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Development of children's actual and perceived motor competence, cardiorespiratory fitness, physical activity, and BMI.

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Abstract

Purpose

To examine synergistic associations between developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, moderate-to-vigorous physical activity (MVPA), and body mass index (BMI) from late childhood to adolescence.

Methods

In this three-year follow-up study, motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI were assessed in 1 167 Finnish school-aged children (girls = 583, boys = 565; Mage = 11.27 ±0.33). MVPA was measured using hip-mounted accelerometers. Developmental trajectories were analyzed using latent growth curve modeling.

Results

The development of motor competence, cardiorespiratory fitness and BMI was positive over time, whereas the development of perceived motor competence and physical activity was negative. The development of BMI was inversely associated with the development of cardiorespiratory fitness and physical activity.

Conclusion

In the transition from late childhood to adolescence, motor competence, cardiorespiratory fitness, and BMI increased, and perceived motor competence and physical activity decreased. However, individual variance in the developmental trajectories was significant. Moreover, children with a greater increase in BMI showed a greater decrease in cardiorespiratory fitness and physical activity from late childhood to adolescence.

Key words: Longitudinal, trajectories, person-oriented approach, latent growth modeling, childhood, adolescence.

Introduction

Obesity is a major health problem globally that has also accelerated in both children and adolescents over recent decades (1). Changes in global food systems and eating behaviors combined with sedentary behaviors have been the main drivers of this trend (2). The current low level of physical activity among children and adolescents (3) is alarming, as the foundations for a physically active lifestyle are laid in childhood (4) and physical activity plays an important role in the prevention of overweight and obesity in children and adolescents (5). These considerations call for more comprehensive investigations into the mechanisms behind the synergistic development of physical activity and BMI in childhood and adolescence (6).

The Developmental Model of Stodden et al. (6, 7), focusing on the role of motor skill competence in physical activity, is a model that describes the dynamic and reciprocal roles of motor competence, perceived motor competence, health-related fitness, physical activity engagement, and weight development in children. According to Stodden et al. (2008) (6) and Robinson et al. (2015) (7), in middle and late childhood, children with higher motor competence which has been conceptualized as fundamental movement skills (stability, locomotor, and object control skills) (8), are better able to engage in different physical activities. The model also suggests that health-related fitness, meaning a set of physical qualities (cardiorespiratory and muscular fitness, joint flexibility, and body composition) (9), acts as a mediator by enabling continued physical activity for longer periods of time, which in turn offers more opportunities for the development of motor competence. Another mediator between motor competence and physical activity engagement proposed by Stodden et al. (2008) (6) is perceived motor competence, which has been conceptualized as children's perceptions of their own motor competence (10). In middle and late childhood, children who demonstrate lower motor competence will also develop lower perceived motor competence, and hence lack the confidence to move and participate in physical activities, as they are more conscious that they will not be successful (6, 7).

Research has demonstrated that motor competence is one of the cornerstones of a physically active lifestyle (6, 7). More specifically, in their systematic review, Logan et al. (2015) (11) found a positive association between motor competence and physical activity from childhood to adolescence. In addition, longitudinal study designs have shown associations between motor competence and the development of BMI in both late childhood and adolescence (12, 13).

Health-related fitness is related to overall health (8) and physical activity engagement (14). Britton et al. (2020) (15) showed that health-related fitness was the strongest predictor for future physical activity in the transition from primary to secondary school. Moreover, cardiorespiratory fitness, in particular, has been found to be inversely related to BMI (16). Longitudinal studies have also shown that a smaller change in developmental pathways (12) or a lower level of cardiorespiratory fitness (17) increases the risk for becoming overweight or obese during childhood.

Perceived motor competence was found in a meta-analysis by Babic et al. (2014) (18) to be one of the strongest cognitive antecedents of physical activity engagement in children and adolescents. Perceived motor competence has also been found to be negatively associated with BMI in cross-sectional studies (19, 20).

The present model of Stodden et al. (2008) (6) has been commonly used to examine physical activity engagement and weight development in childhood (12, 13, 16, 21, 22). However, none of the previous studies have longitudinally assessed all the variables presented in the model of Stodden et al. (2008) (6). Moreover, most of the studies that have used the developmental model, have utilized variable-oriented statistical methods (22). Variable-oriented methods generate the mean slope of the sample and treat differences between individuals as error variance. Instead, a person-oriented method, such as latent growth modeling, allows for inferences about individuals and thus captures individual variances in trajectories over time. Rather than focusing on homogeneous average values, it is important to allow for inter-individual variability in, for example, children's developmental trajectories, as each one manifests a unique developmental trait (12, 22). It should be recognized that most studies in the field of motor development have focused on changes in childhood. However, the transition to adolescence, during which several important physical, psychological, and social changes occur (23), is marked by a rapid decline in physical activity (24). This study is the first to examine synergistic associations between developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, MVPA and BMI from late childhood to adolescence.

The aim of this study was twofold: first, to examine developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, MVPA and BMI, and second, to analyze the reciprocal relationships between these different developmental trajectories from late childhood to adolescence. Based on previously established relationships, we hypothesized that the development of BMI (25), cardiorespiratory fitness (26) and motor competence (27, 21) would be positive, whereas the development of MVPA (28, 24) and perceived motor competence would be negative (29). Moreover, the development of BMI was expected to be inversely associated with the development of cardiorespiratory fitness (12, 16) motor competence (13) and MVPA (28, 30), whereas the development of MVPA would be associated with the development of motor competence (7, 11) and cardiorespiratory fitness (14).

Methods

Participants

A total of 1 167 children (girls = 583, boys = 565) participated in this four-phase follow-up study between 2017 and 2020. Participants were recruited from 35 randomly selected elementary schools from four provinces of Finland. The schools were selected in order to reflect the proportion between students and the population of each province. Every 5^{th} grade student (Mage = 11.27) of the selected schools was invited to participate in the study. Participants included 2 % of all Finnish 5^{th} grade students (a total of 61 062 5^{th} grade children in 2017). The data of each time-point (T0-T3) were collected by the researchers during school hours between August and October in 2017-2020, precisely one, two, and three years after the baseline measurements. The researchers conducted motor competence, anthropometric (height and weight) and cardiorespiratory fitness measurements during PE classes and the questionnaire was administered in the classroom setting. Accelerometers were issued to a sample of participants (n = 663), of whom 591 expressed willingness to wear activity monitors over a period of one week at each time-point. Instructions were given in a letter to the participant and to the participant's parents. Informed written consents from parents or guardians and a verbal consent from the students were obtained prior to the start of the study. The study was approved by the human research ethics committee to the local University.

Measurements

Motor competence. Participants' motor competence was assessed via a throwing-catching combination (31). Participants were instructed to throw a tennis ball directly at a target area 1.5 x 1.5 meters square marked on a wall at 90 centimeters above floor level and to catch the ball after one bounce back from the floor. Throwing distance ranged from 7 to 10 meters depending on the participant's grade and gender. Each measurement comprised 20 trials and the result was the sum of successfully completed throw-catch combinations. This test is used extensively in Finnish sport science studies (22) and has shown an acceptable test-retest reliability (ICC = 0.692, p = 0.000) in children and adolescents (31).

Cardiorespiratory fitness. Participants' cardiorespiratory fitness was assessed with a 20-meter shuttle run test (32). In this test, participants ran continuously along a 20-meter track marked out on the floor by two parallel lines 20 meters apart. Running pace for each 20-meter shuttle was set by the frequency of recorded beeps. Initial running velocity was 8.5 km/h for the first minute, increasing by 0.5 km/h after each successive minute. The test finished when the participant was no longer able to keep pace with the beeps. The result was the number of shuttles run.

Perceived motor competence. Participants' perceived physical competence was assessed using the Finnish version of the sport competence dimension of the Physical Self-Perception Profile (PSPP) (33). Each item was preceded by the stem: "*What am I like*?" and all five items of the PSPP were rated on a five-point scale (e.g., 1 = *I'm among the best when it comes to athletic ability* … 5 = *I'm not among the best when it comes to athletic ability*). A previous study with Finnish children demonstrated acceptable construct validity (CFI = .98, TLI = .97, RMSEA = .074) and internal consistency (Cronbach's alpha .90) (34).

BMI. Participants' BMI was calculated using a weight (kg) and height (m) formula (kg/m^2) (35). 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. Extended international (IOTF) body mass index cut offs values were used to determine participant's weight status (normal weight / overweight) (36).

Device-measured MVPA. Participants' MVPA was measured using Actigraph wGT3X+ accelerometers. An actigraph accelerometer was issued to participants for seven consecutive days. Participants were instructed to wear the device on their right hip at all times during their waking hours, except while bathing or during water-based activities. Data were collected as raw accelerations at a frequency of 30 Hz, standardly filtered, and converted into 15-s epoch counts. Customized Visual Basic Macro for Excel software was used for data reduction. A valid day of physical activity monitoring included measured values ≥500 min/day for at least two weekdays and one weekend day between general waking hours (i.e., 7:00-23:00). Periods of 30 min of consecutive zero counts were defined as non-wear time, and values over 20 000 counts per minute (cpm) were considered spurious accelerations and discarded (37). Cut points (38, 39) were used to calculate MVPA (≥2296 cpm).

Data Analysis

The data were examined for normality, outliers, and missing values. Correlations and descriptive statistics, including means and standard deviations, were computed for observed variables. In addition, Cronbach alphas were determined for the perceived competence scale. Parallel latent growth curve models were used to answer the research questions. The latent variables (slope and level) and the residuals were estimated based on the observed variables. In this context, level refers to the initial points at the baseline and slope to the rate of change in the observed variables over time. The default models for longitudinal development were constructed by fixing the loadings of the latent variables to 1 on the initial level, and from 0 to 3 (T0-T3) on the growth variables. (40). A statistical power analysis suggested that the minimum number of participants to be obtained should be 290 to meet statistical constraints with a confidence level of 95% and a margin of error $p < .05$. Thus, the current sample size of 1 167 was adequate for the main analyses of this study.

The Chi-square test ($\chi 2$) was used to evaluate the model's overall goodness-of-fit to the data. A non-significant difference between the observed and theoretical distributions indicated an acceptable fit to the data. To determine the appropriateness of the model, the standardized root mean square residual (SRMR), root mean square error of approximation (RMSEA), comparative fit index (CFI) and Tucker-Lewis index (TLI) were examined. A cutoff value close to .08 for SRMR indicates acceptable magnitude of a varying quantity, and a value of .06 or less for the RMSEA indicates an excellent fit of the model in relation to the degrees of freedom. CFI and TLI indices greater than .95 are indicative of an excellent model fit. The Missing Completely at Random (MCAR) test and descriptive statics were performed using SPSS Version 26.0 and all subsequent analyses using Mplus Version 8.6.

Results

Descriptive statistics are presented in Table 1. Visual inspection of the data revealed that the data were normally distributed and, based on the standardized values (± 3.00), did not include significant outliers. Missing values (6 606 out of 22 173) accounted for 29.8 % of the data matrix, mainly because accelerometers could not be provided for all participants and also because some participants did not wear the accelerometer for a valid period. Thus, some MVPA scores were missing. However, the MCAR-test ($x^2(28) = 30.32$, p = .348) showed that the MVPA data of participants with and without missing scores were equal. MVPA was measured each year but owing to low participation (n = 131), the fourth measurement did not fit into the model, and hence only the first three measurement points were analyzed. The MCAR test ($\chi^2(6606) = 6954,383$, p = .001) showed that the data matrices with and without missing scores were unequal (41). Closer examination of the data indicated that missing values were missing at random (MAR), as the missing scores did not represent any specific school or group and the student population across schools was relatively heterogeneous. Missing values were not imputed; instead, the statistical program used in the analysis estimated missing scores using mixture likelihood procedures, which has been shown to produce reliable parameter estimates and standard errors under MAR conditions (42).

The correlations between motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI varied from weak to moderate (Table 2). BMI was negatively correlated with all the other variables. The strength of the correlation between motor competence and MVPA decreased over time, whereas the strength of the correlation between perceived motor competence and MVPA increased. The participants' mean age was 11.27 (±0.33) years, mean BMI 18.88 (±3.12) kg/m^2 and 22.4 % were overweight or obese at baseline (T0). The Cronbach's alphas of the perceived competence scale were high at each measurement point (T0 = .87, T1 = .90, T2 = .89, T3 = .89).

The parallel latent growth curve model of BMI, perceived motor competence, motor competence, MVPA, and cardiorespiratory fitness was estimated to detect a reciprocal relationship between the baseline levels (level) and changes (slope) from T0 to T3. The model showed acceptable fit for the present data (Table 3).

Latent growth curve (slope) means indicated, that over a three-year period (T_0-T_3), BMI ($slope_0$), motor competence ($slope_2$), and cardiorespiratory fitness ($slope_4$) increased while perceived motor competence ($slope_1$) and MVPA ($slope_3$) decreased (Table 3, Appendix 1).

The changes in MVPA ($slope_3$) and cardiorespiratory fitness ($slope_4$) were negatively associated with the change in BMI ($slope_0$), indicating that as BMI increased, MVPA and cardiorespiratory fitness decreased. The change in cardiorespiratory fitness was positively associated with the change in motor competence and perceived motor competence, meaning that as cardiorespiratory fitness increased, motor competence and perceived motor competence followed the same increasing pattern. Some other significant relationships between the latent variables were also detected (Table 3).

Squared multiple correlations revealed that the model strongly explained the variance in BMI (T0 = 98%, T1 = 91 %, T2 = 90 %, T3 = 90 %), perceived competence (T0 = 55 %, T1 = 61 %, T2 = 63 %, T = 74 %), motor competence (T0 = 62 %, T1 = 61 %, T2 = 54 %, T = 67 %), MVPA (T0 = 64 %, T1 = 60 %, T2 = 70 %) and cardiorespiratory fitness (T0 = 81 %, T1 = 69 %, T2 = 76 %, T3 = 82 %).

Discussion

This study sought to gain insights into developmental changes in motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI in children from late childhood to adolescence. Therefore, a latent growth model was employed to examine developmental changes in variables, as this approach captures individual variance in these trajectories. The main finding was that a greater increase in BMI was associated with a greater decrease in cardiorespiratory fitness and MVPA across the three-year period. However, the great variance in the development of BMI, cardiorespiratory fitness and MVPA over time indicated the extent of the differences between individuals, which may also reflect differences in timing and pace of maturation (43). Moreover, contrary to the hypothesis, the development of MVPA was not associated with the development of cardiorespiratory fitness or motor competence.

This study demonstrated an increasing trend in BMI from late childhood to adolescence. This was expected, as it is evident that BMI in childhood changes substantially with age and maturation (25, 43) This result showed significant variances between individuals in the development of BMI over time, as also found by Rodrigues et al. (2016) (12). However, the study of Rodrigues et al. (2016) (12) was conducted with elementary students, whereas in this study the participants were older. Thus, the variance in the development of BMI may be explained by the differences in timing and pace of maturation, as the maturation is characterized by changing body composition and stature. Moreover, differences in BMI between sexes tend to rise in adolescence. (43). However, excess weight accumulation in childhood and early adolescence is a multifaceted phenomenon that is also affected by multiple genetic and non-genetic factors, such as environment, socioeconomic status, physical activity, and diet (44).

This study revealed a decreasing trend in MVPA, as also shown by a recent meta-analysis (24) and an empirical study by Janssen et al. (2019) (28). The period from late childhood to adolescence is characterized by multiple physical, psychological, and social changes (23) that are known to be associated with physical activity behavior. According to a recent systematic review (45), highly and moderately active children often undergo developmental change (usually a decline) in physical activity, whereas inactives tend to remain at same level. Thus, physical activity trajectories vary across individuals, as also manifested in this study in the significant variance between children in their MVPA trajectories. However, the change in physical activity does not tell the whole truth. Although active children face a decrease in the level of physical activity, it remains higher than that of originally passive ones. (45).

In this study, motor competence increased over time. This positive development is in line with the findings of the systematic review and meta-analysis conducted by Barnett et al. (2016) (27), who concluded that age is the most consistent correlate of all aspects of motor competence. However, motor competence does not automatically develop with age; instead, to achieve persistent change (46), motor skills need to be taught, reinforced, and repeated (47). This study, in line with Coppens et al. (2019) (21), found significant variance between the children's motor development trajectories, indicating that, over time, differences in motor competence development will become increasingly evident between children who have had enriched and varied movement experiences and those who have not (47). Furthermore, the individual timing and pace of maturation may have influenced development of motor competence, both via motor coordination (48) and increased body weight (49).

The development of cardiorespiratory fitness was positive over time, supporting the established fact that in childhood cardiorespiratory fitness increases with age. However, the timing and pace of change are highly individual. (26) Thus, as expected, variances in the developmental traits of cardiorespiratory fitness were observed over time, of which differences between sexes and maturation-driven changes in body composition may explain a portion (43, 50). Moreover, cardiorespiratory fitness can also be further improved with systematic training and everyday physical activity (26). It should be noted that although cardiorespiratory fitness may reflect past physical activity, most of its benefits only accumulate with sustained vigorous activity (51).

The development of perceived motor competence was negative over time, as also found by Britton et al. (2019) (29). The timing of puberty has been shown to be associated with decreased perceived athletic competence (52). Moreover, some previous studies have shown that as children age, their perception of their own motor competence becomes more accurate; thus, as children age, they tend to form a more realistic estimate of their abilities (6, 7). However, the systematic review and meta-analysis of De Meester et al. (2020) (10) found no age effect to support this theory.

The second research question was to examine the reciprocal relationships between the developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI. The focus was on the developmental patterns of MVPA and BMI, as physical activity has a synergistic relationship with motor competence, perceived motor competence, and cardiorespiratory fitness (6) and also plays a role in the prevention of overweight and obesity in children and adolescents (5).

As expected, children with a greater increase in BMI showed a greater decrease in MVPA, providing further evidence of a developmental association between BMI and physical activity in childhood and adolescence (28). The systematic review by Poitras et al. (2016) (30) revealed that most of the cross-sectional studies reported a favorable association between BMI and MVPA, whereas longitudinal studies reported conflicting results on the relationship between MVPA and adiposity outcomes. The fundamental reason for increasing fatness is an imbalance between energy intake and energy expenditure over time, which may occur as energy expenditure decreases with reduced MVPA (53). Interestingly, the decrease in physical activity has also been explained as a result of weight status, not vice versa (54). As BMI increases, greater energy expenditure is demanded for a given amount of movement (55); this may facilitate faster fatigue, especially in vigorous physical activity, and thus lower the total amount of MVPA. Previous research (56) supports the idea that there may be a bidirectional relationship between weight status and physical activity, which enhances a self-perpetuating vicious circle of obesity and physical inactivity. Likewise, Stodden et al. (2008) (6) argued for unhealthy weight status as an outcome, which feeds back into the model, continuing to load negatively on factors influencing engagement in physical activity. The conclusion of the present study is that the association between the development of MVPA and BMI is reciprocal from late childhood to adolescence.

As expected, children with a greater increase in BMI faced a greater decrease in cardiorespiratory fitness. This finding supports previous longitudinal studies (12, 16, 17). Lima et al. (2017) (16) revealed that VO_{2peak} had the largest total association with body fatness. Rodrigues et al. (2016) (12) found that a negative developmental pathway (low rate of change) of cardiorespiratory fitness was associated with higher odds ratios for overweight/obese status at the end of primary school. Conversely, the recent study by Lopes et al. (2020) (13) found no significant differences in the developmental trajectories of cardiorespiratory fitness between two classes of children with lower or higher BMI development. However, the sample size was small and the class with higher BMI development contained fewer children. The reciprocal nature of the association between the development of BMI and cardiorespiratory fitness may be explained by metabolic cost. Children with higher BMI need to induce greater oxygen uptake for physical activities. Thus, they expend a larger proportion of their cardiorespiratory reserve when performing the same task as their leaner peers. (55). McGavock et al. (2009) (17) examined weight gain in low and high cardiorespiratory fitness groups over a 12-month follow-up. They found that the children in the low cardiorespiratory fitness group gained significantly more weight (17). However, maturation status may have influenced the association between BMI and cardiorespiratory fitness, especially in girls, as puberty-related increase in fat percentage may be related to decline in weight-relative fitness, such as running (43). In conclusion, the association between BMI and HRF may be reciprocal, indicating that cardiorespiratory fitness and BMI may form a self-perpetuating vicious cycle.

Several previous longitudinal studies have shown that the development of motor competence is associated with the development of adiposity (12, 13). However, although expected, this association was not found in this study. One explanation may be the absence of locomotor skill measurements in this study. Locomotor skills, such as hopping, require the movement of body mass through space, and hence excess mass has a negative influence on performance (43). Moreover, no longitudinal association was found between changes in perceived motor competence and BMI, despite the association between these variables found in previous cross-sectional studies (19, 20). Previous studies have shown a positive association between motor competence and physical activity behavior (7). However, no significant association between developmental trajectories was observed in this study. This may indicate that although physical activity decreases, motor competence generally remains unchanged (46). In addition, in contrast to a previous finding that vigorous physical activity was more strongly associated with cardiorespiratory fitness than less vigorous physical activity (51), MVPA was not associated with change in cardiorespiratory fitness in the present study.

The strengths of this study are the large number of participants, a longitudinal design with annual follow-ups, and the use of person-oriented latent growth modeling, which captures individual differences in trajectories over time. Furthermore, the analysis included all the variables presented in the commonly used developmental model of Stodden et al. (2008) (6) and provided further information on the reciprocal relationships between different developmental trajectories. However, the study has its limitations. The model lacked locomotor, stability, and muscular strength measurements, thus health-related fitness only included cardiorespiratory fitness, and motor competence only included object control. In addition, the fourth measurement of MVPA could not be included in the model owing to the participant attrition. The lack of maturation status measurements is a notable limitation because maturation is characterized by several physiological and psychological changes that may influence an individual’s developmental trajectories of BMI, motor competence, perceived motor competence and cardiorespiratory fitness, and their associations (43). While BMI is a widely used measure in tracking changes in adiposity, it is not unproblematic with children and adolescents due to maturational growth and its inability to differentiate muscle mass from fat (35). However, according to previous studies, adiposity change in children should rather be measured with BMI, than BMI z scores (57)

In this longitudinal study from late childhood to adolescence, BMI, cardiorespiratory fitness, and motor competence increased while MVPA and perceived motor competence decreased. Moreover, the variances between subjects were significant in every trajectory, indicating that children develop unique traits depending on their psychological, physiological, and social surroundings. As shown in this study a greater increase in BMI was associated with a greater decrease in MVPA and cardiorespiratory fitness. Unhealthy weight gain in late childhood and adolescence is a multifaceted phenomenon, which seems to be characterized by the negative development of cardiorespiratory fitness and MVPA. Interventions are needed to prevent or at least attenuate this unhealthy developmental trait. While the foundations for healthy weight development and a physically active lifestyle are formed earlier in childhood, a stronger focus on late childhood is called for, as it is a life phase characterized by multiple physical, psychological, and social changes. Thus, further longitudinal investigations are needed to examine the differences in developmental trajectories between children and adolescents with different developmental BMI traits. Moreover, future studies should include the evaluation of maturation and study its effects on development of motor competence, perceived motor competence, cardiorespiratory fitness, BMI, and physical activity.

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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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