European Journal of Sport Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tejs20

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To cite this article: T. Cade Abrams, Bryan M. Terlizzi, An De Meester, Ryan S. Sacko, J. Megan Irwin, Carlos Luz, Luís Paulo Rodrigues, Rita Cordovil, Vítor P. Lopes, Kirsten Schneider & David F. Stodden (2022): Potential relevance of a motor skill “proficiency barrier” on health-related fitness in youth, European Journal of Sport Science, DOI: 10.1080/17461391.2022.2153300

To link to this article: https://doi.org/10.1080/17461391.2022.2153300

EUROPEAN JOURNAL OF SPORT SCIENCE
https://doi.org/10.1080/17461391.2022.2153300

Potential relevance of a motor skill "proficiency barrier" on health-related fitness in youth

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ABSTRACT
This study investigated the potential impact of a motor skill proficiency barrier on measures of cardiorespiratory (CRF) and musculoskeletal (MSF) fitness in youth. A sample of 241 youth (114 girls) aged 10 - 18 years, completed the Motor Competence Assessment battery with composite scores indexed according to age- and gender-adjusted percentile scores. Motor competence (MC) levels were categorized as low ($\leq 25^{\%\text{tile}}$ – proficiency barrier), moderate ($\geq 26^{\%\text{tile}}$ to $< 75^{\%\text{tile}}$), and high ($\geq 75^{\%\text{tile}}$). CRF levels (Health Risk, Needs Improvement, and Healthy) were assessed using the Fitnessgram® 20 m PACER test. Low ($\leq 20^{\%\text{tile}}$), moderate ($\geq 21^{\%\text{tile}}$ to $\leq 80^{\%\text{tile}}$), and high ($\geq 80^{\%\text{tile}}$) MSF levels were assessed using grip strength normative data. Two 3×3 chi-square tests were conducted to determine the probability of MC level predicting CRF and MSF levels. Results demonstrated statistically significant models for performance on both the PACER ($\chi^2[4, N = 241] = 22.65$, $p < .001$) and grip strength ($\chi^2[4, N = 241] = 23.95$, $p < .001$). Strong evidence of a proficiency barrier impacting CRF was noted, as no low skilled youth met the "Healthy" fitness zone standards for PACER performance. Evidence supporting a barrier with grip strength was not as strong, as 20.8% of youth exhibiting low MC displayed high grip strength. However, all individuals with high levels of MC demonstrated at least moderate grip strength. Results emphasize the importance of developing MC during childhood as it may provide a protective effect against unhealthy CRF and MSF across youth.

KEYWORDS
Cardiorespiratory fitness; musculoskeletal fitness; Fitnessgram; childhood; motor development; Motor Competence Assessment battery

Highlights

- These data support the notion of Seefeldt's (1980) proficiency barrier as it relates to CRF, as no youth demonstrating low MC met the healthy fitness zone criteria for PACER performance. The development of MC may both directly and indirectly provide a protective effect against unhealthy CRF levels across childhood and adolescence.
- Evidence supporting a proficiency barrier with MSF as measured by grip strength was not as strong; however, all individuals with high levels of MC demonstrated at least moderate grip strength. Thus, the development of MC may be a protective factor to mitigate low levels of MSF via enhanced neuromuscular function.
- Promoting the development of MC in a variety of developmentally appropriate activities and settings (e.g. MC skills practice, structured and unstructured play, and performance contexts) is important to promote positive trajectories of CRF and MSF across childhood and adolescence.

1. Introduction

Cardiorespiratory fitness and musculoskeletal fitness (i.e. integrated function of muscular strength, muscular endurance, and muscular power; Pillsbury et al., 2013) are important aspects of overall health-related fitness and are important for long-term health outcomes in youth (Ortega et al., 2008; Pillsbury et al., 2013; Stodden et al., 2017). There has been limited success in promoting and sustaining healthy levels of fitness in youth, as recent data suggests a potential secular

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/17461391.2022.2153300.

decline in health-related fitness (HRF) (Eberhardt et al., 2020). In addition, 58% of youth in the United States fail to demonstrate healthy cardiorespiratory fitness (CRF) levels (Gahche, 2014) and only 5.3% of boys and 12.1% of girls aged 15–19 years demonstrate "excellent" levels of musculoskeletal fitness (MSF) as assessed by age- and gender-specific grip strength (≥ $80^{\%\text{tile}}$; Perna et al., 2016). One potential limitation in current fitness interventions in youth is that they fail to address the critical contribution of the development of neuromuscular coordination and control (i.e. motor skill competence; MC) and age-appropriate activity modalities that impact children's overall fitness and habitual health-enhancing physical activity behaviors (Stodden et al., 2008).

MC is demonstrated through a variety of goal-oriented movement skills (e.g. locomotor, object control/projection and stability/mobility) that are developed across youth (Barnett et al., 2022). In addition, MC is a critical antecedent for the development of HRF and health-enhancing physical activity behaviours via both direct and indirect pathways (Barnett et al., 2022; Cattuzzo et al., 2016; Utesch et al., 2019). Enhanced neuromuscular function resulting from the development of MC directly impacts MSF and indirectly impacts CRF through continued participation (i.e. endurance) in activities inherently involving performance of various motor skills (e.g. running, jumping, hopping, throwing, kicking, striking) with high levels of neuromuscular demand (Cattuzzo et al., 2016; Langendorfer et al., 2013; Sacko et al., 2019; Utesch et al., 2019).

The need for adequate levels of MC that are associated with health-enhancing levels of physical activity and physical fitness has recently been addressed (De Meester et al., 2018; Stodden et al., 2013) relative to the notion of a previously hypothesized motor skill "proficiency barrier," which was first described by Seefeldt (1980). Seefeldt's proficiency barrier initially described the potential existence of a critical level of competence in fundamental motor skills (i.e. locomotor, object control/projection and stability/mobility skills) across childhood as an essential foundation for the development of context-specific transitional skills (e.g. sports and structured/non-structured variants of object control/projection and stability/mobility skills). While this seemingly critical idea was postulated over four decades ago, research attempting to confirm this idea has been conducted only recently (Brian et al., 2020; Costa et al., 2021; Pacheco et al., 2021; dos Santos et al., 2022). If a proficiency barrier does exist, its importance relative to contemporary public health is emerging (Brian et al., 2020; De Meester et al., 2018; Stodden et al., 2013; Malina, 2014); although Haubenstricker and Seefeldt (1986) initially suggested that developing a certain level of competence would facilitate successful participation in a variety of physical activities, specifically vigorous activities. Expanding upon Seefeldt's initial conceptual suppositions, children who fail to build an adequate foundational movement repertoire will not be able to successfully participate in activities requiring context-specific motor skills, limiting subsequent opportunities for HRF development (Stodden et al., 2008; Stodden et al., 2013). Consequently, low HRF levels may limit sustained participation in activities that demand a high level of fitness to be successful; thus, further impacting HRF levels (Ré et al., 2016).

Stodden and colleagues (2013), provided preliminary evidence for a proficiency barrier impacting physical fitness noting that participants who demonstrated low MC levels (≤ $35^{\%\text{tile}}$), relative to a sample of 18–25-year-old adults ($N = 187$), were highly unlikely (only 3%) to demonstrate healthy HRF levels of a composite HRF index, while over 98% of adults with high MC levels (≥ $60^{\%\text{tile}}$) demonstrated at least fair fitness levels (≥ $35^{\%\text{tile}}$ fitness levels; Cooper Institute, 2007). However, no studies have examined whether a motor skill proficiency barrier may potentially impact HRF levels earlier in the lifespan. As such, the purpose of this study was to examine the potential impact of a MC proficiency barrier on measures of cardiorespiratory and musculoskeletal fitness in youth.

2. Materials and methods

2.1. Participants

A convenience sample of 241 participants (boys = 127 [52.7%], girls = 114 [47.3%]) with a mean age of 13.52 years ($SD = 1.8$, range = 10.3 - 18.7; please see Supplemental Material for number of participants in each age range by gender) were recruited from three different school districts in the Southeast region of the U.S. The sample consisted of 17.8% African American, 9.5% Hispanic, 60.2% non-Hispanic White, and 11.2% Other; with 1.2% of participants not reporting their ethnic background ($n = 3$). The study was approved by the university's institutional review board and the administration of each school participating in this study. Parents gave their informed consent and youth gave their verbal assent to participate in the study. Participants with a medical concern that could be worsened by physical activity were excluded from the study.

2.2. Procedures

We implemented a cross-sectional design collecting data on MC, MSF, and CRF constructs. We assessed MC using the Motor Competence Assessment (MCA; Luz et al., 2016), which is a valid and reliable product-oriented test battery that assesses quantitative skill performance in three subcategories: a) stability is measured with the shifting platforms and lateral jumping tests, b) locomotor competence with the shuttle run and the standing long jump test, and c) manipulative/object control with kicking and throwing velocity (Rodrigues et al., 2019). All raw performance scores were converted into age- and gender-adjusted percentile scores (Rodrigues et al., 2019).

Shifting platforms (SP): participants moved sideways along a straight line as fast as possible in 20s using two wooden platforms (25 cm × 25 cm × 2 cm with four 3.7 cm feet at the corners). Participants received two points for each successful transfer from one platform to another. Participants completed two trials and the best score was used for data analysis.

Lateral jumping (LJ): participants jumped laterally over a small wooden beam (60 cm length × 4 cm high × 2 cm width) with both feet together, as fast as possible for 15s. Participants completed two trials and the best score was used for data analysis.

Shuttle run (SHR): participants sprinted 10 m, picked up a wooden block (10 cm high, 5 cm in diameter), sprinted back to the starting line, placed the wooden block at or beyond the starting line, then sprinted to pick up a second wooden block, and ran back across the starting line with the second wooden block to complete the trial. The time to complete the shuttle run was measured with a stopwatch. Participants completed two trials and the best (i.e. the fastest) time of the two trials was used for data analysis.

Standing long jump (SLJ): participants jumped as far as possible and landed with two feet. The distance between the start line and the back of the heel closest to the start line was measured to the nearest centimeter and recorded as the distance jumped. Participants completed three trials and the best score (i.e. the furthest jump) was used for data analysis.

Throwing and kicking velocity (TV and KV): participants threw a tennis ball (6.5 cm in diameter; weight 57 g) and kicked a playground ball (21.59 cm in diameter; weight 410g) with "maximal effort" toward a wall from approximately 6 m. Peak ball velocity was measured using a radar gun (Stalker Pro II, Stalker Inc., Richardson, TX). Participants completed three trials of each skill and the highest velocity was used for data analysis.

Composite scores for each subcategory (e.g. stability, locomotor competence, and manipulative/object control) were obtained by calculating the average of the age- and gender-adjusted percentile scores of all skills in each subcategory. Overall MC percentile composite scores were determined by averaging the composite scores for each subcategory and used for data analysis. Similar to previous literature (De Meester et al., 2018), MC levels were categorized as low ($\leq 25^{\%tile}$ – proficiency barrier), moderate ($\geq 26^{\%tile}$ to $< 75^{\%tile}$), and high ($\geq 75^{\%tile}$) to examine their predictive utility in relation to HRF levels (Stodden et al., 2013).

Cardiorespiratory Fitness (CRF): Participants completed the Progressive Aerobic Cardiovascular Endurance Run (PACER; Fitnessgram®) test which has strong validity and reliability in youth (Welk, Going, et al., 2011). Participants run from a starting line to a parallel line 20-meters away, while keeping pace with a pre-recorded audio cadence. The audio cadence pace begins at an initial running speed of 2.36 $m \cdot s^{-1}$ and increases by 0.14 $m \cdot s^{-1}$ at each successive stage (McClain et al., 2006). The PACER test was terminated when a participant was unable to complete two consecutive laps in the allotted time or voluntarily dropped out due to fatigue. The number of laps completed by each participant were converted into an estimated VO_2 max according to age and gender and indexed into three levels according to Fitnessgram® standards ("Health Risk", "Needs Improvement" or "Healthy"; Welk, Maduro, et al., 2011).

Musculoskeletal Fitness (MSF): Participants completed a grip strength assessment using a children's hand grip dynamometer (JAMAR® PLUS +) as a global measure of MSF (Ortega et al., 2008). Grip strength has moderate to strong construct validity ($r = .52$ - $.70$) with one-repetition maximum upper-body and lower-body strength assessments and strong reliability ($r = .71$ - $.90$) in youth (Milliken et al., 2008; Ruiz et al., 2006). Three maximal effort trials on each hand were averaged and used for data analysis (Ortega et al., 2008). Participants' grip strength scores were allometrically scaled to adjust for body mass, height, age, and gender (Kocher et al., 2019) and categorized as low ($\leq 20^{\%tile}$), moderate ($\geq 21^{\%tile}$ to $< 80^{\%tile}$), and high ($\geq 80^{\%tile}$; Pillsbury et al., 2013) using U.S. normative data (Kocher et al., 2019).

2.3. Statistical analysis

We conducted all analyses using the statistical software R, version 4.0.3. We calculated Pearson's bivariate correlations to demonstrate general associations among MC, MSF, and CRF variables. We investigated the potential impact of a MC proficiency barrier on measures of CRF and MSF, by conducting two 3×3 chi-square tests of independence. In both chi-square analyses, we used MC composite scores as the independent variable to determine the probability of MC levels (i.e. Low [$\leq 25^{\%tile}$], Moderate [$\geq 26^{\%tile}$ to $< 75^{\%tile}$], High [$\geq 75^{\%tile}$]) predicting CRF and MSF level classifications. We calculated effect size for each chi-square test of independence using Cramer's V and interpreted the values as follows: .07 - .20 as small; .21 - .34 as medium; $\geq$ .35 as large (Pallant, 2020). We implemented an alpha level of $p \leq .05$ to determine statistical significance.

3. Results

Descriptive statistics for height, weight, estimated VO_2 max, raw grip strength, MCA subcategories and composite MCA scores grouped by MC level, are located in Table 1. Bivariate correlations among MC, CRF, and MSF variables were generally weak to moderate ($r = .20$ - .44; see Table 2 for individual MC, CRF, and MSF correlations). Chi-square analyses demonstrated statistically significant models with medium effect sizes (Pallant, 2020) for both CRF ($\chi^2[4, N = 241] = 22.65$, $p < .001$, $V = .217$) and MSF ($\chi^2[4, N = 241] = 23.95$, $p < .001$, $V = .223$). A post-priori power analysis indicated that our ability to detect medium effects ($V = .217$, .223) for CRF and MSF were .78 and .80, respectively.

Data from the 3×3 chi-square analyses are shown in Tables 3 and 4. No youth exhibiting low MC ($\leq 25^{\%tile}$) met the "Healthy" fitness zone standards for PACER performance (0/24) and only 20.8% (5/24) of youth exhibiting low MC displayed high levels of grip strength ($\geq 80^{\%tile}$). In addition, 87.5% (21/24) of low MC youth demonstrated scores in the "Health Risk" fitness zone for PACER performance and 51.7% (15/29) of youth exhibiting high MC ($\geq 75^{\%tile}$) achieved "Healthy" fitness zone levels of CRF. Only 27.6% (8/29) of high MC youth demonstrated scores in the "Health Risk" fitness zone for PACER performance. All youth (29/29) demonstrating high MC displayed at least moderate levels grip strength ($> 20^{\%tile}$).

Table 1. Means and standard deviations for height, weight, estimated VO_2 max scores, and grip strength by level of motor competence.

	Low MC (*n* = 24)	Moderate MC (*n* = 188)	High MC (*n* = 29)
	M (SD)	M (SD)	M (SD)
Height (cm)	160.48 (13.14)	159.65 (11.60)	156.33 (15.70)
Weight (kg)	73.05 (21.44)	61.72 (19.86)	51.04 (9.93)
Est. VO_2 Max (mL·kg^1·min^1)	35.09 (2.36)	38.27 (4.80)	41.07 (4.60)
Grip Strength (kg)	29.49 (11.93)	29.97 (10.69)	29.93 (8.40)
MCA Stability	12.74 (10.55)	35.97 (20.05)	62.30 (16.57)
MCA Locomotor	7.80 (8.88)	42.81 (26.06)	88.81 (17.77)
MCA Object Control	35.14 (12.91)	75.37 (16.72)	92.61 (8.32)
MCA Overall	17.99 (5.19)	51.32 (13.73)	81.24 (4.47)

Note. Grip Strength was calculated by averaging maximal contraction values for the right and left hands.

4. Discussion

The aim of the current study was to expand Seefeldt's initial conceptualization of a proficiency barrier by examining the potential impact of a MC proficiency barrier on measures of CRF and MSF in youth. In the current sample, *zero* of the 24 (≈ 10% of total sample) youth who performed at or below the $25^{\%tile}$ on the MCA demonstrated "healthy" levels of CRF, which provides indirect evidence of a MC proficiency barrier below the $25^{\%tile}$ in relation to CRF. These results generally correspond with previously published data from early adulthood (Stodden et al., 2013) and indicate the development of MC in childhood and adolescence may have implications for cardiorespiratory health across the lifespan. Approximately 21% of youth below the $25^{\%tile}$ of MC demonstrated grip strength at or above the $80^{\%tile}$ of allometrically scaled grip strength and did not provide sufficient evidence to support a potential MC proficiency barrier at the $25^{\%tile}$. However, the development of high MC may provide a protective effect for MSF as 100% of individuals displaying levels of MC greater than or equal to the $75^{\%tile}$ did not exhibit low levels of grip strength ($\leq 20^{\%tile}$).

The respective relationships demonstrated with MC between CRF and MSF are impacted by both direct and indirect mechanisms that contribute to the development and sustained levels of these two fitness components across youth. The concurrent development of both CRF and MSF is directly impacted by context-specific experiences that establish a foundation of MC (e.g. structured and unstructured play, sports, and specific skill practice; Cattuzzo et al., 2016; Stodden et al., 2014). Effortful practice and performance of various locomotor and manipulative/object control skills found in context-specific activities inherently demand high neuromuscular involvement via inter-

Table 2. Correlations of motor competence (MC) composite, estimated VO_2 max, and allometric grip strength percentile (N = 241).

Variable	M	SD	MC Composite	Est. VO_2 Max (mL·kg^1·min^1)
1. MC Composite	51.68	19.28	—	
2. Est. VO_2 Max (mL·kg^1·min^1)	38.29	4.78	.39** [.28, .49]	—
3. Allometric Grip Strength Percentile	54.52	31.75	.44** [.33, .54]	.20** [.08, .32]

Note. Values in brackets indicate the 95% confidence interval for each correlation.
*$p < .05$. **$p < .01$.

Table 3. Chi-square cross-tabulation for motor competence Levels × PACER healthy fitness zone (HFZ) levels.

	PACER HFZ			
MC Level	Health Risk	Needs Improvement	Healthy	Total
Low (≤ 25$^{\%tile}$)	21	3	0	24
	87.5%	12.5%	0.0%	
Moderate (≥ 26$^{\%tile}$ to < 75$^{\%tile}$)	110	31	47	188
	58.5%	16.5%	25.0%	
High (≥ 75$^{\%tile}$)	8	6	15	29
	27.6%	20.7%	51.7%	
Total	139	40	62	241
	57.7%	16.6%	25.7%	

Note. Percentage values are within each MC Level (i.e. Low, Moderate, High).

and intra-muscular coordination and control (e.g. motor unit recruitment, rate coding, synergistic muscle recruitment strategies; Stodden et al., 2014) as well as endurance (Cattuzzo et al., 2016). Specifically, high effort skill practice inherently exploits mechanical and neuromuscular properties within the kinetic chain, promoting cumulative increases in eccentric muscle loading (preparatory movement phases and passive kinetic chain mechanisms) and subsequent concentric muscle contractions (acceleration phases of movement patterns; Langendorfer et al., 2013). Thus, the development of more advanced skill levels is associated with simultaneous progression in force absorption and force production capabilities (Stodden et al., 2014; Stodden & Brooks, 2013). Additionally, the cardiorespiratory demands of the PACER test are well documented and were definitively linked to a proficiency barrier (≤ 25$^{\%tile}$) in this sample, the greater overall speed, acceleration, and deceleration (i.e. change of direction - agility) speak to the increasing neuromuscular demands at shorter time intervals in later stages of the assessment. Thus, MC seems to promote a global protective effect for both CRF and MSF.

Individuals with low MC do not engage in adequate context-specific practice and performance of the various skills needed to consistently promote advanced coordination and control across multiple skills (Brian et al., 2020; Costa et al., 2021; Pacheco et al., 2021; dos Santos et al., 2022); thus, limiting their opportunities for developing and sustaining MSF (Barnett et al., 2022; Costa et al., 2021; dos Santos et al., 2022; Stodden et al., 2008). This lack of experience in developing various motor skills is undoubtedly linked to a lack of participation in various moderate-to-vigorous physical activities (e.g. structured and unstructured play and sports) that promote CRF (De Meester et al., 2018; Fransen et al., 2014).

Table 4. Chi-square cross-tabulation for motor competence Levels × Allometric grip strength levels.

	Allometric Grip Strength Level			
MC Level	Low (≤ 20$^{\%tile}$)	Moderate (≥ 21$^{\%tile}$ to < 80$^{\%tile}$)	High (≥ 80$^{\%tile}$)	Total
Low (≤ 25$^{\%tile}$)	11	8	5	24
	45.8%	33.3%	20.8%	
Moderate (≥ 26$^{\%tile}$ to < 75$^{\%tile}$)	27	98	63	188
	14.4%	52.1%	33.5%	
High (≥ 75$^{\%tile}$)	0	14	15	29
	0.0%	48.3%	51.7%	
Total	38	120	83	241
	15.8%	49.8%	34.4%	

Note. Percentage values are within each MC Level (i.e. Low, Moderate, High).

The practice of discrete object control/projection skills are not traditionally regarded as a strategy for promoting acute moderate-to-vigorous physical activity (MVPA) levels, hence promoting CRF development (Khodaverdi et al., 2017). However, recent data demonstrates that object control/projection skill practice promotes at least moderate intensity PA in both boys and girls, with vigorous to highly vigorous activity intensity being promoted when practice trials are performed with greater frequency (Sacko et al., 2019). And, as higher skill levels are associated with greater neuromuscular demand, more advanced skill performance elicits higher energy expenditure levels (i.e. activity intensity) than low skilled performance (Sacko et al., 2021). Thus, the process of developing MC both directly (via specific skill practice) and indirectly (via associated locomotor activities performed during play, sports, and practice contexts) promotes the development of CRF. Although high levels of MC did not guarantee that individuals attained high levels of CRF (i.e. 51.7%), results suggest that the development of high MC does provide a protective effect against low levels of CRF. Overall, youth with high MC were over three times less likely to demonstrate low CRF (High MC = 26.7%, Low MC = 87.5%) in this sample than youth with low MC (see Table 3).

As previously noted, this study did not provide sufficient evidence to suggest a potential MC proficiency barrier between low MC (≤ 25$^{\%tile}$) and high levels (≥ 80$^{\%tile}$) of grip strength. However, youth with high MC did not demonstrate low grip strength (≤ 20$^{\%tile}$). In effect, these data indicate the development of high MC may be a protective factor against low levels of MSF as assessed by grip strength, which has been noted as a relatively strong predictor of overall MSF (Ortega et al., 2008; Perna et al., 2016). Many physical activities involving the performance of gross motor skills rely on musculature involved with gripping to effectively coordinate the transfer of forces through the kinetic chain. For example, in striking and throwing performance, the hands and wrists represent the most distal aspect of the body's kinetic chain and are subject to the highest joint angular velocities during skill performance. As such, significant neuromuscular demand is placed on the involved forearm, wrist, and hand musculature in order to efficiently transfer kinetic energy and produce high terminal projectile or implement speeds (e.g. ball, bat, racket, club, etc.; Langendorfer et al., 2013). Similarly, physical activities, such as gymnastics, that require various forms support and/or suspension of one's body weight through the hands (e.g. crawling, climbing, hanging), may stimulate the development of higher levels of grip strength and overall upper body strength. In both of these examples of gross motor skills, the involvement of musculature, specific to gripping, is just one component related to the complex coordination demands in various skills. Other assessments of MSF that involve a greater emphasis on multi-joint coordination and total body strength and power requirements (e.g. deadlifts, squats, crossover hop, supine-to-stand and go, medicine ball throw) may provide a stronger link to a definitive MC cut point that can be used to assess the potential of a MC proficiency barrier in relation to healthy levels of MSF. Thus, additional research is needed to establish specific measurements of MSF in childhood and adolescence and their relationship with a potential MC proficiency barrier.

Beyond the acute enhancement of CRF directly and indirectly influenced by MC development and activities inherently involving skill performance, a focus on MC development may be viable for promoting sustained fitness levels across age because of the impact that MC has on the development of physical self-concept and other motivational factors relating to habitual physical activity behaviors (De Meester et al., 2020; Stodden et al., 2008). Individuals who develop an adequate base of MC in childhood are generally more confident in their abilities and motivated to participate in a wide variety of activities that can concurrently promote further development of MC, CRF, and MSF (De Meester et al., 2016; De Meester et al., 2018; Stodden et al., 2008). Conversely, individuals who fail to acquire a diverse foundation of MC may limit their potential for successful and enjoyable experiences in health-enhancing activities across adolescence and into young adulthood (Seefeldt, 1980).

The current study was limited in a few ways. First, the cross-sectional design only provides indirect evidence to support our hypothesis as an MC level associated with the 25$^{\%tile}$ was implemented based on normative data of the MCA. As the proficiency barrier was originally suggested to impact an individual's capability to successfully apply fundamental motor skills to more complex transitional skills, a definitive proficiency barrier has yet to be firmly established (Costa et al., 2021; Pacheco et al., 2021). Additional longitudinal studies across childhood and adolescence are needed to sufficiently address the proficiency barrier hypothesis. Second, our study did not comprehensively measure MSF (e.g. muscular endurance, strength, and power); however, grip strength is noted as a strong global measure of MSF (Pillsbury et al., 2013). In lieu of normative grip strength cut points being associated with specific health outcomes, we followed the Institute of Medicine's suggested 20th percentile as a proxy for low MSF levels. Third, we did not attempt to delineate a MC proficiency barrier for MSF or CRF based on age groups (i.e. childhood and adolescence). We used age-normed percentile data (MC and grip strength) and age-normed healthy-fitness zones (PACER) data, which demonstrates the global nature of a potential MC proficiency barrier that spanned a wide age range in youth (i.e. 10 - 18). Lastly, the results of this study were based on one sample of youth in the southeastern U.S. and further research is needed with larger samples across childhood and adolescence in multiple countries to confirm the existence of a MC proficiency barrier on CRF and MSF.

5. Conclusion

In summary, failure to acquire adequate levels of competence in a broad foundation of motor skills during childhood and adolescence limits avenues for participating in health-enhancing physical activities, thereby presenting a potential barrier for subsequent progression of CRF and MSF trajectories (Seefeldt, 1980; Stodden et al., 2008). Promoting MC early in life is critical as complex multijoint skill development is a sequential and cumulative process that does not occur without substantial developmentally appropriate experiences across childhood and adolescence. As recent data demonstrates a potential secular decline in MC (Brian et al., 2019; De Meester et al., 2018) and CRF and MSF in youth (Eberhardt et al., 2020), our results emphasize the importance of developing a broad foundation of MC during youth as it both directly and indirectly impacts the development of CRF and MSF. The development of diverse motor skill repertoires in childhood enables individuals to successfully perform in many health-enhancing physical activity contexts (Seefeldt, 1980) that also foster positive self-perceptions and subsequent motivation for longitudinal physical activity engagement and continued development of MC, CRF, and MSF across childhood and adolescence.

Acknowledgments

The authors are grateful to the children and adolescents who participated in this study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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