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Developmental associations of actual motor competence and perceived physical competence with health-related fitness in schoolchildren over a four-year follow-up

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A B S T R A C T

The developmental associations between actual motor competence (MC), perceived physical competence (PC), and health-related fitness (HRF) in schoolchildren were investigated over a four-year period. Participants were 1147 (girls 582, boys 565) schoolchildren aged between 11 and 13 years (M = 11.27 ± 0.33 years) in the beginning of the study. Data were collected at five time points in 2017–2021. MC was measured with three product-oriented (i.e., outcome of the movement) motor competence skill tests: side-to-side jump, five-leaps, and throw-catch. PC was assessed with the Physical Self-Perception Profile. HRF was assessed with the 20m shuttle run, curl-up, and push-up tests. The random intercept cross-lagged panel model with birth month and sex as covariates, was tested using repeated measures (within level) and PC, MC, and HRF levels (between level). The key findings were: 1) PC, MC, and HRF levels were reciprocally associated over time; 2) repeated measures of HRF at each time point were positively associated with PC and MC one year later; 3) PC decreased, MC increased, and HRF remained stable over time; and 4) MC was more important than PC in explaining the variability in HRF levels and repeated measures. The positive reciprocal associations of MC, PC, and HRF from late childhood to early adolescence found in this study are important as they indicate that to support HRF in schoolchildren, both MC and PC can be promoted through investment in MC exercises.

1. Introduction

Physical fitness along with physical activity levels in children and adolescents have declined over the past few decades (Farooq et al., 2019; Fühner, Kliegl, Arntz, Kriemler, & Granacher, 2021). Longitudinal studies have shown that vigorous physical activity in particular is strongly associated with cardiorespiratory fitness (Carson et al., 2014; Janz, Dawson, & Mahoney, 2000). Both cardiorespiratory and muscular fitness have in turn been shown to negate cardiovascular disease risk factors such as overweight and obesity, blood pressure, and lipid profiles (Ortega, Ruiz, Castillo, & Sjöström, 2008; Robinson et al., 2015). Positive associations between motor competence (MC) and health-related fitness (HRF), including cardiorespiratory and musculoskeletal fitness, in children and adolescents have been reported in previous cross-sectional (Cattuzzo et al., 2016) and longitudinal studies (Barnett et al., 2022). Furthermore, Stodden et al. (2008; 2014) suggested that perceived physical competence (PC) and HRF mediate the relationship between actual MC and physical activity. Thus, both PC and MC are equally important factors underlying health outcomes in early childhood. Despite the impressive body of studies on the topic, further research on concurrent developmental associations examined at multiple time points is warranted (Barnett et al., 2022). This study aimed to contribute further to the associations previously established between actual MC, PC, and HRF in schoolchildren from childhood to adolescence.

MC is defined as the mastery of both fine and gross motor skills and movements that enable participation in physical activities (Castelli & Valley, 2007; Henderson & Sugden, 1992). MC also denotes the underlying mechanisms including quality of movements (Gabbard, 2008). Fundamental movement skills, comprising of a person's ability to control objects (e.g., catching, throwing, dribbling), locomotor skills, as when moving the body from one place to another (e.g., running,

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walking, leaping), and stability skills, as when keeping the body in place while moving around its vertical and horizontal axes (e.g., balancing, stretching, bending) (Goodway, Ozmun, & Gallahue, 2019), are acquired in early to late childhood. MC levels typically increase over time (Barnett et al., 2016) through practice, repetition, structural training, and also in part through physical maturation (Vandendriessche et al., 2012; Vandorpe et al., 2012). Boys have been shown to have higher MC skills than girls, especially in activities requiring object control skills (Bardid et al., 2016; Bolger et al., 2018) and girls to have higher locomotor skills than boys (Bolger et al., 2018) reported. The disparities in fundamental movement skills between girls and boys have been found, likely depending on individual variation in skill development during childhood and adolescence (Coppens et al., 2019). However, O'Brien et al. (2022) reported that the movement skill mean differences between girls and boys were compatible with small effect sizes. Barnett, Beurden, Morgan, Brooks, and Beard (2010) concluded that throughout adolescence, boys may also receive greater encouragement and reinforcement as well as more often participate in activities involving object control skills than girls.

PC refers to personal beliefs about one's capability to perform both gross and fine motor tasks (Harter, 1978; Rudisill, Mahar, & Meaney, 1993). Perceived competence in motor skills has been defined as, e.g., perceived motor competence, perceived physical competence, perceived sport competence, perceived motor proficiency, perceived physical ability, and even perceived physical self-concept (Estevan & Barnett, 2018). PC typically decreases from late childhood to early adolescence. One possible reason for this is that children's perceptions of their competencies become more accurate (Robinson et al., 2015; Stodden, Gao, Goodway, & Langendorfer, 2014) and another is that growth spurts, in which their bodies increase in size and shape, may distract their attention away from their motor skill performance (Hands, Larkin, Parker, Straker, & Perry, 2009). In addition, greater accuracy of PC in adolescents have been shown to associate with cognitive development (De Meester et al., 2020; Stodden et al., 2008), whereas overestimation of MC skills has typically been reported within this age group (Philpott et al., 2021). Although boys and girls display similar PC levels in kindergarten, from the elementary school years onwards boys typically report higher PC than girls (Pesce, Masci, Marchetti, Vannozzi, & Schmidt, 2018).

Previous reviews (Barnett et al., 2016; De Meester et al., 2020) on the topic have shown that the cross-sectional associations between actual MC and PC in children and youth are well documented. Moreover, a few follow-up studies have examined the transition from childhood to adolescence (e.g., Barnett et al., 2010; D'Hondt et al., 2014; Vandorpe et al., 2012). De Meester et al. (2020) found that the positive association between actual MC and PC in youth varied from low to moderate. Morano, Bortoli, Ruiz, Campanozzi, and Robazza (2020) suggested that inaccuracy in children's self-perceptions, owing to the limited development of their cognitive skills, may explain the weak associations between actual MC and PC. However, PC is an important correlate of MC (Coppens et al., 2019), as fundamental skill development may be enhanced or hindered by psychological attributes such as PC (Hulteen, Morgan, Barnett, Stodden, & Lubans, 2018). Stodden et al. (2008; 2014) suggested that the associations between actual MC and PC may vary from early childhood (0–8 years) and middle to late childhood (6–12 years). However, PC has shown a longitudinal association with other health behaviours in schoolchildren, such as physical activity (Jaakkola, Yli-Piipari, Watt, & Liukkonen, 2016).

HRF is a multidimensional construct that includes cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, and body composition (Caspersen, Powell, & Christenson, 1985). Cardiorespiratory fitness is the capacity of the respiratory and cardiovascular systems to maintain vigorous activity (Ortega et al., 2008). Muscular strength is the ability to produce force against a maximal resistance, while muscular endurance refers to the ability of producing sub-maximal force over a long period (Smith et al., 2014). Both muscular strength and endurance contribute to muscular fitness, i.e., the ability to produce strength maximally, explosively, or continuously (Ortega et al., 2008; Smith et al., 2014). Flexibility is the ability of an individual joint or of several joints to move through the full range of motion (Institute of Medicine, 2012), and body composition describes the relative percentage of bone, fat, and muscle tissue in the body (Wang, Pierson, & Heymsfield, 1992). Cardiorespiratory fitness typically improves over time, the maximum volume of oxygen capacity increases as children grow (Armstrong & Welsman, 2019), with boys having higher capacity than girls (Tomkinson, Lang, & Tremblay, 2019). Similarly, muscular strength and body composition change along with the body size and muscle mass, which typically increase during pubertal growth spurts (Malina & Bouchard, 1991). In addition, given its multidimensional nature, HRF can be improved by instruction and training (Pate, 1988).

According to the developmental model of Stodden et al. (2008; 2014), the pathway from PC to MC and from MC to HRF are reciprocal when children transition from early childhood to middle and late childhood. In addition, recent reviews have reported positive associations between MC and multiple aspects of HRF (Barnett et al., 2022; Cattuzzo et al., 2016; Utesch, Bardid, Büsch, & Strauss, 2019). For instance, Barnett et al. (2022) showed strong evidence for a positive path from MC to physical fitness but inconclusive evidence for the reverse association. However, they considered the evidence for a longitudinal pathway from actual to perceived MC or vice versa as insufficient. Utesch et al. (2019) concluded that the association between MC and physical fitness was moderate to large, while age showed a small positive mediating effect. Finally, Catuzzo et al. (2016) found strong support for a positive association between MC and both cardiorespiratory and muscular fitness and that the associations between MC and HRF were very similar in girls and boys.

Despite the many studies conducted on the topic, some important aspects remain unclear. Research on the longitudinal relationship between MC, PC, and HRF from early childhood to adolescence using multiple variables and multiple time points is needed (Barnett et al., 2022; Bremer & Cairney, 2016; Utesch et al., 2019). Because PC and MC have been shown to be associated in childhood (Barnett et al., 2022; De Meester et al., 2020) and the associations between MC and HRF (Barnett et al., 2022; Cattuzzo et al., 2016; Utesch et al., 2019) are well documented, the PC and HRF association has received less attention. To fill these research gaps, this study examined the developmental associations of MC, PC, and HRF over five measurement points, including the transition from elementary to middle school. Specifically, children were followed up from the fifth to ninth grade, when physical activity typically decreases (Farooq et al., 2019). Because of the great individual variation in the speed and timing of bodily changes in this age group (Rogol, Roemmich, & Clark, 2002), a multilevel analytical approach with repeated measures can be considered an appropriate method (Hair & Fávero, 2019). This study also extends previous findings by investigating the developmental associations between repeated measures (within-level) and levels (between-level) of PC, MC, and HRF in the same model.

The aims were: 1) to examine the developmental associations of PC, MC, and HRF, including the covariate effects of sex and birth month, in schoolchildren over a four-year period; 2) to analyse changes in concurrent repeated measures of PC, MC, and HRF over time; and 3) to examine whether PC or MC is more important in explaining variability in HRF. Based on previously established associations, both PC and MC were expected to be positively associated with HRF and vice versa (Barnett et al., 2022; Cattuzzo et al., 2016; Utesch et al., 2019). PC was expected to decrease over time (Robinson et al., 2015; Stodden et al., 2014) and MC and HRF to increase over time. PC and MC were expected to show strong reciprocal correlations (Barnett et al., 2022; De Meester et al., 2020).

2. Materials and methods

2.1. Participants

Participants were 1147 (girls 582, boys 565) children aged 11–13 years at baseline ($M = 11.27 \pm 0.33$ years). They were drawn from randomly selected public schools from rural and urban areas in Central Finland (41% of participants), Southern Finland (46%), Eastern Finland (7%), and Northern Finland (7%). About two percent of the Finnish fifth-grade children (61 062 in total) participated in the beginning of the study (Statistics of Finland, 2017). School principals were contacted via emails and all fifth graders were invited to participate through written invitations. Children confirmed their participation by returning their parents' written consents, which were collected by their teachers. Participants represented 35 elementary schools in 2017–2018 and 20 middle schools in 2019–2021. Although participation was open to all children equally, no children with disabilities or special needs participated. The ethical review board of the affiliated university approved the study protocol.

2.2. Procedure

Data were collected using identical procedures during school physical education classes (August to September) in 2017 (T0), 2018 (T1), 2019 (T2), 2020 (T3), and 2021 (T4). The self-report questionnaire included demographics (sex, date of birth) and PC-related structured items (Fox & Corbin, 1989). Supervised by the researchers, participants filled out the questionnaires in their classrooms. They were encouraged to answer honestly and assured that their responses were confidential. As participation was voluntary, no rewards or extra credits were awarded. Children were informed they could withdraw from the study at any time without consequences. MC and HRF data were collected in school physical education classes. The test protocol was equal at each measurement point. The data collection was conducted in the school gym over two 90-min sessions. MC tests were conducted on the first session, in which the throw-catch test was followed by five-leap and side-to-side tests. The curl-up and push up were tested first and the 20 m shuttle run was the last event of the test protocol. Participants were informed about potential risks and safety before each data collection session. To minimise risk for preventable accidents, warm-up games were played before physical tests. The data collection sessions were supervised by teachers. The research team organised the tests and collected the test results. The data were converted to SPSS format by the researchers.

2.3. Measures

PC was assessed using the physical competence subscale of the Physical Self-Perception Profile (Fox & Corbin, 1989). Five items preceded by the stem "What am I like?" were answered on a five-point Osgood scale (1 = I am good at sport … 5 = I am not good at sport). The sum scores of the five items served as PC measures at each time point. The factor structure of the subscale ($\chi^2(5) = 22.67$, $p < .001$, $CFI = 0.98$, $TLI = 0.97$, $RMSEA = 0.074$, $SRMR = 0.020$) has been confirmed in a sample of Finnish schoolchildren (Gråstén, 2014).

MC was assessed using three sex- and age-adjusted MC skill tests (https://www.oph.fi/fi/koulutus-ja-tutkinnot/ohjeet-ja-materiaalit-move-mittauksiin): side-to-side jump (stability) (Kiphard & Schilling, 2007), five-leap (locomotor) (Jaakkola, Sääkslahti, Liukkonen, et al., 2012), and throwing-catching (object control) (Jaakkola, Sääkslahti, Liukkonen, & et al., 2012). The two-legged side-to-side test was performed as consecutive back and forth jumps (15 s) over a small wooden beam (600 × 40 × 20 mm). The test was performed twice with feet parallel. The final score (reps) was the mean of two trials. The throwing-catching test was performed by throwing a tennis ball at a target square (1.5 × 1.5 m) marked 90 cm above floor level from a distance of 7 m for girls and eight for boys. Participants were asked to perform 20 throws from behind the marked line, hit the target area, and catch the ball after one bounce. The total score was the quantity of correctly performed throwing-catching combinations (reps). The 5-leaps test consisted of five consecutive jumps starting with feet together at the start and end of the series of jumps with each intermediate jump starting and landing on alternate legs. The score was measured from the front edge of the participant's feet in the start position to the rear edge of the feet at the end position (cm). Following the procedures of Jaakkola et al. (2021), the standardised mean scores of each three MC tests were summed to calculate an overall MC score. The test-retest intraclass correlations (ICC) have been acceptable in side-to-side jump (.51), five-leap (0.84), and throw-catch (0.69) tests within the sample of Finnish adolescents (Jaakkola, Sääkslahti, Liukkonen, & Iivonen, 2012).

HRF included sex- and age-adjusted cardiorespiratory and muscular fitness tests, in this instance the 20m shuttle run (PACER; Léger, Mercier, Gadoury, & Lambert, 1988), curl-up (Jaakkola, Sääkslahti, Liukkonen, & et al., 2012), and push-up (Jaakkola, Sääkslahti, Liukkonen, & et al., 2012) tests. The PACER test was performed by running along the 20-m track between two lines marked on the gym floor. The running velocity was 8.5 km/h for the first minute followed by an incremental increase of 0.5 km/h per minute, until the participant was no longer able to keep pace with the beeps. The cardiorespiratory fitness score was the number of completed shuttles. In the curl-up test, participants lie on their back on the gym mat with knees bent at about 100°, heels on the floor and feet slightly apart. Arms remained alongside the body and head rested on the floor. Curl-ups were performed by activating the abdominal muscles so that the upper body rose from the floor and the fingers slide between an area marked on the floor. Participants were instructed to perform the movement in time with the audio tape and no breaks were allowed. The score was the number of repetitions up to a maximum of 75. In the push-up test, participants were instructed to maintain a straight line from toes to hips and from hips to shoulders, lower their body so that the elbows were bent to 90°, and push back up to the start position with the palms and toes (boys) or the palms and knees (girls) on the floor. The test score was the number of correctly completed repetitions performed in 60 s. As recently reported by Jaakkola et al. (2021), the standardised mean sum scores including three HRF test results were used as overall HRF score. The muscular fitness and PACER tests have shown adequate reliability in a sample of Finnish adolescents. Specifically, curl up (0.67), push up (0.80), and PACER (0.81) test-retest ICCs were considered high (Jaakkola, Sääkslahti, Liukkonen, & Iivonen, 2012).

2.4. Data analysis

The observed variables were tested for normality, outliers, and missing values, and descriptive statistics including correlations, means, and standard deviations were calculated. Confirmatory factor analysis was conducted to test the factor structure of the PC scale over time. To answer the research questions, the Random Intercept Cross-Lagged Panel model (RI-CLPM) was tested (Hamaker, Kuiper, & Grasman, 2015). The RI-CLPM model included the within- and between-level variables, which were estimated based on the observed variables. The within-level variables consisted of the person-centered repeated measures of PC, MC, and HRF with within-unit fluctuations for each participant over time. The between-level variables comprised the random intercepts, which represented the overall level over time in the latent PC, MC, and HRF variables. Birth month and sex were added into the model as covariates. Birth month was selected over age, as age gaps between children were very small. Model fit was estimated using the Chi-square test ($\chi2$), the root means square error of approximation (RMSEA; 0.08 or less), standardised root means square residual (SRMR; 0.06 or less), comparative fit index (CFI; > 0.95), and Tucker-Lewis index (TLI; > 0.95) (Hair, Black, Babin, & Anderson, 2010). Standardised mean difference effect sizes were estimated to analyse changes in the repeated measures of PC, MC, and HRF over time. The differences in parameter estimates between repeated measures at the within-level and the latent variables at the between-level were analysed using independent t-tests. Preliminary analysis was performed using SPSS 26.0 and RI-CLPM using Mplus 8.4.

3. Results

3.1. Preliminary analysis

The diagnostic analysis for the data was performed. Graphs showed that the data were normally distributed. No significant outliers were detected based on the standardised values of the observed variables. Because the proportion of participants decreased over time, the data matrix included 24% of missing values (16 092 out of 63 855). Closer scrutiny using the Missing Completely at Random test (Little, 1988) indicated that the data matrices with and without missing scores were dissimilar ($\chi^2 = 28\,189.43$, $df = 27\,590$, $p < .01$). The missing values did not represent any specific age, sex, or school variables, and thus were assumed to be missing at random. In these circumstances, no further data modifications were required. Confirmatory factor analysis with five items (I am good at sport/physical activities, I am among the best when it comes to sport/physical abilities, I feel confident when participating in sport/physical activities, I am among the best when it comes to joining sport/physical abilities, I am among the first to join sport/physical activities) at each time point from T0 to T4 supported the factor structure of the PC scale over time ($\chi^2(265) = 1170.48$, $p < .001$, $CFI = 0.93$, $TLI = 0.92$, $RMSEA = 0.055$, $CI\ 90\%$ [0.05, 0.06], $SRMR = 0.036$), indicating good reliability of the results.

3.2. Descriptive statistics

Descriptive statistics including means, standard deviations, minimum and maximum scores, and kurtosis and skewness of the observed and latent variables were examined (Table 1). The mean scores indicated that PC was relatively stable, whereas the means of the MC and HRF variables increased over time. The correlation coefficients of PC, MC, and HRF varied between moderate and strong over time (Table 2). The strongest positive cross-sectional correlations were found between PC and MC at T3, PC and HRF at T3, and MC and HRF at T1.

3.3. Developmental associations between PC, MC, and HRF over time

The four-year developmental associations between PC, MC, and HRF at the within and between level, including the covariate effects of sex and birth month, were tested with the RI-CLPM model (Figure 1). The model showed an acceptable fit to the data ($\chi^2(63) = 230.13$, $p < .001$, $CFI = 0.98$, $TLI = 0.96$, $RMSEA = 0.049$, $CI\ 90\%$ [0.04, 0.06], $SRMR = 0.038$). The standardised results at the between level showed strong positive correlations between PC and MC, PC and HRF, and MC and HRF, indicating that the higher the values of PC and MC, the higher the value of HRF. The associations were reciprocal. That is, the paths from PC to HRF and HRF to PC ($t(2240) = 0.43$, $p = .669$), MC to HRF and HRF to MC ($t(2240) = 0.43$, $p = .669$), and PC to MC and vice versa ($t(2240) = 0.54$, $p = .592$) were equal. MC showed a higher correlation than PC with HRF ($t(2240) = 2.59$, $p = .010$), indicating that it had a more significant role in HRF variability than PC. The covariate effects indicated that boys had higher PC and MC than girls and that older children (i.e., born earlier in the same year) had higher MC and HRF than younger children. The squared multiple correlations revealed that the model explained 7% of the variance of PC and 3% of the variance of MC at the between level.

The standardised results at the within level revealed similar cross-sectional associations between PC, MC, and HRF from T1 to T3, but no associations between PC and MC at T0 and T4. Specifically, the cross-sectional correlations between MC and HRF were stronger than those between PC and HRF at T1 ($t(2240) = 3.40$, $p = .001$) and T2 ($t(2240) = 2.19$, $p = .039$). Repeated HRF measures from T0 to T3 were positively associated with higher PC and MC scores after each year (e.g., HRF T0 to PC and MC T1). In turn, PC T2 was associated only with HRF T3, while MC from T0 to T2 was associated with HRF from T1 to T3, indicating that at the within level MC was more significant than PC in explaining HRF variability. The repeated mean scores for PC decreased ($\beta = 4.99$, $SE = 0.12$, $p < .001$), while the mean scores for MC increased ($\beta = -0.21$, $SE = 0.07$, $p < .01$) and the mean scores for HRF remained stable ($\beta = -0.06$, $SE = 0.07$, $p = .412$) over time. The model explained 16–26% of PC, 27–37% of MC, and 32–57% of the within-level variance of HRF over time.

Table 1
Descriptive statistics of the observed and latent variables at each time point.

	n	Min	Max	M	Sd	Skewness	Kurtosis
PC							
PC T0	1095	1	5	3.48	.81	−.25	−.01
PC T1	1002	1	5	3.47	.88	−.31	−.14
PC T2	881	1	5	3.39	.93	−.31	−.30
PC T3	823	1	5	3.42	.94	−.26	−.38
PC T4	733		5	3.38	.98	−.17	−.41
MC							
Throw-catch T0	1106	0	20	10.40	5.27	−.18	−.87
Throw-catch T1	979	0	20	12.85	4.72	−.52	−.43
Throw-catch T2	866	0	20	11.02	5.03	−.03	.37
Throw-catch T3	782	0	20	12.91	4.80	−.59	−.37
Throw-catch T4	561	0	20	13.41	4.62	−.69	−.19
5-jump T0	1095	4	10	7.74	.88	−.10	.32
5-jump T1	974	4	11	8.20	1.00	−.17	.26
5-jump T2	840	6	12	8.57	1.09	−.09	−.14
5-jump T3	741	3	13	8.99	1.22	−.11	.79
5-jump T4	541	3	14	9.32	1.41	−.16	.67
Side-to-side T0	1089	11	56	37.27	6.54	−.17	.20
Side-to-side T1	982	12	62	39.96	6.91	−.13	.24
Side-to-side T2	850	16	62	44.39	7.12	−.38	.29
Side-to-side T3	746	10	64	46.39	7.46	−1.06	2.81
Side-to-side T4	529	12	67	47.59	8.12	−.75	1.52
MC T0	1067	−9	6	.03	2.37	−.30	.04
MC T1	940	−10	6	−.02	2.39	−.29	.06
MC T2	811	−7	6	.03	2.35	−.23	−.11
MC T3	688	−9	6	.06	2.36	−.48	.51
MC T4	493	−11	6	.05	2.32	−.45	.69
HRF							
20mSRT T0	1057	1	94	36.06	18.33	.49	−.30
20mSRT T1	942	3	112	40.46	20.37	.48	−.24
20mSRT T2	768	0	103	39.13	19.69	.63	−.04
20mSRT T3	674	0	106	44.12	22.00	.50	−.29
20mSRT T4	437	1	107	40.82	22.18	.37	−.37
Curl up T0	1074	0	75	37.85	21.86	.52	−.91
Curl up T1	987	0	75	39.52	21.22	.45	−.89
Curl up T2	843	0	75	39.95	21.31	.42	−.91
Curl up T3	771	0	75	43.39	21.72	.19	−1.20
Curl up T4	528	1	75	46.63	22.64	.03	−1.40
Push up T0	1070	0	75	21.58	12.21	.36	.10
Push up T1	979	0	60	19.34	12.94	.34	−.55
Push up T2	846	0	76	25.54	13.19	.11	−.11
Push up T3	759	0	75	27.36	13.35	.21	.02
Push up T4	503	0	72	29.33	13.38	.43	.09
HRF T0	995	−5	8	.04	2.28	.23	−.37
HRF T1	912	−5	7	.00	2.33	.21	−.56
HRF T2	721	−5	8	.00	2.33	.16	−.36
HRF T3	616	−6	6	.01	2.38	.09	−.60
HRF T4	383	−6	6	.05	2.35	.12	−.73

Table 2
Correlation coefficients between the latent variables at each time point.

	PC T0	PC T1	PC T2	PC T3	PC T4	MC T0	MC T1	MC T2	MC T3	MC T4	HRF T0	HRF T1	HRF T2	HRF T3	HRF T4
PC T0	1	.55[a]	.46[a]	.44[a]	.40[a]	.38[a]	.35[a]	.36[a]	.35[a]	.28[a]	.35[a]	.33[a]	.34[a]	.35[a]	.38[a]
PC T1		1	.67[a]	.60[a]	.54[a]	.49[a]	.45[a]	.47[a]	.48[a]	.41[a]	.48[a]	.47[a]	.51[a]	.49[a]	.51[a]
PC T2			1	.66[a]	.55[a]	.42[a]	.43[a]	.48[a]	.47[a]	.37[a]	.42[a]	.45[a]	.50[a]	.50[a]	.47[a]
PC T3				1	.64[a]	.42[a]	.36[a]	.44[a]	.51[a]	.46[a]	.38[a]	.41[a]	.48[a]	.56[a]	.53[a]
PC T4					1	.39[a]	.40[a]	.38[a]	.46[a]	.43[a]	.38[a]	.39[a]	.40[a]	.50[a]	.53[a]
MC T0						1	.82[a]	.75[a]	.70[a]	.61[a]	.65[a]	.61[a]	.58[a]	.58[a]	.52[a]
MC T1							1	.82[a]	.78[a]	.64[a]	.65[a]	.70[a]	.63[a]	.58[a]	.53[a]
MC T2								1	.79[a]	.66[a]	.59[a]	.64[a]	.67[a]	.67[a]	.59[a]
MC T3									1	.76[a]	.55[a]	.59[a]	.61[a]	.69[a]	.62[a]
MC T4										1	.38[a]	.45[a]	.52[a]	.60[a]	.66[a]
HRF T0											1	.75[a]	.64[a]	.62[a]	.54[a]
HRF T1												1	.74[a]	.69[a]	.56[a]
HRF T2													1	.80[a]	.70[a]
HRF T3														1	.77[a]
HRF T4															1

[a] $p < .001$

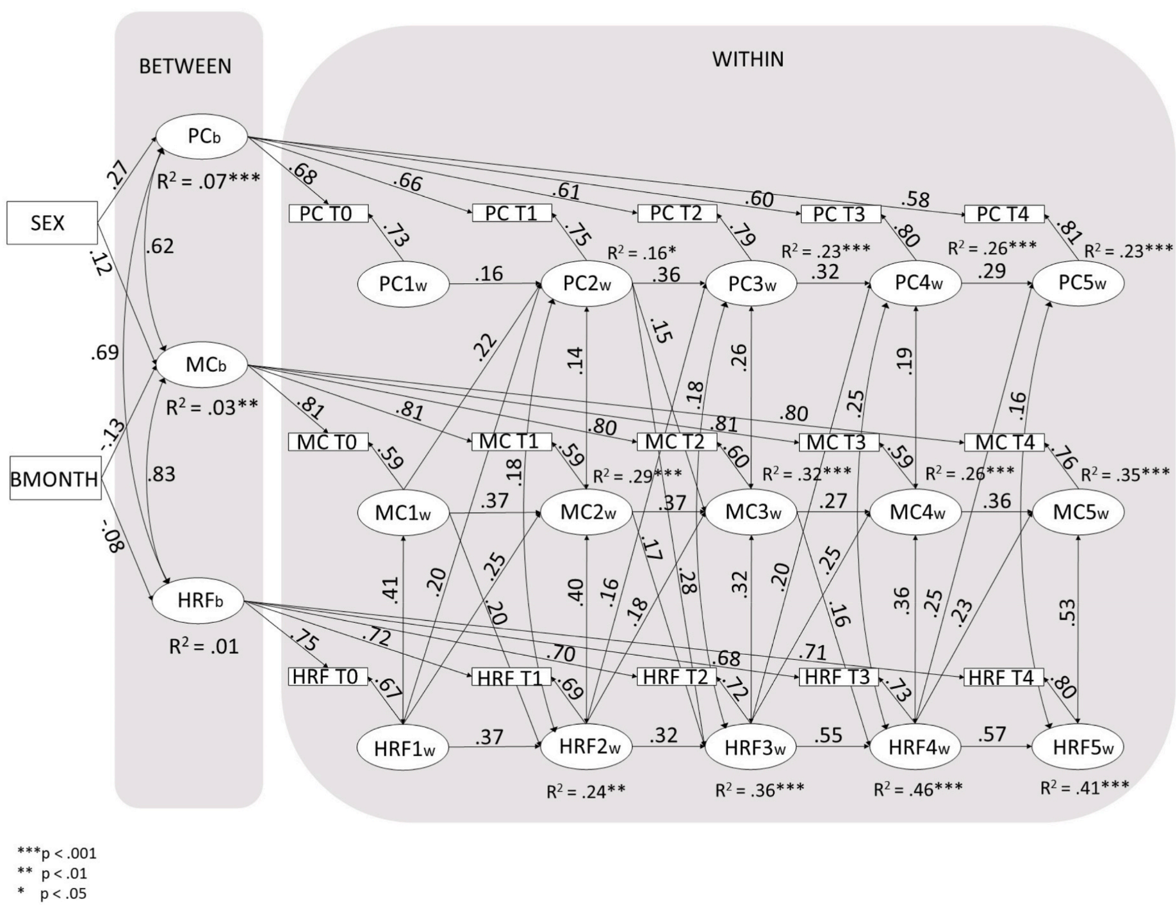

Figure 1. Model for the developmental associations of PC, MC, and HRF over four years.

4. Discussion

This study examined the developmental associations of PC, MC, and HRF levels and repeated measures over four years in Finnish schoolchildren. The key findings were: 1) the levels of PC, MC, and HRF were reciprocally associated with each other; 2) the repeated measures of HRF at each time point were positively associated with PC and MC one year later; 3) the repeated measures of PC decreased, those of MC increased, and HRF remained stable over time; and 4) the MC appeared to be more significant than PC in explaining the variability in the levels and repeated measures of HRF.

Both the PC and MC levels were reciprocally associated with HRF. While earlier studies have showed strong positive evidence for a path from MC to HRF (Barnett et al., 2022; Cattuzzo et al., 2016; Utesch et al., 2019), evidence for the reverse association has rarely been reported (Barnett et al., 2022). In addition, the evidence found for longitudinal actual MC and PC pathways has been insufficient (Barnett et al., 2022). The current finding points to the importance of concurrently promoting MC and PC alongside HRF in late childhood. For instance, before- or after-school programs including a variety of skill practices and considering HRF elements could useful to tackle declining HRF levels (Morano, Robazza, et al., 2020). Although the intention of this study was not to rank cardiorespiratory and muscular fitness in relation to PC and MC, the studies by Smith et al. (2014) and more recently by García-Hermoso et al. (2019) showed that a low level of muscular fitness was especially associated with poor MC skills in children. In addition, Fraser et al. (2021) found that children with low muscular fitness are at higher risk of becoming weak adults. In the current study, higher HRF was always associated with higher HRF after one year. Considering that the data collection started at the fifth grade, an individual could benefit if the HRF level was high before entering the fifth year of the elementary school. Therefore, to reap the greatest positive effects when children transition into adolescence, MC and HRF, including muscular fitness, should be promoted already in the early school years. For example, Morano et al. (2020) found that the after-school program increased participants' activity levels as well as actual MC and PC. Because physical fitness is a synergic combination of cardiorespiratory fitness, muscular strength, muscular endurance, flexibility, body composition (Carpensen et al., 1985), actual MC (Cattuzzo et al., 2016), and PC (Stodden et al., 2008, 2014), focusing on one component does not seem the most sensible approach. Morano, Robazza, et al. (2020) concluded that programs including several intervention components may be the most successful in the school settings.

In fact, the present data, gathered from the fifth to ninth grade participants, showed that the pathway from PC to HRF was strong, indicating that PC as well as MC should be considered in efforts to enhance HRF. This is supported by a seven-month school-based intervention in Italy, in which the intervention group improved physical activity levels, perceived physical ability, and throwing and jumping task performances compared to controls (Morano, Robazza, et al., 2020). Specifically, the after-school program aimed to increase participants' activity levels through a range of enjoyable skill learning experiences and to improve their actual MC and PC. The program included a variety of indoor and outdoor activities (i.e., sport games, circuits, and individual tasks) based on twice-weekly HRF components (i.e., motor skills, flexibility, muscle strength, power, speed, agility, and aerobic fitness). However, the recent review by Hartwig et al. (2021) revealed that most of the interventions aimed at improving cardiorespiratory fitness in schoolchildren have shown only modest increases in physical activity and cardiorespiratory fitness and have also been less effective among those with the greatest need. It may be that many interventions have failed to motivate less physically active children. If so, this should be an important consideration in designing future interventions. Thus, to enhance HRF in schoolchildren from a motivational perspective, both MC and PC should be promoted concurrently by offering exercises that provide opportunities for every child to feel competent rather than physical activities per se. This would help children with lower MC skills to feel motivated and invest more time in developing their perceived and actual abilities. Finally, promoting more vigorous-intensity activities and tailoring muscular fitness training to the individual motivational needs of children could be beneficial.

Our hypothesis that repeated measures of HRF at each time point would be positively associated with PC and MC both cross-sectionally and one year apart was supported. The cross-sectional effect sizes varied from small to moderate, as similarly reported by Utesch et al. (2019). However, the effect sizes of the paths from HRF to MC and PC one year later were relatively small. This indicates that, while not nullifying efforts to enhance HRF, the increases in current HRF do not greatly influence MC or PC later. This may be explained quite simply by the fact that HRF cannot be stored but requires constant training and physical activity (Lambert, Viljoen, Bosch, Pearce, & Sayers, 2009). This in turn leads to stronger cross-sectional than longitudinal associations. Considering the developmental model of Stodden et al. (2008; 2014), a child, who is physically fit and able to participate in physical activities requiring a variety of MC skills, may perceive higher PC than unfit and less skilled peers. Thus, the concurrent development of MC and PC may lead to sustainable HRF trajectories and hence long-term health benefits (Cattuzzo et al., 2016). Moreover, in their longitudinal study, Jaakkola et al. (2016) showed that PA persisted both in the amount and intensity for longer in middle-school students with high PC than in peers who reported themselves as less competent. The direct longitudinal associations from HRF to MC and PC found in this study demonstrate, at least in part, why it is important to promote physical fitness through active lifestyles from the early school years onwards.

As in previous research, PC decreased (Robinson et al., 2015; Stodden et al., 2014) and MC increased (Barnett et al., 2016, 2022) over time. HRF, however, remained stable. This finding contrasts with that of Armstrong and Welsman (2019), who studied cardiorespiratory fitness but not muscular fitness, a difference that may explain some of the inconsistencies between studies. In general, children's physical fitness levels have been shown to decrease over the past few decades (Fühner et al., 2021), apparently owing to increased habitual sedentary time (Aubert et al., 2018). However, the declining trend in PC underlines the importance of motivation as part of a physically active and healthy lifestyle. In their meta-analysis, Pearson, Braithwaite, and Biddle (2015) concluded that in adolescent girls, who are typically less physically active than boys, the most promising physical activity interventions in the school setting are those that also include motivational and physical self-competence components (Aubert et al., 2018). With the increasing reliance on technological devices, exergaming has potential to help promote children's physical fitness (Gao, Zeng, Pope, Wang, & Yu, 2019). In school-based studies, active video games have success in promoting physical self-efficacy and physically activity in children and adolescents (e.g., Gao, Chen, Pasco, & Pope, 2015, 2017). Thus, such games may be an effective alternative means of reducing habitual sedentary time and promoting health and well-being (Gao et al., 2015).

Finally, MC was found to be more important than PC in explaining the variability in HRF levels and repeated measures. This finding was not totally unexpected as in the developmental model of Stodden et al. (2014) the associations between MC and HRF differ from those between PC and HRF. In particular, MC is directly associated with HRF, while PC is indirectly associated with HRF through MC and physical activity. Hence, MC may have stronger effects than PC on HRF. Given that PC is an important motivational factor underlying children's physical activity participation (Jaakkola et al., 2016), MC-based interventions could be used to promote regular physical activity (Barnett et al., 2010). Considering that Philpott et al. (2020) found a small veridical alignment between actual MC and PC, the enhancement of MC skills may also improve children's PC levels (Duncan, Jones, O'Brien, Barnett, & Eyre, 2018). For instance, Pienaar, Gericke, and Plessis (2021) suggested that improving children's object control skills at early ages could be important, as children proficient in movement skills that require the ability to handle objects may be more likely become more physically active and hence healthier adolescents. Vernadakis, Papastergiou, Zetou, and Antoniou (2015) reported that exergames could be used as an alternative to traditional motor skill instruction. In their eight-week exergame intervention with Greek elementary school children, the experimental group improved their object control skills compared to controls. The kinetic games used in the program included a variety of object control skills (e.g., striking a stationary ball, overhand throwing, stationary dribbling, underhand rolling, catching, and kicking). Exergames could be a feasible and up-to-date way to motivate children with low MC and PC in schools and outside school hours when traditional teaching methods are not effective.

The strengths of this study were a longitudinal design that included five measurement points and the use of a cross-lagged model comprising both within- and between-level assessments. However, this study was not free of limitations. While their birth month may indicate height velocity variation in children (Mirvald & Bailey, 1997), biological maturation might more fruitfully have been measured by direct variables, for instance sexual maturation and growth spurts (Beunen, Rocol, & Malina, 2006). A larger range of MC skills, for instance object-control skills such as dribbling and kicking a ball, could have been added. Moreover, the current HRF measurements, which comprised cardiorespiratory and muscular fitness, could also have monitored flexibility and body composition in relation to total HRF levels. Bearing these considerations in mind, future research could focus on collecting longitudinal data on biological maturation variables and all the elements of HRF at multiple time points. Interventions to improve both MC and PC would also be welcomed.

5. Conclusion

This study supported the strong evidence previously found for the paths from MC to HRF. The current findings also provided important results on the reverse association from HRF to both MC and PC in late childhood and early adolescence. In addition, the strong reciprocal association between MC and PC levels was confirmed, while the repeated measures of MC and PC showed low to moderate associations. To support HRF in schoolchildren, both MC and PC could be promoted, for instance, by offering opportunities to practice a variety of physical activities, so that children could invest more time in developing their skills.

Confirmation of ethical compliance

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent was obtained from all individual participants involved in the study.

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Declaration of competing interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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