and body composition will be assessed in all participants.

Cardiorespiratory fitness will be assessed using the PACER portion of the FITNESSGRAM®. Also known as the 20-meter shuttle test, the PACER requires students to "shuttle" back and forth on a 20m course in progressively shorter timed stages until they fail to complete two runs. The PACER is the recommended field test of aerobic fitness for the FITNESSGRAM® test battery required in all Texas public schools. It is widely utilized, simple to perform, and has age and gender criterion reference standards available from each public school in Texas.[27] In the literature, the PACER has been shown reliable with ICC values ranging from 0.78-0.93 in youth ages 8-18.[29-32] Moreover, correlation coefficients between directly measured VO_{2max} and the PACER range from 0.62-0.83.[29,33-36]

Upper body and core muscle strength will measured by the 90° push-up and curl-up portions of the FITNESSGRAM®. Lower body strength will be measured using the standing long jump. The 90° push-up requires students to complete push-ups from an elbow straight position to elbows at 90° with the back and legs straight. Push-ups and curl-ups are completed at a 3 second cadence and continue until the student fails to maintain correct form at the correct cadence twice or can no longer continue. The standing long jump requires children to stand with feet together and jump forward as far as possible keeping feet together and landing upright. A measurement is made from the starting line to the back of the lagging heel. All three tests have been shown reliable and valid for assessing muscle strength in the literature (ICC=0.80-0.99; r=0.75-0.80).[37-39]

Body composition will be assessed using waist circumference (WC), waist circumference to height ratio (WC/HT), BMI, and %BF as measured by the Tanita BF-689 pediatric bioelectrical impedance analysis scale. Waist circumference and WC/HT are common measures of central adiposity associated with obesity and cardiovascular risk within the pediatric population.[40] BMI has been shown to be an accurate measure of adiposity in children provided that basic measuring standards and precautions are taken into account.[41] BMI-for-age will be calculated using the 2000 CDC Growth Charts.[42] Additionally, a BMI-for-age z-score (z-BMI) will be calculated as these scores are more commonly reported in the overweight and obese populations.[41] BMI data from the FITNESSGRAM® test provided by each Texas public school will be used for comparison. Finally, %BF will be obtained using the BF-689 and compared to age and gender specific normative data. This scale has been shown both reliable and valid and an acceptable alternative to DEXA scans (ICC = 0.79-0.99).[43]

Motor skill proficiency will be assessed using the Bruininks-Osteretsky Test of Motor Proficiency – Second Edition (BOT-2) Short Form with knee push-ups. The Short

Form consists of 14 tasks from 8 subtests: fine motor precision, fine motor integration, manual dexterity, bilateral coordination, balance, running speed and agility, upper limb coordination, and strength. It is a screening tool capable of generating a reliable score of overall motor proficiency. Scores will be compared to age and gender specific normative data to determine any potential differences and/or deficits.[20] Internal consistency reliability coefficients for the Short Form with knee push-ups range 0.75-0.86 for 4-8 year olds.[20] Pearson correlations are reported at 0.86-0.87 for test-retest reliability and 0.98 for interrater reliability[20] while criterion validity between the Körper Koördinations Test für Kinder (KTK) and BOT-2 Short Form were reported at 0.61.[44]

PROCEDURES

Full IRB approval will be secured from Texas Woman's University and parental/guardian consent as well as child assent obtained prior to any data collection. Local school districts will be contacted and raw data for all FITNESSGRAM® components grades 3-5 requested. After enrollment, each parent/guardian will complete a paper-based demographic survey including information on ethnicity, socioeconomic status, parent education level, household structure, number of years in homeschool, and physical activity participation, as well as the public school, district, and grade to which the child would be zoned. This information will be used to assess population demographics and control for known confounding variables. In order to maximize participation, enrollment and all data collection will occur during a single test session at a location agreeable to both the participant and research team with the parent/guardian present to minimize child distress.

Body composition data and 5 minute resting heart rate will be collected first on all participants. To minimize measurement error, height, weight, and %BF will be taken barefoot with one layer of light clothing and undergarments after the opportunity to void the bladder. Testing can be delayed or rescheduled if the subject had a large meal or drink within the preceding two hours. WC will be taken on bare skin just above the level of the iliac crests at the midaxillary line after normal subject exhalation without compressing subcutaneous tissue.[45] Following body composition assessment, subjects will complete the FITNESSGRAM® test components (PACER grades 4-5, 90° push-up and curl-up test grades 3-5), standing long jump (ages 6-11) and/or the BOT-2 (grades K-2). Adequate rest intervals will be given between tests as per subject request and/or to allow heart rate and oxygen saturation levels to return to baseline as determined by finger pulse oximetry. Subjects will be allowed to watch a practice test video or live demonstration of each test prior to performing. To minimize performance bias, the only cues or instructions used during testing will be those designated by the respective test protocols. No follow-up will be required. Parents will be provided with an electronic or hard copy of their child's test results and interpretation by request.

DATA ANALYSIS

Participant characteristics will be reported as mean ± standard deviation. If raw FITNESSGRAM® data scores are provided by a local school district, a multivariate analysis of covariance (MANCOVA) for the entire sample will be used to explore differences between public school children and HSC for CRF, upper extremity strength, core strength, BMI and/or %BF while controlling for age and gender. If raw data are not released, Kruskal-Wallis tests will analyze the same constructs using age and gender specific ordinal aggregate data provided by the Texas Education Agency.[46] Data from HSC for standing long jump, WC, WC/HT, and BOT-2 percentile data will be converted into z-scores to allow for within group comparisons (age, gender, etc).[47] Individual BOT-2 items will be compared to available population means.[48,49] All data analysis will be conducted using SPSS (Chicago, IL) software version 23.0 or higher.

INTERPRETATION/LIMITATIONS OF THE STUDY

Limitations of the study include the potential for self-selection bias and a heterogeneous homeschooling environment. Strengths of the study include the *a priori* power analysis, standardized testing protocol, and use of established outcome measures. Results from this study will assess the physical fitness, body composition, and motor skill development of children educated at home. These outcomes are largely unexplored in this expanding and understudied population. In addition, it will highlight any effects of schooling type on physical fitness and body composition. If HSC show increased, decreased, or similar levels of physical fitness and/or body composition, we can infer that the public school environment is beneficial, irrelevant, or detrimental to these same outcomes. As the first study to examine muscle strength or motor skill development in HSC, further research will be needed.

CHAPTER II

REVIEW OF THE LITERATURE

INTRODUCTION

Cardiorespiratory fitness, muscular fitness, body composition, and motor skill proficiency all have important impacts on pediatric health. Thus, it is vital to monitor development in these areas during childhood. Public schools routinely test health-related physical fitness in their students and employ structured physical education curriculum designed to develop all these areas. However, the same is not required for the growing population of children being educated outside of the traditional public school system. Potentially, homeschool children are at risk for having unrecognized health and skill-related physical fitness deficits which can affect both current and future health. Currently, very little research is available in the literature regarding physical fitness among the homeschool population.

To assess cardiorespiratory fitness, the Progressive Aerobic Capacity Endurance Run, or PACER test was utilized in this study. To measure muscular fitness, the 90° push-up test was used to assess the upper body, the curl-up test was used to assess the core, and the standing long jump test was used to assess the lower body. Body composition was assessed using body mass index, waist circumference, waist to height ratio, and bioelectrical impedance analysis. Finally, motor skill proficiency was evaluated using the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition –

Short Form (BOT-2 SF). These tools are commonly used in the literature, allow for rapid assessment in large samples of children, and require minimal equipment or formal training.

HOMESCHOOL CHILDREN

To date, few studies have been published reporting the effect of homeschooling on health-related or skill-related physical fitness in children. In all, four studies were found. Welk et al examined physical fitness, physical activity, and psychosocial correlates of physical activity in 117 homeschool children from central Iowa in 2004.[23] Two years later, Neuville et al compared cardiovascular fitness in 9 homeschool children to 17 public school children.[50] In 2010, Long et al published an article assessing physical activity and nutrition in 36 homeschool and public school matched pairs.[25] Finally, Cardel et al explored differences in body composition, nutrition, and physical activity among 47 homeschool and 48 public school children in 2014.[26]

First, Welk et al measured cardiorespiratory fitness in homeschool children along with physical activity and its psychosocial correlates compared to public school children from the same state.[23] The PACER was used to estimate cardiorespiratory fitness in 117 homeschool children and then compared to a public school sample of 1,234 children. The age of the sample ranged from 9-16 years old and included both males and females. Group mean estimated $VO_{2max,}$ or the highest rate of oxygen uptake during vigorous exercise, was 44.99 mL/kg/min (SD = 5.18) for the public school children and 44.92 for the homeschool children (SD = 5.04). An effect size was calculated as Cohen's *d* at 0.01.

When broken down by gender, male mean estimated VO_{2max} was 46.34 mL/kg/min (SD = 5.23) for the public school children and 45.44 for the homeschool children (SD = 5.08) with an effect size of $d = 0.17$. Female mean estimated VO_{2max} was 43.41 mL/kg/min (SD = 4.64) for the public school children and 43.98 for the homeschool children (SD = 4.88) with an effect size of $d = -0.12$. There were no significant main effects for cardiorespiratory fitness when calculated as VO_{2max}. Moreover, there was no significant difference in physical activity levels as measured by 3 days of accelerometry between the 2 groups.[23]

However, there was a significant interaction between gender and schooling type when the number of PACER laps was used to estimate cardiorespiratory fitness ($F(1, 1,346) = 5.57$, $p = 0.018$).[23] Three-way ANOVAS (gender x age x school type) also revealed a significant interaction for estimated VO_{2max} ($F(2, 664) = 8.77$, $p = 0.002$). Older (14-16 years) homeschool males had estimated VO_{2max} levels 14% lower ($d = 0.88$) than their public school counterparts while this value was only 2% lower in younger (9-11 years) homeschool males ($d = 0.24$). Interestingly, no similar effects were seen in females.[23]

Overall, this study showed that there were no significant differences between estimated VO_{2max} between homeschool and public school children as a whole. However, it did highlight potential effects of age, gender, and school type on cardiorespiratory fitness among high school-aged males. Notable weaknesses included the use of homeschoolers from different communities across the state, introducing regional fitness variability into the study, and a failure to collect and control for demographic variables.[23] As the first research published comparing cardiorespiratory fitness between homeschool children and their public school peers, it provided preliminary findings and gave direction for future research.

Two years later, Neuville et al published a study exclusively examining cardiorespiratory fitness between homeschool and public school children.[50] Using 9 homeschool children and 17 public school children aged 10-14 years, they compared VO_{2max} levels between groups using the 1 mile run test. Body composition as BMI was also assessed. The homeschool children had an average BMI of 17.7, mean mile run time of 9.0 minutes, and mean VO_{2max} of 48.7 mL/kg/min, while the public school children had an average BMI of 22.7, a mean mile run time of 11.3 minutes, and mean VO_{2max} of 42.2 mL/kg/min. Moreover, results from a *t*-test found a significant difference ($t(24) = 2.636$, $p < 0.05$) in estimated VO_{2max} between homeschool and public school students.[50]

Written for a small undergraduate journal, the study design and presentation of the Neuville et al study are weak. First, a small sample size was used and then divided into uneven groups.[50] Moreover, there was a lack of standardization in testing conditions such that the homeschool students completed their testing on an indoor track in a climate controlled environment while the public school students performed their test on an outdoor track in cooler weather while wearing additional layers of bulky winter clothing. In short, while this research did find significantly higher cardiorespiratory fitness levels in 10-14 year old homeschool children as compared to their public school peers, sample size and study design detract from the strength of their findings.

Both the Welk et al and Neuville et al studies found significant differences in cardiorespiratory fitness in at least a subset of their sample populations.[23,50] However, demographic characteristics of the homeschool and public school samples were neglected in both studies and a matched-pair design was not used in either study. Controlling for known confounding variables such as body composition and matching subjects with similar demographic characteristics will improve the strength of any resulting conclusions. Moreover, both studies report conflicting results in regard to fitness differences between homeschool and public school children. Welk et al found lower levels of cardiorespiratory fitness in older homeschool males aged 14-16 years and no difference between the group as a whole or any other subsets.[23] This would seem to suggest a negligible effect of schooling-type on cardiorespiratory fitness, especially in the older elementary school population. On the other hand, Neuville et al found homeschool children to have significantly higher cardiorespiratory fitness among 10-14 year olds compared to public school children the same age.[50] This is in direct conflict with the findings of Welk et al. Clearly, more research is needed to both clarify and strengthen evidence of any difference in cardiorespiratory fitness between homeschool and public school children.

Apart from differences in cardiorespiratory fitness, differences in physical activity and nutrition between children schooled at home and their public school peers have also been published in the literature. In 2010, Long et al examined physical activity and nutrition in homeschool and public school children aged 7-11 years old.[25] Homeschool and public school children were matched based upon age, gender, ethnicity, and BMI category. In all, 36 matched pairs were included in the study. Overall, they found that public school children had more steps and moderate-to-vigorous physical activity than their homeschool peers but no difference in dietary intake.[25] Unlike the cardiorespiratory fitness studies, Long et al did control for demographic variables including parental education level, marital status, and socioeconomic status.[25] Although the sample size was still relatively small, this study was well designed and provided important information on physical activity and nutrition among homeschool children and drew comparisons to public school children. Physical activity and nutrition can affect cardiorespiratory fitness and body composition. The findings by Long et al are pertinent as they imply that public school children expend more energy than homeschool children while maintaining a similar energy intake thus giving public school children a more desirable energy balance. In turn, this could place public school children at a health-related physical fitness advantage over homeschool children.

Most recently, homeschool children were studied to compare their nutrition, activity, and body composition to public school children by Cardel et al.[26] In all, 47 homeschool and 48 public school white/non-Hispanic children aged 7-12 years were enrolled in the study. Body composition was calculated both as age and gender specific BMI as well as percent body fat as determined by dual energy x-ray absorptiometry.

Dietary intake was determined by 24-hour recalls and physical activity was assessed using accelerometers. After examining the data, this study found homeschool children to have significantly lower (mean ± SD; $p < 0.05$) BMI percentile (54.55 ± 27.52), total fat mass (6.75 kg ± 3.54 kg), percent body fat (20.26 ± 7.39), and trunk fat (2.57 kg ± 1.61 kg) compared to their public school peers (63.33 ± 25.72; 8.41 kg ± 4.92 kg; 22.76 ± 8.79; 3.36 kg ± 2.38 kg respectively).[26]

While homeschool children were obviously shown to have significantly better body composition than public school children, there was no significant difference in physical activity levels between the two groups.[26] Calculated as active minutes per day (mean ± SD), homeschool children averaged 55.79 ± 30.94 minutes while public school children averaged 61.65 ± 31.73 minutes. Although public school children had increased active time, the difference was not statistically significant. This finding is in conflict with the conclusion of Long et al that public school children have significantly more physical activity than homeschool children.[25] However, it should be noted that this discrepancy could be accounted for by differences in instrumentation and outcome assessment as Long et al assessed physical activity as step counts with an activity monitor while Cardel et al employed accelerometers to measure active minutes per day.[25,26] The lack of difference in physical activity between homeschool and public school children reported by Cardel et al supports the same finding by Welk et al who also used accelerometry to determine physical activity.[23]

Finally, Cardel et al found that public school children who ate school lunch consumed on average 120 total additional kilocalories per day compared to homeschool children.[26] Results from the dietary recalls also showed that public school children consumed significantly more (mean ± SD; $p < 0.05$) grams of *trans* fat (6.75 ± 2.83) and total sugar (127.23 ± 40.53) along with significantly fewer grams of fiber (12.83 ± 4.67) and servings of fruit and vegetables (2.59 ± 1.81). Thus, while physical activity may not have explained the differences in body composition found between the two groups, dietary intake might. This significantly less healthy diet among public school students is in direct conflict with the report by Long et al which found no significant difference in dietary intake.[25] Although the sample was relatively small and ethnically homogenous, Cardel et al did control for known confounding variables including age, gender, pubertal stage (≤ Tanner Stage 3), and socioeconomic status.[26] In short, this study supports findings that total physical activity does not differ between public and homeschool children but offers conflicting evidence for differences in dietary intake. It is also the only study to examine differences in body composition between groups and found that homeschool children had significantly better anthropomorphic measurements on every assessment compared to their public school peers.

All in all, the literature supports findings that there is no significant difference in physical activity level between homeschool and public school students as assessed by accelerometry.[23,26] However, conflict exists regarding potential differences in cardiorespiratory fitness and dietary intake between the two groups.[23,25,26,50] Finally, it suggests that homeschool children are thinner and leaner compared to public school children although there is only one study addressing differences in body composition.[26] Accordingly, more research is needed to clarify conflicting findings regarding cardiorespiratory fitness and nutrition in homeschool students as well as to support initial findings regarding body composition.

OUTCOME MEASURES

Health-related physical fitness measures like cardiorespiratory fitness, muscular fitness, and body composition as well as skill-related measures like motor skill proficiency are all related to different aspects of a child's overall health. In addition, each outcome must be assessed independently to determine potential effects of deficits in one particular area. However, these same constructs can be interrelated as well. Therefore, the relationships between cardiorespiratory fitness, muscular fitness, body composition, and motor skill proficiency also warrant examination.

Cardiorespiratory Fitness

Cardiorespiratory fitness (CRF), also known as aerobic fitness or cardiorespiratory endurance, allows the body to perform dynamic activities at moderate-to-high intensities for extended periods of time using large muscle groups. In essence, it is a measure of how effectively the circulatory and respiratory systems deliver oxygen to skeletal muscle.[51] Recently, data have shown a decline in cardiorespiratory fitness in boys among American school-aged children.[52] Cardiorespiratory fitness can be directly assessed in the lab or estimated in the field. The most common laboratory tests to assess cardiorespiratory fitness in children include treadmill or cycle ergometer graded exercise tests using expired gases analyses.[51] Tests are performed until volitional exhaustion, a plateau in oxygen uptake is seen, or various other termination criteria are met, including adverse changes in vital signs.[51]

The most common measure of cardiorespiratory fitness is VO_{2max}, or the highest rate of oxygen uptake during vigorous exercise. This number is calculated when a plateau in oxygen consumption is seen during maximal graded exercise tests in the lab despite increasing workload.[51] Should a plateau not be achieved prior to exercise test termination, VO_{2peak}, or the highest oxygen consumption rate during the test, can also be recorded.[51] In either case, VO_2 can be reported in absolute or relative terms. Absolute VO_2 is a measure of oxygen uptake during non-weight bearing activity like cycling and is reported in liters per minute (L/min) or milliliters per minute (mL/min). This measure is directly related to body size and explains the higher values of VO_2 often seen in males.[51] On the other hand, relative VO_2 is reported in milliliters per kilogram per minute (mL/kg/min) thus accounting for body mass. Relative VO_2 is a better estimate of oxygen consumption during weight-bearing activities like running, but can be inaccurate in very large or small individuals.[51] Finally, relative VO_2 can also be reported according to the amount of fat-free mass an individual possesses. This measurement is independent of changes in body weight and is reported in milliliters per kilogram of fat-free mass per minute (mL/kgFFM/min).[51] While various measures of VO_2 can be found in the literature, they are not interchangeable and the subtle differences should be noted.

Regardless, $VO_{2\,max}$ is the accepted gold standard for measuring cardiorespiratory fitness.[51]

While laboratory tests are ideal to collect the most reliable and valid assessments of VO_{2max} in children, they are time consuming, non-portable, can only assess a single subject at a time, and require special equipment operated by trained personnel. Accordingly, field tests have been developed to estimate VO_{2max} in larger samples of children with minimal cost, equipment, or training. Two of the more common field tests of cardiorespiratory fitness in youth include the mile (1600 m) run and the 20-meter shuttle run test.[51] The one mile run test uses an age and gender specific formula to estimate VO_{2peak} in children ages 5-17 based upon their completion time.[51] The 20-meter shuttle test, on the other hand, uses a different age and gender specific equation to estimate VO_{2max}.[51] The 20-meter shuttle test is also known as the Progressive Aerobic Capacity Endurance Run or PACER. Both tests are frequently used in research and are administered as part of national youth physical fitness surveys in numerous countries including the United States, Canada, and throughout Europe.

Irrespective of the test utilized, it is important to assess cardiorespiratory fitness in elementary school-aged youth. Low cardiorespiratory fitness levels in this age group have been linked to increased insulin resistance as well as increased cardiovascular and cardiometabolic disease risk.[53-61] It has also been correlated to physical activity levels later in life. Finally, high cardiorespiratory fitness levels have been associated with improvements in mental status and cognition including enhanced academic performance.

As such, cardiorespiratory fitness is an important outcome measure not only to determine a child's physical health but perhaps their mental health as well.

Low cardiorespiratory fitness has been associated with insulin resistance in children. Insulin resistance has been shown to predict development of hypertension, heart disease, cancer, type 2 diabetes, and stroke in adults.[62] However, the relationship has been less well studied in children. In 2011, Parrett and colleagues reported an association between aerobic fitness and insulin measures in a sample of 46 children aged 7-11 years old.[53] They found cardiorespiratory fitness to have a significant inverse relationship to both the homeostasis model assessment of insulin resistance (HOMA-IR) (r = -0.40, $p < 0.05$) and fasting insulin levels (r = -0.43, $p < 0.05$). The inverse relationship between fasting insulin levels and cardiorespiratory fitness was further clarified in another study involving 148 non-obese children aged 8-13 years old in 2015.[54] After controlling for age, gender, and percent body fat by dual energy x-ray absorptiometry, cardiorespiratory fitness ($VO_{2peak}/kg_{LBM}/min$) as determined by a treadmill based graded exercise test was still shown to be an independent predictor of fasting insulin ($p = 0.018$). Conversely, a cross-sectional study done by Curtis et al in 2012 involving 203 healthy 11-14 year old children showed that while cardiorespiratory fitness (PACER VO_{2max} z-score) was a significant predictor of insulin resistance (HOMA-IR) in males (r = -0.21, $p = 0.004$), it was not a significant predictor in females.[55] Furthermore, neither race nor ethnicity was found to be a significant independent predictor of HOMA-IR in females ($p = 0.02$).[55]

While these studies point out important correlations between cardiorespiratory fitness and the risk of developing type 2 diabetes, they say nothing regarding the influence of cardiorespiratory fitness on children who already have type 1 diabetes. HbA_{1C} levels are important indicators of glycemic control and used to formally diagnose the presence of type 1 diabetes mellitus. Using a sample of 239 children aged 8-18 years old with diagnosed type 1 diabetes, Lukacs and colleagues concluded that VO_{2max} estimates derived from the 20-meter shuttle run test were a significant predictors of HbA_{1C} levels.[56] Using multiple regression analysis, VO_{2max} was the only significant predictor of HbA_{1C} levels ($B = -0.093$, $SE(B) = 0.016$, $\beta = -0.353$, $t = -5.813$, $p < 0.001$) while age, gender, insulin dosage, BMI z-score, and duration of diabetes were not. Moreover, cardiorespiratory fitness was able to explain 12.5% of the variance in glucose control. Finally, Lukacs et al also related cardiorespiratory fitness to health-related quality of life in this same subject population ($r = 0.435$, $p < 0.001$).[56] In other words, as cardiorespiratory fitness increased in a child with type 1 diabetes, their HbA_{1C} levels decreased while their blood glucose control and health-related quality of life increased. Together, the literature shows that cardiorespiratory fitness can be used both to estimate the risk of developing type 2 diabetes in children and improve outcomes in children who already have type 1 diabetes.

In addition to a relationship with insulin resistance, it is commonly known that low levels of aerobic fitness are associated with increased risk of developing cardiovascular disease among adults. However, as with insulin resistance, the link between cardiorespiratory fitness and cardiovascular disease in children is less well documented. In 2014, Bergmann et al examined the association between cardiorespiratory fitness as measured by the 9 minute run/walk test and various cardiovascular risk factors in a sample of 1,442 children aged 7-12 years old.[63] Cardiovascular disease risk factors included total cholesterol levels and blood pressure. They found that cardiorespiratory fitness was a significant ($p < 0.05$) inverse predictor of systolic blood pressure, diastolic blood pressure, and total cholesterol levels in both genders. When the children were divided into fit and unfit groups by cardiorespiratory fitness levels, adjusted odds ratios (95% CI) showed that the unfit children had a 1.40 ($p = 0.006$), 1.63 ($p = 0.024$), and 1.87 ($p < 0.001$) significantly higher risk of having increased total cholesterol, systolic blood pressure, and diastolic blood pressure respectively. This study also noted that cardiorespiratory fitness levels had a stronger association with total cholesterol levels than body mass index and discussed the possibility that this was due in part to the higher oxidative capacity of skeletal muscle mitochondria in fit children. Finally, when unfit/overweight, fit/overweight, unfit/normal, and fit/normal children were compared, unfit/overweight children had significantly higher total cholesterol levels ($p < 0.05$) than the fit/normal weight children. However, the fit/overweight children did not have significantly higher total cholesterol levels compared to their fit/normal weight peers, suggesting that cardiorespiratory fitness, not BMI, plays a more important role in maintaining healthy total cholesterol levels in overweight children.[63]

This association between cardiorespiratory fitness and cholesterol was also highlighted in a study by Twisk et al.[57] The association between VO_{2max} and cardiovascular disease was tracked longitudinally in 181 youth from age 13 to 27 years old. It was shown that VO_{2max} as measured on a maximal treadmill test had a significant inverse relationship with both total cholesterol ($\beta = -0.09$, $p = 0.05$) and the total cholesterol/high-density lipoprotein ratio ($\beta = -0.15$, $p < 0.01$). Together, these 2 studies support a link between cardiorespiratory fitness and cardiovascular disease risk as measured by cholesterol levels in youth.

Using a different approach to cardiovascular disease risk assessment, a study conducted by Goncalves et al did not find cardiorespiratory fitness to be predictive of clustered cardiovascular disease risk in a sample of 290 boys and girls aged 6-10.[64] The 20-meter shuttle run test was used to estimate VO_{2max}. Cardiovascular disease risk was defined as the presence of three of the following: elevated systolic or diastolic blood pressure, high low-density lipoproteins, high triglycerides, high blood glucose, elevated insulin levels, or low high-density lipoproteins. A receiver operating characteristic (ROC) curve analysis determined that cardiorespiratory fitness did not predict clustered cardiovascular disease risk in either boys or girls. Similarly, Klakk et al examined cardiovascular risk factors and cardiorespiratory fitness in 7-11 year old children (n = 365-729) and found cardiorespiratory fitness to be a nonsignificant predictor of individual or clustered risk in girls after adjusting for adiposity ($\beta = -0.03 - 0.05$, $p = 0.30\text{-}0.87$).[65] However, the relationship between cardiorespiratory fitness and clustered cardiovascular disease risk after adjusting for adiposity remained significant in boys ($\beta = -0.17$, $p = 0.02$). These 2 studies indicate conflicting reports regarding an association between cardiorespiratory fitness and cardiovascular disease risk in children and suggest a confounding influence of gender. However, this conflict is not unexpected given the lack of consistent outcome measures.

Cardiorespiratory fitness is also associated with cardiometabolic disease risk in children. Unlike associations between cardiorespiratory fitness and cardiovascular disease in children, the literature is more consistent regarding this link between cardiorespiratory fitness and cardiometabolic risk. Poor cardiorespiratory fitness levels have been linked to the development of cardiovascular disease, type 2 diabetes, and the metabolic syndrome.[58,59,61,66] The metabolic syndrome is diagnosed in children over the age of 10 if they have the presence of abdominal obesity (waist circumference ≥ 90th percentile) plus 2 or more of the following: elevated triglycerides, low levels of high-density lipoprotein (HDL)-cholesterol, hypertension, or elevated plasma glucose.[61] In 2012, Bailey et al found that clustered cardiometabolic risk was significantly lower ($F = 9.79$, $p < 0.001$) in children with high cardiorespiratory fitness compared to those with low cardiorespiratory fitness after controlling for age, gender, ethnicity, and socioeconomic status.[59] This study was completed using a sample of 100 children aged 10-14.[59]

In a second study of 88 children aged 8-11 years old, Houston and colleagues also found that VO_{2max} estimated from the 20-meter shuttle run had a significant association with clustered cardiometabolic risk ($B = 2.509$, $p = 0.001$).[58] Furthermore, they concluded that children classified as unfit using a VO_{2max} cut-off score of 46.6 mL/kg/min for boys and 41.9 mL/kg/min for girls had an odds ratio of 12.30 (95% CI = 2.64 – 57.33) for being classified in the high-risk cardiometabolic group.[58] Finally, in the study by Parrett et al examining the association between cardiorespiratory fitness and insulin mentioned previously, cardiometabolic risk scores for the metabolic syndrome were also shown to be significantly higher in the low cardiorespiratory fitness/high fat group than the high cardiorespiratory fitness/high fat group.[53] This significant difference remained regardless of assessing body composition by BMI ($p = 0.008$) or percent body fat ($p = 0.025$).[53] This is an important observation as it implies that while cardiorespiratory fitness may not independently decrease cardiometabolic risk in children with healthy body composition, it may offer a protective effect in children with higher levels of body fat.

Since cardiorespiratory fitness has a consistent link with cardiometabolic disease in children, cut-off scores are useful to determine level of risk. In 2007, Ruiz et al published VO_{2max} cut-off scores for assessing cardiometabolic risk in 873 children aged 9-10 as part of the European Youth Heart Study.[67] A VO_{2max} value of 37.0 mL/kg/min for girls and 42.1 mL/kg/min for boys from a maximal ergometer bike test was shown to have significant ($p < 0.001$) discriminatory accuracy between children at low and high metabolic risk.[67] In 2012, ROC field-test aerobic fitness thresholds were generated by Boddy et al to assess cardiometabolic risk in 9-13 year old children.[60] Using the number of laps completed during the 20-meter shuttle run test, a mean threshold of 33 shuttles for boys and 25 shuttles for girls was shown to significantly separate those with higher and lower cardiometabolic risk scores ($p < 0.001$).[60] Together, these two studies provide cut-off scores to assess cardiometabolic risk in large numbers of children using either a laboratory or field test of cardiorespiratory fitness.

In addition to these associations with cardiovascular and cardiometabolic disease risk, cardiorespiratory fitness has also been linked to parasympathetic cardiac activity and C-reactive protein levels.[68-71] Parasympathetic cardiac activity can be measured non-invasively using resting heart rate variability, as the two outcomes have a direct relationship. Moreover, resting heart rate variability has been associated with insulin resistance in obese children and adolescents as well as increased systolic blood pressure.[68] In a sample of 28 overweight and obese children aged 12-16, higher cardiorespiratory fitness was associated with greater parasympathetic cardiac activity in both genders ($r = 0.663$, $p < 0.05$).[68] As such, the association with parasympathetic cardiac activity provides yet another link between cardiorespiratory fitness and cardiac disease risk.

Additionally, C-reactive protein is an independent marker of inflammation and cardiovascular disease.[72] In 170 African children aged 7-10 years old, poor cardiorespiratory fitness as determined by the 20-meter shuttle run test had an independent association with increased salivary C-reactive protein levels (OR = 3.9, $p = 0.001$).[69] In addition to the association with C-reactive protein level, cardiorespiratory fitness was also an independent predictor of the salivary C-reactive protein secretion rates (OR = 2.7, $p = 0.02$).[69] The link between cardiorespiratory fitness and serum C-reactive protein was also highlighted in another sample of 45 prepubescent children aged 7-11 years in 2010.[71] In this study, cardiorespiratory fitness as VO_{2peak} from a treadmill graded exercise test was inversely associated with C-reactive protein ($r = -0.37$, $p < 0.05$). In short, both studies concur that increased cardiorespiratory fitness is related to decreased markers of inflammation and cardiovascular disease in children.

In addition to decreased risk of cardiovascular and cardiometabolic disease, cardiorespiratory fitness levels in children have been associated with physical activity levels in adulthood.[73,74] It is well-known that higher levels of physical activity offer numerous health benefits. However, it should be noted that to date this association between CRF in childhood and physical activity in adulthood has been reported significant only in males.[73,74] For instance, Jose et al examined predictors of leisure time physical activity during the transitional period from adolescence to adulthood in 962 girls and 797 boys aged 7-15.[73] They found that cardiorespiratory fitness as determined by the mile run was associated with being persistently active into adulthood (adjusted RR = 0.85, $p < 0.01$) after adjusting for outside school sports participation, active fathers, sports competency, and enjoyment of sport. However, this association was only true in males.[73] Moreover, a study reported in 2011 by Huotari et al examined the ability of cardiorespiratory fitness data taken as adolescents (12-18 years old) to predict physical activity in the same subjects (n = 1525) as 37-43 year old adults.[74] In agreement with

Jose et al, they also found a weak significant association between cardiorespiratory fitness levels and adult leisure time physical activity in males ($r_s = 0.19$, $p < 0.05$; OR = 0.24, 95% CI: 0.07 - 0.81) but not females.[74] Together, these studies suggest that cardiorespiratory fitness levels as boys may be linked to lifelong physical activity in these same subjects as men.

Beyond improvements in physical health, cardiorespiratory fitness has also been linked to improvements in mental function. In a 2013 literature review, Haapala examined relationships between cardiorespiratory fitness and motor skills to cognition and academic performance.[19] In short, the literature showed that higher levels of cardiorespiratory fitness had beneficial effects on several areas of cognition including inhibitory control, working memory, and academic performance. Inhibitory control is the ability to control one's thoughts, feelings, and behaviors in order to overcome external temptation or internal predisposition and accomplish a task at hand.[18] In other words, it is the capacity to finish a task while overcoming old habits, ignoring impulses, and disregarding distractions.[18] The ability to focus and complete assignments is important for academic success. Thus, as improved levels of cardiorespiratory fitness were associated with improved inhibitory control in children, cardiorespiratory fitness levels are relevant to a student's ability to succeed in the classroom.[19]

Furthermore, Haapala also found evidence in the literature linking higher levels of cardiorespiratory fitness to improved working memory in children.[19] Working memory is responsible for manipulation of information in the mind and learning about relationships between stimuli. This, too, is important for cognition and academic success. Also known as relational memory, working memory allows for organization of information. This relational memory has been associated with higher levels of cardiorespiratory fitness and improved hippocampal encoding. In fact, the relationship between cardiorespiratory fitness and relational memory has been shown to be mediated by bilateral hippocampal volume.[75]

Thus far, cardiorespiratory fitness has been linked to inhibitory control and working memory in children. Along with cognitive flexibility, these two components comprise cognitive control. Cognitive control is required to concentrate and experience success in school and life.[18] Using children ages 9-10 years old, it was shown that children with higher levels of cardiorespiratory fitness as determined by a treadmill test demonstrated more flexible modulation of their resources for cognitive control compared to their less fit counterparts.[16,76] They were also shown to have better activation of the frontal and parietal regions of the brain. In short, this study suggests that cardiorespiratory fitness plays a role in the adaptation of the brain to complete and sustain specific task related goals.[76] Within this same age range, children with lower levels of cardiorespiratory fitness were also shown to have increased number and frequency of errors as well as more omissions on a cognitive control task.[77] This suggests poorer vigilance and sustained attention levels in less fit children, which could contribute to poorer academic performance.

Beyond increased activation of the frontal and parietal lobes, 9-10 year old children with high levels of cardiorespiratory fitness have also been shown to have other changes in brain structure compared to less fit children in the literature. These changes include larger bilateral putamen, globus pallidus, and hippocampal volumes associated with improved cognitive performance.[14,75] Interestingly, children with larger bilateral putamen and higher levels of cardiorespiratory fitness have also been shown to have other changes in brain composition in a longitudinal study.[78] These changes include decreased gray matter thickness in the superior temporal lobe, superior frontal cortex, and lateral occipital cortex. Notably, this decreased gray matter thickness is associated with improved performance in mathematics.[78]

Clearly, cardiorespiratory fitness has been associated with improvements in both cognition and brain structure that may contribute to academic success. However, there is also evidence of a direct link between cardiorespiratory fitness and academic performance in the literature.[19] Standardized testing is a common method of assessing academic knowledge. Remarkably, Haapala's review found evidence of higher standardized testing scores in children with higher cardiorespiratory fitness levels compared to children with lower cardiorespiratory fitness levels. However, the author cites serious differences in the association between cardiorespiratory fitness and academic performance depending upon the cardiorespiratory fitness test used. In general, field tests rather than laboratory tests of cardiorespiratory fitness seem to be linked with academic performance.[19] This is an important consideration that deserves further research.

However, a 2011 study of 170 children ages 7-11 did find a relationship with standardized test performance using a laboratory measure of cardiorespiratory fitness.[79] Davis and Cooper found VO_{2peak} as measured on a treadmill test to be weakly but significantly related to both the planning and attention portions of the Cognitive Assessment System ($r = 0.26$ and 0.22 respectively; $p < 0.01$) and the Woodcock-Johnson Tests of Achievement III math and reading sections ($r = 0.25$ and 0.29 respectively; $p < 0.01$).[79] In field testing, Welk et al found modest associations ($r = 0.41$) between cardiorespiratory fitness as determined by the FitnessGram® test and the Texas Assessment of Knowledge and Skills (TAKS) test in 36,835 Texas public school children grades 3-12.[80] Moreover, this association remained true after controlling for other confounding variables including minority status, socioeconomic status, class size, and school size.[80]

Finally, Van Dusen et al completed a larger study also involving the FitnessGram® test and the Texas Assessment of Knowledge and Skills (TAKS) test with 254,743 Texas students grades 3-11.[81] In agreement with Welk et al, they also found cardiorespiratory fitness to have a direct relationship with standardized academic test performance. They reported a standardized mean difference effect size of 0.17 (95% CI: 0.15 – 0.19) for reading scores in males, 0.34 (95% CI: 0.32 – 0.35) for math scores in males, 0.27 (95% CI: 0.25 – 0.29) for reading scores in females, and 0.33 (95% CI: 0.31

– 0.35) for math scores in females.[81] Although causality cannot be inferred from these cross-sectional studies, there is clearly evidence of a relationship between cardiorespiratory fitness and academic performance in the literature.

Certainly, cardiorespiratory fitness is an important component of health for elementary school-aged children. It has been shown to be associated with insulin resistance, cardiovascular and cardiometabolic disease, participation in physical activity throughout the lifespan, cognitive functioning, and academic performance. Thus, accurate assessment of cardiorespiratory fitness is crucial. Accordingly, it is important to identify and control for confounding factors that may potentially skew results.

It is common knowledge that cardiorespiratory fitness is improved with exercise and physical activity.[51] However, a 2011 study by Dencker et al examined the contributing factors for absolute VO_{2peak} in 436 children ages 6-7 years old and found the main predictors of cardiorespiratory fitness in order of most to least influence to be fat-free mass, maximal heart rate, sex, and age.[82] The most important contributing factor was the amount of fat-free mass, which explained 36-44% of the variance in VO_{2peak}. Interestingly, moderate-to-vigorous physical activity as measured by accelerometers only explained an additional 3-6% of the variance in cardiorespiratory fitness. Moreover, the influence of gender on cardiorespiratory fitness could not be explained either by physical activity, body composition, or maximal heart rate. Dencker et al also noted that when VO_{2peak} was corrected for body mass (mL/kg/min) as appropriate for running and other weight bearing activities, total body fat replaced fat-free mass as the most important predictor.[82] Thus, it is important in assessing cardiorespiratory fitness in children that body composition, age, and gender are accounted for while physical activity may have less influence than previously assumed.

Muscular Fitness

Muscular fitness encompasses multiple components including muscle strength, muscle power, and muscle endurance. By definition, muscle strength is the ability of the muscle to produce a given force against resistance.[83] Overall, it is the most widely studied component of muscle fitness.[84] Dynamometry, one-repetition maximum, free weights, isokinetic machines, and field tests can all be used to assess muscle strength.[51] Muscle power, or explosiveness, is the speed at which the given force can be created.[83] Muscle power is often measured by explosive tests like the standing long jump.[85,86] Finally, muscle endurance is the ability of muscle groups to perform for extended time periods at submaximal levels of force and is another key component of muscular fitness.[51] Performing maximum repetitions of dynamic exercises such as the pull-up test, push-up test, and sit-up tests can determine muscle endurance in the field.[51]

As shown, muscle strength, muscle power, and muscle endurance measure different constructs and should not be used as interchangeable terms. However, the literature most commonly refers to muscular fitness in terms of muscle strength and often fails to differentiate between the different components.[84] Accordingly, muscular fitness will be considered muscle strength unless otherwise noted. Muscular fitness is affected by many factors in children including age, gender, pubertal status, and physical activity.[87]

Even television viewing time as toddlers has been shown to inversely predict muscle power in elementary school-aged children.[88]

Within the last 4 years, the literature contains 4 separate systematic reviews addressing muscular strength in children. Most recently, Thivel et al searched the literature to examine muscle strength and fitness among obese children aged 6-18 years.[83] Overall, they found obese children and adolescents to have lower levels of muscular fitness when compared to their healthy weight peers. They also noted that unlike field tests of muscular fitness, laboratory tests showed higher absolute values of muscular fitness in obese youth. However, correcting for body composition negated any differences. This finding supports the use of field based testing among the obese pediatric population as an acceptable alternative to laboratory testing.[83]

In 2015, Muehlbauer et al examined associations between lower extremity muscle fitness (power and strength) and balance across the lifespan.[89] Among children, they found a relationship (back-transformed $r = 0.57$) between muscular fitness and balance calculated from three separate studies. Notably, this relationship decreased over time suggesting that age and maturation may affect this association.[89]

In 2014, Smith et al performed a systematic review and meta-analysis exploring health benefits of muscular fitness among children ages 4-19 years.[87] After examining 110 studies that met criteria, they found evidence of strong direct associations between muscular fitness and both bone health and measures of self-esteem including perceived physical appearance, physical self-worth, global self-esteem, and perceived sports competence.[87] This association between bone health and muscle mass was found in both trabecular and cortical bone.[90] Smith et al also found strong evidence of an inverse association between muscular fitness and measures of adiposity including both total and central adiposity.[87] Pooled effect sizes were calculated for both perceived sports competence (r = 0.39; 95% CI = 0.34 – 0.45) and adiposity (r = - 0.25; 95% CI = - 0.41 – - 0.08). However, they found inconsistent associations in the literature supporting relationships between muscular fitness and musculoskeletal pain or cognitive ability.[87]

Finally, Artero et al searched the literature and reported links between muscular strength and cardiovascular risk factors in 2012.[84] This review included studies examining this association among children and adolescents and found inverse associations between muscular strength and clustered cardiometabolic disease risk, insulin resistance, and inflammatory proteins associated with cardiovascular disease. Interestingly, these protective effects of muscular fitness on cardiovascular health weakened, but generally remained significant after allowing for the effect of cardiorespiratory fitness. Moreover, evidence was found showing that in overweight and obese children and adolescents, higher levels of muscular fitness may partially counteract other adverse cardiovascular risk factors.[84] Together, these systematic reviews highlight several important correlates to muscular fitness including obesity, bone health, self-esteem, and risk of developing cardiovascular disease.

Building upon the evidence found in the literature review by Artero et al, several more recent studies support a link between muscular fitness and cardiovascular or cardiometabolic disease in elementary school-aged children.[85,86,91] However, there is conflicting opinion regarding the independent nature of this relationship.[85,86,91] In 2012, Magnussen et al studied the relationship between muscular fitness and risk factors for cardiovascular disease in 1,642 Australian youth aged 9 (n = 600), 12 (n = 562), and 15 (n = 480) years.[85] Muscular fitness was assessed as strength, power, and endurance using dynamometry, standing long jump, and push-ups respectively. Cardiovascular disease risk factors including BMI, blood pressure, blood lipids, and waist circumference were assessed for a relationship with muscular fitness both independently and as a clustered risk score after adjusting for age and gender. Results revealed a significant inverse association ($p < 0.05$) between clustered cardiovascular disease risk and each component of muscular fitness including strength, endurance, and power. Further analysis controlling for participant BMI eliminated the significant association between clustered cardiovascular disease risk and muscular strength but retained the significant associations with muscular power and endurance ($p < 0.001$). Moreover, the relationship with muscular power remained significant ($p_{\text{trend}} \leq 0.001$) across participants with low, moderate, and high levels of cardiorespiratory fitness as measured by the mile run test. In short, this study suggests that muscular strength, power, and endurance all have inverse associations with cardiovascular disease risk in youth and that this association with muscular power is independent of BMI and cardiorespiratory fitness.[85]

In addition to the cardiovascular disease risk factors assessed by Magnussen et al, Steene-Johannessen et al examined the relationship between muscular fitness and multiple inflammatory markers as one component of their 2013 study.[86] Muscular fitness was again assessed using multiple components including isometric strength (grip strength for weight), power (standing long jump), and endurance (sit-up and trunk extensor tests). The mean of the sex-specific standardized test scores was used to calculate a composite muscular fitness score. Inflammatory markers included C-reactive protein, a known predictor of cardiovascular disease, and leptin, another marker of inflammation associated with vascular dysfunction and insulin resistance in youth. Significant graded associations ($p \leq 0.001$) between muscular fitness and both C-reactive protein and leptin were found for all participants. Moreover, this significant association between C-reactive protein and muscular fitness ($\beta = -0.122$, $p < 0.002$) was shown to be independent of both waist circumference and aerobic fitness level after controlling for numerous confounding variables including age, gender, and pubertal stage. Overall, muscular fitness as determined by power, strength, and endurance was shown to have a significant independent association with two important markers of inflammation in children.[86] In other words, muscular strength and conditioning may decrease cardiovascular disease in youth as well as improve insulin sensitivity.

However, there is conflicting evidence in the literature regarding the independent relationship between muscular fitness and cardiometabolic disease risk. In 2015, Diez-Fernandez et al reported BMI to be a mediator of the relationship between muscular fitness and cardiometabolic risk in 1,158 Spanish 8-11 year olds.[91] A sum of z-scores for muscular strength (grip strength for weight) and power (standing long jump) was used to calculate muscular fitness. Age- and gender-specific z-scores for waist circumference, triglyceride to high-density lipoprotein ratio, mean arterial pressure, and fasting insulin were summed to assess risk of cardiometabolic disease. While they did find significant ($p < 0.001$) graded associations between muscular fitness and risk of cardiometabolic disease in both genders, this association disappeared after controlling for participant BMI. When examining each risk factor independently, BMI was shown to be a complete mediator for the relationship between muscular fitness and all cardiometabolic disease risk factors in both genders. The only exception was fasting insulin in girls, where BMI was shown to be a partial mediator. All in all, their study supported the link between muscular fitness and cardiometabolic disease risk but found this relationship to be mediated by body mass index.[91] Thus, while the literature does support associations between muscular fitness and cardiovascular disease in children, the independent nature of this association warrants further research to reach consensus.

Body Composition

Body composition is a term that breaks down a person's total body weight or mass down to specific components. The most common divisions include fat mass and fat-free mass.[92] Fat mass includes both essential and nonessential fats while fat-free mass includes all other body components like water, muscle, and bone.[51] When referring to the ratio of fat mass to total body mass, the term percent body fat is often used. A healthy body fat percentage is vital to good health. Fats, also known as lipids, are required for numerous physiological functions. Essential lipids like phospholipids are used to build cell membranes; transport and store fat soluble vitamins like A, D, E, and K; and assist in nervous and endocrine system functions including growth, maturation, and reproduction. Nonessential lipids such as triglycerides are stored as adipose tissue by the body to provide thermal insulation and serve as energy reserves.[51] Thus, fat mass levels that are too low can create health problems and lead to physiological dysfunction.

However, fat mass levels that are too high, as seen in individuals who are overfat or obese, also pose certain health risks.[51] The term overfat refers to individuals with percent body fat ranges above the normal level while the term overweight refers to individuals with total body mass above normal levels. This is an important distinction as increased health risks are associated with higher levels of body fat, not total body mass. However, many people fail to properly differentiate between the two terms. So, for the purposes of this paper the term overweight will refer to above normal levels of body fat unless otherwise noted.

Much research has been done on the effects of high levels of fat in both adults and children. Overweight and obese individuals have a decreased life expectancy and are at increased risk for developing several adverse health conditions including hypertension, heart disease, stroke, type 2 diabetes, osteoarthritis, obstructive pulmonary disease, and certain cancers.[51,92] Furthermore, the cost-of-illness to treat obese children creates an economic burden on the healthcare system. In a recent systematic review, Pelone et al noted that in the United States, the annual healthcare burden to treat childhood obesity is $14.1 billion dollars.[93] Fortunately, body composition deficits respond well to diet and exercise. Recently, overall levels of student physical activity have increased and the number of obese school-aged children in the United States has plateaued.[4] Additionally, obesity prevalence in the United States is currently declining as children mature in age with a rate of 4.0% in preschoolers, 3.2% in school-aged children, and 1.8% in adolescents.[94]

Although rates have plateaued and are declining with age in the US, it has been noted that obesity tracks over time. That means that obese children are still more likely to become obese adults, especially if their obesity carries over from childhood into adolesence.[24,92,95] In fact, a recent systematic review and meta-analysis found that 55% of obese children will become obese adolescents while 70% of obese adolescents will become obese adults beyond age 30.[96] Therefore, it is critical to identify high levels of body fat in children to prevent obesity from tracking into adulthood, decrease disease risk, and increase life expectancy.

Numerous methods exist to assess body composition in children, each with their own specific strengths and weaknesses. In the laboratory, body composition can be measured using reference standards including a multicomponent approach (body density, total body water, and total bone mineral), densitometry (underwater weighing or air displacement plethysmography), or dual energy x-ray absorptiometry.[24,51] However, these methods are expensive and non-portable, require extensive training, and are not practical for screening large numbers of children.

In the field, the most common means of assessing body fat involve skinfold measurements or bioelectrical impedance analysis.[92] Skinfold measurements involve the use of calipers to measure skinfold thickness at standardized tests sites (usually triceps and calf) which are then used in equations to predict body fat. Bioelectrical impedance analysis sends an imperceptible trace electrical current through the body and measures resistance to current flow. As fat mass offers greater resistance to flow as compared to fat-free mass, this resistance is inserted into equations to estimate percent body fat. Bioelectrical impedance analysis is faster, less invasive, and easier to use compared to skinfold measurements.

Body mass index is also commonly used to indicate body composition. However, it does not directly assess body composition but is rather an estimate of how appropriate an individual's weight is in relationship to his or her height. This can lead to inaccurate body composition classification, especially in individuals with high levels of muscle mass. Nevertheless, is still widely used and a good indicator of body composition in most of the population.[92] Error rates for the laboratory measures of body composition including the multicomponent approach are around 2% while densitometry and dual energy x-ray absorptiometry error rates range from 2.5-3%. Among field measurements, skinfold measurements and bioelectrical impedance analysis error rates range 3-4%, and BMI has an error rate of >5%.[24] Relatively, the error rates for field measurements are only slightly higher than laboratory measurements, but offer more portability and ease in body composition assessment.

Whether measured in the lab or in the field, childhood obesity has been linked to type 2 diabetes, glucose intolerance, and insulin resistance in the literature.[97] In a study conducted by Watson et al in 148 9-13 year old children, both percent body fat using dual energy x-ray absorptiometry ($r = 0.27$; $p < 0.001$) and body mass index z-score ($r = 0.33$; $p < 0.002$) were weakly but significantly related to fasting insulin.[54] Moreover, body mass index z-score remained a significant predictor ($p = 0.043$) of fasting insulin levels after running a multivariate analysis including age, gender, percent body fat, BMI z-score, and cardiorespiratory fitness.[54]

In a second study, Henderson et al tracked the influence of adiposity on insulin dynamics over a 2-year period in 630 children aged 8-10 years at baseline.[98] Adiposity was assessed as percent body fat by x-ray absorptiometry and all regression models accounted for age, gender, and pubertal stage. Over time, both adiposity and changes in adiposity proved to be central to changes in insulin dynamics. Specifically, for each additional 1% of body fat noted in a child between the ages of 8-10, insulin resistance measured as HOMA-IR increased by 3.2% (95% CI = 2.8% - 3.6%; $p < 0.001$) 2 years later. Additionally, the same 1% of body fat at age 8-10 also increased the area under the curve by 0.5% (95% CI = 0.09% - 0.8%; $p = 0.02$) for the insulin to glucose ratio thirty minutes into a glucose tolerance test taken 2 years later on the same children. This increase in the area under the curve was true after controlling for physical activity, screen time, and fitness as additional covariates.[98] In short, body composition plays a significant role in insulin dynamics and a high body mass index in childhood has also been associated with increased diabetes incidence as an adult (OR = 1.70; 95% CI = 1.30 – 2.22).[95]

In addition to its role in insulin dynamics, body composition also plays a role in cardiovascular health and cardiometabolic disease risk. In a sample of 1,442 7-12 year olds by Bergmann et al, body mass index was shown to have more influence on blood pressure than cardiorespiratory fitness in both genders.[63] Interestingly, body mass index was associated with significantly ($p < 0.05$) lower readings for both systolic and diastolic blood pressure while percent body fat was only associated with significantly ($p < 0.05$) lower systolic blood pressure readings. Nevertheless, when compared with cardiorespiratory fitness, body mass index was shown to be independently associated with both total cholesterol and blood pressure in youth.[63]

While body composition is related to total cholesterol and blood pressure readings in youth, it has also been linked to C-reactive protein. This inflammatory marker is another important risk factor for the development of cardiovascular disease. In a 2012 study by Naidoo et al, children with normal body mass indexes were shown to have significantly lower C-reactive protein secretion rates and concentration levels as compared to their obese counterparts.[69] Additionally, when compared to cardiorespiratory fitness, body mass index in the overweight or obese range (≥ 85% percentile) was an independent predictor (OR = 2.5; 95% CI = 1.1 – 5.9; $p = 0.03$) of an elevated C-reactive protein secretion rate. Together, these findings suggest a strong relationship between body composition as determined by body mass index and a child's inflammatory status and thus his or her risk for developing cardiometabolic disease.[69]

Although body composition has been linked to individual risk factors for cardiovascular and cardiometabolic disease in children, it has also been associated with clustered risk for the same diseases. Using data from 290 children ages 6-10 years, various anthropometric variables were examined for his or her ability to predict cardiovascular disease risk.[64] Clustered cardiovascular disease risk was identified by the presence of three of the following factors: elevated systolic or diastolic blood pressure, elevated triglycerides, elevated low-density lipoproteins, elevated blood glucose or insulin levels, and low high-density lipoproteins. In general, body composition was a good predictor in both genders. Particularly, body mass index, waist circumference, and waist to height ratio had significant areas under the receiver operating characteristic curves (range = 0.62 – 0.76; $p < 0.001$). This indicates that these three measures can be used to identify clustered cardiovascular disease risk in 6-10 year old children.[64]

In a separate study, Parrett et al were able to relate adiposity to clustered metabolic disease risk in a sample of 46 children aged 7-12 years.[53] Adiposity was assessed as percent body fat as determined by dual energy x-ray absorptiometry while metabolic disease risk was a summed score of age- and gender-corrected z-scores for the following: HOMA-IR, triacylglycerol, total cholesterol to high-density lipoprotein cholesterol ratio, insulin, waist circumference, and mean arterial pressure. Individually, percent body fat was significantly correlated with each of the 6 metabolic risk factors (*r* range = -0.32 - -0.63; all $p < 0.05$). Moreover, percent body fat was also shown to be an independent predictor of clustered metabolic disease risk ($\beta = 0.49$; $p = 0.005$) when compared with physical activity and cardiorespiratory fitness. It also explained 9.5% of the variance. In summary, adiposity has been shown to be a significant predictor of metabolic disease risk in elementary school children.[53]

Body composition has also been shown to affect a child's cognition and academic performance. In general, adverse levels of body composition have been shown to affect a child's social and psychological health as well as his or her school performance.[97] Socially, overweight and obese children are frequently teased, bullied, negatively stereotyped, and discriminated against by his or her peers. This can in turn lead to lower levels of self-esteem, poor body image, and even poor academic performance. Overweight and obese children commonly have fewer friends than his or her normal weight counterparts. This further isolates them socially and forces more solitary and sedentary play. Overweight and obese children also often find more difficulty keeping up with his or her peers during physical activity which exacerbates the teasing, negative self-image, and social isolation they may already be experiencing. Negative associations with socialized physical activity further intensify the problem by decreasing the desire to participate in physical activity. In turn, this decreases total energy expenditure and increases weight gain.[97]

Psychologically, body composition issues can lead to depression, poor self-esteem, body dissatisfaction, and/or the development of eating disorders.[97] However, depression can be either a consequence or a cause of childhood obesity and is not always significantly associated with increased body mass index.[99] In self-esteem domains, the literature is conflicted as to whether or not overweight and obese children suffer from lower global self-esteem but seems to suggest higher deficits in the physical and social domains.[97] Body dissatisfaction is propagated by westernized ideals of lean, muscular males and thin females. Accordingly, body mass index has a direct linear relationship with body dissatisfaction among girls while boys experience lower body satisfaction at both ends of the body mass index spectrum. This means the girls who are more overweight generally have lower body satisfaction while boys who are either very lean or very large also have lower body satisfaction. Finally, overweight and obese youth, particularly females, also experience a higher rate of disordered eating as compared to their normal weight peers.[97]

Academically, overweight and obese children are more likely to struggle if they also have chronic health conditions like diabetes or asthma that may cause them to miss school more frequently.[97] However, the literature is divided on the relationship between scholastic achievement and body composition. In a study of 170 overweight but healthy 7-11 year olds, Davis and Cooper found poor levels of body composition were associated with poor cognitive test scores, academic achievement, and behavior.[79] Looking closer, waist circumference (r = -0.16 and -0.25 for planning and simultaneous sections respectively), percent body fat (r = -0.22 and -0.16 for attention and planning sections respectively), visceral fat (r = -0.19 and -0.18 for planning and simultaneous sections respectively), and subcutaneous abdominal fat (r = -0.19 and -0.24 for planning and simultaneous sections respectively) were all significantly ($p < 0.05$) related to poor performance on 2 of the 4 sections of the Cognitive Assessment System test. BMI z-score (r = -0.23 and -0.20), waist circumference (r = -0.28 and -0.21), percent body fat (r = -0.23 and -0.20), and subcutaneous abdominal fat (r = -0.31 and -0.22) were all significantly ($p < 0.05$) associated with both sections (math and reading respectively) of the Woodcock-Johnson Tests of Achievement III. Finally, BMI z-score (r = 0.16 and 0.15) and waist circumference (r = 0.19 and 0.16) were associated with increased behavior issues on two of the four subsections of Conners' Parent Rating Scale.[79] However, the cross-sectional nature of this study does not mean that childhood obesity causes cognitive, academic, or behavioral issues but rather suggests an association.

Next, Kamijo et al explored relationships between adiposity and both cognitive control and academic achievement in 126 children aged 7-9 years.[100] Body mass index, percent body fat by dual energy x-ray absorptiometry, and abdominal fat mass were all examined for associations with cognitive control (Go-NoGo task) and academic achievement (Wide Range Achievement Test 3rd edition) while controlling for age, gender, IQ, socioeconomic status, and cardiorespiratory fitness level. Results showed that on the NoGo task which required extensive amounts of inhibitory control, BMI (partial correlation (pr) = -0.20, $t_{119} = 2.17$; $p = 0.03$), percent body fat (pr = -0.21, $t_{119} = 2.37$; $p = 0.02$), and abdominal fat mass (pr = -0.21, $t_{119} = 2.39$; $p = 0.02$) were all linked to poorer result accuracy. Interestingly, no associations between body composition and the Go task, which required lesser amounts of inhibitory control, were found. Finally, Kamijo et al examined academic achievement using the 3 subsections of the Wide Range Achievement Test 3rd edition for reading, spelling, and arithmetic. They reported significant associations with reading for percent body fat ($pr = -0.19$, $t_{119} = 2.12$; $p = 0.04$) and abdominal fat mass ($pr = -0.21$, $t_{119} = 2.33$; $p = 0.02$), spelling for body mass index ($pr = -0.21$, $t_{119} = 2.37$; $p = 0.02$) and percent body fat ($pr = -0.18$, $t_{119} = 1.97$; $p = 0.05$) as well as abdominal fat mass ($pr = -0.21$, $t_{119} = 2.39$; $p = 0.02$), and arithmetic for body mass index ($pr = -0.28$, $t_{119} = 3.20$; $p = 0.002$) and abdominal fat mass ($pr = -0.20$, $t_{119} = 2.22$; $p = 0.03$).[100] Notably, abdominal fat mass was the only measure of adiposity significantly related to lower scores in all 3 areas. When considered as a whole, these results suggest that high levels of body fat are associated with poorer cognitive control and academic achievement in preadolescent children.

Conversely, Roberts et al reported no effect of body mass index on scholastic achievement after including fitness level as a covariate in their 2010 study.[101] Their sample involved 1,989 children in grades 5, 7, and 9 and utilized standardized school achievement tests. Age- and gender-specific body mass index classification was compared to math, reading, and language scores while controlling for socioeconomic status (free lunch program), gender, parental education, and ethnicity. Higher quintiles of BMI-for-age did relate to significantly lower scores on the math and reading tests (linear trend, $p_{\text{math}} = 0.007$; $p_{\text{reading}} = 0.028$) and math and language tests (linear trend, $p_{\text{math}} = 0.013$; $p_{\text{language}} = 0.073$) when analyzed initially. However, when including their cardiorespiratory fitness level in the model, all significant relationships between body mass index and standardized test score disappeared.[101] Although the sample was slightly older and standardized scholastic achievement tests were used, this study seems to suggest that cardiorespiratory fitness levels may mediate the relationship between body composition and academic achievement.

Predictors of poor body composition in children are another important area of research. Without doubt, childhood obesity is a multifaceted issue and many resources have been devoted to determining the cause. In its simplest form, childhood obesity results from an energy imbalance. When more energy is consumed than expended, excess energy is stored as fat.[97] Risk factors include poor diet, low levels of physical activity, and high levels of sedentary behavior. Age and gender moderate these risk factors. Additionally, school policies, parental preferences, and demographics also affect childhood diet and activity.[97]

Barriuso et al recently conducted a systematic review on socioeconomic variables and their relationship to child and adolescent obesity in high-income countries.[102] They found that 60.4% of studies found an inverse relationship between socioeconomic status and child/adolescent weight status. This means that as socioeconomic status increased, unhealthy classification decreased. No relationship was found in 18.7% of studies while 20.9% found a relationship that varied by a confounding variable like age, gender, or ethnicity. However, only 1.1% of studies found a direct relationship. They concluded that in rich countries, the positive relationship between socioeconomic status and unhealthy child/adolescent weight classification has almost disappeared. Notably, they found that among socioeconomic status indicators, parental education level, with a stronger association with maternal education level, resulted in the highest proportion of inverse relationships. In other words, the more educated the mother, the healthier the child or adolescent.[102]

Regarding energy intake, increases in dietary caloric content have been attributed to sugary beverages, fast food consumption, snack foods, and larger portion sizes.[97] However, dairy intake seems to play a protective role in childhood obesity according to a recent systematic review and meta-analysis examining 46,011 children with an average 3-year follow-up.[103] For each additional serving of dairy consumed each day, they found the risk of being classified as overweight or obese decreased by 13% (OR = 0.87; 95% CI = 0.74 – 0.98) and percent body fat was reduced by 0.65% (β = 0.65; 95% CI = -1.35 – 0.06; $p = 0.07$).[103]

Regarding energy expenditure, decreased activity levels have been attributed to increased use and availability of electronic media, concern for child predators during outdoor activity or walking to/from school, and parental lifestyle.[97] In their meta-analysis examining the role television watching plays in risk for childhood obesity, Zhang et al concluded that increased time spent watching television was associated with an increased risk of developing childhood obesity after examining data from 106,169 children.[104] Specifically, they reported that the multivariable-adjusted overall odds ratio of being classified as obese between the highest and lowest time spent watching television was

1.47 (95% CI = 1.33 – 1.62). In other words, children who spent the most time watching television were 1.5 times more likely to be classified as obese. Moreover, a dose-response relationship was seen with each additional hour of television resulting in a 13% increased risk of childhood obesity ($p < 0.001$). Notably, this association was found in both genders.[104]

In determining risk for childhood obesity, increasing evidence supports the role of genetics.[97] Genetics are one of the leading causes currently being investigated for their role in childhood obesity. Basal metabolic rate, or the amount of energy used to maintain normal body function at rest, accounts for roughly 60% of the body's energy expenditure but is likely not the reason for increasing obesity. Body mass index has been found to be 25-40% heritable in the literature.[97] After a meta-analysis of genome-wide association studies examining childhood body mass index, 15 loci (ADCY3, GNPDA2, TMEM18, SEC16B, FAIM2, FTO, TFAP2B, TNN13K, MC4R, GPR61, LMX1B, OLFM4, ELP3, RAB27B, ADAM23) were found to have statistically significant ($p < 5 \times 10^{-8}$) associations with childhood body mass index.[105] Many of these loci are also associated with adult obesity. Unfortunately, when all 15 alleles were combined into a single risk score, this score only explained only 2% of the variance in childhood body mass index.[105]

Overall, while genetics may seem to play a large role in the development of childhood obesity, less than 5% of childhood obesity cases are accounted for by genetics.[97] Most often, a genetic predisposition must be combined with behavioral and/or environmental factors to effect body composition classification. Thus, while genetics can contribute to the development of childhood obesity, they are not responsible for the dramatic rise seen in the last several decades.[97] Genetics are simply one component that contributes to childhood obesity along with diet, physical activity, demographic, environmental, cultural, and family characteristics.

Motor Skill Proficiency

Another important component of a healthy child is developing motor skill proficiency. Also known as motor skill competence or motor coordination, these terms refer to the mastery of specific fundamental movement skills that serve as building blocks for more complicated movements required for participation in many sports and physical activities.[106] Most often, these fundamental movement skills refer to gross motor skills and can be broken down into 3 broad categories: locomotor skills, manipulative or object control skills, and stability skills. Locomotor skills include tasks like running and hopping. Object control skills include tasks like throwing and catching. Stability skills include tasks that challenge balance. Development of motor skill proficiency has been alleged to improve multiple areas of a child's life including social and cognitive development in addition to the obvious physical gains.[106]

After a systematic review of the literature, Lubans et al found several studies that examined potential benefits of motor skill competency on global self-concept, cardiorespiratory fitness, perceived physical competence, muscular fitness, flexibility, weight status, decreased sedentary behavior, and physical activity.[106] In general, they found strong positive associations between motor skill competency and physical activity in children. Additionally, a positive relationship between motor skill competency and cardiorespiratory fitness was found along with a negative relationship with weight status. However, lack of a sufficient number of studies prevented conclusions on the remaining domains.[106]

The negative relationship between gross motor skills and unhealthy body composition is supported in two other studies published after the systematic review. In 2013, D'Hondt et al published a longitudinal analysis examining the effect of an overweight or obese classification on gross motor coordination.[107] Their sample followed 50 children classified as overweight or obese and 50 normal weight children aged 6-10 years at baseline. Gross motor coordination was assessed using the Körper Koördinations Test für Kinder (KTK) at baseline and again 2 years later to explore the effect of body composition on longitudinal gross motor skill development. Between the 2 groups, overweight or obese children performed significantly poorer ($p < 0.05$) on the KTK at both baseline and 2-year follow-up. More importantly, there was a significant time and group interaction indicating that not only did the overweight and obese children perform more poorly at baseline, they also failed to progress with gross motor skill development over the following 2 years as compared to their normal weight peers. In conclusion, they found that body mass index was a significant negative predictor of gross motor performance 2 years later.[107]

In a second study published in 2014, Khalaj and Amri also noted discrepancies in gross motor skills between normal weight and obese preschool (mean age = 4.87 years;

SD = 0.49) and early elementary school (mean age = 7.34 years; SD = 0.63) children.[108] With a larger sample of 160 children (80 obese and 80 normal weight), they found significant differences in gross motor scores for both obese preschool children ($F(1,78) = 544.76$; $p < 0.001$) and early elementary school children ($F(1,78) = 244.228$; $p < 0.001$). While this conclusion is interesting on its own, they also noted that when the 2 age groups of obese children were compared, the elementary school children performed significantly worse than the preschool children for their age and gender overall ($F(1,78) = 9.883$; $p < 0.002$). This was also true for the locomotor ($F(1,78) = 18.128$; $p < 0.001$) and object control ($F(1,78) = 27.385$; $p < 0.001$) sections. This would seem to suggest that while obese children seem to have greater deficits in gross motor skill competency in both preschool and early elementary school, the early elementary school group seems to be more susceptible to greater consequences of gross motor skill developmental delays.[108]

Separate from the relationship with body composition, motor skill proficiency in children has also been shown to be a predictor of lower extremity injury and future levels of fitness as adolescents.[109,110] In a 2016 study that included 1,244 children ages 8-14 years old, Larsen et al performed several motor performance tests and then followed lower extremity injury occurrence among the sample for 15 months.[109] They consistently found poor balance to be a predictor of increased risk of injury including traumatic injury to the foot (IRR = 1.09 – 1.15) and overuse injuries of the foot (IRR = 1.65). They also noted that strong performance on the single leg hop for distance task was shown to be a negative predictor for traumatic knee injury (IRR = 0.66 = 0.68). While they cautioned that more studies are needed to confirm and clarify their findings, this study did find motor skills to have predictive ability for future lower extremity injuries in 8-14 year olds.[109] These findings are important as injury also hinders future sports participation.

Finally, motor skill proficiency can track from childhood into adolescence. In 2008, Barnett et al published a longitudinal study that examined motor skill proficiency in 7-12 year olds before retesting them again for cardiorespiratory fitness levels 6 years later.[110] In total, 244 children completed all study requirements. Among this population and after controlling for gender, a significant relationship was found between childhood object control proficiency and adolescent cardiorespiratory fitness ($B = 0.093$; 95% CI = 0.021 – 0.165; $p = 0.012$). These object control tasks included kick, catch, and overhand throw. On average, children with high levels of object control were able to complete more than 6 additional laps on the 20-meter shuttle run test as adolescents as compared to their age/gender matched peers with low object control proficiency. Moreover, this relationship with object control proficiency was able to explain 25.9% of the total variance seen in fitness levels as adolescents ($R^2 = 0.259$). Notably, there was not a significant relationship between the childhood locomotor skill tasks. Performance tasks included hop, side gallop, vertical jump, and sprint run and adolescent fitness. In conclusion, this study showed that children with good object control proficiency in elementary school were more likely to become fit adolescents.[110]

In 2013, Haapala published a systematic review that examined both cardiorespiratory fitness and motor skills and their associations with cognition and academic performance.[19] By and large, Haapala concluded that better motor skills are associated with improved academic performance and may be beneficial to cognition. However, it was also noted that the evidence for motor skills is primarily based upon cross-sectional studies and that the effect of cardiorespiratory fitness was often left out of the analyses.[19] These 2 factors weaken the conclusions that can be drawn about any associations between motor skills and cognitive or academic performance.

Looking closer, Haapala goes on to explore the evidence for potential links in the literature between motor skills and inhibitory control.[19] Although several studies addressed this link, the evidence was inconsistent. For example, manual dexterity and whole body coordination were shown to decrease reaction times in 2 different tests of inhibitory control in 2 different studies. However, a third study found sideways jumping motor skills to decrease reaction times in a third test of inhibitory control but no relationship between manual dexterity and whole body coordination. Haapala also states that only reaction times were found to be significant while accuracy on the inhibitory tasks was ignored. As reaction time is a questionable measure of inhibitory control, the evidence for an association between inhibitory control and motor skills is conflicting and weak at best.[19]

Haapala also found evidence for a link between whole body coordination and manual dexterity with improved item memory.[19] This link was supported in several studies. One study even showed that gross motor development during early childhood could predict item memory during later childhood. Furthermore, improved dynamic balance was also shown to increase item memory scores 9 months later. However, links between spatial working memory and motor skills are again inconsistent.[19]

In regards to academic performance, Haapala found evidence to support a positive link between motor skills and academic performance.[19] Children with better overall motor skills had higher grade point averages than their peers with lower motor skills. Longitudinal studies have also shown that fine motor skills in early childhood can predict improvements in math and reading later. On the other hand, there is limited and inconsistent evidence in the literature from longitudinal studies to support the concept that interventions aimed at improving motor skills will also improve academic performance.[19]

Two years later, van der Fels et al did another systematic review of the literature that focused on associations between cognitive and motor skills in typically developing children aged 4-16 years.[111] Motor skill studies were broken down into categories including gross motor skills, fine motor skills, bilateral body coordination, object control, and total motor score. Overall, there were limited to no associations between motor skills and cognitive skills. This was especially true for gross motor skills and total motor scores. However, they did find strong evidence for a moderate-to-strong relationship between fine motor skills and visual processing and weak evidence of a weak-to-moderate relationship for fine motor skills with fluid intelligence and short-term memory. Moreover, there was strong literary evidence for a weak-to-moderate link between fluid intelligence and bilateral body coordination.[111]

Finally, van der Fels et al found strong evidence for a weak relationship between object control and visuospatial working memory.[111] In short, they found little evidence of links between gross and total motor skills with cognition but did find relationships with cognition for fine motor skills, bilateral body coordination, and object control. This was especially true for children under the age of 12.[111] This would concur with Haapala's findings that motor skills may be beneficial to cognition.

In addition to these 2 systematic reviews, a study published in 2013 examined the association between gross motor skills and academic achievement in 596 children aged 9-12 years.[112] Gross motor skills were assessed using the Körper Koördinations Test für Kinder test. Cardiorespiratory fitness as measured by the 20-meter shuttle run test, socioeconomic status, and body composition were all controlled for in their data analysis. In both genders, children who performed poorly on the gross motor skills test (< 70 motor quotient) were significantly more likely to have low score on standardized academic achievement tests. Specifically, the adjusted odds ratio for girls was 7.861 (95% CI = 2.739 – 22.559; $p < 0.001$) and 6.815 for boys (95% CI = 2.075 – 22.379; $p = 0.002$). Overall, this study showed gross motor skills to be a significant predictor of academic achievement and found children who struggled with motor skills to be 6-7 times more likely to also struggle academically.[112]

Predictors of motor skill development are scare in the literature. With the exception of age, there are very few studies supporting specific predictors of motor skill competency in youth. However, Barnett et al examined just that in a 2016 systematic review and meta-analysis.[113] They likewise found age to have a small to medium effect size on motor competence. Object control skills (r = 0.37; 95% CI = 0.29 - 0.35; p = 0.812), locomotor skills (r = 0.44; 95% CI = 0.37 – 0.51; p = 0.271), and stability skills (r = 0.34; 95% CI = 0.29 – 0.39; p = 0.511) were all shown to increase with age. Moreover, there was a small effect size of gender on object control skills (r = 0.23; 95% CI = 0.09 – 0.36; p = 0.009) with males outscoring females. Concerning body composition, Barnett et al reported strong literary evidence for a negative relationship between body mass index and motor coordination and composite scores. This relationship held true for other measures of adiposity as well including percent body fat and waist circumference. Socioeconomic status had inconsistent associations with motor skills and there was no evidence of an effect of ethnicity. In regards to overall motor scores, increased age is associated with increased motor skill competency while increasing adiposity is associated with decreasing motor skill competency in typically developing children ages 3-18.[113]

Interrelationships between Outcome Measures

Cardiorespiratory fitness, muscular strength, body composition, and motor skill proficiency were all proposed to be interrelated by Stodden et al through their novel concept published in 2008.[114] Their theory is based upon a reciprocal relationship between motor skill competence and physical activity participation. They propose that from ages 2-5 years old, physical activity participation may help promote motor skill competence and that this relationship strengthens through middle and later childhood. Enhanced motor skill performance in middle and later childhood will drive self-selection of higher levels of physical activity in children with higher levels of motor skills. This higher level of physical activity will in turn enhance health-related physical fitness components including cardiorespiratory fitness, body composition, and muscular fitness.[114] In other words, physical activity participation driven by improved motor skill competency could explain associations seen between the constructs.

Stodden's theory was reexamined in 2015 by Robinson et al secondary to an increase in the investigations exploring these same relationships.[115] They found literary evidence to support a positive association between motor skill proficiency and physical activity levels throughout childhood. Moreover, they found relationships between motor competence and both cardiorespiratory and muscular fitness that strengthened from childhood into adolescence. Finally, motor skill performance is both a cause and effect of body composition and an inverse relationship between the two is also found throughout childhood and adolescence.[115]

In addition to interrelationships between all 4 constructs, evidence for relationships between pairs of constructs also exists. Summaries for each pair of interrelationships can be found below. However, associations between pairs vary by construct and are not always consistent in the literature.

In 2014, Peterson et al examined the relationship between cardiorespiratory fitness and muscle strength as part of their larger study exploring strength and cardiometabolic risk in 1,421 sixth grade students.[116] They found that estimated VO_{2max} (mL/kg/min) was significantly different (mean (SE); $p < 0.01$) among the lowest and highest strength tertiles for both boys (40.28 (0.62) vs. 44.16 (0.69)) and girls (33.51 (0.49) vs. 36.33 (0.66)). Moreover, there was also a significant difference ($p < 0.01$) among the lowest and middle strength tertiles for both boys (40.28 (0.62) vs. 43.54 (0.52)) and girls (33.51 (0.49) vs. 37.37 (0.35)). This data shows that as muscular strength increases, cardiorespiratory fitness also significantly increases in this population.[116] However, further targeted research investigating a link between cardiorespiratory fitness and muscular strength in children is scarce.

In general, higher levels of cardiorespiratory fitness are associated with body composition changes including increased levels of fat-free mass and decreased levels of fat mass. As mentioned previously, Dencker et al examined the predictors of cardiorespiratory fitness in 436 children ages 6-7 years old.[82] They found the main predictor of cardiorespiratory fitness to be fat-free mass which explained 36-44% of the variance in VO_{2peak}.[82] Tompuri et al found fat mass as determined by dual energy x-ray absorptiometry to be inversely related to VO_{2max} estimated from cycle ergometry in both genders ($r < -0.64$; $p < 0.01$).[117] Bailey et al also support this inverse relationship by reporting a significant ($p < 0.05$) association ($r = -0.43$) between waist circumference and cardiorespiratory fitness in 100 children ages 10-14.[59] Finally, Parrett et al found a significant ($p < 0.001$) inverse correlation between cardiorespiratory fitness (VO_{2peak}) and both body mass index ($r = -0.68$) and percent body fat ($r = -0.75$) in their study of 7-12 year olds.[53]

Nevertheless, some studies report declining national trends in cardiorespiratory fitness among youth that are occurring independently of changes in body mass index.[52,118] Physiologically, fat mass has no effect on the body's ability to consume oxygen.[24] Furthermore, much of the inconsistency in the literature can be accounted for by differences in outcome measures assessing either body composition or cardiorespiratory fitness. Recall that laboratory values obtained by non-weight bearing activities such as cycle ergometer tests negate the effect of body mass. However, relative or weight bearing measures of VO_{2max} divide the absolute lab values by body mass (kg) and automatically place children with more body mass at a disadvantage. Therefore, overweight and obese children are less likely to achieve high scores on field tests of aerobic fitness. Generally, this disadvantage is accepted among field tests as increased fat mass is also associated with increased disease risk.[24] Interestingly, high levels of cardiorespiratory fitness have been shown to have protective effects against cardiovascular disease risk factors in the presence of poor body composition in children.[53,63] Thus, the relationship between cardiorespiratory fitness and body composition appears to be largely inverse but is also confounded by other variables. Moreover, cardiorespiratory fitness carries important implications for protective health effects in overweight and obese youth.

Within the literature, cardiorespiratory fitness and motor skills have been shown to have a consistently positive correlation.[19,106] In their systematic review, Lubans et al found 4 studies that examined potential associations between these 2 constructs in children and adolescents.[106] All of these studies reported a positive relationship between cardiorespiratory fitness and motor skill performance indicating that more fit children also demonstrated improved motor skill proficiency compared to their less fit counterparts.[106]

In a more recent systematic review of the literature, 12 of 12 studies examining the relationship between cardiorespiratory fitness and motor skills found a positive association.[119] Moreover, these 12 studies all assessed the independent nature of the association between cardiorespiratory fitness and motor competence. They proceed to suggest that this strong relationship between high levels of cardiorespiratory fitness and high levels of motor competence can be explained by physical activities that enhance health-related physical fitness. In other words, participation in physical activities and sports may concurrently improve both motor skill performance and cardiorespiratory fitness. This can be seen in the inherent locomotor and object control skills developed through aerobic activities like sports, physical education classes, and leisure physical activities.[119]

On the whole, muscular fitness and body composition have a negative relationship in the literature. Thivel et al found that obese 6-18 year olds had less muscular strength than children their same age and gender with a healthy weight status.[83] This inverse association was also found by Smith et al who noted decreasing levels of muscular fitness with increasing total and central adiposity.[87] Moreover, the inverse relationship between muscular strength and body composition may also mediate the relationship between decreased muscular fitness and increased risk of cardiometabolic disease in both genders.[91] Díez-Fernández showed BMI to be a complete mediator for the relationship between muscular fitness and all cardiometabolic disease risk factors in both genders.[91]

Thus, increased levels of muscular strength are also commonly associated with improved body composition in children and may also have protective implications in the link between muscular fitness and cardiometabolic disease. This inverse relationship between muscular strength and body composition is the logical result of the definition of body composition. Increased levels of fat-free mass like bone and muscle tissue concurrently increase the ratio of fat-free mass to total mass thus improving body composition classification.

Regarding motor competence and musculoskeletal fitness, Cattuzzo et al found strong evidence of a positive association in healthy children and adolescents in their 2016 systematic review.[119] Overall, they found that 7 of 11 studies supported this relationship between improved muscular strength or endurance and improved motor skill performance. Similar to the relationship between cardiorespiratory fitness and motor skills, the relationship between muscular fitness and motor skills can also be explained by participation in sports and physical activity. Many sports and leisure physical activities require ballistic skills that create high muscular demand on the body through both concentric and eccentric contractions. Motor skills like throwing, kicking, jumping, running, and striking all demand high velocity and power thereby also improving muscular fitness. Therefore, it is proposed that physical activity participation could explain the positive association seen with muscular fitness and motor skills.[119]

In 2010, Lubans et al found 9 studies in their systematic review of the literature that examined potential associations between motor skill performance and body composition in children and adolescents.[106] Of the 9 studies, 6 of them found inverse relationships between the motor skills and body mass index suggesting that children with lower BMI also showed improved motor skill performance. However, the remaining 3 studies found no relationship between body composition and motor skill performance.[106]

In a more recent systematic review published in 2016, Cattuzzo et al found 33 studies examining the association between motor competence and body composition in healthy children and adolescents.[119] In 27 of the 33 studies, a negative association between the 2 constructs was supported. This led them to conclude that there was strong evidence of an inverse a link between motor skills and body weight with poor motor skill performance accompanied by unhealthy body composition as well as enhanced motor skill performance with optimal body composition. Three reasons were discussed to explain this relationship. First, increased levels of fat mass may increase the difficulty of completing motor tasks like jumping or hopping that require the entire body mass to be projected. Second, higher levels of body fat may cause less efficient movement patterns that can increase the difficulty performing motor skills that involve high velocity object projection like throwing a ball. Finally, because motor skill performance is improved by physical activity participation and children with poor body composition often have less participation in physical activity, overweight and obese children are less likely to have opportunities to develop their motor skills.[119]

In summary, cardiorespiratory fitness, muscular fitness, body composition, and motor skill proficiency have all been shown to be related to important markers of childhood health in the literature. Cardiorespiratory fitness has been linked to insulin resistance, cardiovascular and cardiometabolic disease, lifelong physical activity, cognition, and academic performance. Muscular fitness has also been shown to be related to bone health, self-esteem, and cardiovascular and cardiometabolic disease. Body composition has likewise been linked to insulin resistance, cardiovascular and cardiometabolic disease, cognition, and academic performance. Finally, motor skill proficiency has been shown to be related to physical activity levels, cardiorespiratory fitness, risk of injury, future levels of physical activity as adolescents, and academic achievement. In addition to these associations, it has been shown that the four constructs are also interrelated. In conclusion, cardiorespiratory fitness, muscular fitness, body composition, and motor skill proficiency all warrant examination in the elementary school population to assess overall childhood health.

INSTRUMENTATION

Regardless of the outcome measure being tested, the reliability and validity of the collected data rely heavily upon the instrument being used. While other factors can contribute to reliable results including standardized testing procedure and rater experience and training, instrument selection is key to conducting sound research.

Careful attention must be paid to the development and testing, reliability and validity, and appropriate use of each tool being used to collect data. Otherwise, vast amounts of time and resources can be devoted to collecting data of little scientific value. Accordingly, each instrument being used to assess cardiorespiratory fitness, muscular fitness, body composition, and motor skill proficiency among elementary aged homeschool children will be investigated in the literature.

Cardiorespiratory Fitness

To assess cardiorespiratory fitness, the Progressive Aerobic Capacity Endurance Run or PACER will be used. It has been shown to be both reliable and valid in the literature and allows for testing large amounts of children with minimal equipment. As discussed previously, cardiorespiratory fitness can be assessed in the laboratory or in the field. It is most commonly assessed as VO_{2max}, or the highest rate of oxygen uptake during vigorous exercise. Unless only a small number of children are being assessed and all are able to travel to a laboratory for testing, field tests are a much more practical method of estimating $VO_{2max.}$ The 20-meter shuttle run test is a common field test of cardiorespiratory fitness in youth.[51] It was originally developed by Leger and Lambert in 1982 and revised by Leger in 1988.[21] Known as the Progressive Aerobic Capacity Endurance Run or PACER, the PACER is the recommended test for aerobic capacity within the FitnessGram® battery of youth fitness tests.[21]

The PACER test is a progressive multistage fitness test.[21] It requires children to run back and forth for a distance of 20-meters at progressively faster rates. When compared to the one mile run test, the 20-meter shuttle run test has shown higher reliability values in the literature.[32] Furthermore, the design has several advantages as compared to the 1 mile run test or other common field test of cardiorespiratory fitness in youth.[21] First, the PACER automatically builds in a warm-up for children. By starting at a slower pace and building speed, the child's body and muscles are allowed to adjust to the increase in activity gradually. Additionally, it requires less space and can be completed indoors in most gymnasiums. This makes for a weather independent testing environment that can be climate controlled. There is also a 15-meter test version which requires less space. The completed 15-meter laps can then be converted to 20-meter test equivalents for analysis.[21]

Moreover, the PACER allows almost every child to experience some amount of success during fitness testing. Rather than having to complete an entire mile, students can be successful by completing one or more 20-meter lap(s).[21] The increasing intensity design also encourages students to be more fit without ostracizing the less fit. With the mile run, less fit students are left alone in the field while their peers watch them struggle to complete their test. With the PACER, the less fit are eliminated early while the more fit are left alone in the field to continue their test.[21] Thus, positive experiences with physical fitness testing are more likely to occur with the PACER than the mile run. This is especially important among less fit children who are in greatest need of positive associations with fitness assessment.

The object of the PACER is to complete as many 20-meter distances, or laps, as possible.[21] It requires very little equipment: a 20-meter nonslip surface, a CD player or electronic device and speaker, a measuring tape, marker cones, tape and/or chalk, and score sheets. The 20-meter distance is measured off and marked with cones, tape, or chalk. If needed, 40-60 inch running lanes can also be marked. The PACER test comes with a CD which plays the preset running cadence. Students are allowed to listen to the cadence for several minutes before testing as well as to complete at least 2 practice sessions. Students are notified by a beep when they should have reached the line for each 20-meter lap. Each level lasts 1 minute with 9 seconds to run 20-meters on the first level. As each level progresses, the PACER decreases the time allowed to run the 20-meter distance by approximately 0.5 seconds. A triple beep sequence signals the end of each level and an increase in pace. If a child fails to reach the line before the beep, he or she turns around in his or her current location and continues to test. When a child fails to reach the line twice, either consecutive or non-consecutive laps, testing is completed. The test score is calculated by determining the number of completed laps including the lap of the first missed distance. Students are encouraged to move to a designated cool-down area after testing.[21]

The number of completed laps is then inserted into an equation to estimate VO_{2max}.[51] A number of different equations have been developed and evaluated to estimate VO_{2max} from the PACER and 20-meter shuttle run test. The original equation was developed by Leger et al from 188 children aged 8-19 years.[120] Estimated VO_{2max} (VO_{2max}') was calculated as follows:

$$VO_{2max}' = 31.025 + (3.238 \text{ x speed in km/h}) - (3.248 \text{ x age}) + (0.1536 \text{ x speed x age})$$

where age was in years and speed was the maximum speed achieved during the PACER. This equation was shown to be less accurate than one later developed for FitnessGram® by Mahar et al from 135 children aged 12-14 years where:

$$VO_{2max}' = 50.945 + (0.126 \text{ x PACER laps}) + (4.946 \text{ x gender}) - (0.655 \text{ x BMI})$$

and gender = 1 for boys and 0 for girls. As shown, this updated equation used PACER laps instead of speed and accounted for the effect of gender and BMI. These equations were again revisited along with cross-validated regression model equations developed from 244 children ages 10-16 by Mahar et al in 2011.[120] Resulting VO_{2max} estimates from all equations were then compared to criterion-referenced VO_{2max} values obtained from laboratory graded exercise treadmill tests. Results of this study led to yet another updated equation adopted by FitnessGram® where:

$$VO_{2max}' = 41.76799 + (0.49261 \text{ x PACER}) - (0.00290 \text{ x PACER}^2) - (0.61613 \text{ x BMI}) + (0.34787 \text{ x gender x age})$$

and PACER was equal to the number of completed PACER laps. This equation was developed in an attempt to improve accuracy by accounting for known confounding variables including age, gender, and BMI.[120] In their sample, this equation performed the best with a correlation of $r = 0.75$ and $SEE = 6.17$ mL/kg/min between estimated and directly measured VO_{2max}.[120]

In 2009, FitnessGram® released Version 9.0 which again updated the way in which VO_{2max} was calculated from the PACER.[24] In an effort to create one estimated VO_{2max} value from either test of aerobic capacity offered by FitnessGram® (PACER and one mile run test), PACER laps were equated to mile run times by Zhu et al.[121] These mile run equivalencies were then inserted into the accepted formula for VO_{2max} estimation using mile run times:

$$VO_{2max}' = (0.21 \text{ x } (\text{age x gender})) - (0.84 \text{ x BMI}) - (8.41 \text{ x mile time}) + (0.34 \text{ x mile time x mile time}) + (108.94)$$

where age was age in years and gender = 1 for boys and 0 for girls.[24,122] The VO_{2max} estimates from the PACER mile run equivalencies were found to be highly associated with VO_{2max} estimates from the mile run ($r = 0.79$, $p < 0.001$) and allowed for comparison between the two FitnessGram® aerobic capacity tests.[121] Accordingly, this new formula utilizing mile run PACER equivalencies was adopted by FitnessGram® Version 9.0.[24] This FitnessGram® equation was also shown to predict peak VO_2 in 8-10 year old children better than other popular equations including the original by Leger.[123]

In 2013, FitnessGram® once again updated their program with Version 10.0.[24] Along with the new version, they adopted new PACER algorithms that retained age and gender but did not require the use of height/weight. The choice to eliminate BMI from the calculation was based upon research cited by The Cooper Institute that claimed while BMI affected VO_{2max} estimated from mile run times, it did not affect PACER estimated VO_{2max}. They also stated that the new formula offered “reasonable predictive utility while also facilitating use in school based programs.”[24] This statement is supported in the literature as some schools do not allow for measurement of height and weight for their students. Moreover, the correlation between measured and estimated VO_{2max} using the updated formula eliminating BMI were reported with an r value of $r = 0.70$.[124] The formula is proprietary to Human Kinetics and The Cooper Institute but a spreadsheet using the updated formula is available for use from the California Department of Education.[125] Due to the eliminated BMI variable, the new VO_{2max} equation requires the same number of PACER laps to be completed by children of any size if they are the same age and gender and eliminates the body composition bias.

In addition to the equations used to estimate VO_{2max} by FitnessGram®, numerous other equations exist.[120,123] Because of this, the reliability and validity of the PACER or 20-meter shuttle run test becomes more complicated. However, the reliability and validity of the PACER have been continuously assessed, updated, and published.[24] Intrarater reliability for the PACER in children and adolescents has been reported at 0.89 while interrater reliability ranges from $r = 0.64 – 0.93$ in the FitnessGram® reference guide.[24] In the literature, the PACER has been shown reliable with correlation values ranging from 0.78-0.93 in youth ages 8-18.[29-33] When studied for criterion validity within the last 10 years, validity coefficients ranged from 0.65 – 0.76 with *SEE* ranging from 5.3 – 6.4 mL/kg/min according to FitnessGram®.[24] In the literature, correlation coefficients between directly measured VO2max and the PACER range from 0.62-0.83.[29,33-36]

In 2015, Mayorga-Vega et al published a meta-analysis examining the criterion-related validity of the 20-meter shuttle run test.[126] This study included comparison of field and laboratory measurements of cardiorespiratory fitness in both adults and children. Overall, they found an overall weighted mean correlation of $r_p = 0.78$ (95% CI: 0.72 – 0.85) between laboratory and field measurements using the PACER among children. They also noted that improved correlation resulted when other variables were included in the value calculation such as age, gender, and BMI. This led them to conclude that the 20-meter shuttle run is a useful alternative to laboratory tests, especially when other confounding variables are included.[126]

More specifically, Scott et al compared the PACER to a laboratory graded exercise test using 45 children ages 10-15.[127] Published when the PACER mile run equivalency equation was in use, they examined whether or not the PACER was able to elicit the same peak exercise response in children as the laboratory test. After examining the Bland-Altman plots and data analysis, they found no significant differences between the PACER and the graded exercise test in their abilities to elicit peak VO_2, heart rate, respiratory exchange ratio, or rate of perceived exertion. In other words, the PACER test was able to elicit a similar physiological response to exercise as the laboratory measure and further advocates its use as an alternative test. [127]

As the PACER has been shown to yield both reliable and valid measures of cardiorespiratory fitness, it is a useful test to assess health-related physical fitness in children. The PACER establishes an estimated VO_{2max} value which has been correlated to health risk in the literature. FitnessGram® has created criterion-referenced standards based on scientific evidence defining minimal scores required to minimize disease risk and maximize function.[24] In 2013, these cut-off scores resulted in children being placed in 1 of 3 health categories based upon their estimated VO_{2max}: Healthy Fitness Zone, Needs Improvement, or Needs Improvement-Health Risk. Currently, the FitnessGram® test battery is required in all Texas public schools to monitor the health of their students and aggregate data is publicly available.[27] However, it is important when placing children into these health categories by estimated VO_{2max} values that the equation being used is appropriate for the most current classifications.

To negate the issue of VO_{2max} estimation equations, cardiorespiratory fitness can also be compared between children using only the number of laps completed. Similar cut-off scores to the FitnessGram® classifications have been established by Boddy et al in a ROC estimating cardiometabolic risk in 9-13 year olds.[60] Using only the number of laps completed, 33 shuttles for boys and 25 shuttles for girls was shown to significantly decrease health risk ($p < 0.001$).[60] Regardless of the classification system being used, it is important that the 20-meter shuttle run test is used appropriately. There is valid concern about the ability of younger children to appropriately pace themselves throughout the test in order to obtain accurate results.[24] This explains the lack of criterion-referenced standards in children younger than age 9. Moreover, it is designed to be completed by typically developing children without disabilities.[24] Accordingly, the test is not appropriate for use in these populations until otherwise validated. All in all, the literature supports use of the PACER as a reliable and valid field test of cardiorespiratory fitness in typically developing children aged 9 years and above.

Muscular Fitness

To measure muscular fitness, the 90° push-up test was used to assess the upper body, the curl-up test was used to assess the core, and the standing long jump test was used to assess the lower body. These tests have been shown to be reliable and valid and allow for field testing of large samples with minimal equipment or training. Muscular fitness tests can be used to assess the health and function of the musculoskeletal system. Upper body and abdominal muscles are important for functional activities and posture while lower body muscles are important for locomotion. Accordingly, different tests are used to assess the fitness of different muscle groups. The FitnessGram® 90° push-up test was used to assess upper body muscular fitness, the FitnessGram® curl-up test was used to assess abdominal muscular fitness, and the standing long jump test was used to assess lower body muscular fitness. Each test was discussed separately and examined for reliability and validity in the literature.

The FitnessGram® 90° push-up test is a test of upper body strength and endurance.[21] It requires children to assume the standard prone push-up position with hands directly under or slightly wider than shoulder width, fingers outstretched, legs straight and feet slightly apart with the toes extended. The straight line created by the head, back, legs, and heels should be maintained throughout the test. Beginning with elbows extended, the child lowers the chest toward the floor by bending the elbow to 90° of flexion and then raises the chest back up to the elbows extended position. This counts as 1 repetition. Children continue to perform 1 repetition approximately every 3 seconds (20 push-ups per minute) until they experience 2 consecutive or non-consecutive breaks in form. Form breaks include failure to achieve 90° of elbow flexion or full elbow extension as well as failure to maintain a straight back or the correct cadence speed. The first form break is included in the score, which consists of the number of repetitions performed. The object is to complete as many repetitions as possible while maintaining correct cadence and form. The same test is used for both boys and girls and no modifications are made for gender.[21]

While pull-ups and the flexed arm hang are also common field tests of upper body muscular fitness, the FitnessGram® 90° push-up test requires no equipment and allows for a greater chance of a successful student experience.[21] For this reason, the 90° push-up test is the recommended test of upper body strength and endurance for the FitnessGram® test battery.[21] In addition to the convenience of requiring no equipment, studies have found 95% of girls and boys over 8 years of age can successfully complete at least 1 repetition.[24] This allows students to have a positive experience with fitness testing and gives them a realistic chance for success. Moreover, 90° push-up scores seem to improve more with physical training than chin-ups, pull-ups, or the flexed arm hang, making them more responsive to change.[24] This can become an important motivating factor and encourage students to keep working toward muscular fitness.

In general, intraclass reliability coefficients for the 90° push-up test range from 0.64 – 0.99 in children grades 3-6.[24] Reliability is improved by having adults score the test rather than students who consistently overscore other students. This could be due in part to their inability to consistently assess a 90° angle at the elbow.[24] Face validity of the 90° push-up test is straightforward. However, criterion validity remains largely unexplored in children and adolescents and is affected by body mass.[21] The primary study examining reliability and validity of the 90° push-up test was published by Baumgartner et al in 2002 as a series of 4 separate but related studies using college aged males and females.[37] Intertester reliability coefficients of 0.75 and 0.88 were calculated for women and men respectively. Test-retest reliability for women was 0.95 – 0.97 and 0.98 – 0.99 for men. For criterion validity, the 90° push-up test was compared to the number of bench press repetitions at 70% body weight for men and 40% body weight for women. This resulted in validity correlation coefficients of 0.80 for women and 0.87 for men.[37]

Among adolescents, a single study exists involving the 90° push-up test as part of a fitness test battery using 63 adolescents aged 13-15.[128] A rank order repeatability intraclass correlation coefficient value was calculated at 0.73 (95% CI: 0.54 – 0.84). However, no other analysis was conducted.[128] Among children, test-retest reliability was calculated among 62 children aged 10-12 years old by Saint Romain and Mahar in

2001.[129] Overall, they found a test-retest proportion of agreement between two trials of 0.97 and concluded that the test had acceptable test-retest reliability in this population. [129] In short, the reliability and validity of the 90° push-up test has been reported in a study involving college aged men and women. However, more research is needed to support use of this test or suggest a more appropriate measure among children and adolescents. For now, it remains a widely accepted test of upper body muscular fitness in youth.[21] Due to lack of sufficient research on criterion referenced standards for muscular fitness in children, criterion reference standards for the 90° push-up test exist as part of the FitnessGram® test battery based solely upon expert opinion after analyzing the National Children and Youth Fitness Study I and II data as well as the Canadian National Norms.[24]

Apart from upper body muscular fitness, core muscular fitness including abdominal strength and endurance also contributes to overall function, posture, and low back health in youth.[21] The curl-up test is the recommended test of abdominal strength and endurance for the FitnessGram® test battery. To complete the curl-up test, the student lies supine on a mat with both knees flexed to approximately 140°, feet slightly apart and flat on the floor, and arms extended at the sides along the trunk. Feet should be placed as far from the buttocks as possible while still remaining on the floor to decrease the difficulty of the movement. With the trunk resting on the ground and shoulders relaxed, a flat measuring strip (3 inches wide for 5-9 year olds and 4.5 inches wide for ages 10 and up) is placed under the student's knees so that his or her fingertips barely touch the top edge. The student then curls up the trunk while sliding the fingers along the measuring strip and keeping the heels on the ground until the furthest edge is reached. The trunk and head are lowered back to the mat and fingers back to the nearest edge of the measuring strip to complete one repetition. Repetitions continue at a cadence of 20 repetitions/minute (1 repetition approximately every 3 seconds) until form is broken for the second consecutive or non-consecutive time. Form breaks occur when the heels leave the mat, the head does not return to the mat, fingertips do not reach the farthest edge of the measuring strip, or the cadence is not maintained. As with the 90° push-up test, the first broken form counts as a successful repetition. Repetitions continue until the second form break with the goal of completing as many repetitions as possible with correct form.[21]

The test position for the curl-up test is based upon electromyography (EMG) studies examining abdominal muscle activity.[24] EMG research showed that a finger excursion of about 4 inches along the sides of the trunk paired with bent knees and unsecured feet resulted in maximal contraction of the rectus abdominis muscle and lower abdominal stabilizers. Additional EMG studies have shown that the abdominal musculature is only responsible for the initial 30-45° of trunk flexion while the hip flexors are primarily responsible for the remainder of the sit-up motion.[24] This evidence supports the use of a curl-up test rather than a sit-up test.

Interrater reliability coefficients for the curl-up test with knees bent and feet unsecured range from 0.62 – 0.91 among elementary school children.[24] Test-retest reliability coefficients range from 0.70 – 0.89 in the same age group.[24] In a separate study examining child and teacher reported FitnessGram® curl-up scores among 10-12 year old children, Patterson et al found teacher rated test-retest reliability (ICC) to be 0.89 (95% CI = 0.78 – 0.94) for males and 0.86 (95% CI = 0.74 – 0.92) for females.[38] Moreover, child rated scores were significantly higher than teacher rated scores implying that children may not be accurate raters for this test.[38] Even more so than the 90° push-up test, evidence of criterion validity among children and adolescents for the curl-up test is scarce.[24]

Use of the curl-up test as a measure of abdominal muscle strength and endurance is based largely upon face validity and EMG studies.[24] However, there is a dearth of accepted criterion tests for abdominal endurance to which the curl-up test can be compared. This further complicates the ability to establish criterion validity of the curl-up test. As with the 90° push-up test, the curl-up test is a popular and widely accepted test of muscular fitness that lacks sufficient reliability and validity evidence in youth. Once again, criterion reference standards for the curl-up test exist as part of the FitnessGram® test battery based solely upon expert opinion after analyzing the National Children and Youth Fitness Study I and II data as well as the Canadian National Norms.[24]

To assess lower body muscular strength and power, the standing long jump test or standing broad jump test is often used in children. Unlike the 90° push-up and curl-up tests, the standing long jump is not part of the FitnessGram® test battery, which contains no test of lower extremity muscular fitness. Notably, the standing long jump test requires minimal equipment and is very time efficient.[130] To complete the standing long jump, children stand behind a starting line with feet together before pushing off and jumping forward as far as possible. The distance is measured from the starting line to the back of the lagging heel. The test is usually repeated twice and the highest score retained.[130] It is a common test of lower extremity explosive strength and is used in multiple fitness testing batteries.[131,132]

In a 2010 study using 94 children aged 6-17 years, Castro-Pinero et al studied the ability of the standing long jump to serve as a single general measure of muscular fitness in youth after controlling for sex, age, and BMI.[130] When compared to other tests of lower body muscle strength and power tests, the standing long jump showed strong associations with R^2 values ranging from 0.829 – 0.864. Moreover, when compared to muscle strength tests for the upper body, it also showed strong associations with R^2 values of 0.694 – 0.851. This led them to conclude that the standing long jump test could stand alone as a general assessment for both upper and lower body muscular fitness in children.[130] Having a single test to assess whole body muscular fitness saves both time and resources, which becomes increasingly important when testing large numbers of children.

The reliability and validity of the standing long jump has been evaluated in several studies. In 2015, Fernandez-Santos et al evaluated the standing long jump test using 363 healthy children aged 6-12 years.[39] They found it to have a test-retest ICC value of 0.94 (95% CI = 0.93 – 0.95), no significant differences between trials, and a systematic error of nearly 0. Moreover, it had the strongest association with the criterion standard of the 1 repetition maximum leg extension test whether corrected for body weight ($r = 0.79$; $p < 0.01$) or uncorrected ($r = 0.40$; $p < 0.01$) as compared to the other tests of lower body muscle tests (squat jump, countermovement jump, and Abalakov jump test). Thus, they were able to conclude that while all lower body tests they evaluated were both reliable and valid, the standing long jump is the most valid when compared to the 1 repetition maximum test.[39] Milliken et al also found the standing long jump test to be a valid means of assessing lower extremity muscular fitness in 90 children aged 6-12 years as it explained 44.4% of the variance in 1 repetition maximum leg press strength when also considering BMI.[133] This finding was true regardless of child age or gender.[133]

The standing long jump test has also been shown to have no systematic bias or difference between the sexes among children and adolescents.[131,134,135] Additionally, it has been used as a standard of muscular power to which new test batteries are compared.[128] Important for testing in large groups of school-aged children, the standing long jump test was also found to be feasible and safe to be performed in school settings.[135] Finally, normative data has been established for the standing long jump from 12,618 children aged 6-18 years old.[136] Although normative data are not available on American children, this European sample is the closest available match and allows for an acceptable frame of reference. Thus, the standing long jump has been shown to be a reliable, valid, and useful test of muscular fitness in youth in the literature.

Body Composition

For the purposes of this research, body mass index, waist circumference, waist to height ratio, and bioelectrical impedance analysis will be the main focus. These techniques are commonly used in the literature, allow for rapid assessment in large samples of children, and require minimal equipment or formal training. Body composition assessment in children has received much attention in the literature recently secondary to growing concern about childhood obesity. Accordingly, there are many laboratory and field techniques available to measure pediatric body composition. While body mass index, waist circumference, waist to height ratio, and bioelectrical impedance analysis are complimentary, each of these tests also stands alone by offering unique correlations to different constructs in the literature.

Body mass index is a calculation based upon weight and height reported as kilograms per square meter.[137] BMI varies by age and gender in children and should be measured in centiles or z scores to account for this variation. The World Health Organization definitions are used worldwide and define ideal pediatric BMI as < 1 z score for age and gender, at risk for overweight as 1 z score above the mean, overweight as 2 z scores above the mean, and obese as 3 z scores above the mean. However, it is important to remember that BMI is only a simple ratio of weight-for-height and does not directly measure body composition. Mass from muscle or bones is not taken into account with BMI. Accordingly, it is recommended that BMI be used in conjunction with supplemental measures of body fat assessment like bioelectrical impedance analysis.[137]

In a recent systematic review of the literature, BMI was shown to be a very popular method of assessing body composition in 7-10 year old children with 78% of the included studies reporting BMI.[138] Body mass index was also shown to have strong correlations with body fat as assessed by skinfolds and bioelectrical impedance analysis and moderate to weak correlations with assessments of body fat by dual energy x-ray absorptiometry, air displacement plethysmography, or isotope dilution.[138] Additionally, Javed et al recently conducted a systematic review and meta-analysis of BMI and its ability to diagnose obesity in children up to age 18 years.[139] In all, 37 articles were included in the meta-analysis from 53,521 children aged 4-18 years. Pooled sensitivity was calculated at 0.73 (95% CI = 0.67 – 0.79) and pooled specificity at 0.93 (95% CI = 0.88 - 0.96). It was also noted that BMI failed to identify over 25% of children with obesity giving it limited diagnostic ability.[139]

Waist circumference is also commonly used to estimate central adiposity in youth as a supplemental measure of body composition.[137] Particularly, waist circumference may be a more useful indicator of the effect of physical activity and exercise on body composition change. Weight and BMI may remain the same after exercise programs due to increases in muscle mass. However, waist circumference will often decrease due to a decrease in central obesity. Waist circumference may be measured at the level of the umbilicus or midway between the iliac crest and lower ribs. The measuring tape must be kept level and parallel to the floor and measurement is taken after normal exhalation.[137,140] Waist circumference is known to vary by age, gender, and height in children, and centile charts are recommended for appropriate assessment.[137]

In Jensen's recent systematic review, waist circumference was shown to perform similarly to BMI, showing strong correlations with body fat as assessed by skinfolds and bioelectrical impedance analysis and moderate to weak correlations with assessments of body fat by dual energy x-ray absorptiometry, air displacement plethysmography, or isotope dilution.[138] In 2011, Stomfai et al studied waist circumference reliability in 5 European countries on 125 children aged 2-5 years and 164 children aged 6-9 years.[141] Overall, they found intrarater technical error of measurement to be 0.41 cm – 0.79 cm and inter-observer technical error of measurement to be 0.50 cm – 0.62 cm. Moreover, interrater agreement was calculated as R as a percentage at 88%. In short, they found waist circumference to have acceptable intra- and interrater reliability among children.[141]

When considering the use of waist circumference to assess body composition in children, a measurement site must be chosen. It can be assessed at the level of the umbilicus but as the location of this landmark can vary in obese children, it is commonly assessed using bony landmarks and measured midway between the iliac crest and lower ribs.[137] However, it has also been measured at the level of the superior border of the iliac crest and at the minimal waist.[140] While differences in measurement site can lead to differences in body composition classification, there seems to be no difference in measurement site and its relationship to abdominal fat or cardiometabolic risk factors. Moreover, all 4 sites have been shown to be highly correlated with each other (r = 0.97 –

0.99).[140] In other words, it is important to standardize test position for appropriate body composition classification but the relationship between waist circumference and central adipose tissue or cardiometabolic risk does not seem to vary by location.

In 2013, Bogornia et al examined body mass index and waist circumference and his or her relationship to total body fat mass and trunk fat mass as measured by dual energy x-ray absorptiometry in a sample of 6,495 children aged 9 years and 6,567 children aged 11 years.[142] Body mass index and waist circumference were both shown to have strong significant ($p < 0.0001$) relationships with both total body fat mass ($r > 0.80$) and percent body fat ($r > 0.80$). Moreover, body mass index and waist circumference were also highly correlated with each other in this age group ($r = 0.91$-0.92; $p < 0.0001$). BMI was able to explain 67% of the variance in total body fat among normal weight boys and 71% of the variance in overweight boys. For girls, BMI explained 73% of the variance in total body fat among normal weight girls and 73-75% of the variance in overweight girls. Overall, this study shows BMI and waist circumference to be strongly associated with measures of central and total adiposity in 9 and 11 year old children.[142]

To remove the effect of age, gender, and height on waist circumference, a waist circumference to height ratio has been proposed.[137] This results in a simple proportion of central circumference to height. In a recent systematic review, waist circumference to height ratios were reported to be a better measure for predicting risk of cardiovascular disease in children than BMI and capable of identifying children with increased metabolic disease risk.[137] This ratio has also been shown to have a moderate correlation with assessments of body fat as measured by air displacement plethysmography and skinfolds in a separate systematic review involving 7-10 year old children.[138]

Recently, Brambilla et al compared the waist to height ratio to simple waist circumference and body mass index and examined their ability to predict adiposity in 2,339 children aged 8-18 years.[143] They found that waist to height ratio was able to explain 64% of the variance in percent body fat as measured by dual energy x-ray absorptiometry compared to only 31% explained by waist circumference alone or 32% by BMI. The addition of child age and gender into the analysis resulted in waist to height ratio explaining 80% of the variance as compared to 72% explained by waist circumference alone or 68% by BMI. Notably, the addition of ethnicity did not enhance predictive ability. Thus, they concluded that the waist to height ratio was a better predictor of pediatric adiposity than waist circumference alone or body mass index.[143]

Values at or above 0.5 for the waist to height ratio have been proposed to predict central adiposity.[137,144] This would imply that children should strive to keep their waist circumference to less than half their height.[144] This cut-off of ≥ 0.5 has been reported to have a sensitivity of 99% and specificity of 72% for identifying central obesity.[40] With regards to identifying a BMI ≥ 85th percentile in children aged 2-18 years, waist to height ratio is reported to have a sensitivity of 83% and specificity of 77%.[40] However, while the universal cut-off of 0.5 originally proposed by McCarthy and Ashwell is convenient,[144] some researchers are pushing for age- and gender-specific ratios among children.[145]

Bioelectrical impedance analysis is another field measure of body composition that can be used in children. Using an imperceptible electrical current, the resistance to flow through the body is calculated.[137] The resulting drop in voltage from tissue impedance is then used in device-specific formulas to estimate percent body fat. However, it should be noted that impedance can be increased by resistance to current flow from bone and body fat or decreased by enhanced conductivity of lean body mass. Lean body mass contains high levels of fluid and electrolytes which improve current flow. Accordingly, bioelectrical impedance analysis accuracy is dependent upon hydration status of the subject. In addition to hydration status, accuracy of bioelectrical impedance analysis devices is highly dependent on the accuracy of the prediction equation, appropriateness of the electrode size and uniform placement for the test population, and fasting and hydration status of the subject. Thus, recommended standardization of test technique includes having subjects fast appropriately and empty their bladders before measurement. Bioelectrical impedance analysis can be measured hand-to-foot or foot-to-foot. Foot-to-foot devices have been shown to classify groups of children as overweight or obese but hand-to-foot devices have been shown more useful to individually assess overweight or obese children.[137]

In 2013, Talma et al performed a systematic review of the literature on the use of bioelectrical impedance analysis in children and adolescents.[146] In general they found bioelectrical impedance analysis to be a practical means of assessing percent body fat in children and adolescents after reviewing 50 articles in the literature. This conclusion is based upon good reliability with intraclass coefficients ≥ 0.82. However, criterion validity and measurement error were both found to be unsatisfactory.[146] As noted before, the predictive ability of bioelectrical impedance analysis is device specific due to electrode size and placement as well as the equation being used. Accordingly, the device selected must be appropriate for the test population.

The Tanita BF-689 (Tanita Corporation, Tokyo, Japan) is a bioelectrical impedance analysis scale designed exclusively for use with the pediatric population.[43] It has been investigated for both reliability and validity in children aged 5-11 years and found to be both reliable and valid in this population. Specifically, intraclass correlation coefficients were found to be 0.999 (95% CI = 0.999 - 0.999) for test-retest reliability and 0.788 (95% CI = -0.167 – 0.942) for absolute agreement with dual energy x-ray absorptiometry criterion validity. Moreover, sensitivity for obese classification was found to be 0.43 while specificity was 1.0. This shows that children classified as obese by the BF-689 were truly obese 100% of the time. More importantly, the device showed no gender or proportional bias, indicating that it was equally useful in both girls and boys of all body composition classifications.[43] In short, while the accuracy of bioelectrical impedance analysis in youth varies widely by device, the Tanita BF-689 provides reliable and valid measurements of percent body fat in the elementary school population.

In conclusion, body mass index, waist circumference, waist to height ratio, and bioelectrical impedance analysis are all common field tests of body composition used in the pediatric population. They have all been studied in the literature and have their own strengths and limitations. Ideally, they can be used in conjunction to form a more complete and accurate picture of a child's body composition.

Motor Skill Proficiency

Motor skill proficiency was evaluated using the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition – Short Form (BOT-2 SF). The BOT-2 SF offers an overall perspective of a child's motor skill development and is a reliable and valid method of screening large samples of children in a minimal amount of time. Moreover, it is widely used and recognized by rehabilitation professionals. The complete Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2) is an individual assessment of both fine and gross motor skills designed for 4-21 year olds.[147] It is intended to be administered without formal training by physical therapists, occupational therapists, researchers, and others who might have need to screen for or diagnose children with motor impairments. The BOT-2 exists in both a Complete Form and a Short Form and is a 2005 revision of the original Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) published in 1978. This revision occurred as a result of input from focus groups of regular users of the BOTMP, product surveys, and a review of the available literature on the original tool. The BOT-2 was created to make the BOTMP's content more functionally relevant, expand coverage of motor skills, improve assessment in 4 and 5 year old children, expand the available normative data age range, and allow for more individualized instruction for each item.[147]

The sample used to create the normative data for the BOT-2 included 1,520 American children ages 4-21 using stratified random sampling for gender, ethnicity, socioeconomic status, and disability.[147] Final sample demographics were targeted to match census and Department of Education report demographics and resulted in a nationwide group of white (60.2%), Hispanic (18.4%), African American (15.1%), and "other" (6.3%) ethnicities. Maternal education level was also distributed throughout the sample except for Hispanic mothers who had a lower education level compared to the sample as a whole. Special education status was present in 168 of the children and separate data are available for children with developmental coordination disorder, mild to moderate mental retardation, and high-functioning autism/Asperger's disorder.[147]

Four motor area composites comprise the BOT-2: fine manual control, manual coordination, body coordination, and strength and agility.[147] Fine manual control assesses motor skills involved in coordinating and controlling the distal hand and finger muscles. Manual coordination assesses motor skills needed for object manipulation like coordinating and controlling the arms and hands. Body coordination assesses motor skills that control and coordinate large muscle groups needed for posture and balance. Finally, strength and agility components assess coordination and fitness motor skills necessary for physical activity as well as recreational and competitive sports.[147]

Each motor composite is then divided into 2 subtest areas.[147] Fine manual control is divided into fine motor precision and fine motor integration. Manual coordination becomes manual dexterity and upper limb coordination. Body coordination is divided into bilateral coordination and balance while strength and agility becomes running speed and agility and strength. These subtests are made up of 53 separate items on the Complete Form and 14 on the Short Form.[147] Short Form items include drawing lines through paths-crooked and folding paper (fine motor precision), copying a square and star (fine motor integration), transferring pennies (manual dexterity), jumping in place-same sides synchronized and tapping feet and fingers-same side synchronized (bilateral coordination), walking forward on a line and standing on one leg on a balance beam-eyes open (balance), one-legged stationary hop (running speed and agility), dropping and catching a ball-both hands and dribbling a ball-alternating hands (upper limb coordination) and knee or full push-ups and sit-ups (strength).[20]

Administering the Short Form takes 15-20 minutes compared with 45-60 minutes for the Complete Form.[147] An additional 5 minutes should be allotted for preparation and up to 20 minutes for scoring due to multiple steps and tables required to score the BOT-2.[147] Scoring the Short Form varies by item with raw scores assigned for meeting specific criteria (copy a square) or number of repetitions completed (sit-ups).[20] Multiple trials are allowed on several items and points assigned based upon the best performance. Item raw scores are summed to make a total point score. In turn, this total point score can be converted using various tables into an age and gender specific standard score with accompanying 90% and 95% confidence intervals, z-score, percentile rank, and a descriptive category. Descriptive categories range from “well-below average” to “well-above average” motor skill proficiency.[20]

Notably, several of the items have a known ceiling effect in older children and the greatest gains in the majority of the motor skills tested are shown between the ages of 4 and 8 years old.[20] A floor effect for children under 6 years of age where younger children could not complete the skill on the Short Form has also been reported.[48] Additionally, caution should be used when using the BOT-2 SF to determine eligibility for special education or therapy services.[147] Because the test is scored as a total point score, weaknesses in one motor composite might be masked by strengths in another area. Thus, the BOT-2 SF is appropriate to screen children with suspected global motor delays but further testing might be needed to identify specific areas of weakness. In other words, a child with poor gross motor skills but strong fine motor skills might be missed for services if his or her total BOT-2 SF score is still in an acceptable range. When determining eligibility for services, the Complete Form and resulting 4 motor composite scores are more appropriate.[147]

Reliability of the BOT-2 Short Form has been reported in several articles. For test-retest reliability with a test interval of 7-42 days, the BOT-2 SF had r values ≥ 0.80.[44] The inter-rater reliability coefficient for the Short Form with knee push-ups was 0.98.[44] Internal consistency values were ≥ 0.80 for all ages but slightly lower in 4 to 8 year olds.[147] Lucas et al also examined the reliability of the BOT-2 SF in 30 Australian Aboriginal children aged 7-9 years exposed to alcohol *in utero*.[148] They found interrater reliability ICC values from 0.88 – 0.92 and test-retest ICC values from 0.62 – 0.73.

However, it should be noted that the median test-retest interval was 45 days, which might have led to lower agreement.[148]

In addition to reliability, validity of the BOT-2 SF is also available in the literature. Deitz et al reported that content validity was established by using input from focus groups and regular users, a Rasch analysis, and evidenced by increasing scores as age increased.[147] Content validity was also noted as a correlation coefficient of $r = 0.80$ between the BOT-2 SF and BOT-2 Complete Form.[44] Moreover, a significant relationship was found between the Körper Koördinations Test für Kinder (KTK) motor skills assessment and the BOT-2 SF of $r = 0.61$ ($p < 0.001$) to establish convergent validity.[44] Construct validity was shown by the ability of the BOT-2 SF to discriminate between children with and without diagnosed motor delays by assigning significantly lower ($p \leq 0.001$) scores in those with diagnosed delays.[48]

However, some concern has been raised as to the appropriateness of each item included on the Short Form. In an article published in 2012 using 113 typically developing American children aged 6–10 years, Brahler et al examined how well each individual item correlated to its respective overall subtest score.[48] Of the 4 subtests they examined, 3 of the 4 contained items that did not correlate well with the total subtest score. The exception was found on the strength subtest, where knee push-ups ($r = 0.865$) and sit-ups ($r = 0.572$) both correlated well and contributed to the overall score. For precision, folding paper correlated well ($r = 0.756$) but a ceiling effect was noted for drawing lines through paths-crooked ($r = 0.0$). Likewise, on the balance subtest standing on one leg on a balance beam-eyes open correlated well ($r = 0.713$) while walking forward on a line had a ceiling effect ($r = 0.0$). Finally, both tests on the fine motor integration subtest correlated poorly ($r = 0.264$ for copying a star; $r = 0.232$ for copying a square). These poor associations and ceiling effects indicate that each item included on the Short Form may not be appropriate or contribute substantially to the overall subtest score.[48] Thus, limited conclusions regarding strengths and weaknesses in each subtest area can be drawn from the BOT-2 SF and other assessments should be used to determine qualifications for therapy services.

In summary, the BOT-2 SF has been shown to be a reliable, valid, and clinically useful test of motor skill proficiency in children. Moreover, normative data for typically and non-typically developing American children ages 4 to 21 years old have been established. However, examiners should be cautious when using the BOT-2 SF to determine a child's performance in one particular domain and rather use the total score as a screening tool for children who might warrant closer investigation. Regardless, the BOT-2 remains one of the most frequently used tests of fine and gross motor skills for children grades K-12 by physical and occupational therapists.[48]

NEED FOR CURRENT STUDIES

As shown by the lack of literary evidence regarding health-related and skill-related physical fitness in homeschool students, little is known about this subset of the pediatric population. To date, only 2 studies have been published examining the cardiorespiratory fitness of children educated at home. Unfortunately, each study reached a different conclusion. Thus, more studies are needed to clarify these conflicting conclusions. Additional studies will also add to the scarce body of knowledge currently available regarding the health-related physical fitness of homeschool students.

Although only 2 studies are available examining cardiorespiratory fitness in homeschool students, there are currently no studies examining muscular fitness in this population. Muscular fitness has been shown to have its own associations with bone health and self-esteem, as well as cardiovascular and cardiometabolic disease. As such, future research examining this construct among a neglected pediatric population is more than needed. Moreover, research studies examining muscular fitness in homeschool students will serve to eliminate this current gap in the pediatric physical fitness literature.

Regarding body composition in homeschool students, only 1 study was found in the literature directly addressing this topic. Therefore, more studies are needed to support or refute these initial findings. Additionally, this study only addressed body composition using body mass index and percent body fat. However, the literature has shown other measures of body composition including waist circumference and waist to height ratio to also have predictive ability for childhood disease. Thus, future studies should also employ these measurement techniques to expand the current body of knowledge. Finally, the single available study drew comparisons between public school and homeschool students. While important to note in order to assess any effect of schooling type on body composition, it does not provide any specific conclusions about the health of the homeschool population alone. In other words, future research should also describe the health of the homeschool population itself and how it relates to this population's risk for cardiovascular and cardiometabolic disease. This information is crucial to ensure that any increased risk is highlighted and addressed with proper intervention in order to prevent future health issues. Assessing the cardiovascular and cardiometabolic disease risk of homeschool children will also fill another current gap in the literature.

Lastly, motor skill proficiency in the homeschool population has also been completely neglected in the literature. Since motor skills are linked to lifelong physical activity, they deserve regular assessment during the early elementary school years when the primary gains typically occur. This information is necessary to identify any potential deficits and allow for timely correction in order to prevent any effect on future physical activity levels. In summary, future research in homeschoolers should be directed at clarifying conflicting conclusions regarding cardiorespiratory fitness, making initial investigations into muscular fitness and motor skill proficiency, and supporting or refuting initial findings regarding body composition.

CONCLUSION

As cardiorespiratory fitness, muscular fitness, body composition, and motor skill proficiency have all been shown to have important impacts on childhood health, it is important to regularly screen children for deficits in these areas. Accordingly, public schools routinely assess health-related physical fitness in their students. With a large and expanding population of children being educated outside of the traditional public school system, many children are not being regularly assessed for these key components of physical fitness. Without periodic assessments, homeschool children are at increased risk for developing undiagnosed deficits in these areas which can impact both current and future health.

The Progressive Aerobic Capacity Endurance Run, 90° push-up test, curl-up test, standing long jump, body mass index, waist circumference, waist to height ratio, bioelectrical impedance analysis, and BOT-2 Short Form have all been shown to be reliable and valid field tests for elementary school children. Furthermore, they allow for rapid screening of large amounts of children with minimal training or equipment. In short, the results from these tests are crucial to both expand the current body of available evidence regarding elementary aged homeschool students and accurately assess the health of this expanding and overlooked population.

CHAPTER III

PHYSICAL FITNESS IN HOMESCHOOL CHILDREN

INTRODUCTION

Homeschooling is a growing trend within the United States. Almost 2 million children are currently educated outside of the traditional public school system.[11] While core academic curricular content is often required by the state, homeschool children are not subject to state-regulated physical education classes, physical activity initiatives, or regular fitness testing.[12] Families may choose to enroll their children in structured physical activities like organized sports or homeschool physical education classes but have no requirement to do so. Without mandated time spent in physical activity, the potential for deficits in muscular fitness and cardiorespiratory fitness increases. Without regular fitness testing, the potential for these deficits to go undiagnosed and persist throughout childhood also increases. Muscular fitness and cardiorespiratory fitness are both key aspects of health-related physical fitness in children and deficits in one or both areas can result in numerous health consequences.

In the literature, high levels of muscular fitness have been associated with decreased risk of cardiovascular disease in children independent of body mass and cardiorespiratory fitness.[84,86] Improved muscular fitness has also been correlated with improved bone health, enhanced self-esteem, and decreased adiposity in children.[84,87]

Moreover, high levels of muscular fitness may partially counteract other adverse cardiovascular risk factors in overweight and obese children and adolescents.[84] Thus, the importance of muscular health in children goes far beyond the stereotypical role of enhanced movement, posture, and injury prevention.[21]

As with muscular fitness, high cardiorespiratory fitness levels in elementary school-aged children have also been linked to decreased cardiovascular and cardiometabolic disease risk as well as insulin resistance.[53-61] It has been well documented that children with high levels of cardiorespiratory fitness also demonstrate higher physical activity levels later in life. [73,74] In addition to physical gains, cardiorespiratory fitness improves inhibitory control, allowing children to better regulate their behavior, attention, and emotions as well as improve academic performance.[14-19] As such, cardiorespiratory fitness is an important outcome measure not only to determine a child's physical health but perhaps their mental health as well.

The increasing popularity and unregulated structure of homeschooling creates an unknown and at-risk population in regard to muscular and cardiorespiratory fitness. Little work has been published to date investigating these outcomes among this growing population. Thus, the purpose of this research was to compare muscular fitness and cardiorespiratory fitness between elementary school-aged homeschool and public school children. It was hypothesized that homeschool children would show significantly different fitness levels in both areas from their public school peers.

METHODS

Participants

This cross-sectional study was completed as part of Fitness Assessment in the Homeschooled: The FAITH Study in the spring of 2016. Full Institutional Review Board approval, parental informed consent, and child assent was secured prior to any participant enrollment or data collection. Homeschool families with children ages 8-11 years old who had completed at least 1 year of homeschool were recruited by email, homeschool support groups, co-operatives, and word of mouth. Children were excluded if they were enrolled in any form of homeschooling which required physical education and/or formal fitness testing, including online public school. An *a priori* power analysis for a 2-tailed *t*-test with an alpha level of 0.025, power of 0.90, and medium effect size ($d = .6$) indicated that a total sample size of 142 children (71 per group) would be needed.

To create the public school comparison group, redacted FitnessGram® raw scores were provided as an open record request from a local school district for all children aged 8-11 years old. Elementary school demographics for the district, including ethnic composition and socioeconomic status, were examined to identify the campus most closely aligned with the homeschool sample. Campus data were then sorted into age- and gender-specific groups from which a random number generator was used to select public school students to create age- and gender-matched homeschool and public school pairs.

Procedures

Homeschool children completed all testing during a single test session in local parks or at their home as per parental preference. No follow-up was required. During child testing, parents completed a household demographic survey for each child, including organized sports participation. The curl-up test, 90° push-up test, and Progressive Aerobic Capacity Endurance Run (PACER) portions of the FitnessGram® test battery (version 10.0; Human Kinetics, Champaign, IL) were used to assess abdominal and upper body strength and endurance as well as cardiorespiratory fitness. To mimic public school fitness testing, only children ages 9-11 completed the PACER test. All 3 tests are commonly used in children and have been shown to be both reliable and valid in the literature.[24,30-36] Intraclass reliability coefficients for the 90° push-up test range from 0.64 – 0.99 in children grades 3-6 while interrater reliability coefficients for the curl-up test with knees bent and feet unsecured range from 0.62 – 0.91.[24] The PACER reliability coefficients in the literature for youth range from 0.77-0.93 and validity correlation coefficients with directly measured VO_{2max} range from 0.62-0.83.[29-36]

Height and weight were assessed with the children barefoot and wearing a single layer of light clothing over undergarments. Raw counts of the number of repetitions or laps completed were obtained by trained raters and then used to place participants into age- and gender-specific health risk categories. Participants were classified as healthy or needs improvement for muscular strength and endurance and healthy, needs improvement, or needs improvement-health risk for cardiorespiratory fitness. All raters were trained and followed standardized test procedures as per test administration guidelines to increase result accuracy.[21,24] Public school data were collected as part of usual practice as per state requirements by trained test administrators within the public school system using the same standardized test procedures.

Statistical Analysis

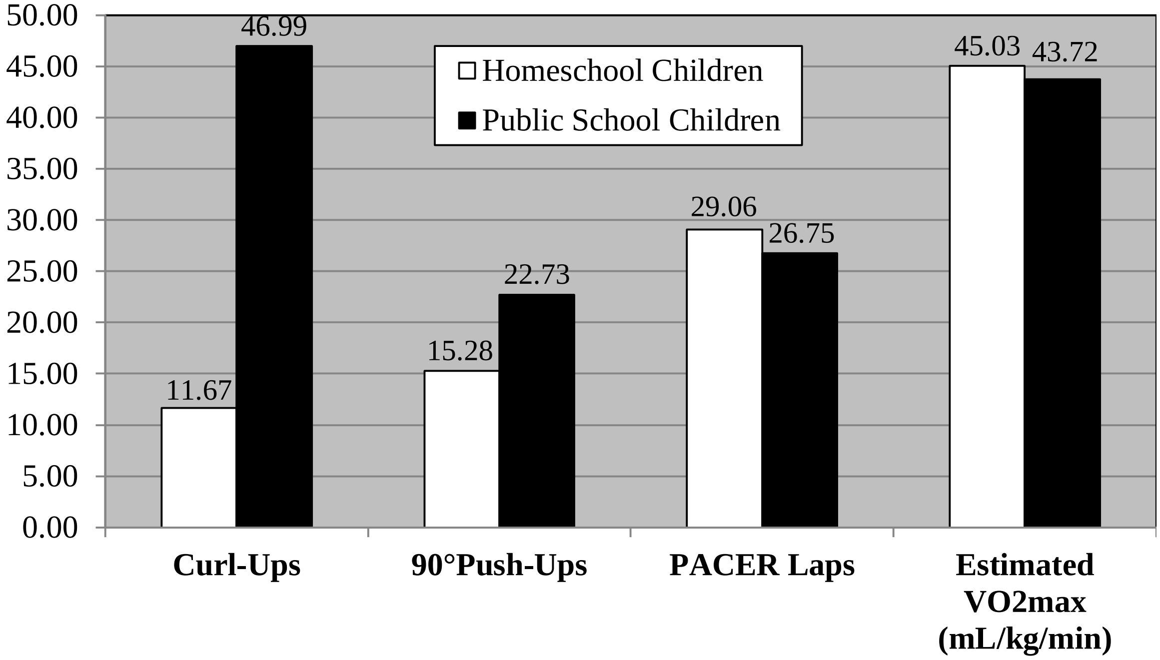
Descriptive statistics for the sample were calculated using means and standard deviations or simple counts and frequencies. Independent *t*-tests were used to analyze differences in the total number of curl-ups, 90° push-ups, and PACER laps between the two groups as well as differences in estimated VO_{2max}. Chi-square tests were used to determine differences in FitnessGram® classification for abdominal and upper body strength and endurance as well as aerobic capacity. All statistical analysis was conducted using an alpha level of 0.05 and IBM SPSS software (v. 23.0; Chicago, IL).

RESULTS

The final sample contained 150 children (75 homeschool and 75 public school). Each group had a mean age (SD; [Range]) of 9.41 years (1.07; [8-11]) and contained slightly more females (51%) compared to males (49%). Homeschool children were predominantly white (85%) but also reported Hispanic (3%), African American (3%), Asian (3%), biracial (5%), and other ethnicities (1%). Campus-wide ethnicity breakdown for public school children was also predominantly white (69%) but reported Hispanic (18%), African American (4%), Asian (5%), and biracial (4%) ethnicities as well. As determined by federal free and reduced price lunch, 5.6% of the public school campus population and 4.0% of homeschool children were classified as economically disadvantaged.[153] On average, homeschool children had a BMI of 16.86 (2.77; [12.73 – 27.96]) and public school children had a BMI of 17.91 (2.95; [14.10 – 29.40]). Overall, 86.7% of the homeschool children and 85.3% of the public school children achieved a healthy FitnessGram® BMI classification (healthy fitness zone or very lean). Among homeschool children, 77.3% reported participation in organized sports with an average of 3.69 hours per week (3.02; [0-13]).

Mean group performance by schooling type for each FitnessGram® test is shown in Figure 1. Two 9 year old homeschool children declined to participate in the PACER test, resulting in a sample size of 110 participants (54 homeschool and 56 public school) for total laps completed. The PACER equation for FitnessGram® 10.0 does not allow for $VO2_{max}$ estimations in children younger than age 10. Thirty-six homeschool children were aged 10-11 years, resulting in a sample size of 72 for $VO2_{max}$ estimation. All other tests were run on the total sample size of 150 (75 per group).

Figure 1. Average fitness test performance by schooling type



Homeschool children showed significantly lower abdominal strength and endurance ($t(148) = -11.441$, $p < 0.001$, 95% CI = -41.42, -29.22) with a large effect size ($d = -1.86$) as well as lower upper body strength and endurance ($t(148) = -3.610$, $p < 0.001$, 95% CI = -11.53, -3.37) with a medium effect size ($d = -0.59$). There were no significant differences in cardiorespiratory fitness between groups as measured by total PACER laps ($t(108) = 0.879$, $p = 0.381$, 95% CI = -2.89, 7.51) or estimated VO_{2max} ($t(70) = 1.187$, $p = .239$, 95% CI = -0.89, 3.51). Chi-square tests revealed significant differences in abdominal strength and endurance classification ($\chi^2(1) = 35.503$, $p < 0.001$) as well as upper body strength and endurance classification between groups ($\chi^2(1) = 4.881$, $p =$

0.027). Odds ratios revealed public school children were 14.38 (abdominal) and 3.21 (upper body) times more likely to achieve healthy classification for muscle strength and endurance than homeschool children. There were no significant differences in aerobic capacity classification between groups ($\chi^2(1) = 1.444$, $p = 0.486$). Contingency tables for FitnessGram® classification between groups are shown as Tables 1 (abdominal), 2 (upper body), and 3 (aerobic capacity).

Table 1. FitnessGram® abdominal strength and endurance classification by schooling type

	Healthy Fitness Zone	**Needs Improvement**	**Total**
Homeschool	37	38	75
Public School	70	5	75
Total	107	43	150

Table 2. FitnessGram® upper body strength and endurance classification by schooling type

	Healthy Fitness Zone	**Needs Improvement**	**Total**
Homeschool	61	14	75
Public School	70	5	75
Total	131	19	150

Table 3. FitnessGram® aerobic capacity classification by schooling type

	Healthy Fitness Zone	Needs Improvement	Needs Improvement-Health Risk	Total
Homeschool	30	6	0	36
Public School	27	8	1	36
Total	57	14	1	72

DISCUSSION

This study found 8-11 year old homeschool children to have significantly lower levels of both abdominal and upper body muscular fitness as compared to their age- and gender-matched public school peers but no difference in cardiorespiratory fitness. These significantly lower levels of muscular fitness also corresponded to significantly lower classifications on both measures of muscular fitness. Children attending public school were over 3 times more likely to have healthy upper body musculature and over 14 times more likely to have healthy abdominal musculature as assessed by the 90° push-up and curl-up tests compared to homeschool children.

To the author’s knowledge, this is the first study to examine muscular fitness among homeschool children. As such, there is no other research available to which these results can be compared. The deficits seen in both upper body and abdominal muscular fitness indicate the potential for other health related differences among homeschool children, including increased risk for cardiovascular and cardiometabolic disease, decreased bone health, and lower self-esteem.[84,86,87] Of particular concern is the drastic deficit in abdominal musculature, as these muscles are responsible for key aspects of core stabilization including posture and low back health.[21] While not investigated in this study, future research should also explore these outcomes to determine the full extent of health consequences resulting from deficits in muscular strength seen among homeschool children.

Due to the increased health risks seen with poor muscular fitness, child healthcare providers should recommend calisthenics and muscular fitness programs to homeschool children who exhibit deficits. Although a majority (77.3%) of our sample reported engaging in some form of organized sports, simply engaging in physical activity is insufficient to improve the health of the musculoskeletal system. These results also point to the need for fitness experts including physical therapists, certified athletic trainers, and licensed personal trainers to be involved with the homeschool population during elementary school. Gains in muscular fitness during these years can have lifelong benefits.

Although large deficits were seen in muscular fitness among homeschool children, their cardiorespiratory fitness levels were shown to be equal to their public school peers in our study. This finding agrees with another study performed by Welk et al on 117 homeschool children aged 9-16 years in 2004.[23] They also found no deficits in cardiorespiratory fitness when 9-11 year old homeschool children were compared to age and gender public school matches. Unlike their research, this study added strength to their initial findings by controlling for demographic variables including ethnicity and socioeconomic status. Nevertheless, these findings support their initial research showing that homeschooling has no detrimental effect on cardiorespiratory fitness among older elementary school children. This is of special interest due to the noted deficits in muscular fitness. Healthy levels of cardiorespiratory fitness may counteract the increased risk of cardiovascular and cardiometabolic disease associated with low levels of muscular fitness.

On the other hand, the conclusion that there is no effect of schooling type on cardiorespiratory fitness is in direct conflict with a study by Neuville et al on 9 homeschool children aged 10-14 years.[50] Their study found significantly higher levels of cardiorespiratory fitness in homeschool children compared to their public school peers.[50] However, the small sample size and admitted lack of test condition standardization could explain the discrepancy in findings. In their study, homeschool children performed the one-mile run indoors while public school children ran outdoors in winter clothing. Moreover, they also neglected to control for demographic characteristics which again could explain the difference in conclusions.

Strengths of this study include a large sample size and demographic similarities between homeschool and public school groups. The use of randomly selected age and gender matched pairs from groups of children with similar ethnic and socioeconomic backgrounds adds strength to these conclusions. BMI has also been suggested to mediate the relationship between muscular fitness and cardiovascular disease risk among children.[91] Thus, it is important to note that these study samples also had similar BMI in homeschool and public school children.

Limitations of the study include lack of direct data collection from public school children. The use of third party data can decrease the reliability of the results, especially since many schools employ a student rating system. Under this system, students are responsible for counting the number of repetitions their classmates complete for all 3 tests used in this study. However, all public school data were collected by trained FitnessGram® test administrators who are responsible for annually collecting and reporting reliable data to the state. Also, a practice effect for FitnessGram® testing must be acknowledged among public school students. FitnessGram® testing is completed every year in public schools and physical education teachers often insert activities and drills into their curriculum designed to strengthen FitnessGram® test results. However, the tests are designed for students to be equally successful regardless of practice and the large deficits seen in muscular fitness are difficult to attribute to differences in data collection and practice effect alone.

In conclusion, homeschooling showed detrimental effects on both upper body and abdominal muscular fitness among 8-11 year old children with public school children over 3 and 14 times more likely to be classified as healthy for both tests respectively. There was no detrimental effect of homeschooling noted on cardiorespiratory fitness. More research is needed to support our initial findings regarding muscular fitness in homeschool children and to strengthen and clarify findings on cardiorespiratory fitness among the same population.

CHAPTER IV

BODY COMPOSITION IN HOMESCHOOL CHILDREN

INTRODUCTION

Recent data indicate that 1.8 million American children receive schooling outside of the public school system.[11] This number has almost doubled since 2003 and indicates an increasing trend in homeschool education.[11] Unlike public school children, homeschool children are not subject to state regulations including physical education classes, physical activity initiatives, or regular fitness testing.[12] Compared to their public school peers, homeschool children have been shown to have similar or lower levels of physical activity.[23,25,26] Due to decreased energy expenditure, homeschool children are at a potentially higher risk for poor body composition and corresponding deficits in cardiovascular health.

Poor body composition has been linked to cardiometabolic disease such as type 2 diabetes, hypertension, inflammatory markers, and cardiovascular disease among children.[63,64,69,97] In addition to increased disease risk, childhood obesity has also been shown to affect a child’s social and psychological health as well as his or her academic performance.[97] Socially, overweight and obese children are frequently teased, bullied, negatively stereotyped, and discriminated against by his or her peers.[97] Psychologically, body composition issues can lead to depression, poor self-esteem, body dissatisfaction, and/or the development of eating disorders.[97] Academically, unhealthy body composition has been associated with poor cognitive test scores, academic achievement, and behavior.[79] More specifically, increased abdominal fat has been associated with significantly lower standardized test scores in reading, spelling, and arithmetic on standardized tests in children aged 7-9 years.[100]

Body mass index (BMI) is commonly used to assess body composition in children. However, it does not directly assess body composition but is rather an estimate of how appropriate an individual's weight is in relationship to his or her height. This can lead to inaccurate body composition classification, especially in individuals with high levels of muscle mass. Nevertheless, body mass is still widely used and a good indicator of body composition in most of the population.[92] Bioelectrical impedance analysis (BIA) measures percent body fat (%BF) and can be used as a compliment to BMI in children to distinguish between lean and fat mass.[146] The term overfat refers to individuals with fat mass above the normal levels while the term overweight refers to individuals with total body mass above normal levels. This is an important distinction as increased health risks are associated with higher levels of fat mass, not body mass. To further clarify a child's body composition, waist circumference (WC) is often used to assess central adiposity and may be a better indicator of cardiovascular disease (CVD) risk than BMI.[150,151] In short, BMI, %BF, and WC offer complimentary perspectives on a child's overall body composition. BMI indicates a child's proportionality as body mass, %BF indicates adiposity as fat mass, and WC indicates CVD risk as central adiposity.

A recent systematic review and meta-analysis found that 55% of obese children will become obese adolescents and 70% of obese adolescents will become obese adults beyond age 30.[96] Thus, it is critical to identify unhealthy body composition in children during elementary school to prevent deficits from tracking into adulthood, decrease disease risk, and increase life expectancy. However, little information is available in the literature regarding body composition and corresponding cardiovascular disease risk within the homeschool population. The purpose of this research was therefore to describe the body composition of elementary school-aged homeschool children in terms of body mass, fat mass, and central adiposity, assess their corresponding risk of cardiovascular disease, and determine any factors related to CVD risk among this population. It was hypothesized that homeschool children would show poor body composition and high cardiovascular disease risk that was affected by socioeconomic status, primary caregiver education level, and organized sports participation but unaffected by age, gender, or ethnicity.

METHODS

Participants

This cross-sectional study was completed as part of Fitness Assessment in the Homeschooled: The FAITH Study. Full Institutional Review Board approval was secured prior to any participant enrollment or data collection. Homeschool families with children ages 5-11 years old who had completed at least 1 year of homeschool were recruited by email, homeschool support groups, co-operatives, and word of mouth in

April and May of 2016. Homeschool children who were enrolled in online public school or other homeschool models which required physical education or fitness testing were excluded. An *a priori* power analysis for a 2-tailed Mann-Whitney test (2 groups) indicated a total sample size of 108 children would be needed with a medium to large effect size ($d = 0.65$), an alpha level of 0.05, and a power of 0.90.

Variables

Outcome variables included BMI, percent body fat, and waist circumference along with their respective classifications. BMI and BMI *z*-scores, as well as age- and gender-specific BMI percentiles, were determined using Centers for Disease Control (CDC) growth charts.[42] Standard CDC cut-offs were used for BMI classification with >5th percentile indicating underweight, ≥5th - <85th percentile indicating healthy weight, ≥85th - <95th percentile indicating overweight, and ≥95th percentile indicating an obese classification. Body composition classification by percent body fat was automatically calculated by the Tanita BF-689 pediatric bioelectrical impedance analysis scale (Tanita Corporation, Tokyo, Japan) using preprogrammed indwelling normative data.[28] Body fat classifications included underfat, healthy, overfat, or obese. CVD risk was determined using age-, gender-, and ethnicity-specific waist circumference cut-off scores previously established for American children.[152] Predictor variables for CVD risk related to central adiposity included age, gender, ethnicity, socioeconomic status, primary caregiver education level, and organized sports participation.

Procedure

Parental/guardian informed consent and child assent in children age 8 and older were obtained for all participants prior to study enrollment. All data were collected during May 2016. Each child attended a single test session with no follow-up required. Test sessions were offered in a group setting at local parks or at participants' homes as per parental preference. While their child was being tested, parents filled out a demographic survey, including household characteristics and current organized sports participation information for each child. Children completed the entire test session with bare feet and one layer of light clothing over undergarments. Parents were asked to have their children observe a 2-hour fasting window and give them an opportunity to void their bladder prior to testing to optimize body composition assessment accuracy.

Height was measured using a portable stadiometer (Neewer® Stature Meter) with children facing away from the device and heels together. Children's weight, percent body fat, and age/gender-specific %BF classification were calculated using the Tanita BF-689 (Tanita Corporation). Reliability and validity of this device has been confirmed in the literature with an ICC of 0.99 for test-retest reliability and an ICC = 0.79 for absolute agreement with dual energy x-ray absorptiometry scans.[43] Children's feet were guided onto the BIA foot sensors by the raters to ensure optimal contact and centralized heel placement. Waist circumference (WC) was assessed using a non-elastic measuring tape placed parallel to the floor midway between the iliac crest and lower ribs on bare skin. The measurement was taken after normal participant exhalation without compressing subcutaneous tissue. Waist circumference measurements were taken by a single tester with 3 years of experience taking the measurement.

Statistical Analysis

Descriptive statistics including means, standard deviations, and range were calculated for continuous variables as well as counts and percentages for discrete variables. Chi-square tests were utilized to examine differences between dichotomous predictors including gender, ethnicity (white, non-white), and organized sports participation (yes/no) and CVD risk groups. Mann-Whitney *U* tests were used to determine differences in the distribution of child age, primary caregiver education level, socioeconomic status, or average hours per week of organized sports between CVD risk groups. Significantly uneven distributions were followed up with chi-square tests to determine if there was a significant difference in CVD risk classification between groups. All statistical analyses were completed using SPSS software (v. 23.0; Chicago, IL).

RESULTS

One hundred forty-five children enrolled in the study with 1 child declining to participate in testing. The final sample included 144 homeschool children ages 5-11 years old (52% male, 48% female). One child with a BMI *z*-score of -16.64 was excluded from final data analysis as an extreme outlier, resulting in a final sample size of 143 children. Three families declined to disclose their total annual gross household income. Socioeconomic differences between CVD risk groups were determined from a sample of 140. All other analyses, including sample descriptive characteristics, were calculated from the total sample of 143.

Table 4 presents the demographic characteristics of the sample. The sample had a mean age (SD; [Range]) of 8.34 years (1.85; [5.00-11.75]). All children were in households with at least 2 adults, an average of 3.94 children (1.45; [1-8]), and 66.4% had primary caregivers who did not work outside the home. Average weekly organized sports participation was 3.27 hours (2.90; [0-13]) per child.

Table 4. Participant characteristics of the total body composition subsample

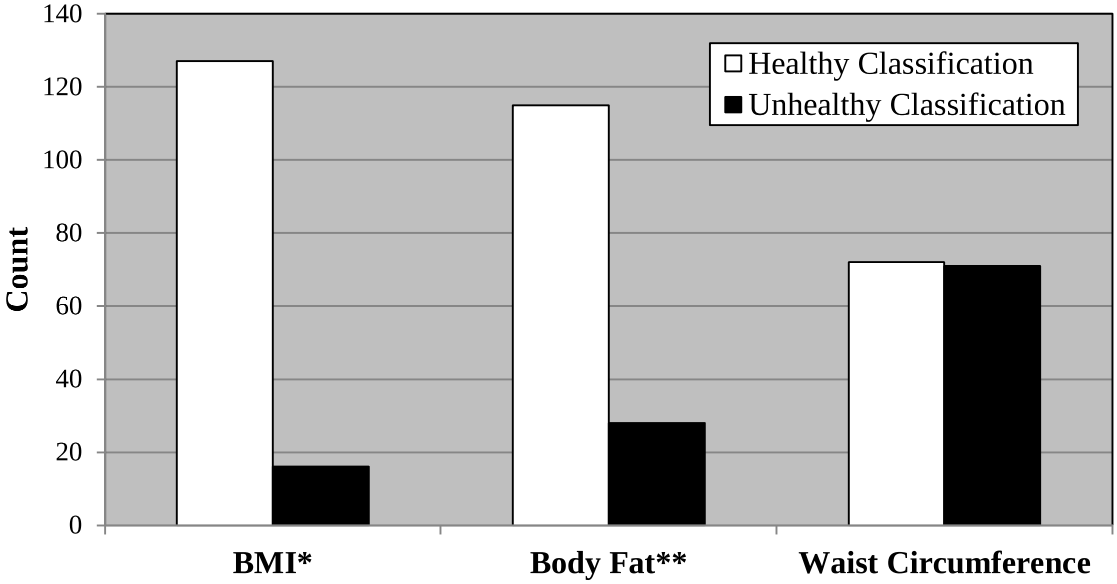
Characteristic	Number of Subjects (Total n=143)	Sample Percentage (%)
Gender		
Male	74	51.7
Female	69	48.3
Ethnicity		
White	121	84.6
Hispanic	3	2.1
African American	5	3.5
Asian	5	3.5
Biracial	8	5.6
Other	1	0.7
Gross Annual Household Income		
< $60K	19	13.3
$60K - < $100K	47	32.9
≥ $100K	74	51.7
Undisclosed	3	2.1
Maternal Education Level		
High School Graduate or Some College	14	9.8
Trade School or Associate Degree	14	9.8
Bachelor’s Degree	80	55.9
Graduate Degree	35	24.5
Organized Sports Participation		
Yes	107	74.8
No	36	25.2

As a group, homeschool children had a BMI z-score of -0.11 (0.97; [-3.47 – 2.53]), BMI of 16.31 (2.42; [12.73 – 27.96]), percent body fat of 18.41 (5.61; [5.00 – 39.70]), and waist circumference of 58.63 cm (6.95; [47.00 – 82.50]). Age- and gender-specific classifications by BMI, %BF, and WC can be seen in Table 5. Overall, 11.2% of the sample had an unhealthy body composition classification by body mass (overweight or obese) which increased to 19.6% when classified by fat mass (overfat or obese) and 49.7% when classified by central adiposity. The change in unhealthy classification by assessment technique is shown in Figure 2.

Table 5. Participant classification by BMI, percent body fat, and waist circumference

Characteristic	Number of Subjects (Total n=143)	Sample Percentage (%)
Body Mass Index (kg/m^2)		
Underweight	9	6.3
Healthy	118	82.5
Overweight	10	7.0
Obese	6	4.2
Percent Body Fat		
Underfat	28	19.6
Healthy	87	60.8
Overfat	21	14.7
Obese	7	4.9
Waist Circumference		
No increased cardiovascular disease risk	72	50.3
Increased cardiovascular disease risk	71	49.7

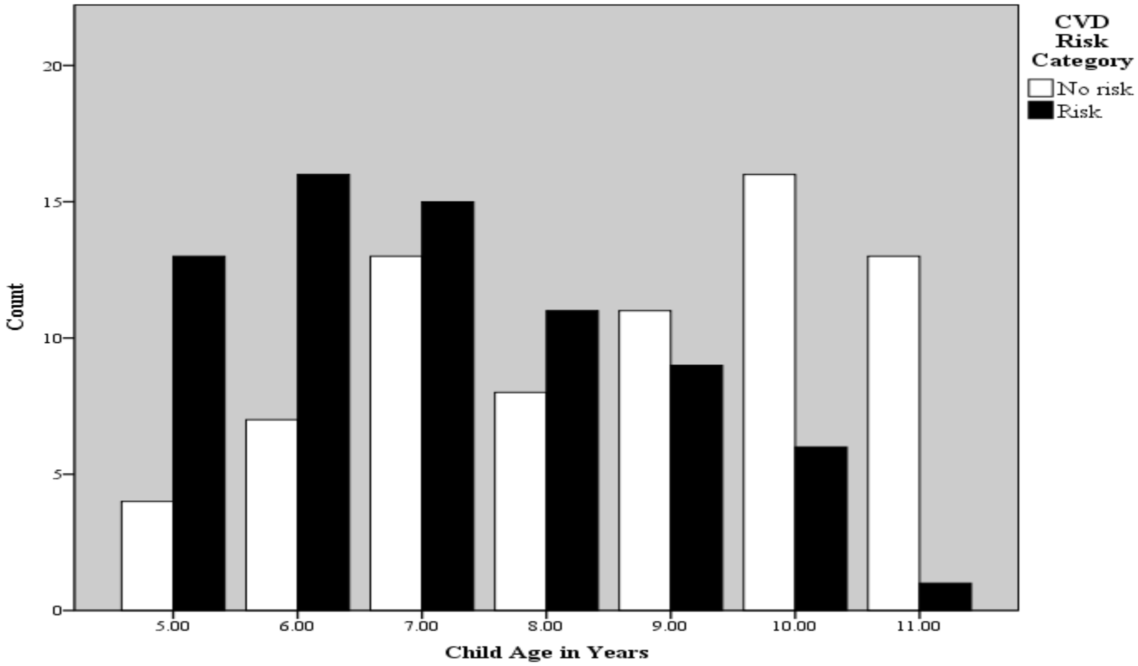
Figure 2. Dichotomized classification by BMI, percent body fat, and waist circumference



*Healthy = underweight or healthy weight; unhealthy = overweight or obese
**Healthy = underfat or healthy; unhealthy = overfat or obese

Chi-square tests revealed no significant differences in CVD risk between genders ($\chi^2(1) = 0.062, p = 0.804$), ethnicity groups ($\chi^2(1) = 0.927, p = 0.336$), or organized sports participants ($\chi^2(1) = 0.002, p = 0.961$). Mann-Whitney *U* tests showed an uneven distribution of age between CVD risk groups (U = 1,427, $z = -4.559$, $p < 0.001$) with more young children in the risk group (mean age = 7.62 years) versus no risk group (mean age = 9.04) and a large effect size ($d = 0.83$).[149] The distribution of CVD risk classification by age is shown in Figure 3. A follow-up chi-square test also revealed a significantly higher CVD risk among younger (5-8 year olds) versus older (9-11 year olds) children ($\chi^2(1) = 16.360, p < 0.001$) with a medium effect size ($\varphi = .34$). However, there were no significantly uneven distributions of primary caregiver education (U = 2,568, $z = 0.056$, $p = 0.955$), total annual gross household income (U = 2,369, $z = -0.336$, *p* = 0.737), or average hours per week of organized sports activity (U = 2,539, *z* = -0.069, *p* = 0.945) between CVD risk groups.

Figure 3. Central adiposity related clustered cardiovascular disease (CVD) risk prevalence by age among homeschool children



DISCUSSION

The purpose of this research was to describe the body composition of elementary school-aged homeschool children in terms of body mass, fat mass, and central adiposity, assess their corresponding risk of cardiovascular disease, and determine any factors related to CVD risk among this population. It was hypothesized that homeschool children would show poor body composition and high cardiovascular disease risk that was affected by socioeconomic status, primary caregiver education level, and organized sports participation but unaffected by age, gender, or ethnicity. This study found elementary aged homeschool children to predominantly have healthy body mass and fat mass levels but elevated levels of central adiposity resulting in almost half being classified as increased risk for cardiovascular disease. As shown in Figure 1, levels of healthy body composition classification sequentially decreased as determined by body mass to fat mass to central adiposity. It is often assumed that a healthy BMI or percent body fat indicates healthy body composition. However, this study clearly shows that high levels of abdominal fat can coexist with both normal BMI and percent body fat. This combination of low BMI and high waist circumference along with increased CVD risk in children has also been seen in other pediatric populations.[151] Accordingly, waist circumference should be included in routine body composition assessments regardless of child BMI or %BF classification to screen for cardiovascular risk in elementary aged homeschool children. As BMI does not indicate fat mass and %BF does not account for fat distribution, it is possible for children with low BMI and %BF to still have increased levels of central adiposity. Central adiposity can be quickly and easily assessed in a non-invasive manner using waist circumference measurements and is an important indicator of cardiovascular disease risk.[150,151]

The low body and fat mass levels shown in the sample agree with the single study available in the literature examining body composition in homeschool children by Cardel et al.[26] After assessing BMI and %BF by dual energy x-ray absorptiometry, they found homeschool children to have significantly lower BMI percentile, total fat mass, percent body fat, and trunk fat compared to their public school peers.[26] This research supports this thin, lean body composition profile among homeschool children despite the hypothesis that they would have poorer body composition secondary to similar or decreased levels of physical activity compared to public school children. Cardel et al also found homeschool children to consume on average 120 total fewer kilocalories per day, significantly less *trans* fat and total sugar, and significantly more fiber, fruits, and vegetables.[26] Thus, while physical activity may not explain the differences in body composition found in homeschool children, dietary intake might. However, it should be noted that this significantly less healthy diet among public school students is in direct conflict with research by Long et al which found no significant difference in dietary intake.[25] Regardless of the cause for body composition differences, this study supports findings of lower body and fat mass among homeschool children.

Unlike Cardel et al's research which showed significantly lower levels of trunk fat in homeschool children, the results of this study showed almost half of homeschool children had increased central adiposity. Notably, Cardel et al completed their study using 47 children aged 7-12 years while the present study was completed using 143 children aged 5-11 years.[26] This research found age was the only significant difference noted between CVD risk groups according to central adiposity and that age had a large effect size. As seen in Figure 2, elevated levels of CVD risk prevail until after the age of 8 when healthy levels begin to outnumber unhealthy levels. If central adiposity is more prevalent in homeschool children under the age of 9, the younger and larger sample used in this study could explain the difference in findings. The dominance of unhealthy CVD risk classification in children ages 5-8 years old also highlights the increased importance of measuring waist circumference in homeschool children in this younger age group.

No difference in central adiposity was noted due to gender, ethnicity, socioeconomic status, primary caregiver education level, or organized sports participation. These results agree with work done by Barriuso et al, who concluded that in rich countries, the positive relationship between socioeconomic status and unhealthy child/adolescent weight classification has almost disappeared.[102] However, this study's findings disagree with this same research which found parental education level, with a stronger association with maternal education level, to have a significantly inverse relationship with child body composition. In other words, Barriuso et al found healthier children among more educated mothers.[102] It should be noted that primary caregivers in our sample were predominantly college educated (91.2%) with almost 25% holding a graduate degree. This homogeneity in advanced primary caregiver education in this study could explain the discrepancy in findings. Finally, while physical activity levels can affect body composition, sports participation in this sample may not have been of sufficient duration or intensity to result in body composition change.

Study limitations include a lack of ethnic and socioeconomic diversity among participants. However, the predominantly white high socioeconomic status seen in the sample matches the homeschool population seen in other studies.[23,25,26] Thus, generalizability among homeschool children should not be affected by the sample demographics.

In conclusion, homeschool children show increased risk of cardiovascular disease secondary to high levels of central adiposity regardless of body mass or fat mass. Due to the increased prevalence of cardiovascular disease risk as measured by waist circumference among this population, homeschool children, especially under the age of 9, should have waist circumference regularly assessed to screen for cardiovascular disease risk. As the first study to examine waist circumference in this population and age range, further research is needed to support these initial findings.

CHAPTER V

MOTOR SKILL PROFICIENCY IN HOMESCHOOL CHILDREN

INTRODUCTION AND PURPOSE

Motor skill proficiency is an important component of child development. Also known as motor skill competence or motor coordination, this term refers to the mastery of specific fundamental movement skills. These gross and fine motor skills serve as building blocks for more complicated movements required for participation in many sports and physical activities.[106] Improved motor skills during elementary school have been associated with increased physical activity, improved cardiorespiratory fitness, and healthier weight classification.[106] Motor skill development also improves self-efficacy, eases the transition to sports, and increases enjoyment of physical activity throughout the lifespan.[21] Moreover, motor skills in children have been shown to predict future risk of lower extremity injury and fitness levels as adolescents.[109,110]

Development of motor skill proficiency has been alleged to improve other areas of a child's life including social and cognitive development in addition to the obvious physical gains.[19,106] Longitudinal studies have shown that fine motor skills in early childhood can predict improvements in math and reading later.[19] Links between fine motor skills, bilateral body coordination, and object control with cognition have also been reported for children under the age of 12.[111] The literature shows gross motor skills to be a significant predictor of academic achievement as well.[19,112] In fact, children aged 9-12 who struggle with motor skills are 6-7 times more likely to also struggle academically.[112] Therefore, developing motor skill proficiency in children during early elementary school is important not only for optimal physical development but cognitive development as well.

As motor skills are so important to child development, public schools employ structured classroom and physical education activities designed to develop age-appropriate motor skills in their students. However, recent data indicate that 1.8 million American children receive schooling outside of the public school system.[11] Homeschool children are not subject to regulated curriculum or physical education classes.[12] Instead, parents assume full responsibility for all aspects their child's education including academic, social, and physical development. Homeschooling occurs in a wide variety of formats including online public schools, individual families, and religious or secular cooperatives. Outside of the traditional gym and classroom, homeschool children have different opportunities for developing motor skills than their public school peers. However, the potential effect of homeschooling on motor skill proficiency has not been reported in the literature.

Therefore, the purpose of this study was to describe overall motor skill proficiency among early elementary aged homeschool children, examine any differences between subgroups of homeschool children, and assess any differences in motor skill task performance in homeschool students compared to public school students. It was hypothesized that homeschool students would demonstrate motor skills that improved with lower body mass index (BMI) and sports participation but that were unaffected by gender, socioeconomic status, and primary caregiver education or employment. No hypothesis regarding overall motor skill proficiency or task performance compared to public school students was formulated secondary to lack of sufficient information.

METHODS

Participants

This cross-sectional exploratory study was completed as part of Fitness Assessment in the Homeschooled: The FAITH study. Full Institutional Review Board approval was secured prior to any enrollment or data collection. Homeschool families with children ages 5-11 in the Greater Houston Area were contacted in April and May of 2016 through email, homeschool support groups, co-operatives, and word of mouth. Interested families completed study enrollment, including parental informed consent and child assent in 8 year old participants, during a single testing session. No follow-up was required. Data collection was completed in group settings at local parks or the participants' home as per parental preference in May 2016. A study size of at least 53 participants was determined using an *a priori* power analysis for *t*-tests to determine a difference between one sample and a population mean with an alpha level of .025, power of .90, and medium effect size (*d* = .5).

Typically developing male and female children of all ethnicities and socioeconomic statuses who had completed at least 1 year of homeschooling were included in the study. Children enrolled in online public schools or other organizations which required physical education classes and/or regular fitness testing were excluded. A subset of the entire FAITH study population consisting of children aged 5-8 years completed motor skill proficiency testing. This younger age range subset was selected as the greatest gains in motor skill proficiency using the Bruininks-Oseretsky Test of Motor Proficiency – Second Edition Short Form are shown between the ages of 4-8 with a ceiling effect beyond this range.[20]

Assessment

Motor skill proficiency was assessed using the Bruininks-Oseretsky Test of Motor Proficiency – Second Edition Short Form (BOT-2 SF). The BOT-2 SF is an efficient means of screening overall motor proficiency in children and has been shown to be both reliable and valid in the literature.[20,44,147,148] It contains 14 items from 8 subtests, including drawing lines through paths-crooked and folding paper (fine motor precision subtest), copying a square and star (fine motor integration subtest), transferring pennies (manual dexterity subtest), jumping in place-same sides synchronized and tapping feet and fingers-same side synchronized (bilateral coordination subtest), walking forward on a line and standing on one leg on a balance beam-eyes open (balance subtest), one-legged stationary hop (running speed and agility subtest), dropping and catching a ball-both hands and dribbling a ball-alternating hands (upper limb coordination subtest), and knee or full push-ups and sit-ups (strength subtest). Knee push-ups were used with all participants unless they expressed a preference for full push-ups. Individual item scores were summed to create an overall raw score between 0-88.

Participant height and weight were assessed using a portable stadiometer (Neewer® Stature Meter) and digital pediatric scale (Tanita Corporation BF-689). Parents also completed a demographic survey that included information on household characteristics and organized sports participation. To minimize bias, all 3 raters (physical therapist, occupational therapist, and student physical therapist assistant) were blinded to population mean and participant subgroup with the exception of gender. Raters were trained on test administration prior to data collection and used standard test kits and administration guidelines as outlined in the BOT-2 manual to improve interrater reliability.[20]

Variables

Outcome variables included BOT-2 SF standardized score and standardized score classification. Raw scores were converted to standardized scores that ranged from 20-80 (median = 50) using age and gender specific charts to allow for comparison between participants. Participants were then classified into 1 of 5 descriptive categories (well below average, below average, average, above average, well above average) using a standardized score classification chart. Average classification corresponded to ± 1 standard deviation from the mean (SD), below/above average to ± > 1 but < 2 SD, and well below/well above to ± > 2 SD.

Categorical independent variables were used to explore potential differences between subgroups of homeschool children. Binary independent variables were utilized to allow for maximum number of participants in each BOT-2 SF motor skill category. Motor coordination is known to be affected by BMI and gender, while socioeconomic status has inconsistent associations and ethnicity has no known effect.[113] Thus, gender (male vs. female), BMI (underweight or normal vs. overweight or obese), and socioeconomic status (≥ $75K gross annual household income vs. <$75K) were examined as independent variables. Additional variables hypothesized to affect motor skills included organized sports participation (yes vs. no), hours of organized sports per week (≥ 2.5 hours vs. < 2.5 hours or roughly above or below sample mean), primary caregiver education level (bachelor's degree or higher vs. associate degree or some college), and primary caregiver employment status (employed part-time or full-time vs. unemployed).

Population means for 8 of the 14 items on the BOT-2 SF were published by Brahler et al using 113 typically developing public school children aged 6-10 years.[48] These population means and standard deviations were used to compare homeschool motor task performance to public school children.

Data Analysis

Outliers were assessed using box plots and indicated all data should be used in the final analysis. As parametric assumptions were met, independent samples *t*-tests were used to examine differences in BOT-2 SF standardized score between homeschool subgroups. Mann-Whitney *U* tests were performed on subgroups with significant differences to determine if the difference in score also equated to a significant difference in motor skill proficiency classification.

Summary *t*-tests were run to assess differences between homeschool children and population means for 6 individual BOT-2 SF test items. The remaining 2 items published by Brahler were not appropriate for comparison secondary to a ceiling effect in public school students. On these 2 tasks (drawing lines-crooked and walking forward on a line), public school students unanimously achieved perfect scores resulting in a SD of 0.[48] To closer resemble the reference population of 6-10 year old public school children, data from 5-year-old homeschool children was excluded for these comparisons.

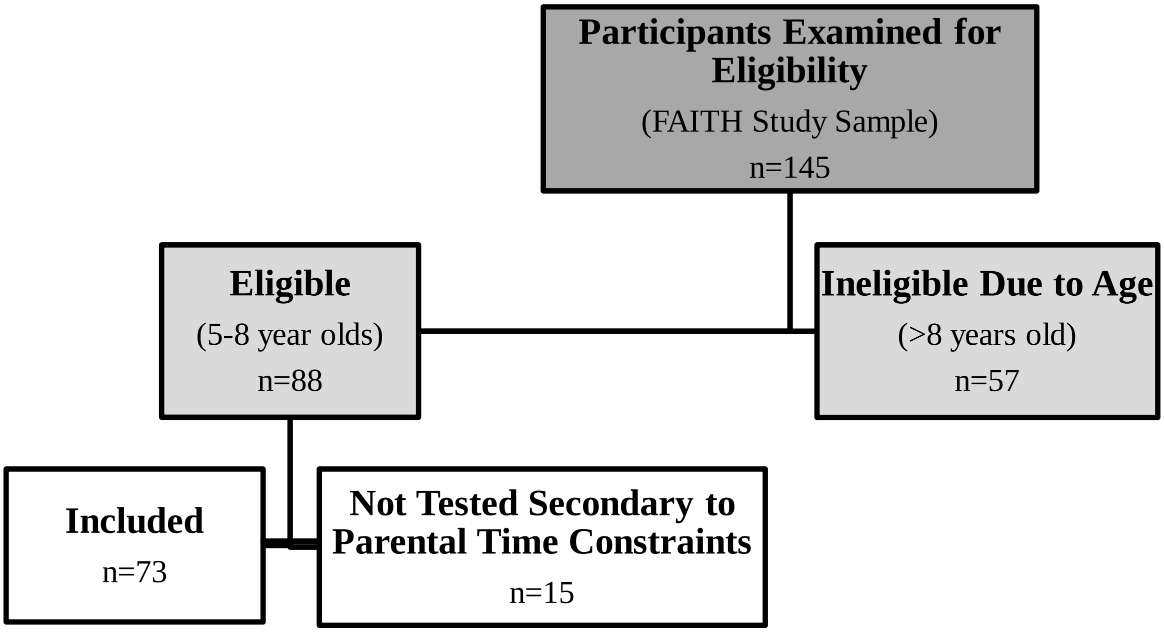
Effect sizes for each test were calculated using Pearson's *r* with .10 indicating a small effect, .30 a medium effect, and .50 a large effect.[149] Alpha levels were set at .05. All data analyses were completed using SPSS software (IBM) version 23.

RESULTS

Participants

Of the 145 participants enrolled in the FAITH Study, 73 completed the BOT-2 SF. A participant flow diagram is shown in Figure 4. The most common reason for non-participation among eligible participants was parental time constraint. The 73 included participants completed all study components and were included in the data analysis with one exception. Gross annual household income was missing for 1 participant as 1 parent declined to report this information. This participant was excluded only from the socioeconomic subgroup comparison. Remaining comparisons included all 73 participants.

Figure 4. Motor skill proficiency subsample participant flow diagram



The final participant population had a mean age of 7.00 years (SD = 1.04, Range [5.0-8.9]), was predominantly white (86.3%), had a normal BMI classification for age/gender (82.2%), and participated in organized sports (mean hours/week = 2.77, SD = 2.84, Range [0-13]). Household demographics indicated high socioeconomic status (mode gross annual income = $75K - $150K, Range [$30K - $150K+]) with all households having at least 2 adults (mean = 2.26, SD = 1.00, Range [2-7]) and an average of 4 children (mean = 4.08, SD = 1.50, Range [1-8]). Primary caregivers were educated (mode = bachelor’s degree, Range[some college-master’s or doctoral degree]) and were primarily unemployed (mode = unemployed, Range[unemployed-employed full-time]). More specific participant demographics are found in Table 6.

Table 6. Participant characteristics for the total motor skill proficiency subsample

Characteristic	Number of Participants (Total n=73)	Sample Percentage (%)
Age (years)		
5	15	20.5
6	21	28.8
7	22	30.1
8	15	20.5
Gender		
Male	35	47.9
Female	38	52.1
Ethnicity		
White	63	86.3
Hispanic	1	1.4
African American	3	4.1
Asian	3	4.1
Biracial	3	4.1
BMI Classification (kg/m^2)		
Underweight	5	6.8
Normal	60	82.2
Overweight	6	8.2
Obese	2	2.7

Group and Subgroup Scores

As a whole, the sample population scored slightly above the BOT-2 SF standardized score scale mean of 50 with an average standardized score of 53.49 (SD = 9.701, Range [31, 76]). Six participants (8.2%) were classified as "below average," 43

(58.9%) as “average,” 19 (26.0%) as “above average,” and 5 (6.8%) as “well above average” for their age/gender. Differences in BOT-2 SF standardized score between subgroups are summarized in Table 7. Significant differences were seen between homeschool children who participated in 2.5 or more hours per week of organized sports as compared to those who did less than 2.5 hours per week ($t(71) = 2.549$, $p = .013$, 95% CI = 1.22, 9.95) with a small to medium effect size ($r = .29$) as well as between participants whose primary caregiver was employed versus unemployed ($t(71) = -3.875$, $p < .001$, 95% CI = -13.29, -4.26) with a medium effect size ($r = .42$). No other significant differences in standardized score were found between homeschool subgroups.

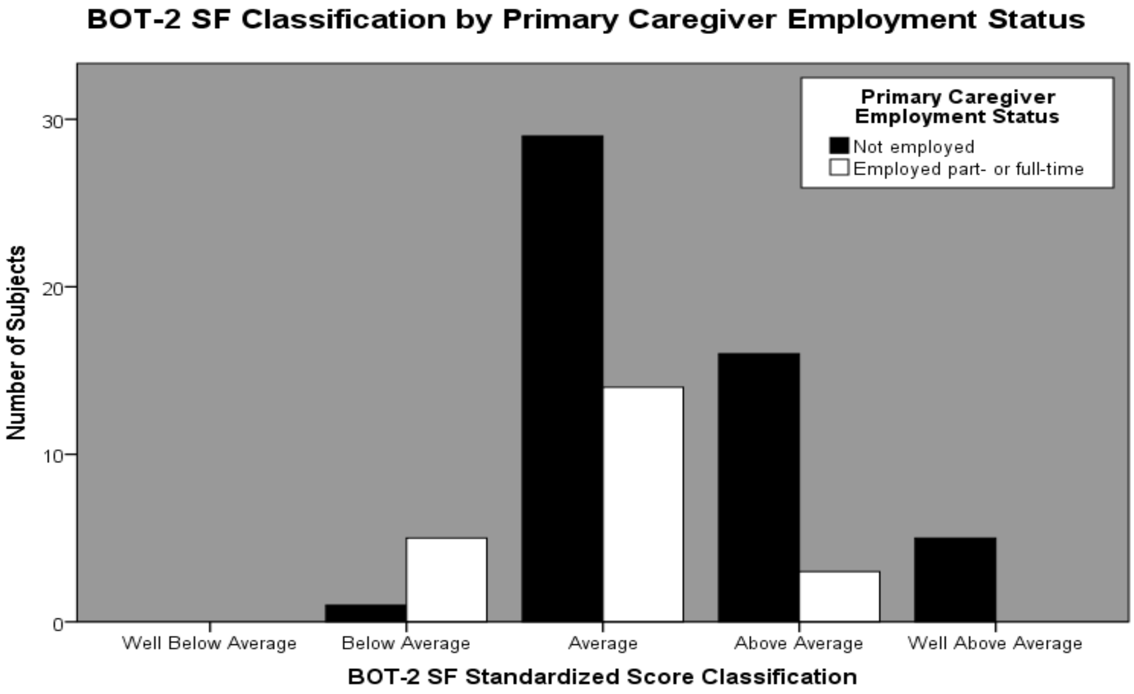
Mann-Whitney U tests revealed that the distribution of BOT-2 SF standardized score classification did not vary significantly between participants who participated in ≥ 2.5 hours of organized sports per week (mean rank = 41.26) compared to those who participated in < 2.5 hours per week (mean rank = 33.08, $U = 814.0$, $z = 1.87$, $p = .062$, $r = .22$). However, there was a significant difference in BOT-2 SF standardized score between participants whose primary caregiver was employed (mean rank = 26.66) versus unemployed with a medium effect size (mean rank = 41.46, $U = 333.5$, $z = -3.10$, $p = .002$, $r = -.36$). This difference in classification is by primary caregiver employment status is shown graphically in Figure 5.

Table 7. Homeschool children subgroup differences in BOT-2 SF standardized score

Group 1 (n) vs. Group 2 (n)	Group 1 BOT-2 SF Score (mean (SD))	Group 2 BOT-2 SF Score (mean (SD))	Independent *t*-test (*t*)	Significance (*p*-value)	95% Confidence Intervals	Effect Size (*r*)
Gender: Males (35) vs. Females (38)	54.63 (8.90)	52.45 (10.39)	.959	.341	-2.35, 6.72	.113
BMI: Normal/Underweight (65) vs. Overweight/Obese (8)	53.57 (9.92)	52.88 (8.29)	-.190	.850	-7.99, 6.60	.023
Organized Sports Participation: Yes (50) vs. No (23)	53.62 (10.09)	53.22 (9.02)	.164	.871	-4.50, 5.31	.019
Hours/Week Organized Sports: ≥ 2.5 (35) vs. < 2.5 (38)	56.40 (10.12)	50.82 (8.59)	2.549	.013*	1.22, 9.95	.290
Gross Annual Household Income: ≥ $75K (50) vs. < $75K (22)	53.78 (8.70)	53.14 (11.98)	.257	.798	-4.56, 5.65	.031
Primary Caregiver Education: Bachelor's Degree or Higher (60) vs. Associate Degree or Some College (13)	53.50 (10.01)	53.46 (8.54)	.013	.990	-5.92, 6.00	.002
Primary Caregiver Employment: Employed (22) vs. Unemployed (51)	47.36 (9.25)	56.14 (8.71)	-3.875	< .001**	-13.29, -4.26	.418

* = significant at the $p = .05$ level; ** = significant at the $p = .01$ level

Figure 5. Number of participants in each BOT-2 category by primary caregiver employment group



Population Means

Significant differences from the public school population mean were found in homeschool children for folding paper ($t(169) = -3.49$, $p = .001$, 95% CI = -1.39, -.39) with a small to medium effect size ($r = .26$), copying a square ($t(169) = -3.86$, $p < .001$, 95% CI = -.44, -.14) with a small to medium effect size ($r = .29$), and knee push-ups ($t(160) = 3.58$, $p < .001$, 95% CI = .48, 1.66) with a small to medium effect size ($r = .27$). Although data analysis was not feasible for drawing lines-crooked and walking forward on a line, no ceiling effect was noted in homeschool children as seen with the public school population mean. Specific differences in homeschool children compared to public school population means are seen in Table 8.

Table 8. Differences between homeschool children and established public school population means by motor task

BOT-2 Subtest and Motor Tasks (n=# of homeschool participants)	**Homeschool Mean (mean (SD))**	**Population Mean (mean (SD))**	**Summary *t*-test (*t*)**	**Significance (*p*-value)**	**95% Confidence Intervals**	**Effect Size (*r*)**
Fine Motor Precision Subtest						
Folding Paper (n=58)	4.86 (1.81)	5.75 (1.45)	-3.49	.001**	-1.39, -.39	.259
Drawing Lines Through Paths – Crooked (n=58)	4.25 (1.54)	7.00 (0.00)	N/A	N/A	N/A	N/A
Fine Motor Integration Subtest						
Copying a Square (n=58)	4.59 (.65)	4.88 (.34)	-3.86	< .001**	-.44, -.14	.285
Copying a Star (n=58)	3.52 (1.71)	3.48 (.93)	.198	.843	-.34, .44	.015
Balance Subtest						
Standing on One Leg on a Balance Beam – Eyes Open (n=58)	3.64 (.77)	3.70 (.61)	-.558	.577	-.27, .15	.043
Walking Forward on a Line	3.96 (.35)	4.00 (.00)	N/A	N/A	N/A	N/A
Strength Subtest						
Knee Push-Ups (n=49)	4.92 (1.85)	3.85 (1.70)	3.58	< .001**	.48, 1.66	.272
Sit-Ups (n=58)	3.34 (1.79)	3.65 (.98)	-1.47	.144	-.72, .10	.112

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

DISCUSSION

Overall, homeschool children demonstrated average age- and gender-specific motor skill proficiency. Children who participated in more than 2.5 hours per week of organized sports, as well as children whose primary caregiver was not employed outside the home, had significantly higher overall motor skill proficiency scores. Children of unemployed primary caregivers also had significantly higher motor skill classification than those of primary caregivers who were employed. Finally, homeschool children scored significantly lower on 2 of 3 fine motor tasks but significantly higher on 1 of 3 gross motor tasks compared to public school children.

The first finding that homeschool children demonstrated average age- and gender-specific motor skill proficiency would seem to suggest that homeschooling has no detrimental effect on motor skill development. Since homeschool children showed average motor skill classification and scored slightly above the scale median as a total sample population, homeschool families and pediatric healthcare providers can be reassured that homeschool children are not at an increased risk for motor skill deficits. This result held true across both genders, BMI classifications, socioeconomic categories, primary caregiver education levels, and regardless of whether children participated in organized sports or not. Unlike other published research which showed motor skills to be negatively affected by increased BMI, this study found no difference in motor skill proficiency between underweight/normal children and overweight/obese participants.[106-108] However, our sample population was largely composed of participants classified as normal by BMI. With only 8 participants in the overweight/obese categories, this may have affected the results.

Since motor skills are often facilitated during organized sports participation, it was unexpected to find no differences in standardized scores between homeschool children who participated in organized sports versus those who did not. However, significant differences were seen when children were divided not simply by participation but rather by time spent in organized sports per week. Those who were engaged in less than roughly the sample mean of 2.5 hours scored significantly lower on the BOT-2 SF. Together, these findings suggest that simply participating in organized sports does not enhance motor skill proficiency but rather a threshold of at least 2.5 hours per week may be needed to see a significant improvement in motor skill performance.

Notably, homeschool children whose primary caregiver was not employed outside the home scored significantly higher on overall motor proficiency compared to those whose primary caregiver worked part-time or full-time. This not only held true for a higher standardized BOT-2 SF score but a higher motor skill categorization as well. In fact, the only children classified as “well above average” or +2 SD above the mean all had unemployed primary caregivers. The reason for this remains largely unclear. However, rather than implying that caregiver employment might be detrimental to child motor skill development, it might hint at differences in homeschooling environments. Caregivers who are employed may be more likely to place their children in homeschool groups or other cooperative learning environments during their work hours than those who are unemployed. Homeschooling environments were not explored in this study and further research would be required to determine potential causes for this difference between homeschool children with employed versus unemployed primary caregivers.

Finally, homeschool children demonstrated significantly different motor task performance when individual BOT-2 SF items were compared to established population means for public school children. Even though scores indicated average overall motor skill proficiency among the homeschool population, individual item analysis showed significant fine motor deficits compared to public school children. This was true for 2 of the 3 analyzed fine motor tasks (folding paper and copying a square), with the fourth (drawing lines through paths-crooked) showing a large difference in group means but no statistical analysis secondary to a perfect score ceiling effect among public school children. Folding paper has been shown to be significantly ($r = .756$, $p = .001$) correlated to the overall precision subtest score making it a strong indicator of fine motor skill performance.[48] Since homeschool children scored significantly lower on this motor task, it can be concluded that homeschool children had significant deficits in fine motor precision compared to their public school peers.

No significant difference was seen between homeschool and public school children on the balance subtest and homeschool children scored significantly higher on 1 of the 2 strength subtest tasks. More specifically, homeschool children scored significantly higher than public school children on the knee push-up task. As with folding paper, knee push-ups were strongly correlated ($r = .865$, $p = .001$) to the strength subtest total score making it a strong indicator of muscle strength. These results would indicate above average upper body strength among homeschool children compared to their public school peers.

This discrepancy between average overall BOT-2 SF scores and above or below average individual task scores agrees with prior research done on the BOT-2. Because the BOT-2 SF includes both fine and gross motor tasks as a total point score, it is not uncommon for weaknesses in one motor composite to be masked by strengths in another area.[147] This was clearly seen in our test results with homeschool children showing average overall scores but significantly lower fine motor precision and integration task scores and significantly higher upper body strength. In short, the BOT-2 SF is appropriate to screen children for global motor delays but further testing might be needed to identify specific areas of weakness.[147] In other words, a child with poor fine motor skills but strong gross motor skills might be missed for services if his or her total BOT-2 SF score is still in an acceptable range. Therefore, further research utilizing the BOT-2 Complete Form and resulting 4 motor composite scores might be needed to confirm the presence of fine motor skill deficits among homeschool children.

This was a cross-sectional study and as such, causality cannot be implied from these results. Generalizability of results is also limited to typically developing homeschool children aged 5-8 years who do not participate in required physical education. Study limitations included a relatively homogenous sample of white children from higher socioeconomic classes in two parent homes. However, ethnicity has not been shown to affect motor skill proficiency in the literature and the sample is assumed to be representative of the homeschool population at large. Moreover, the sample used to compare population means for individual motor tasks consisted of public school children aged 6-10 years (mean = 7.88 years) while the homeschool sample contained children aged 6-8 (mean = 7.39 years). This slightly higher age range could have resulted in higher scores for the public school population. As the first study to examine motor skill proficiency in the homeschool population, future research is needed to confirm and further clarify these initial findings.

In conclusion, homeschooling shows no detrimental effects on overall motor skill proficiency among 5-8-year-old children. However, fine motor skill deficits and gains in upper body strength may have been masked by an overall total score. To improve motor skill proficiency among early elementary aged homeschool children, 2.5 or more hours of organized sports participation per week can be recommended.

CHAPTER VI

CONCLUSION

STATEMENT OF THE PROBLEM

Recent data indicate that 1.8 million American children receive schooling outside of the public school system and are not subject to state regulations including physical education classes, physical activity initiatives, or regular fitness testing.[11] However, little information is available regarding the physical fitness, body composition, or motor skill development of children educated at home.

REVIEW OF METHODOLOGY

This descriptive exploratory study examined physical fitness, body composition, and motor skill development among homeschool children and compared them to their public school counterparts and peers. Health-related physical fitness outcomes included cardiorespiratory fitness, muscle strength, and body composition as waist circumference, BMI, and percent body fat (%BF). Motor skills included fine motor, balance, and gross motor components.

SUMMARY OF FINDINGS

After examining the data, homeschool children were shown to have poor upper body and abdominal muscular fitness among 8-11 year olds compared to their public school peers. They were also shown to have deficits in fine motor task performance among 5-8 year olds that were not present in public school children of the same age and gender. Compared to other children their age, homeschool children also showed high levels of central adiposity among the entire sample of 5-11 year olds, with almost half showing an increased risk for cardiovascular disease. This increased central adiposity and corresponding cardiovascular disease risk was significantly more prevalent in homeschool children under 9 years of age.

However, homeschooling showed no detrimental effects on overall motor skill proficiency among 5-8 year olds nor cardiorespiratory fitness among 9-11 year olds. The overall sample also showed good body mass and fat mass levels among 5-11 year olds. Moreover, homeschool children between the ages of 5-8 years old were shown to have significantly better upper body strength compared to their age and gender matched public school peers.

CLINICAL RELEVANCE

Physical therapy professionals are movement system experts throughout the lifespan. Regular screening of cardiorespiratory fitness, muscle strength, body composition, and motor skill development are all part of good practice. Currently, there is a growing emphasis on proactive versus reactive healthcare, especially with the childhood obesity epidemic. Physical therapy education gives clinicians the necessary tools to promote the health of pediatric clients by monitoring and improving muscular strength, cardiorespiratory endurance, and body composition.

Additionally, this research identified several trends among homeschool children including poor upper body and abdominal muscular fitness, increased cardiovascular disease risk secondary to elevated levels of central adiposity, and deficits in fine motor skill task performance. By raising clinician awareness of these deficits, skilled therapy interventions can be implemented to prevent long-term health consequences. Promoting the health and wellness of typically developing children also expands the limited perception of physical therapy professionals only serving children who have been injured or with special needs.

Finally, health and wellness is an expanding part of physical therapy practice. Screenings and interventions for cardiorespiratory fitness, muscle strength, body composition, and motor skill development can all be completed without a physician referral. This is important in states like Texas that still have limited direct patient access. In short, physical therapists and physical therapist assistants can use their unique skills to improve the health and wellness of their communities, including homeschool children.

IMPLICATIONS FOR THE FUTURE

This research utilized outcomes that have been largely unexplored in an expanding and understudied population. More research is needed to support the initial findings regarding the effect of homeschooling on muscle strength in 8-11 year olds, body composition in children under the age of 7, and motor skill development among 5-8 year olds. Motor skill development should also be examined in greater detail among 5-8 year olds to avoid potential masking of fine motor deficits and/or gross motor strength by the use of overall motor skill proficiency scores. Future research should also focus on exploring these same outcomes in an expanded population of homeschool children to include adolescents in a larger geographic area. Finally, research investigating the potential effect of physical therapy interventions within this population on these same outcomes is also warranted.

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Institutional Review Board
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DATE: March 3, 2016

TO: Physical Therapy - Houston

FROM: Institutional Review Board (IRB) - Houston

Re: Approval for Fitness Assessment in the Homeschooled: The FAITH Study (Protocol #: 18919)

The above referenced study was reviewed at a fully convened meeting of the Houston IRB (operating under FWA00000178). The study was approved on 3/2/2016. This approval is valid for one year and expires on 3/2/2017. The IRB will send an email notification 45 days prior to the expiration date with instructions to extend or close the study. It is your responsibility to request an extension for the study if it is not yet complete, to close the protocol file when the study is complete, and to make certain that the study is not conducted beyond the expiration date.

If applicable, agency approval letters must be submitted to the IRB upon receipt prior to any data collection at that agency. A copy of the approved consent form with the IRB approval stamp is enclosed. Please use the consent form with the most recent approval date stamp when obtaining consent from your participants. A copy of the signed consent forms must be submitted with the request to close the study file at the completion of the study.

Any modifications to this study must be submitted for review to the IRB using the Modification Request Form. Additionally, the IRB must be notified immediately of any adverse events or unanticipated problems. All forms are located on the IRB website. If you have any questions, please contact the TWU IRB.

cc. Physical Therapy - Houston
Physical Therapy - Houston
Graduate School