Gross Motor Skills and Cardiometabolic Risk in Children: A Mediation Analysis

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ABSTRACT

BURNS, R. D., T. A. BRUSSEAU, Y. FU, and J. C. HANNON. Gross Motor Skills and Cardiometabolic Risk in Children: A Mediation Analysis. *Med. Sci. Sports Exerc.*, Vol. 49, No. 4, pp. 746–751, 2017. **Purpose**: The purpose of this study was to examine the linear relationship between gross motor skills and cardiometabolic risk, with aerobic fitness as a mediator variable, in low-income children from the United States. **Methods**: Participants were a convenience sample of 224 children (mean ± SD age = 9.1 ± 1.1 yr; 129 girls and 95 boys) recruited from five low-income elementary schools from the Mountain West Region of the United States. Gross motor skills were assessed using the Test for Gross Motor Development, 3rd Edition. Gross motor skills were analyzed using a locomotor skill, a ball skill, and a total gross motor skill score. Aerobic fitness was assessed using the Progressive Aerobic Cardiovascular Endurance Run that was administered during physical education class. A continuous and age- and sex-adjusted metabolic syndrome score (MetS) was calculated from health and blood marker measurements collected in a fasted state before school hours. Total effects, average direct effects, and indirect effects (average causal mediation effect) were calculated using a bootstrap mediation analysis method via a linear regression algorithm. **Results**: The average causal mediation effect of gross locomotor skills on MetS scores, using aerobic fitness as the mediator variable, was statistically significant ($\beta = -0.055$, 95% confidence interval = −0.097 to −0.021, $P = 0.003$). The model explained approximately 17.5% of the total variance in MetS with approximately 43.7% of the relationship between locomotor skills and MetS mediated through aerobic fitness. Ball skills did not significantly relate with cardiometabolic risk. **Conclusion**: There is a significant relationship between gross locomotor skills and cardiometabolic risk that is partially mediated through aerobic fitness in a sample of low-income children from the United States. **Key Words:** CHILDREN, HEALTH, LOCOMOTOR SKILLS, METABOLIC SYNDROME

Gross motor skill competency in children is paramount for optimal physical development and may affect participation in free-living physical activity (17,27,29). Children who have low levels of gross motor skills may also have low levels of self-efficacy for physical activity, which compromises health-related fitness and can exacerbate health risk if low levels track through adolescence and into adulthood (9,30,32). Aerobic fitness, estimated using aerobic capacity or $\dot{V}O_{2peak}$, has been shown to moderately associate with clustered cardiometabolic biomarkers in children and adolescents (34). Indeed, high levels of aerobic fitness may have a protective effect on cardiometabolic health, even if a child is overweight (14). Despite the recent research examining the correlates of gross motor skills and aerobic fitness in children (6,7,17), no studies to the author's knowledge have linked these two constructs together with cardiometabolic health. Given the developmental model proposed by Stodden et al. (29), postulating that increases in gross motor skills may increase participation in free-living physical activity and thus decrease risk of obesity-related diseases, it is reasonable to assume that increases in gross motor skills will also lead to increases in aerobic fitness, which will then directly link to cardiometabolic health outcomes. Therefore, aerobic fitness may mediate the relationship between gross motor skills and cardiometabolic health in children.

All children can benefit from optimal levels of gross motor skills and aerobic fitness; however, low-income children may especially benefit (21). Children from low-income families have relatively fewer opportunities to participate in free-living moderate-to-vigorous physical activity (MVPA) during the day, have a lack of sufficient play equipment or safe play areas to participate in MVPA, and, if of an ethnic minority, have a greater prevalence of unfavorable cardiometabolic biomarkers compared with non-Hispanic Caucasian children and/or children of a higher socioeconomic classification (8,21,23). Indeed, it has been shown that low socioeconomic status children display lower levels of MVPA compared with higher socioeconomic status children (15,16).

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Submitted for publication July 2016.
Accepted for publication November 2016.

0195-9131/17/4904-0746/0
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DOI: 10.1249/MSS.0000000000001147

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Therefore, it is important to understand the possible pathways linking gross motor skills, aerobic fitness, and cardiometabolic health so that practitioners, including school personnel, can implement effective preventative strategies at an early age. Although the linkage between gross motor skills and cardiometabolic health via aerobic fitness is logical, no research has provided empirical evidence supporting this potential relationship. Therefore, the purpose of this study was to examine the relationship between gross motor skills and cardiometabolic risk, and the mediating effect of aerobic fitness, in low-income children from the United States.

METHODS

Participants

The participants were a convenience sample of 224 elementary school-age children (mean ± SD age = 9.1 ± 1.1 yr; 129 girls 95 boys) recruited from five low-income schools receiving governmental financial assistance from the Mountain West region of the United States. Students were recruited from the third to the fifth grades. The sample distribution per grade level included 85 third graders, 54 fourth graders, and 85 fifth graders. Approximately 60.6% of the sample was of Hispanic/Latino ethnicity, 13.7% were Pacific Islander, 10.0% were Caucasian, 7.8% were African American, 3.5% were Asian, and approximately 4.0% were classified as other. Written assent was obtained from the students, and written consent was obtained from the parents before data collection. The university institutional review board approved the protocols used in this study.

Instrumentation

Gross motor skills. The Test for Gross Motor Development, 3rd Edition (TGMD-3), was the instrument used to assess gross motor skills. The content sampling, time sampling, and interscorer differences of the second edition of this instrument (TGMD-2) was determined to be acceptable with coefficients of 0.87, 0.88, and 0.98, respectively (31). The second edition of the instrument also demonstrated good content description, criterion prediction, and construct identification validity evidence using a sample of 1208 individuals in 10 states from the United States (31). At the time of data collection, the reliability and the validity of the TGMD-3 have not yet been published.

The TGMD-3 assesses gross motor competency across 13 movement skills within separate locomotor and ball skill subtests. The locomotor subtest has a total score of 46, and the ball skills subtest has a total score of 54. The six locomotor test items consisted of running, galloping, hopping, skipping, horizontal jumping, and sliding. The seven ball skill test items consisted of two-handed and one-handed striking, dribbling, overhand throwing, underhand throwing, catching, and kicking. Each student performed the test items across two trials that were each scored based on three to five specific performance criteria, depending on the testing item (0 = did not perform correctly; 1 = performed correctly). Data used for analysis included the locomotor subtest score, the ball skills subtest score, and a gross motor test score (locomotor subtest score + ball skill subtest score; TGMD-3).

Aerobic fitness. Aerobic fitness was assessed using the 20-m Progressive Aerobic Cardiovascular Endurance Run (PACER), administered during each student's physical education class. The PACER was conducted on a marked gymnasium floor with background music provided by a compact disk. Each student was instructed to run from one floor marker to another floor marker across a 20-m distance within an allotted time frame. The allotted time given to reach the specified distance incrementally shortened as the test progressed. If the student twice failed to reach the other floor marker within the allotted time frame, the test was terminated. Students performed the PACER in sex-specific groups of 8–12 children during PE. The PACER has demonstrated acceptable test–retest reliability with scores ranging from ICC = 0.82–0.93 and evidence for criterion-related validity (22). The final score was recorded in laps.

Cardiometabolic Measures

Waist circumference was measured in a private screening area where three abdominal circumference measurements were taken at the level of the superior border of the iliac crest on the participant's right side using a standard measuring tape. All measurements were estimated to the nearest 1 cm with the average of the three measurements used in the data analysis (1).

Blood pressure was measured using an electronic blood pressure device (CONTEC08A; Contec Medical Systems Co., Qinhuangdao, China). Systolic blood pressure (SBP) and diastolic blood pressure (DBP) measurements were taken on each participant's right arm with the right arm rested and elevated at heart level and both feet flat on the ground. Participants were allowed to relax in a private room for 5 min before measurements were taken.

Each student's cardiometabolic blood markers were collected using the Cholestech LDX system (Alere Inc., Waltham, MA). Individual markers included total cholesterol, LDL cholesterol, HDL cholesterol, triglycerides, and blood glucose. A capillary blood sample was collected between the hours of 6:00 a.m. and 8:00 a.m. before the commencement of the school day. Blood samples were collected in a fasted state, verbally verified by both the student and the student's parent or guardian before collection of the blood sample. Blood samples were collected via a finger stick on each student's right index finger using a 40-μL capillary tube and immediately injected into the Lipid Profile-Glucose Cassette (Alere Inc.) and subsequently analyzed. The puncture site was cleaned and bandaged and all materials were properly disposed of in a biohazard container.

Procedures

Aerobic fitness assessment was conducted during each child's physical education class using the aforementioned

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procedures. Gross motor skills were measured approximately 1–3 wk before administering the PACER. For each gross motor skill item, the researcher demonstrated the movement to the student before collecting data and was then scored based on the aforementioned protocol. Because of data collection feasibility and time limitations, all scoring was coded live, acknowledging that this method is not the current standard for assessing qualitative movement descriptors. Each member of the research team was trained for several months before the start of data collection using a sample of children from a different school. The score for interobserver agreement, or the agreement of scoring between different testers/raters, was ICC = 0.93. The intraobserver agreement, or the agreement of scoring within the same tester/rater over time, for the first rater was ICC = 0.90 and for the second rater was ICC = 0.92. The cardiometabolic blood markers were collected 1 wk after administering the PACER. Students reported to school and then proceeded to enter a private screening area for collection of anthropometric, blood pressure, and cardiometabolic biomarker measurements. A trained member of the research team collected measurements to maintain testing consistency.

Data processing. There is no standard for calculating a continuous metabolic syndrome composite score in children; however, the inclusion of various health components has been supported by previous research using factor analysis (12). A continuous and age- and sex-adjusted metabolic syndrome score (MetS) was calculated using each child's fasting triglycerides, blood glucose, HDL cholesterol, waist circumference, and SBP and DBP. MetS scores were adjusted to account for a potentially moderating influence of age and sex on cardiometabolic health within the sample. An estimated mean arterial pressure (MAP) score was calculated from SBP and DBP values using the following equation: MAP = ((2 × DBP) + SBP)/3. The MAP score was used for the derivation of MetS because it incorporated both SBP and DBP into a single measure. The derivation of the MetS scores included regressing each child's age and sex onto the aforementioned parameters and calculating an individual standardized residual score (z-score) per measure. Because HDL cholesterol is inversely related to cardiometabolic risk, the HDL residual z-score was multiplied by -1 (13). The MetS was the sum of all calculated age- and sex-adjusted residual z-scores with a higher MetS score representing a more unfavorable cardiometabolic profile. These procedures were in accordance to those recommended by Eisenmann et al. (13) where in which the unadjusted MetS score's construct validity was supported using receiver operating curve analysis.

Data analysis. An *a priori* power analysis was conducted in STATA using a two-predictor multiple linear regression analysis with a medium sized effect and a two-sided P value of 0.05. The obtained sample size was determined to be adequate to achieve 80% statistical power. Data were screened for outliers using box plots and were checked for Gaussian distributions using k-density plots. Pearson product–moment correlations were used to examine the linear relationship among all measurements. Correlations were considered strong if $r > 0.60$, moderate if $r = 0.30$ to 0.60, and weak if $r < 0.30$ (26). Because no statistically significant correlations were found between balls skills and MetS scores, ball skills were not explored further in the mediation analysis.

The primary analysis consisted of a causal mediation analysis followed by a sensitivity analysis using STATA's "mediation" package. The used algorithm consisted of that outlined by Imai et al. (20). The parameters of interest included the average causal mediation effect (ACME), which was the average mediated effect between locomotor skills and cardiometabolic risk (i.e., MetS) via aerobic fitness (i.e., PACER scores); the average direct effect (ADE), which was the ADE of the predictor (i.e., locomotor skills) on the outcome variable (i.e., MetS scores) without use of the mediator; and the total effect (TE), which was the entire effect locomotor skills had on MetS scores (TE = ACME + ADE). STATA's "medeff" command was used to calculate these bootstrapped averaged effects for 1000 iterations.

A sensitivity analysis using STATA's "medsens" command was used to identify the value of rho or ρ, the correlation of error terms between the mediator and outcome regression models, in which the value of ACME would be zero. The value of ρ reflects the degree of confoundedness that would need to be had where there would be no mediation effect in the locomotor skills → MetS potential causal pathway. Essentially, the sensitivity analysis allowed for the examination of how an averaged estimate (i.e., ACME) would change for different degrees of violation of the sequential ignorability assumption. Further details regarding the aforementioned statistical procedures and a further explanation of the sequential ignorability can be found by referring to Hicks and Tingley (19). Alpha level was set at $P < 0.05$, and all analyses were conducted using STATA 14.0 statistical software package (College Station, TX).

RESULTS

Table 1 provides the descriptive statistics for the total sample and within each sex and grade level. Boys displayed higher ball skills scores compared with girls (mean difference = 6.1, $P < 0.001$) and higher TGMD-3 total scores compared with girls (mean difference = 6.2, $P < 0.001$). No other statistical differences were found between sexes on any other measure. Regarding grade-level differences, the fifth-grade children displayed higher ball skills scores compared with the third graders (Mean difference = 5.9, $P < 0.001$) and higher TGMD-3 total scores compared with the third graders (Mean difference = 8.9, $P < 0.001$). No other statistical differences were found among grade levels on any other measure. Table 2 is a correlation matrix displaying the Pearson correlation coefficients among PACER, gross motor skills, and MetS. Locomotor skills displayed a linear, positive, and weak-to-moderate correlation with both PACER and MetS ($P < 0.001$), whereas ball skills only displayed

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TABLE 1. Descriptive statistics.

	Total Sample (*N* = 224)	Girls (*n* = 129)	Boys (*n* = 95)	Third Grade (*n* = 85)	Fourth Grade (*n* = 54)	Fifth Grade (*n* = 85)
PACER Laps	30.2 ± 20.8	27.9 ± 17.5	33.5 ± 25.5	26.2 ± 15.8	29.5 ± 19.2	37.9 ± 28.2
Locomotor subtest	32.8 ± 6.2	32.8 ± 5.8	33.0 ± 6.7	31.1 ± 6.0	33.9 ± 6.0	34.1 ± 6.8
Ball skills subtest	38.7 ± 8.7	36.0 ± 8.0	**42.1 ± 8.6***	36.1 ± 8.6	39.1 ± 7.9	**42.0 ± 8.4***
TGMD-3 total score	71.6 ± 12.7	68.9 ± 11.4	**75.1 ± 13.5***	67.2 ± 12.3	73.0 ± 10.9	**76.1 ± 12.3***
Triglyceride (mg·dL^{-1})	112.6 ± 82.8	122.0 ± 94.1	122.0 ± 94.1	102.4 ± 72.9	117.3 ± 91.5	130.7 ± 97.4
HDL cholesterol (mg·dL^{-1})	44.6 ± 13.1	44.4 ± 12.1	44.7 ± 14.1	44.1 ± 11.8	47.5 ± 14.6	42.4 ± 13.8
WC (cm)	71.0 ± 12.3	70.4 ± 12.7	71.9 ± 11.6	68.3 ± 10.5	70.8 ± 12.7	74.0 ± 12.9
Glucose (mg·dL^{-1})	86.1 ± 9.6	86.2 ± 10.0	86.1 ± 9.1	83.7 ± 7.6	86.2 ± 10.9	87.6 ± 8.6
MAP (mm Hg)	82.5 ± 11.1	81.5 ± 10.9	83.8 ± 11.2	81.6 ± 10.7	81.0 ± 9.6	83.5 ± 11.3
MetS (*z*-score sum)	−0.02 ± 3.2	0.0 ± 3.4	−0.04 ± 3.0	0.0 ± 2.6	−0.2 ± 3.3	0.32 ± 3.7

Data are presented as mean ± SD. BMI, body mass index; WC, waist circumference. Bold denotes statistical significance between sexes or among grade levels.
*$P < 0.05$.

a linear, positive, and weak correlation with PACER ($P < 0.05$). Figure 1 is a schematic diagram showing the relationship between locomotor skills and MetS and the mediating effect of PACER. Results from the bootstrap mediation analysis yielded a statistically significant ACME (ACME = −0.055, 95% confidence interval [CI] = −0.097 to −0.021, P = 0.003), a nonstatistically significant ADE (ADE = −0.071, 95% CI = −0.154 to 0.011, P = 0.105), and a statistically significant TE (TE = −0.126, 95% CI = −0.210 to −0.036, $P < 0.001$). The model explained approximately 17.5% of the total variance in MetS. Approximately 43.7% of the locomotor skill TE was mediated via PACER.

Figure 2 is a graph showing the relationship between ACME as a function of ρ. The value of ρ at which ACME = 0 was $\rho = -0.35$, or the correlation in error terms between the mediator and outcome regression models (due to unobserved confounding variables) will have to be $\rho = -0.35$ for there to be no PACER mediating effect.

DISCUSSION

The main finding from this study was that the relationship between gross locomotor skills and cardiometabolic risk is mediated through aerobic fitness levels in low-income children. The current study incorporated blood marker, blood pressure, and waist circumference measurements into a clustered metabolic syndrome composite score (MetS) and examined the linear relationship between gross motor skills, measured by the TGMD-3, with MetS using aerobic fitness as a potential mediator variable. Aerobic fitness and its relationship to health outcomes have been studied extensively in the literature in children (9,28,34). Also, gross motor skills and its correlation with physical activity and health-related fitness measures have been studied extensively (10,25,30), but links to direct cardiometabolic health markers is lacking.

For the past several decades, there has been an emphasis in physical education and in other physical activity settings on improving health outcomes by improving the levels of health-related fitness in children (33). This emphasis has been spurred by numerous research studies establishing a link between specific components of health-related fitness and health outcomes (7,9,34). The five domains of health-related fitness include body composition, aerobic fitness, muscular strength and endurance, and flexibility (33). Despite this emphasis, the development of gross motor skills should not be neglected in physical education or after school programs, given the established links between fundamental motor skill and health-related fitness constructs in children and adolescents (4,5,25).

Gross motor skills, in the context of the TGMD-3, include both locomotor skills and ball skills (31). There have been relationships found between locomotor skills and physical activity and health-related fitness measures (6,24,25). Hardy et al. (18) found that low competence in fundamental movement skills related to inadequate aerobic fitness, and in boys, low competency in object control skills related to not meeting the 60-min·d^{-1} MVPA physical activity recommendation. Because of these relationships, it was recommended

TABLE 2. Pairwise Pearson product–moment correlations.

	MetS	PACER Laps	Locomotor Skills	Ball Skills	TGMD-3 Scores
MetS	–				
PACER laps	**−0.35****	–			
Locomotor skills	**−0.21****	**0.32****	–		
Ball skills	−0.03	**0.18***	**0.42****	–	
TGMD-3 total score	−0.12	**0.28****	**0.78****	**0.90****	–

Bold denotes statistical significance.
*$P < 0.05$.
**$P < 0.001$.

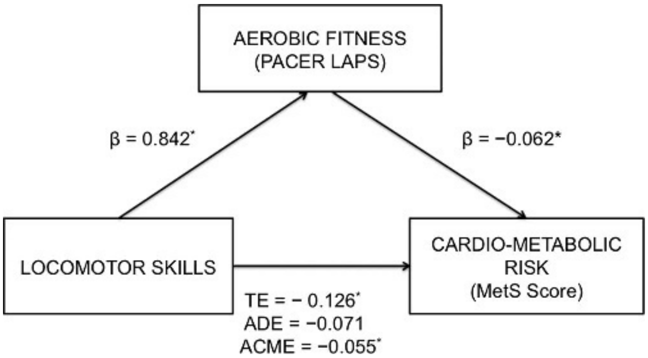

FIGURE 1—A schematic diagram displaying the coefficients relating gross locomotor skills with cardiometabolic risk and the mediating effect of aerobic fitness. Parameters estimated based off of 1000 simulations; *$P < 0.05$.

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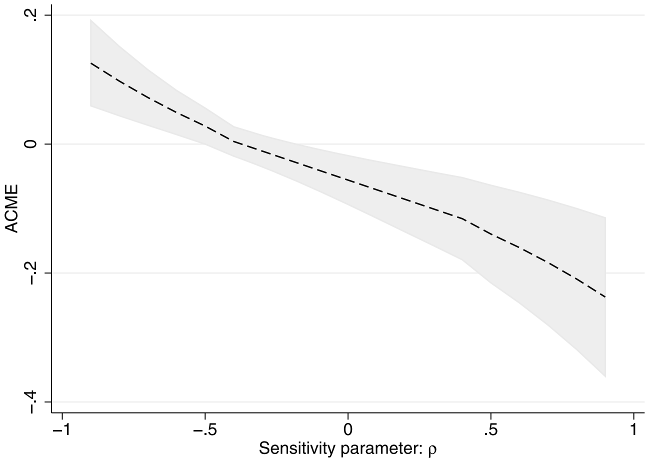

FIGURE 2—Average causal mediation effect as a function of the degree of violating the sequential ignorability assumption.

that interventions be used at an early age for children to improve fundamental movement skill competence. In addition, Hardy et al. (18) suggested that children who are overweight or obese tend to have low competency in locomotor skills partially because of the biomechanical factors of having higher body mass and that overweight or obese children also have low competency for object control movements, especially in movements that require greater locomotion to perform such as one-arm throwing and kicking. The relationships between ball skills (i.e., object control skills) and physical activity have been established in other research as well (11). Indeed, Barnett et al. (4) showed that object control scores collected during childhood significantly predicted adolescent self-reported physical activity 7 yr later, providing evidence that object control proficiency relates to long-term physical activity behaviors. However, the lack of relationship found in this study between ball skills and MetS may be attributable to the youth of the sample, as the relationship between ball skills and health outcomes may manifest as the child tracks into adolescence and into young adulthood.

Despite these established relationships, a potential causal pathway between locomotor skills and aerobic fitness has only been speculative. It has been suggested that competency in gross locomotor skills is needed before a child can engage in optimal levels of MVPA on a daily basis to become physically fit (17). The complex movements involved in games and sports that children participate in to increase physical activity levels may require locomotor skill competency (27). Thus, if a child is competent in locomotor skills, the resultant exposure to physical activity may lead to improved aerobic fitness over time (27). Moreover, it is the physiological trait of having higher levels of aerobic fitness that has been shown to attenuate risk of disease in children and adolescents (9,34).

Much like the postulated relationship between gross motor skills and aerobic fitness, the relationship between gross motor skills and cardiometabolic health is speculative. Stodden et al. (29) postulated a directional relationship among gross motor skills and obesity-related diseases. An extension of the proposed developmental and theoretical pathway can be added in that gross motor skill competency increases the chronic exposure to ambulatory physical activity, which may positively and directly affect aerobic fitness, which may independently affect disease risk (29). The results from this study suggest that locomotor skills significantly relate to a clustered MetS and this relationship is mediated via aerobic fitness. Therefore, the importance of this study is that it provides empirical evidence that the relationships between gross motor skills and cardiometabolic health in youth in middle to late childhood (i.e., third to fifth graders may be 1) specific to locomotor skills, not ball skills, and 2) that the inverse relationship between locomotor skills and cardiometabolic health may be because of the direct effect locomotor skills has on aerobic fitness. However, it is recommended that these data not be generalized beyond this age-group as other studies have shown a greater influence of ball skills on physical activity and health-related fitness outcomes (2,3,5).

Practically, the results from this study provide important implications. It is evident from this study that higher levels of locomotor skills may have a protective effect on cardiometabolic health in low-income children. Practitioners working with low-income children before, during, or after school hours need to be aware of the importance of developing locomotor skills at an early age so that the child can participate in a variety of activities to improve health-related fitness levels. Although directly emphasizing health-related fitness, specifically aerobic fitness, is also important, locomotor skills may be an antecedent to improve aerobic fitness in young children and thus should be an emphasis in physical education curricula or after school programs. Giving attention to low-income children who are struggling with locomotor skill competency may ultimately help the child to improve these skills so that they can achieve optimal aerobic fitness levels and attenuate incidence of early onset cardiometabolic disease risk factors.

There are limitations to this study that should be considered before the results can be generalized. First, the convenience sample consisted of low-income children from the Mountain West region of the United States; therefore, the external validity of the results is questionable if generalized to other regions or to samples with different ethnic and/or socioeconomic representations. The primary limitation is the cross-sectional design of the study. This study only provides empirical evidence of a possible causal mechanism. Longitudinal and experimental research designs are preferable to make valid causal inferences, therefore the statistically significant ACME and nonstatistically significant ADE provides need for additional research to support the causative link.

The results provide insights on how the development of locomotor skills may affect aerobic fitness, which will in turn affect cardiometabolic biomarkers in children from low-income families. The results suggest that the development of

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advanced locomotor skills should be an important emphasis in low-income child development programs for the child to successfully participate in a variety of physical activities and improve aerobic fitness levels. Locomotor skill competency is important for child health and may attenuate risk for cardiometabolic disease as children track through adolescence and into adulthood.

This study was funded the U.S. Department of Education (grant no. S215F140118). The authors thank the students who participated in this study and the graduate research assistants that aided in the data collection process.

The authors report no relevant conflicts of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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