

This is a self-archived version of an original article. This version may differ from the original in pagination and typographic details.

Author(s): Kolunsarka, Iiris; Gråsten, Arto; Huhtiniemi, Mikko; Jaakkola, Timo

Title: Development of Children's Actual and Perceived Motor Competence, Cardiorespiratory Fitness, Physical Activity, and BMI

Year: 2021

Version: Accepted version (Final draft)

Copyright: © 2021 by the American College of Sports Medicine

Rights: In Copyright

Rights url: <http://rightsstatements.org/page/InC/1.0/?language=en>

Please cite the original version:

Kolunsarka, I., Gråsten, A., Huhtiniemi, M., & Jaakkola, T. (2021). Development of Children's Actual and Perceived Motor Competence, Cardiorespiratory Fitness, Physical Activity, and BMI. *Medicine and Science in Sports and Exercise*, 53(12), 2653-2660.
<https://doi.org/10.1249/mss.0000000000002749>

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

3 Kolunsarka, I¹., Gråsten, A¹., Huhtiniemi, M¹., Jaakkola, T¹.

4 ¹Faculty of Sport and Health Sciences, University of Jyväskylä, Finland

5 Running head: Physical activity and BMI.

6 Date of submission 30.4.2021 (revised 7.7.2021)

7 Corresponding author:

8 MSc Iris Kolunsarka

9 University of Jyväskylä, Faculty of Sport and Health Sciences

10 Rautpohjankatu 8

11 P.O. Box 35 (L)

12 40014 Jyväskylän Yliopisto

13 Finland

14 Email: iiris.a.kolunsarka@ju.fi

Abstract

15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38

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.

39 **Introduction**

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

48 The Developmental Model of Stodden et al. (6, 7), focusing on the role of motor skill
49 competence in physical activity, is a model that describes the dynamic and reciprocal roles of
50 motor competence, perceived motor competence, health-related fitness, physical activity
51 engagement, and weight development in children. According to Stodden et al. (2008) (6) and
52 Robinson et al. (2015) (7), in middle and late childhood, children with higher motor
53 competence which has been conceptualized as fundamental movement skills (stability,
54 locomotor, and object control skills) (8), are better able to engage in different physical
55 activities. The model also suggests that health-related fitness, meaning a set of physical
56 qualities (cardiorespiratory and muscular fitness, joint flexibility, and body composition) (9),
57 acts as a mediator by enabling continued physical activity for longer periods of time, which in
58 turn offers more opportunities for the development of motor competence. Another mediator
59 between motor competence and physical activity engagement proposed by Stodden et al.
60 (2008) (6) is perceived motor competence, which has been conceptualized as children's
61 perceptions of their own motor competence (10). In middle and late childhood, children who
62 demonstrate lower motor competence will also develop lower perceived motor competence,

63 and hence lack the confidence to move and participate in physical activities, as they are more
64 conscious that they will not be successful (6, 7).

65 Research has demonstrated that motor competence is one of the cornerstones of a
66 physically active lifestyle (6, 7). More specifically, in their systematic review, Logan et al.
67 (2015) (11) found a positive association between motor competence and physical activity from
68 childhood to adolescence. In addition, longitudinal study designs have shown associations
69 between motor competence and the development of BMI in both late childhood and
70 adolescence (12, 13).

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

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

82 The present model of Stodden et al. (2008) (6) has been commonly used to examine
83 physical activity engagement and weight development in childhood (12, 13, 16, 21, 22).
84 However, none of the previous studies have longitudinally assessed all the variables presented
85 in the model of Stodden et al. (2008) (6). Moreover, most of the studies that have used the
86 developmental model, have utilized variable-oriented statistical methods (22). Variable-
87 oriented methods generate the mean slope of the sample and treat differences between

88 individuals as error variance. Instead, a person-oriented method, such as latent growth
89 modeling, allows for inferences about individuals and thus captures individual variances in
90 trajectories over time. Rather than focusing on homogeneous average values, it is important to
91 allow for inter-individual variability in, for example, children's developmental trajectories, as
92 each one manifests a unique developmental trait (12, 22). It should be recognized that most
93 studies in the field of motor development have focused on changes in childhood. However, the
94 transition to adolescence, during which several important physical, psychological, and social
95 changes occur (23), is marked by a rapid decline in physical activity (24). This study is the first
96 to examine synergistic associations between developmental trajectories of motor competence,
97 perceived motor competence, cardiorespiratory fitness, MVPA and BMI from late childhood
98 to adolescence.

99 The aim of this study was twofold: first, to examine developmental trajectories of motor
100 competence, perceived motor competence, cardiorespiratory fitness, MVPA and BMI, and
101 second, to analyze the reciprocal relationships between these different developmental
102 trajectories from late childhood to adolescence. Based on previously established relationships,
103 we hypothesized that the development of BMI (25), cardiorespiratory fitness (26) and motor
104 competence (27, 21) would be positive, whereas the development of MVPA (28, 24) and
105 perceived motor competence would be negative (29). Moreover, the development of BMI was
106 expected to be inversely associated with the development of cardiorespiratory fitness (12, 16)
107 motor competence (13) and MVPA (28, 30), whereas the development of MVPA would be
108 associated with the development of motor competence (7, 11) and cardiorespiratory fitness
109 (14).

110 **Methods**

111 *Participants*

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

128 *Measurements*

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

137 *Cardiorespiratory fitness.* Participants' cardiorespiratory fitness was assessed with a
138 20-meter shuttle run test (32). In this test, participants ran continuously along a 20-meter track
139 marked out on the floor by two parallel lines 20 meters apart. Running pace for each 20-meter
140 shuttle was set by the frequency of recorded beeps. Initial running velocity was 8.5 km/h for
141 the first minute, increasing by 0.5 km/h after each successive minute. The test finished when
142 the participant was no longer able to keep pace with the beeps. The result was the number of
143 shuttles run.

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

151 *BMI.* Participants' BMI was calculated using a weight (kg) and height (m) formula
152 (kg/m^2) (35). Height was measured to the nearest .1 cm using portable measuring equipment.
153 Body weight was measured to the nearest .1 kg using calibrated scales, with the children
154 wearing light clothing and barefoot. Extended international (IOTF) body mass index cut offs
155 values were used to determine participant's weight status (normal weight / overweight) (36).

156 *Device-measured MVPA.* Participants' MVPA was measured using Actigraph
157 wGT3X+ accelerometers. An actigraph accelerometer was issued to participants for seven
158 consecutive days. Participants were instructed to wear the device on their right hip at all times
159 during their waking hours, except while bathing or during water-based activities. Data were
160 collected as raw accelerations at a frequency of 30 Hz, standardly filtered, and converted into
161 15-s epoch counts. Customized Visual Basic Macro for Excel software was used for data

162 reduction. A valid day of physical activity monitoring included measured values ≥ 500 min/day
163 for at least two weekdays and one weekend day between general waking hours (i.e., 7:00-
164 23:00). Periods of 30 min of consecutive zero counts were defined as non-wear time, and values
165 over 20 000 counts per minute (cpm) were considered spurious accelerations and discarded
166 (37). Cut points (38, 39) were used to calculate MVPA (≥ 2296 cpm).

167 *Data Analysis*

168 The data were examined for normality, outliers, and missing values. Correlations and
169 descriptive statistics, including means and standard deviations, were computed for observed
170 variables. In addition, Cronbach alphas were determined for the perceived competence scale.
171 Parallel latent growth curve models were used to answer the research questions. The latent
172 variables (slope and level) and the residuals were estimated based on the observed variables.
173 In this context, level refers to the initial points at the baseline and slope to the rate of change in
174 the observed variables over time. The default models for longitudinal development were
175 constructed by fixing the loadings of the latent variables to 1 on the initial level, and from 0 to
176 3 (T0-T3) on the growth variables. (40). A statistical power analysis suggested that the
177 minimum number of participants to be obtained should be 290 to meet statistical constraints
178 with a confidence level of 95% and a margin of error $p < .05$. Thus, the current sample size of
179 1 167 was adequate for the main analyses of this study.

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

190 **Results**

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

207 The correlations between motor competence, perceived motor competence,
208 cardiorespiratory fitness, MVPA, and BMI varied from weak to moderate (Table 2). BMI was
209 negatively correlated with all the other variables. The strength of the correlation between motor
210 competence and MVPA decreased over time, whereas the strength of the correlation between
211 perceived motor competence and MVPA increased. The participants' mean age was 11.27
212 (± 0.33) years, mean BMI 18.88 (± 3.12) kg/m^2 and 22.4 % were overweight or obese at baseline
213 (T0). The Cronbach's alphas of the perceived competence scale were high at each measurement
214 point (T0 = .87, T1 = .90, T2 = .89, T3 = .89).

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

219 Latent growth curve (slope) means indicated, that over a three-year period (T₀-T₃), BMI
220 (slope₀), motor competence (slope₂), and cardiorespiratory fitness (slope₄) increased while
221 perceived motor competence (slope₁) and MVPA (slope₃) decreased (Table 3, Appendix 1).

222 The changes in MVPA (slope₃) and cardiorespiratory fitness (slope₄) were negatively
223 associated with the change in BMI (slope₀), indicating that as BMI increased, MVPA and
224 cardiorespiratory fitness decreased. The change in cardiorespiratory fitness was positively
225 associated with the change in motor competence and perceived motor competence, meaning
226 that as cardiorespiratory fitness increased, motor competence and perceived motor competence
227 followed the same increasing pattern. Some other significant relationships between the latent
228 variables were also detected (Table 3).

229 Squared multiple correlations revealed that the model strongly explained the variance
230 in BMI (T₀ = 98%, T₁ = 91 %, T₂ = 90 %, T₃ = 90 %), perceived competence (T₀ = 55 %, T₁
231 = 61 %, T₂ = 63 %, T = 74 %), motor competence (T₀ = 62 %, T₁ = 61 %, T₂ = 54 %, T = 67
232 %), MVPA (T₀ = 64 %, T₁ = 60 %, T₂ = 70 %) and cardiorespiratory fitness (T₀ = 81 %, T₁
233 = 69 %, T₂ = 76 %, T₃ = 82 %).

234 **Discussion**

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

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

257 This study revealed a decreasing trend in MVPA, as also shown by a recent meta-
258 analysis (24) and an empirical study by Janssen et al. (2019) (28). The period from late

259 childhood to adolescence is characterized by multiple physical, psychological, and social
260 changes (23) that are known to be associated with physical activity behavior. According to a
261 recent systematic review (45), highly and moderately active children often undergo
262 developmental change (usually a decline) in physical activity, whereas inactives tend to remain
263 at same level. Thus, physical activity trajectories vary across individuals, as also manifested in
264 this study in the significant variance between children in their MVPA trajectories. However,
265 the change in physical activity does not tell the whole truth. Although active children face a
266 decrease in the level of physical activity, it remains higher than that of originally passive ones.
267 (45).

268 In this study, motor competence increased over time. This positive development is in
269 line with the findings of the systematic review and meta-analysis conducted by Barnett et al.
270 (2016) (27), who concluded that age is the most consistent correlate of all aspects of motor
271 competence. However, motor competence does not automatically develop with age; instead, to
272 achieve persistent change (46), motor skills need to be taught, reinforced, and repeated (47).
273 This study, in line with Coppens et al. (2019) (21), found significant variance between the
274 children's motor development trajectories, indicating that, over time, differences in motor
275 competence development will become increasingly evident between children who have had
276 enriched and varied movement experiences and those who have not (47). Furthermore, the
277 individual timing and pace of maturation may have influenced development of motor
278 competence, both via motor coordination (48) and increased body weight (49).

279 The development of cardiorespiratory fitness was positive over time, supporting the
280 established fact that in childhood cardiorespiratory fitness increases with age. However, the
281 timing and pace of change are highly individual. (26) Thus, as expected, variances in the
282 developmental traits of cardiorespiratory fitness were observed over time, of which differences
283 between sexes and maturation-driven changes in body composition may explain a portion (43,

284 50). Moreover, cardiorespiratory fitness can also be further improved with systematic training
285 and everyday physical activity (26). It should be noted that although cardiorespiratory fitness
286 may reflect past physical activity, most of its benefits only accumulate with sustained vigorous
287 activity (51).

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

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

301 As expected, children with a greater increase in BMI showed a greater decrease in
302 MVPA, providing further evidence of a developmental association between BMI and physical
303 activity in childhood and adolescence (28). The systematic review by Poitras et al. (2016) (30)
304 revealed that most of the cross-sectional studies reported a favorable association between BMI
305 and MVPA, whereas longitudinal studies reported conflicting results on the relationship
306 between MVPA and adiposity outcomes. The fundamental reason for increasing fatness is an
307 imbalance between energy intake and energy expenditure over time, which may occur as
308 energy expenditure decreases with reduced MVPA (53). Interestingly, the decrease in physical

309 activity has also been explained as a result of weight status, not vice versa (54). As BMI
310 increases, greater energy expenditure is demanded for a given amount of movement (55); this
311 may facilitate faster fatigue, especially in vigorous physical activity, and thus lower the total
312 amount of MVPA. Previous research (56) supports the idea that there may be a bidirectional
313 relationship between weight status and physical activity, which enhances a self-perpetuating
314 vicious circle of obesity and physical inactivity. Likewise, Stodden et al. (2008) (6) argued for
315 unhealthy weight status as an outcome, which feeds back into the model, continuing to load
316 negatively on factors influencing engagement in physical activity. The conclusion of the
317 present study is that the association between the development of MVPA and BMI is reciprocal
318 from late childhood to adolescence.

319 As expected, children with a greater increase in BMI faced a greater decrease in
320 cardiorespiratory fitness. This finding supports previous longitudinal studies (12, 16, 17). Lima
321 et al. (2017) (16) revealed that VO_{2peak} had the largest total association with body fatness.
322 Rodrigues et al. (2016) (12) found that a negative developmental pathway (low rate of change)
323 of cardiorespiratory fitness was associated with higher odds ratios for overweight/obese status
324 at the end of primary school. Conversely, the recent study by Lopes et al. (2020) (13) found no
325 significant differences in the developmental trajectories of cardiorespiratory fitness between
326 two classes of children with lower or higher BMI development. However, the sample size was
327 small and the class with higher BMI development contained fewer children. The reciprocal
328 nature of the association between the development of BMI and cardiorespiratory fitness may
329 be explained by metabolic cost. Children with higher BMI need to induce greater oxygen
330 uptake for physical activities. Thus, they expend a larger proportion of their cardiorespiratory
331 reserve when performing the same task as their leaner peers. (55). McGavock et al. (2009) (17)
332 examined weight gain in low and high cardiorespiratory fitness groups over a 12-month follow-
333 up. They found that the children in the low cardiorespiratory fitness group gained significantly

334 more weight (17). However, maturation status may have influenced the association between
335 BMI and cardiorespiratory fitness, especially in girls, as puberty-related increase in fat
336 percentage may be related to decline in weight-relative fitness, such as running (43). In
337 conclusion, the association between BMI and HRF may be reciprocal, indicating that
338 cardiorespiratory fitness and BMI may form a self-perpetuating vicious cycle.

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

353 The strengths of this study are the large number of participants, a longitudinal design
354 with annual follow-ups, and the use of person-oriented latent growth modeling, which captures
355 individual differences in trajectories over time. Furthermore, the analysis included all the
356 variables presented in the commonly used developmental model of Stodden et al. (2008) (6)
357 and provided further information on the reciprocal relationships between different
358 developmental trajectories. However, the study has its limitations. The model lacked

359 locomotor, stability, and muscular strength measurements, thus health-related fitness only
360 included cardiorespiratory fitness, and motor competence only included object control. In
361 addition, the fourth measurement of MVPA could not be included in the model owing to the
362 participant attrition. The lack of maturation status measurements is a notable limitation because
363 maturation is characterized by several physiological and psychological changes that may
364 influence an individual's developmental trajectories of BMI, motor competence, perceived
365 motor competence and cardiorespiratory fitness, and their associations (43). While BMI is a
366 widely used measure in tracking changes in adiposity, it is not unproblematic with children and
367 adolescents due to maturational growth and its inability to differentiate muscle mass from fat
368 (35). However, according to previous studies, adiposity change in children should rather be
369 measured with BMI, than BMI z scores (57)

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

384 the evaluation of maturation and study its effects on development of motor competence,
385 perceived motor competence, cardiorespiratory fitness, BMI, and physical activity.

386 **Acknowledgements**

387 This study was funded by The Finnish Ministry of Education and Culture.

388 **Conflict of Interest**

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

394

References

- 396 1. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index,
397 underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416
398 population-based measurement studies in 128·9 million children, adolescents, and
399 adults. *Lancet*. 2017 Dec 16;390(10113):2627-42.
- 400 2. Blüher M. Obesity: global epidemiology
401 and pathogenesis. *Nat. Rev. Endocrinol*. 2019 May 1;15(5):299-98.
- 402 3. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical
403 activity among adolescents: A pooled analysis of 298 population-based surveys with
404 1·6 million participants. *Lancet Child Adolesc. Health*. 2020 Jan 1;4(1):23-35.
- 405 4. Aaltonen S, Latvala A, Rose R, et al. Motor development and physical activity: A
406 longitudinal discordant twin-pair study. *Med. Sci. Sports. Exerc*. 2015
407 Oct;47(10):2111-8.
- 408 5. Katzmarzyk PT, Barreira TV, Broyles ST, et al. Physical activity, sedentary time, and
409 obesity in an international sample of children. *Med. Sci. Sports. Exerc*. 2015
410 Oct;47(10):2062-9.
- 411 6. Stodden DF, Goodway JD, Langendorfer SJ, et al. A developmental perspective on
412 the role of motor skill competence in physical activity: An emergent relationship.
413 *Quest*. 2008 May;60(2):290-306.
- 414 7. Robinson LE, Stodden DF, Barnett LM, et al. Motor competence and its effect on
415 positive developmental trajectories of health. *Sports Med*. 2015 Jul 23;45(9):1273-84.

- 416 8. Goodway JD, Ozmun JC, Gallahue DL. Understanding motor development: infants,
417 children, adolescents, adults. 8th ed. Burlington, MA: Jones & Bartlett Learning; 2021.
418 424 p.
- 419 9. Bouchard C, Shephard, RJ. Physical activity, fitness and health: The model and key
420 concepts. In: Bouchard C, Shephard RJ, Stephens T. (eds.) Physical Activity, Fitness
421 and Health. 1994. Champaign, IL: Human Kinetics.
- 422 10. De Meester A, Barnett, LM, Brian, A, et al. The relationship between actual and
423 perceived motor competence in children, adolescents and young adults: A systematic
424 review and meta-analysis. *Sports Med.* 2020 Nov 1;50(11):2001-49.
- 425 11. Logan SW, Kipling Webster E, Getchell N, Pfeiffer KA, Robinson LE. Relationship
426 between fundamental motor skill competence and physical activity during childhood
427 and adolescence: A systematic review. *Kinesiology review.* 2015 Nov;4(4):416-26.
- 428 12. Rodrigues LP, Stodden DF, Lopes VP. Developmental pathways of change in fitness
429 and motor competence are related to overweight and obesity status at the end of
430 primary school. *J. Sci. Med. Sport.* 2016 Jan;19(1):87-92.
- 431 13. Lopes VP, Utesch T, Rodrigues LP. Classes of developmental trajectories of body
432 mass index: Differences in motor competence and cardiorespiratory fitness. *J. Sports
433 Sciences.* 2020 Jan 29;38(6):1-7.
- 434 14. Dencker M, Andersen LB. Accelerometer-measured daily physical activity related to
435 aerobic fitness in children and adolescents. *J. Sports Sciences.* 2011 Jun 01;29(9):887-
436 95.
- 437 15. Britton U, Issartel J, Symonds J, Belton S. What keeps them physically active?
438 Predicting physical activity, motor competence, health-related fitness, and perceived

- 439 competence in Irish adolescents after the transition from primary to second-level
440 school. *Int. J. Environ. Res. Public Health*. 2020 Apr 21;17(8):2874.
- 441 16. Lima RA, Pfeiffer KA, Bugge A, Møller NC, Andersen LB, Stodden DF. Motor
442 competence and cardiorespiratory fitness have greater influence on body fatness than
443 physical activity across time. *Scand. J. Med. Sports*. 2017 Dec;27(12):1638-47.
- 444 17. McGavock JM, Torrance BD, McGuire KA, Wozny PD, Lewanczuk RZ.
445 Cardiorespiratory fitness and the risk of overweight in youth: The healthy hearts
446 longitudinal study of cardiometabolic health. *Obesity*. 2009 Sep;17(9):1802-7.
- 447 18. Babic MJ, Morgan PJ, Plotnikoff RC, Lonsdale C, White RL, Lubans DR. Physical
448 activity and physical self-concept in youth: Systematic review and meta-analysis.
449 *Sports Med*. 2014 Jul 23;44(11):1589-601.
- 450 19. Southall JE, Okely AD, Steele JR. Actual and perceived physical competence in
451 overweight and nonoverweight children. *Pediatr. Exerc. Sci*. 2004 Feb;16(1):15-24.
- 452 20. Jones RA, Okely AD, Caputi P, Cliff DP. Perceived and actual competence among
453 overweight and non-overweight children. *J. Sci. Med. Sport*. 2010 Nov;13(6):589-96.
- 454 21. Coppens E, Bardid F, Deconinck FJA, et al. Developmental change in motor
455 competence: A latent growth curve analysis. *Front. Physiol*. 2019 Oct 2;10:1273.
- 456 22. Jaakkola T, Yli-Piipari S, Stodden DF, et al. Identifying childhood movement profiles
457 and tracking physical activity and sedentary time across 1 year. *Transl. Sports Med*.
458 2020 Sep;3(5):480-7.
- 459 23. Pate RR, Dowda M, Dishman RK, Colabianchi N, Saunders RP, McIver KL. Change
460 in children's physical activity: Predictors in the transition from elementary to middle
461 school. *Am. J. Prev. Med*. 2019 Mar;56(3):65-73.

- 462 24. Farooq A, Martin A, Janssen XX, et al. Longitudinal changes in moderate-to-
463 vigorous-intensity physical activity in children and adolescents: A systematic review
464 and meta-analysis. *Obes. Rev.* 2020 Jan;21(1):12953.
- 465 25. Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK,
466 1990. *Arch. Dis. Child.* 1995 Jul;73(1):25-9.
- 467 26. Raghuveer G, Hartz J, Lubans D, et al. Cardiorespiratory fitness in youth: An
468 important marker of health: A scientific statement from the american heart
469 association. *Circulation.* 2020 Aug 18;142(7):101-18.
- 470 27. Barnett LM, Lai SK, Veldman SLC, et al. Correlates of gross motor competence in
471 children and adolescents: A systematic review and meta-analysis. *Sports Med.* 2016
472 Feb 19;46(11):1663-88.
- 473 28. Janssen X, Basterfield L, Parkinson KN, et al. Non-linear longitudinal associations
474 between moderate-to-vigorous physical activity and adiposity across the adiposity
475 distribution during childhood and adolescence: Gateshead Millennium Study. *Int. J.*
476 *Obes.* 2019 Apr;43(4):744-50.
- 477 29. Britton Ú, Belton S, Issartel J. Small fish, big pond: The role of health-related fitness
478 and perceived athletic competence in mediating the physical activity-motor
479 competence relationship during the transition from primary to secondary school. *J.*
480 *Sports Sci.* 2019 Jul 29;37(22):2538-48.
- 481 30. Poitras VJ, Gray CE, Borghese MM, et al. Systematic review of the relationships
482 between objectively measured physical activity and health indicators in school-aged
483 children and youth. *Appl. Physiol. Nutr. Me.* 2016 Jun;41(6):197-239.

- 484 31. Jaakkola T, Sääkslahti A, Liukkonen J, Iivonen S. Peruskoululaisten fyysisen
485 toimintakyvyn seurantajärjestelmä [The system to develop and follow Finnish
486 students' physical fitness and motor skills]. University of Jyväskylä: Faculty of Sport
487 and Health Sciences; 2012.
- 488 32. Leger LA, Lambert J. A maximal multistage 20-m shuttle run test to predict VO₂
489 max. *Eur. J. Appl. Physiol.* 1982 Jun;49(1):1-12.
- 490 33. Fox KR, Corbin CB. The Physical self-perception profile: development and
491 preliminary validation. *J. Sport Exercise Psy.* 1989 Dec;11(4):408-30.
- 492 34. Gråstén A. Students' Physical Activity, Physical Education Enjoyment, and
493 Motivational Determinants through a Three-Year School- Initiated Program. *Studies*
494 *in Sport, Physical Education, and Health* 205: University of Jyväskylä; 2014. 138 p.
- 495 35. Nuttall F. Body mass index: Obesity, BMI, and health: A critical review. *Nutr.* 2015
496 May;50(3):117-28.
- 497 36. Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for
498 thinness, overweight and obesity. *Pediatr. Obes.* 2012 Aug;7(4):284-94.
- 499 37. Heil DP, Brage S, Rothney MP. Modeling physical activity outcomes from wearable
500 monitors. *Med. Sci. Sports. Exerc.* 2012 Jan;44(1):50-60.
- 501 38. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two
502 objective measures of physical activity for children. *J. Sports Sci.* 2008 Dec
503 15;26(14):1557-65.
- 504 39. Trost SG, Loprinzi PD, Moore R, Pfeiffer K. Comparison of accelerometer cut points
505 for predicting activity intensity in youth. *Med. Sci. Sports Exerc.* 2011 Jul;43(7):1360-
506 8.

- 507 40. Muthén LK, Muthén BO. (1998-2015). Statistical Analysis with Latent Variables
508 User's Guide. 7th ed. Los Angeles, CA: Muthén & Muthén. 876 p.
- 509 41. Little RJA, Rubin DB. Statistical analysis with missing data. 2nd ed. Hoboken, New
510 Jersey: John Wiley & Sons, Inc; 2002. 389 p.
- 511 42. Hunt L, Jorgensen M. Mixture model clustering for mixed data with missing
512 information. *Comput. Stat. Data Anal.* 2003 Jan 28;41(3):429-40.
- 513 43. Malina RM, Bouchard C, Bar-Or O. Growth, Maturation, and Physical Activity. 2nd
514 ed. Human Kinetics; 2004. 712 p.
- 515 44. Han JC, Lawlor DA, Kimm SY. Childhood obesity. *Lancet.* 2010 May
516 15;375(9727):1737-48.
- 517 45. Lounassalo I, Salin K, Kankaanpää A, et al. Distinct trajectories of physical activity
518 and related factors during the life course in the general population: A systematic
519 review. *BMC Public Health.* 2019 Mar 06;19(1):271.
- 520 46. Lai S, Costigan SA, Morgan PJ, Lubans DR. Do school-based interventions focusing
521 on physical activity, fitness, or fundamental movement skill competency produce a
522 sustained impact in these outcomes in children and adolescents? A systematic review
523 of follow-up studies. *Sports Med.* 2014 Jan;44(1):67-79.
- 524 47. Morgan PJ, Barnett LM, Cliff DP, et al. Fundamental Movement Skill Interventions
525 in Youth: A Systematic Review and Meta-analysis. *Pediatrics.* 2013
526 Nov;132(5):1361-83.
- 527 48. Brown KA, Patel DR, Darmawan D. Participation in sports in relation to adolescent
528 growth and development. *Transl Pediatr.* 2017 Jul;6(3):150-9.

- 529 49. Drenowatz C, Greier K. Association of biological maturation with the development of
530 motor competence in Austrian middle school students – a 3-year observational study.
531 *Transl Pediatr.* 2019 Dec;8(5):402-11.
- 532 50. Armstrong N, Welsman J. Traditional and new perspectives on youth
533 cardiorespiratory fitness. *Med. Sci. Sports Exerc.* 2020 Dec;52(12):2563-73.
- 534 51. Gralla MH, McDonald SM, Breneman C, Beets MW, Moore JB. Associations of
535 objectively measured vigorous physical activity with body composition,
536 cardiorespiratory fitness, and cardiometabolic health in youth: A review. *Am. J.*
537 *Lifestyle. Med.* 2016 Jan 6; 13(1):61-97.
- 538 52. Baker BL, Davison KK. I know I can: A longitudinal examination of precursors and
539 outcomes of perceived athletic competence among adolescent girls. *J. Phys. Act.*
540 *Health.* 2011 Feb;8(2):192-9.
- 541 53. Hill JO, Wyatt HR, Peters JC. Energy balance and obesity. *Circulation.* 2012 Jul
542 3;126(1):126-32.
- 543 54. Hjorth MF, Chaput J-P, Ritz C, et al. Fatness predicts decreased physical activity and
544 increased sedentary time, but not vice versa: Support from a longitudinal study in 8-
545 to 11-year-old children. *Int. J. Obes.* 2014 Jul;38(7):959-65.
- 546 55. Norman A, Drinkard B, McDuffie JR, Ghorbani S, Yanoff LB, Yanovski JA.
547 Influence of excess adiposity on exercise fitness and performance in overweight
548 children and adolescents. *Pediatrics.* 2005 Jun 1;115(6):690-6.
- 549 56. Pietilainen KH, Kaprio J, Borg PAJ, et al. Physical inactivity and obesity: A vicious
550 circle. *Obesity.* 2012 Jan 1;16(2):409-14.

551 57. Berkey CS, Colditz GA. Adiposity in Adolescents: change in actual BMI works better
552 than change in BMI z score for longitudinal studies. *Ann. Epidemiol.* 2007
553 Jan;17(1):44-50.