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Impact of motor competence profiles on adolescents' physical activity and cardiorespiratory fitness across four years.

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Abstract

Introduction

Physical activity levels have decreased over past decades with most adolescents neither meeting the current physical activity recommendations nor demonstrating adequate cardiorespiratory fitness. Motor competence (MC) is foundational for a physically active lifestyle; however, children demonstrate significant differences in their levels of MC in a broad foundation of movement skills. This study investigated developmental patterns of physical activity and cardiorespiratory fitness in children across 4 years based on their longitudinal MC profiles.

Methods

The data included annual measurements of MC, accelerometry-measured moderate-to-vigorous physical activity (MVPA), and cardiorespiratory fitness over 4 years from the age 11 to 15 ($n = 1147$, girls 582, boys 565). Latent profile analysis was used to identify longitudinal MC profiles and latent growth curve modeling to examine intercepts and slopes (s) of MVPA and cardiorespiratory fitness in these MC profiles.

Results

Three different longitudinal MC profiles were identified: low, moderate, and high. The MC profiles showed significant differences in intercepts of cardiorespiratory fitness and MVPA. The high MC profile showed the highest intercepts for both, but also a statistically significant decline in MVPA over time ($s = -3.36$, $p < .001$). Cardiorespiratory fitness increased similarly in all three profiles over time: low ($s = 1.20$, $p < .01$), moderate ($s = 1.28$, $p < .001$), high ($s = 2.21$, $p < .001$).

Conclusion

These results highlight the long-term associations between different MC profiles and development of MVPA and cardiorespiratory fitness. Adolescents with lower MC demonstrated lower levels of MVPA and cardiorespiratory fitness, indicating decreased participation in physical activities that can optimally enhance cardiorespiratory fitness. However, significant differences in MVPA levels between MC profiles faded over time in adolescence, whereas significant differences in cardiorespiratory fitness remained.

Key words: motor proficiency barrier, motor development, person-oriented, longitudinal study.

Introduction

Physical activity is important for a healthy lifestyle and for the prevention of overweight and obesity (1). Increasing the amount and intensity of physical activity also positively impacts cardiorespiratory fitness, and hence cardiometabolic health, in adolescents (2). As majority of youth do not meet current physical activity guidelines (3) nor demonstrate adequate cardiorespiratory fitness (4), it is important to identify the critical factors that impact long-term physical activity and fitness behaviors and habits (5, 6).

Motor competence (MC) refers to goal-directed movement skill levels that involve large muscle groups (7), including locomotor (moving the body from one place to another), object projection/control (ability to manipulate and project an object), and balance skills (ability to maintain a controlled body position during task performance) (8). While all children can develop MC through context-specific free play and structured physical activities (5), not all children reach the same level (9, 10) as not all may have the same opportunities to learn these skills (5). It is crucial to understand that the physical activity environment impacts not only the learning of MC skills, but also the amount and intensity (e.g., light, moderate, vigorous) of physical activity, which impacts cardiorespiratory fitness (5). Thus, while all physical activity is beneficial, exploring and learning a wide variety of movement skills and being able to transfer those skills to higher-level movement applications provides a diversified foundation for both directly (via greater neuromuscular demand) (11) and indirectly (via sustained activities associated with practice, gameplay, and performance) enhancing cardiorespiratory fitness (12). Better cardiorespiratory fitness allows children to continue physical activities for longer periods of time and thus provides more opportunities for motor development and physical activity accumulation (5, 7).

Physical activity levels tend to decrease across childhood (13), whereas cardiorespiratory fitness, enhanced by physiological growth and maturation, tends to increase (14). However, these trajectories show significant inter-individual variation (9, 15), which may partly be explained by different levels of MC (16). Previous reviews have concluded that MC is positively associated with physical activity (7, 17, 18) and cardiorespiratory fitness (17, 19, 20). However, understanding the skill level needed to facilitate enhanced physical activity and fitness trajectories remains unknown. In 1980, Seefeldt (21) introduced the idea of a motor skill proficiency barrier, below which individuals would find learning advanced skills more difficult. Haubenstricker and Seefeldt (22) also considered that adequate levels of MC are important for promoting successful participation in physical activities, specifically vigorous ones. Malina (23) also favored researching the idea of a motor skill proficiency barrier given the limited success of efforts to mitigate current negative trends in physical activity, fitness and increasing obesity levels in children and adolescents.

Previous longitudinal studies have reported less favorable development of cardiorespiratory fitness (9, 24, 25, 26) and physical activity (27, 28) in individuals with low MC. However, a recent systematic review (18) noted that further longitudinal evidence is required to demonstrate a direct pathway from MC to physical activity. Thus, the developmental pathways of physical activity and cardiorespiratory fitness based on different MC profiles over time may be better understood using person-oriented methods. This study is the first to identify data-driven longitudinal MC profiles for studying the latent growth curves of both device-measured physical activity and cardiorespiratory fitness. The study had three aims: 1) to identify and study subgroups of children based on their MC scores over four years; 2) to investigate intercepts and slopes of physical activity and cardiorespiratory fitness in each MC subgroup over four years; and 3) to examine the relationship between development of physical activity and cardiorespiratory fitness in each MC subgroup.

Methods

Participants

This four-year follow up study was conducted during 2017-2021 in four cities in south, north, central, and east Finland. Participants were all consenting 5th graders (n = 1147) in 35 randomly selected elementary schools and accounted for 2 % of the same-age Finnish population (Mage at baseline 11.37±0.33). All samples were representative of their local population. Data were collected five times in the years 2017-2021 (T0-T4) annually between August and October. Cardiorespiratory fitness, MC and anthropometric data were collected during school hours in indoor gym settings by trained researchers. Device-measured MVPA was assessed using accelerometers. Verbal consent from the participating children and written consent from their guardians was obtained prior to study start. The study was approved by the University of Jyväskylä ethics committee for human research.

Measurements

Motor competence (MC). In the first data collection (T0), participants performed the 5-leaps test, throw-catch combination and three KTK (Körperkoordinations Test für Kinder) (29) subtests: walking backwards, jumping laterally, and moving sideways. Thereafter, the 5-leaps test, jumping laterally and throw-catch combination were performed annually each fall (T1-T4). The *5-leaps* test was conducted by performing five consecutive horizontal jumps with joined feet position at the start. From the starting feet position, participants were instructed to jump forward using the leg of choice and, after four further leaps, land on both feet. The result was expressed in meters as the overall distance covered. The *throw-catch combination* was performed by throwing a tennis ball at a target square (90 cm x 90 cm) marked on a wall at 90 cm above floor level and then catching the ball after one return bounce. Both the 5-leaps and throw-catch combination tests are extensively used in Finnish sport science studies (30).

Participants were instructed to perform 20 trials and the result was the sum of successfully completed trials. Throwing distance depended on the participant's grade and gender and ranged from 7 to 10 meters. *Walking backwards* consisted of walking backwards on each of three balance beams 6 cm, 4.5 cm, and 3 cm wide, respectively. After a practice trial, participants were instructed to slowly walk backwards on the 6-cm beam, trying to avoid contact with the ground. 9 trials, 3 per beam were performed. The result was the sum of all error-free steps backwards across trials. The maximum score for each trial was 8, and thus the potential maximum score was 72. *Jumping laterally* consisted of jumping over a dividing line as quickly as possible for 15 seconds. Participants were instructed to take off from and land on both feet simultaneously. The result was the sum of jumps across two trials. *Moving sideways* required participants to move small wooden blocks in a sequence from left to right, continually placing the feet on the block just moved to the right. Participants were instructed to move the blocks as quickly as possible for a period of 20 seconds. The result was the number of moves summed across two trials. As the MC variables were not commensurate, they were standardized as Z-scores.

Cardiorespiratory fitness. The 20-meter shuttle run test (31) was used to assess cardiorespiratory fitness. Participants ran back and forth between two parallel lines 20 meters apart. The running pace for each 20-meter shuttle was determined by the frequency of recorded beeps. The initial running velocity was 8.5 km/h for the first minute, increasing by 0.5 km/h for each minute thereafter. The result was the number of completed shuttles. Participants were instructed to terminate the test when they were no longer able to keep pace with the beeps.

Device-measured MVPA. Participants' MVPA was assessed using Actigraph wGT3+ accelerometers. Participants were instructed to wear the accelerometer on their right hip for seven consecutive days. Accelerometers were removed while sleeping and bathing or doing water-based activities. Data were collected as raw accelerations at a 30-Hz frequency and converted into 15-s epoch counts. Data were reduced using Customized Visual Basic Macro for Excel software. A valid day of physical activity monitoring comprised measured values ≥500 min/day on at least two weekdays and one weekend day between normal waking hours (i.e., 7:00-23:00). Consecutive zero counts lasting 30 min were defined as non-wear time and values over 20 000 counts per minute considered spurious accelerations and discarded (32). Cut points from Evenson et al. (33) were used to calculate MVPA (≥2296 cpm).

Anthropometric measurements. Height was measured to the nearest .1 cm using portable measuring equipment. Body weight was measured to the nearest .1 kg using calibrated scales, with the children wearing light clothing and barefoot. Participants' body mass index was calculated using a weight (kg) and height (m) formula (kg/m^2). Participants peak height velocity was identified to predict maturity. The maturity offset was calculated using equation with age and height from T0 to T4 following the procedures of Moore et al. (34).

Data analysis

Descriptive statistics, including means and standard deviations, were calculated for the observed variables, and outliers and missing values were examined. For nested groups (i.e., different school classes, between-group differences in the observed motor competence, MVPA and cardiorespiratory fitness variables were analyzed using intraclass correlations (ICC). After the preliminary analysis, a two-step analysis (regression auxiliary model) was implemented to identify longitudinal MC profiles based on MC measurement z-scores at T0-T4 and to examine intercepts and slopes in MVPA and cardiorespiratory fitness in each MC profile. In the first analysis, MC latent profiles were estimated, and Bose-Chaudhuri-Hocquenghem (BCH) weights saved. In the subsequent analysis, latent growth curve models, using BCH weights, conditional on the MC latent profile variable, were estimated (35).

Latent profiles analysis aims to identify types or groups of people that have different configural profiles of personal attributes, such as motor skills (balance skills, locomotor skills, object control skills). Thus, mean Z-scores for all MC measurements at each time point (T0-T4) were entered simultaneously into the latent profile analysis. The analysis was conducted for from two to five profiles to confirm the optimal number of profiles. Statistical indicators included Akaike's information criterion (AIC), Bayesian information criterion (BIC), the adjusted BIC (ABIC), entropy, and the adjusted Lo-Mendell-Rubin likelihood ratio test (ALMR-LTR). Models with low AIC, BIC and ABIC indices and higher entropy indicate better fit to the data. In the ALMR-LTR, a p-value > .05 suggested that the k-pattern solution did not fit the data any better than the k-1 solution. Additionally, to avoid problematic models, profiles containing less than 5% of participants were excluded. After selecting the best-fitting model, based on these statistical indices, each MC profile was assigned a descriptive label. In the second analysis, latent growth curve models for physical activity and cardiorespiratory fitness were estimated to examine intercepts and slopes over time in each MC profile, where intercept describes the baseline from which the slope begins at T0, and slope describes the rate of change. ANOVA with Tukey's Post Hoc analyses was performed to identify statistical differences in variables' mean levels between the MC profiles. Logistic regression coefficients were used to estimate the odd ratios of the MC profiles to achieve MVPA guidelines. Descriptive statistics, ANOVA, logistic regression and the missing completely at random (MCAR) test were performed using SPSS 26.0. The model was estimated using Mplus Version 8.6.

Results

Descriptive statistics (means and standard deviations) for each measurement in each MC profile and the significant differences between profiles are presented in Table 1. Participants' mean age at baseline (T0) was 11.27 ±0.32 years. Correlations between MC variables and MVPA and cardiorespiratory fitness at each time point are presented in table 2. Correlations varied from low to moderate. The strongest correlations were found between cardiorespiratory fitness and the 5-leaps test. As the proportions of students completing all the measurements decreased annually, missing values (11 594 out of 32 116) accounted for 36 % of the data. However, closer inspection of the data revealed that the missing values were not attributable to any specific school or group. The Missing Completely at Random (MCAR) test indicated that missing values ($\chi^2(11\ 607) = 10\ 905$, $p < .001$) were missing at random (MAR). Missing values were assessed using the mixture likelihood procedure that has been shown to generate reliable parameter estimates and standard errors under MAR conditions (36). The data with nested groups, i.e., collected from school classes, were expected to display a hierarchical structure. The ICC p-values indicated small but significant variation between school classes in cardiorespiratory fitness and MC measurements (see Table 3). Thus, the regression auxiliary model was implemented using the complex model option to control for non-independence of observations due to nesting in school classes. As the number of participants willing to wear the accelerometer decreased annually, the differences between wearers and non-wearers at T4 was tested with the independent sample T-test. No significant between-group difference in MVPA was found at T0-T4.

Latent profile analysis. Latent profile memberships based on annual MC z-scores at T0-T4 were identified. As presented in table 4, with the increasing number of profiles from two to three AIC, BIC and ABIC indices decreased. However, after the three-profile solution, the AIC, BIC and ABIC indices decreased only marginally. The entropy was the highest in three-class solution. Although, the ALMR-LTR p-value (.066) suggested that three-profile solution did not significantly improve the model compared to two-profile solution, after careful consideration of all the indices together (AIC, BIC, aBIC, ALMR-LTR and entropy), the three-profile model was selected for further analysis. Profiles were derived from the MC z-scores for the 5-leaps, throw-catch combination, and jumping laterally tests at five time points (T0, T1, T2, T3, T4) and walking backwards and moving sideways tests at the first time point only (T0). As presented in table 1, the low MC profile contained about one-fifth, the moderate MC profile nearly half and the high MC profile 30 % of the participants. Both genders were almost equally distributed across all profiles and there were no significant differences in maturation offsets between profiles at T0-T4. BMI differed significantly between all three profiles at T0-T3, but at T4 only low MC profile differed significantly from other two (See table 1). The three MC profiles were labeled low, moderate, and high based on their MC mean values (see table 1) and z-score levels at each time point (see figure 1). Differences in mean MC scores for each assessment between profiles were significant, relatively large, and equal at each timepoint (see table 1). For example, in the throw-catch combination test, the mean annual score in the low MC profilers was 7.2/20 compared with the 15.6/20 in the high MC profilers. Thus, the low MC profilers' object control skills scores were 54 % lower than those of the high MC profilers. The difference in the 5-leaps test also favored the high MC profilers (9.5m vs. 7.4m). Thus, the low MC profilers' locomotor skill scores were 22 % lower than those of the high MC profilers.

MVPA and cardiorespiratory fitness based on MC profiles over time. Latent growth curves were estimated for each of the three MC profiles to examine intercepts and slopes of MVPA and cardiorespiratory fitness. Results showed that intercepts of MVPA and cardiorespiratory fitness were significantly different between MC profiles. Intercepts were lowest in the low MC profile and highest in the high MC profile (see table 5). The MVPA intercept was over 25 minutes higher in the high MC profile compared to the low MC profile. Slopes indicated that there were not significant changes in MVPA in the low or moderate MC profiles over time. However, the high MC profile showed a significant negative slope (s = -3.36) in MVPA, indicating that MVPA significantly decreased over time (from 70 to 56 min) (see figure 2). Mean MVPA levels were significantly different across all profiles at first three time points. At the fourth time point, only the difference between high and low MC profiles was significant and there were no significant differences between profiles at the last time point (see table 1). Depending on the year, 46-64 % of the high MC profilers engaged in over 60 minutes of MVPA per day, compared to 24-36 % of the moderate and 6-22 % of the low MC profilers (see table 1). Moreover, the odd ratios showed that the high MC children were 3.5 to 16 times more likely to meet the guidelines than their low MC peers (see table 1).

The CRF intercept was, on average, 32 laps higher in the high MC profile compared to the low MC profile. The slopes of cardiorespiratory fitness demonstrated statistically significant increase in each MC profile. There were no significant differences in slopes, indicating that cardiorespiratory fitness increased similarly in all three MC profiles (see table 5 and figure 3). Mean CRF levels were significantly different between MC profiles at all time points (see Table 1). Differences in laps across profiles were fairly consistent and ranged from 14 and 30 laps at each time point, representing differences in mean VO_2max estimates of up to 7 ml/kg/min between profiles (31).

A significant positive correlation ($r = .646$, $p < .01$) was found between the slopes in MVPA and cardiorespiratory fitness, but only in the high MC profile, indicating that the steeper the decrease in MVPA, the slighter the increase in cardiorespiratory fitness (see table 5).

Discussion

This study examined physical activity and cardiorespiratory fitness trajectories from late childhood to adolescence based on different longitudinal profiles of MC. A two-step model was applied to study both profiles and their distal outcomes. Three MC profiles were identified: low, moderate, and high. Differences in mean MC scores between profiles were significant and generally large and consistent over time, indicating MC levels are generally determined earlier in childhood. The intercept of MVPA at T0 was highest in the high MC profile (70.13 min/day), which was 14 more min/day and 25 min/day higher than intercepts of MVPA of the moderate

(56.67) and low MC profiles (44.82), respectively. The slope of MVPA was significant and negative only in the high MC group, resulting in that differences in mean MVPA levels between profiles were not significant at the last time point between profiles. Second, the cardiorespiratory fitness intercept was highest in the high MC profile and lowest in the low MC profile. Moreover, positive slope indicated that cardiorespiratory fitness increased in each profile, although the cardiorespiratory fitness slopes showed no significant inter-profile differences. Thus, mean cardiorespiratory fitness levels remained significantly different between profiles over time.

While childhood may be the most opportune time to develop competence in various motor skills (8), variation in the development of children's MC is dramatic (9, 10). Based on the literature, children with a low level of MC are at risk for low physical activity (6, 16, 18, 27, 28) and poor physical fitness (9, 19, 20, 24, 25, 26). However, none of these previous studies have studied the development of MVPA and cardiorespiratory fitness simultaneously. Our large longitudinal data sample indicated that children present different levels of MC over time and that children with low MC have both lower physical activity and lower cardiorespiratory fitness over time in adolescence.

The MC profiles significantly differed by their intercepts and annual mean levels of MVPA. These results support previous findings that children with lower levels of MC have lower levels of physical activity (6, 27), but also provided more detailed information about the differences in MVPA levels over time. The present study, depending on the year (T0-T3), found that mean MVPA level was 17 to 25 minutes/day more in the high MC profilers than in their low MC profile peers. Whereas for example, interventions aimed at improving physical activity in children have reported differences of 3-14 minutes per day between control and intervention groups (37). Thus, promoting motor competence in children should be considered as a possible tool to positively affect engagement in physical activity. At the last time point (T4) differences between profiles were not significant. However, the sample size at T4 was relatively small (n = 70), as the proportion of students willing to wear accelerometer decreased from year to year. Thus, the results should be addressed with caution. The inter-profile differences in physical activity levels demonstrate the potential importance of improving MC in all children. Furthermore, this difference is important, as previous studies have consistently shown strong evidence of a favorable relationship between physical activity and several cardiometabolic biomarkers and bone health in children (38). Janssen et al. (39) found that the least favorable cardiometabolic risk factor was observed in children whose mean MVPA was less than 60 min/day. The result of this study suggests, based on percentile of children reaching the recommendation that children in low MC profiles are more likely to demonstrate higher cardiometabolic health risk.

Although research generally demonstrates that children's physical activity decreases over time (13), the trend is not universal (40). The present results are unique, as no significant change in MVPA was observed over the four years in either the low or moderate MC profile, whereas the high MC profile showed a significant decrease. Lounassalo et al. (40), in a recent systematic review, reported similar results, showing that physical activity of highly and moderately active children often decreases, but generally remains higher than that of initially more passive peers. However, the result of this study showed that despite of having high MC, MVPA significantly decreased over time in adolescence and differences in physical activity levels between children with different MC levels diminished over time. Adolescents with high MC may have the skills and confidence to be more physically active than their peers with low MC (5), but that does not necessary mean they will be.

Intercepts as well as annual mean levels of cardiorespiratory fitness significantly differed between the MC profiles. The intercept of cardiorespiratory fitness was significantly lower in the low than other two MC profiles. Moreover, the moderate MC profile had a significantly lower intercept of cardiorespiratory fitness than the high MC profile. These findings are consistent with previous empirical studies have shown that children with lower MC have lower levels of cardiorespiratory fitness (24, 25, 26), but also provide more detailed information about differences in cardiorespiratory fitness levels over time. Differences in mean levels of cardiorespiratory fitness were significant and relatively large and consistent between MC profiles over time. Cardiorespiratory fitness has been shown to be independently associated with clustered cardiovascular disease risk in children (41). In 2016, Ruiz and his colleagues (41) published a meta-analysis that reported cardiorespiratory fitness cut points to avoid cardiovascular disease risk in children and adolescents. According to the cut points reported by Ruiz et al. (2016) (41), boys in the low MC profile had an elevated risk for cardiovascular disease at T1-T4, as on average, they fell below the cut points (30-47 laps). Girls in the low MC profile had an elevated risk for cardiovascular disease only at T4, as on average, they fell below the cut point (21 laps).

The present results also demonstrated that cardiorespiratory fitness generally increased with age. However, according to Raghuveer et al. (14) the rate of change partly depends on the ability to be physically active, which, in turn, may depend on one's MC level (5, 7, 17, 18). While the slope in cardiorespiratory fitness was more favorable in the high than in the other two MC profiles, the difference only trended towards significance ($p = .100$ and $p = .112$). A previous study by Hands (24) reported an increase in the difference between high and low MC groups in shuttle-run times over ten years. Thus, it is evident that children and adolescents with poor MC or low fitness are unlikely to catch up with their peers (24, 26, 41). Children with higher MC also demonstrate higher energy expenditure during object control skill performance due to the increased neuromuscular demands of higher-level performance (11). Moreover, participation in activities that require continued performance of object control skills offers greater opportunities for sustained participation (both in acute performance and over time) in different physical activities that enhance cardiorespiratory fitness (12). A recent meta-analysis (42) also suggested that improving fitness levels in youth may be associated with healthy weight maintenance and reduced cardiometabolic risk. Thus, adolescents' MC levels may impact their health parameters later in life (19, 20).

Studies have shown that physically active adolescents have higher cardiorespiratory fitness (14). However, the strength of the association has been small to moderate (43), which may be explained by insufficient vigorous physical activity in youth since cardiorespiratory fitness has been shown to be primarily related to vigorous physical activity (44). During adolescence, coupled with maturation and growth, adequate intensity physical activity function to increase cardiorespiratory fitness (14). In this study, MVPA either decreased or remained stable depending on the MC profile, whereas cardiorespiratory fitness increased in each MC profile. However, there was a significant positive association between the slopes of MVPA and cardiorespiratory fitness, but only in the high MC profile. One way to interpret this finding is that, although mean engagement in MVPA significantly decreased over time in high MC profile, those individuals who decreased less appeared to improve cardiorespiratory fitness more. Since previous studies have shown that vigorous physical activity may improve cardiorespiratory fitness (44), the absence of a significant association between slopes of MVPA and cardiorespiratory fitness in the low and moderate MC profiles may be due to a lack of vigorous physical activity. Blomqvist et al. (45), for example, found that children with higher MC also showed relatively higher vigorous physical activity.

This study provided some support for the potential existence of a motor proficiency barrier impacting healthy levels of physical activity and cardiorespiratory fitness (22). In this study, 83 % of the low MC participants did not meet the physical activity guidelines (60 min/day) at age 11, a proportion comparable to that reported by De Meester et al. (6), who noted that 89% did not meet the 60 min/day threshold. In contrast, 65% of the high MC children met the 60 min/day guideline at age 11. Moreover, the physical activity trajectory of the low MC children remained unchanged over the 4 years, and they also had the lowest levels of cardiorespiratory fitness over time. While we did not specifically test for a MC proficiency barrier, our data indicate that the low MC children (21 % of the sample) may have remained below such a barrier and thus had difficulty engaging in physical activity and promote cardiorespiratory fitness during late childhood and adolescence relative to peers with higher MC. In addition, their poor cardiorespiratory fitness indicates that they do not engage in enough vigorous physical activity (44), which may be a consequence of a lack of competence in a variety of skills and the ability to participate successfully with peers (11, 12, 46).

The multiple strengths of this study include a) 4-year longitudinal data, b) a large and representative cross-Finland sample, c) an objective MVPA measure, and d) the use of person-oriented analyses. Moreover, this is a novel design for investigating the associations of MC levels on physical activity and cardiorespiratory fitness trajectories. However, this study has its limitations. MC was evaluated only by product-oriented measurements, whereas the inclusion of both product- and process-oriented measures may yield a more comprehensive picture of MC (47). Moreover, objectively measured physical activity was based on a minimum three-day snapshot (two weekdays and one weekend day) and was not measured in all participants; thus, the findings should be interpreted with caution. Last, while longitudinal data does not demonstrate a causal impact of MC on MVPA and cardiorespiratory fitness (i.e., intervention), it is important to consider the physical activity context (46). Most physical activities that children engage in, require competence in a variety of movement skills (i.e., physical education, structured games, sports). Thus, higher levels of skill facilitate successful and continued participation in multiple types of activities over time and would impact physical activity and cardiorespiratory fitness both directly and indirectly (5, 11, 48). The differences in MC levels across profiles suggest that, indeed, skill levels were developed prior to age 11 in this study. To suggested physical activity (or fitness) promote MC, would be logical only if the context of the activity and the behaviors during it would be known (46). This argument supports our conclusion that MC is a critical antecedent for promoting and sustaining adequate physical activity and cardiorespiratory fitness levels across childhood and adolescence.

Conclusion

By highlighting the associations between MC and the intercept and development of MVPA and cardiorespiratory fitness, this study supports the conceptual model of Stodden et al. (5). To enhance physical activity and cardiorespiratory fitness in adolescents, an individual's level of motor competence should not be ignored as it also impacts perceptions of competence and the motivation to be physically active, both additional critical determinants of physical activity behaviors (49). Therefore, promoting physical activity in adolescents may require a more individualized approach focusing on their established competencies (or lack thereof), and motivational (autonomy) and social (relational) factors (50). Clearly, MC is not the only factor associated with physical activity and cardiorespiratory fitness development; thus, future studies should include other factors, such as motivation, social environment, and perceived competence in their analyses to further increase the understanding of individual differences between children with different physical activity habits.

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Conflict of Interest

The authors declare that there are no conflicts of interest. Authors do not have any professional relationships with companies or manufacturers who will benefit from the results of this study. The results of this study do not constitute endorsement by ACSM. Additionally, the authors declare that the results are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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Figure 1. MC measurements' mean standard scores at T0-T4 for each MC profile. *Footnote: Standard deviations of MC standard scores ranged between 0.6-1.0. W = Walking backwards, M = Moving sideways, L = 5-leaps, J = Jumping laterally, T = Throw-catch combination, MC = Motor competence.

Figure 2. Development of MVPA in each MC profile. *Footnote: vertical axis = min/day, red line = low MC profile, blue line = moderate MC profile, green line = high MC profile, MC = Motor competence, MVPA = moderate to vigorous physical activity.

Figure 3. Development of cardiorespiratory fitness in each MC profile. *Footnote: vertical axis = laps, red line = low MC profile, blue line = moderate MC profile, green line = high MC profile, MC = Motor competence.

Table 1. Descriptive statistics.

Measurement	Time	n	All M (SD)	Low MC profile M (SD)	Moderate MC profile M (SD)	High MC profile M (SD)
Object control skills: throw-catch combination (number of successful trials)	T0	1106	10.40 (5.28)	5.65 (4.46) M,H	9.98 (4.43) L,H	14.43 (3.82) L,M
	T1	970	12.86 (4.74)	8.21 (4.31) M,H	12.58 (4.04) L,H	16.31 (3.06) L,M
	T2	860	10.93 (4.88)	6.0 (4.05) M,H	10.49 (4.04) L,H	14.75 (3.36) L,M
	T3	779	12.91 (4.81)	7.79 (4.38) M,H	12.59 (4.02) L,H	16.50 (2.86) L,M
	T4	559	13.4 (4.83)	8.38 (4.61) M,H	13.03 (3.94) L,H	16.26 (.3.18) L,M
Locomotor skills: 5-leaps test (distance covered in meters)	T0	1099	7.74 (.89)	6.86 (.71) M,H	7.64 (.64) L,H	8.51 (.67) L,M
	T1	964	8.21 (1.01)	7.09 (.83) M,H	8.1 (.72) L,H	9.06 (.71) L,M
	T2	838	8.58 (1.10)	7.45 (.85) M,H	8.44 (.84) L,H	9.50 (.79) L,M
	T3	738	8.99 (1.22)	7.80 (1.09) M,H	8.83 (.95) L,H	9.97 (.94) L,M
	T4	539	9.31 (1.41)	7.97 (1.33) M,H	9.06 (1.11) L,H	10.22 (1.22) L,M
Locomotor skills: KTK jumping laterally (the sum of jumps across two trials)	T0	1089	74.55 (13.10)	60.93 (10.41) M,H	73.25 (9.56) L,H	85.96 (9.13) L,M
	T1	972	79.91 (13.88)	62.20 (9.29) M,H	78.65 (8.71) M,H	92.73 (9.38) M,H
	T2	848	88.65 (14.56)	72.01 (11.16) M,H	87.56 (10.65) M,H	101.40 (9.76) M,H
	T3	743	92.76 (14.94)	73.61 (16.33) M,H	92.72 (9.05) M,H	103.75 (9.89) M,H
	T4	527	95.10 (16.58)	79.10 (15.68) M,H	91.99 (14.13) M,H	106.37 (12.26) M,H
Locomotor skills: KTK moving sideways (sum of moves across two trials)	T1	1057	48.75 (9.46)	40.05 (8.15) M,H	47.98 (7.43) L,H	55.9 (7.48) L,M
Locomotor skills: KTK walking backwards (sum of error free steps across 9 trials)	T2	678	50.18 (13.94)	36.33 (13.18) M,H	49.01 (12.05) L,H	57.54 (10.72) L,M
MVPA (min/day)	T3	452	58.78 (22.96)	44.22 (16.69) M,H	55.26 (20.71) L,H	69.63 (23.13) L,M
	T4	285	55.08 (20.84)	43.94 (16.72) M,H	53.29 (19.45) L,H	62.97 (21.45) L,M
	T2	208	52.9 (21.75)	41.58 (16.59) H	50.42 (21.65) H	60.37 (21.30) L,M
	T3	130	57.48 (25.60)	46.41 (16.80) H	54.68 (26.20) L,H	63.66 (26.09) L
	T4	70	51.64 (24.20)	46.84 (31.08)	49.24 (22.97)	56.0 (23.47)
Percentage of participants achieving MVPA guidelines / odd ratio for achieving MVPA guidelines.	T0	452	43.36 %	17.11 % / ref	36.23 % / 2.75	63.91 % / 8.80
	T1	285	35.79 %	13.46 % / ref	30.77 % / 2.96	53.39 % / 8.00
	T2	208	32.69 %	5.88 % / ref	29.35 % / 6.65	47.56 % / 16.00
	T3	130	37.69 %	21.05 % / ref	30.19 % / 1.62	50.0 % / 3.75
	T4	70	32.86 %	22.22 % / ref	24.24 % / 1.12	46.43 % / 3.50
Cardiorespiratoy fitness (shuttles completed)	T0	1057	36.06 (18.33)	20.30 (11.34) M,H	34.24 (15.04) L,H	50.18 (16.86) L,M
	T1	933	40.62 (20.34)	24.06 (12.62) M,H	38.63 (17.62) L,H	53.98 (19.50) L,M
	T2	765	39.10 (19.58)	22.55 (11.74) M,H	36.63 (15.33) L,H	53.41 (19.90) L,M
	T3	673	44.12 (22.02)	25.89 (13.78) M,H	40.82 (17.95) L,H	60.85 (20.98) L,M
	T4	436	40.91 (22.14)	23.73 (13.36) M,H	37.88 (19.90) L,H	53.83 (21.54) L,M
Maturation offset	T0	1107	-1.30 (.80)	1.27 (.74)	-1.30 (.82)	-1.22 (-79)
	T1	1071	-.38 (.85)	-.36 (.78)	-.35 (.85)	-.43 (.88)
	T2	839	.54 (.90)	.52 (.81).	.57 (.89)	.51 (.95)
	T3	648	1.40 (.86)	1.32 (.74)	1.43 (.87)	1.40 (.91)
	T4	577	2.24 (.80)	2.28 (.77)	2.26 (.80)	2.19 (.83)
Body mass index (kg/m^2)	T0	1120	18.88 (3.12)	20.49 (4.10) M,H	18.85 (2.87) L,H	17.81 (2.08) L,M
	T1	1012	19.56 (3.41)	21.41 (4.35) M,H	19.57 (3.27) L,H	18.42 (2.31) L,M
	T2	836	20.32 (3.36)	21.83 (4.19) M,H	20.39 (3.31) L,H	19.32 (2.41) L,M
	T3	646	20.01 (3.37)	22.40 (4.28) M,H	21.08 (3.37) L,H	20.20 (2.51) L,M
	T4	578	21.44 (3.21)	23.57 (4.38) M,H	21.22 (2.99) L,H	20.78 (2.43) L

Note 1. M = mean, MC = motor competence, SD = standard deviation, MVPA = moderate-to-vigorous physical activity, ref = reference value, KTK = *Körperkoordinations Test* für Kinder.
Note 2. . The letters (L = low MC profile, M = moderate MC profile, H = high MC profile) indicate the profiles between which there is a significant difference $p < .05$

Table 2. Correlations between variables at each time point (T0-T4)

	Time	Object control skills: throw-catch combination	Locomotor skills: 5-leaps test	Locomotor skills: KTK jumping laterally	Locomotor skills: KTK moving sideways	Locomotor skills: KTK walking backwards	MVPA
Locomotor skills: 5-leaps test	T0	436***					
	T1	.398***					
	T2	.425***					
	T3	.401***					
	T4	.332***					
Locomotor skills: KTK jumping laterally	T0	.420***	.480***				
	T1	.428***	.567***				
	T2	.376***	.522***				
	T3	.461***	.498***				
	T4	.374***	.495***				
Locomotor skills: KTK moving sideways	T0	.403***	.439***	.562***			
Locomotor skills: KTK walking backwards	T0	.403***	.411***	.437***	.456***		
MVPA	T0	.352***	.325***	.265***	.266***	.165**	
	T1	.228***	.369***	.281***			
	T2	.289***	.304***	.232**			
	T3	.194*	.412***	.241**			
	T4	.340*	.275*	.108			
Cardiorespiratory fitness	T0	.471***	.580***	470***	.425***	.346***	.478***
	T1	.385***	.536***	.422***			.373***
	T2	.395***	.568***	.479***			.335***
	T3	.401***	.621***	.504***			.515***
	T4	.397***	.566***	.497**			.332***

Note 1. MVPA = moderate-to-vigorous physical activity, KTK = *Körperkoordinations Test* für Kinder.

Table 3. Intraclass correlation coefficients between classes from T0 to T4

	Grouping variable	Time	β	SE	p
MVPA	Class	T0	.04	.03	.133
		T1	.04	.04	.298
		T2	.07	.06	.279
		T3	.05	.11	.640
		T4	.02	.09	.844
Cardiorespiratory fitness	Class	T0	.10	.02	.000***
		T1	.03	.02	.087
		T2	.10	.03	.001**
		T3	.06	.03	.014*
		T4	.03	.03	.291
5-leaps	Class	T0	.08	.02	.001**
		T1	.10	.02	.000***
		T2	.08	.02	.000***
		T3	.03	.01	.030*
		T4	.09	.03	.001**
KTK: Jumping laterally	Class	T0	.14	.03	.000***
		T1	.27	.03	.000***
		T2	.14	.03	.000***
		T3	.09	.03	.000***
		T4	.14	.05	.002**
Throw-catch combination	Class	T0	.10	.03	.000***
		T1	.09	.02	.000***
		T2	.12	.03	.000***
		T3	.07	.02	.001**
		T4	.08	.03	.003**

Note 1. ***p < .001, **p < .01, *p < .05.
Note 2. SE = standard error, MVPA = moderate-to-vigorous physical activity, KTK = *Körperkoordinations Test* für Kinder.

Table 4. Profile class solution

Classes	Parameters	AIC	BIC	ABIC	LT 5 %	pLMR	Entropy
2-solution	19	36941.87	37204.21	37039.04	0	.019	.85
3-solution	**70**	**35569.75**	**35922.89**	**35700.55**	**0**	**.066**	**.86**
4-solution	88	35185.96	35629.91	35350.39	0	.453	.82
5-solution	106	34830.40	35365.16	35028.47	0	.620	.81

Note 1. Bold indicates the most reasonable solution.
Note 2. AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion, ABIC = Adjusted Bayesian Information Criterion, LT = less than, pLMR = p-value for Adjusted Lo-Mendell-Rubin Ratio Test.

Table 5. The parameter estimates for parallel latent growth curve models of each MC profile.

		Low MC profile	Moderate MC profile	High MC profile
MVPA	Intercept (SD)	44.82 (1.46) *** MH	56.67 (1.56)*** LH	70.13 (1.89)***LM
	Slope (SD)	.89 (.18) H	-1.44 (1.14)	-3.36 (.73)*** L
Cardiorespiratory fitness (CRF)	Intercept (SD)	20.00 (.11)*** MH	34.94 (.83)*** LH	52.00 (1.04)***LM
	Slope (SD)	1.20 (.14)**	1.28 (.29)***	2.21 (.52) ***
Correlation	$Slope^{CRF}$ / $Slope^{MVPA}$	-.385	.245	.646**

Note 1. CRF = Cardiorespiratory fitness, MVPA = moderate-to-vigorous physical activity, SD = standard deviation, MC = motor competence.
Note 2. $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$.
Note 3. The letters (L = low MC profile, M = moderate MC profile, H = high MC profile) indicate the profiles between which there is a significant difference p < .05

Figure 1.

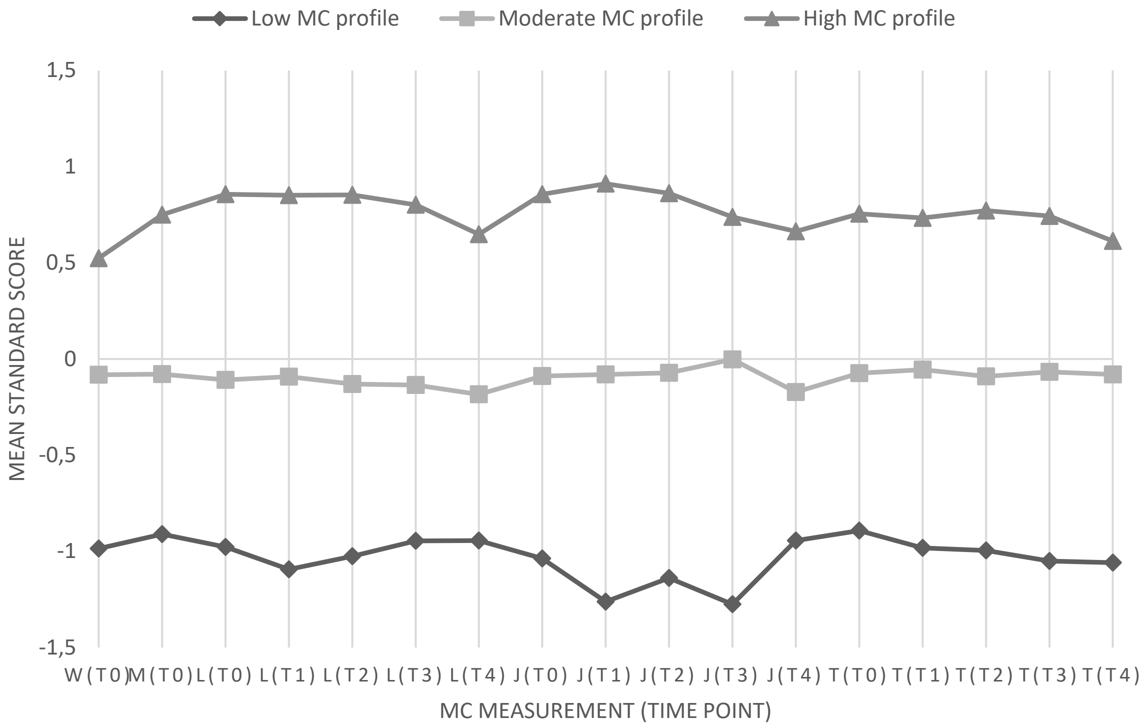


Figure 2

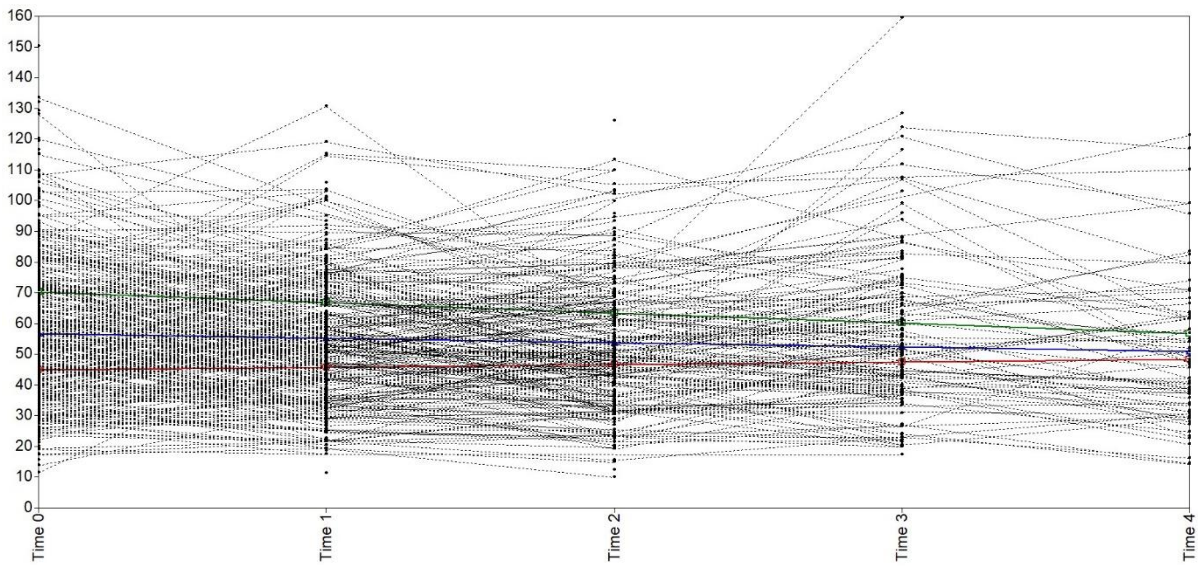
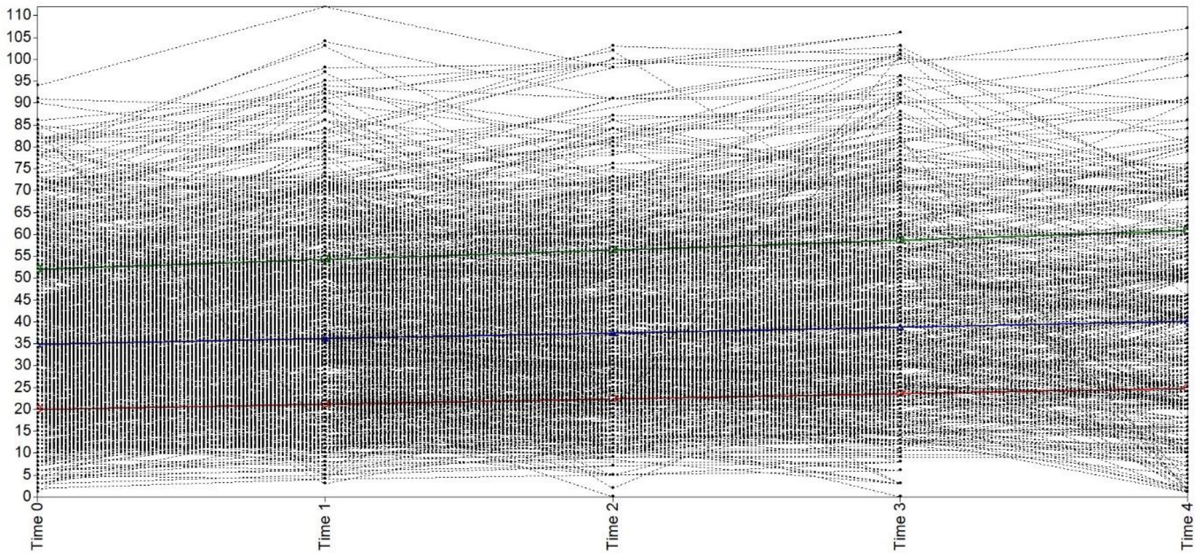


Figure 3



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