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Longitudinal associations among cardiorespiratory and muscular fitness, motor competence and objectively measured physical activity

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Abstract

Objectives: This study aimed to investigate cross-lagged associations in motor competence, cardiorespiratory fitness, muscular fitness and accelerometer-based moderate-to-vigorous physical activity (MVPA) engagement.

Design: One-year prospective follow-up study.

Method: A sample was 491 (275 girls; *M* at baseline = 11.27, SD = .32) Finnish physical education students. Students' motor competence was assessed by 1) two-legged jumping from side to side test, 2) throwing-catching combination test and 3) 5-leaps test. Their cardiorespiratory fitness was analyzed by a 20-meter shuttle run test and muscular fitness by curl-up and push-up tests. Additionally, students' MVPA was measured objectively by hip-worn accelerometers.

Results: Results demonstrated that: 1) cardiorespiratory fitness measured at Grade 5 was the only significant predictor of later MVPA and this association appeared only in the boys' group, 2) MVPA assessed at Grade 5 significantly predicted cardiorespiratory fitness in the girls' group, 3) cardiorespiratory fitness collected at Grade 5 associated with muscular fitness, locomotor and stability skills in both girls and boys, and 4) locomotor skills measured at Grade 5 predicted significantly muscular fitness, locomotor and manipulative skills in both sex groups.

Conclusions: Elementary school years are important in providing students with experiences in physical activity (PA) which leads to improvements s in cardiorespiratory health. Additionally, this study showed that cardiorespiratory fitness collected at Grade 5 associated with later muscular fitness, and locomotor and stability skills in both sex groups. These findings are noteworthy because muscular fitness in youth has several health-related benefits and motor competence in childhood and adolescence has positive association with later PA engagement.

Keywords: Motor competence, cardiorespiratory fitness, muscular fitness, physical activity

Practical implications

•Special attention should be directed towards facilitating children's cardiorespiratory fitness and MVPA during elementary school years.

•Commuting to and from school, active school recess, physical education classes, intensive extracurricular and sport club activities and are possible contexts to contribute students' cardiorespiratory fitness and MVPA.

•Practitioners should plan MVPA intensity physical activities which include elements of targeting to develop muscular fitness, and stability, locomotor and manipulative skills.

No competing agreements, professional relationships and financial interests existed where a third party may benefit from the presented results.

1. Introduction

According to the international recommendations, children and youth aged 5–17 should accumulate at least 60 minutes of moderate-to-vigorous intensity physical activity (MVPA) daily.[1] However, studies have demonstrated that only a small portion of children and youth meet the guidelines in Western countries.[2] This trend is also evident in Finland where only 21-40% of youth under 18 years of age meet physical activity (PA) recommendations.[3] A plethora of researchers are working in the field to find out possible antecedents of physically active lifestyle in childhood and adolescence.[4,5] Physical performance factors have found to be significantly linked with PA engagement.[5]

A basis of motor competence can be assessed based on three categories fundamental movement skills; stability, locomotor and manipulative skills.[6] Stodden et al. [7] have suggested that these types of skills provide a foundation for lifetime physical activities. Empirical studies have supported this suggestion showing that motor competence is linked with self-reported PA from childhood to adolescence[8] and from adolescence to early adulthood.[9] Additionally, cross-sectional studies have demonstrated that, in childhood, boys' manipulative skills[10,11] and locomotor skills[10] are associated with objectively measured PA. For girls, this association was found only between locomotor skills and objectively measured PA.[10] Previous studies also have demonstrated that manipulative skill competence is related to self-reported PA in adolescence.[12] However, there is only one study to investigate the associations between locomotor, manipulative skills, and PA engagement over time. Barnett et al.[8] showed that manipulative skills rather than locomotor skills, predicted elementary school children's self-reported MVPA 6-7 years later.

Health-related fitness consists of cardiorespiratory endurance, musculoskeletal fitness, flexibility and a healthy body weight status[13], and is suggested to be a significant physical antecedent of PA engagement. Empirical studies have supported this assertion by demonstrating that health-related physical fitness levels in childhood and adolescence predict PA engagement in adulthood[9,1415] For example, Jaakkola et al.[9] found that physical fitness (composite score of aerobic and muscular fitness) assessed at the age of 13 predict self-reported MVPA engagement 6 years later. Additionally, Dennison et al.[14] indicated that physically active (self-reported PA) 23- to 25-year-old young adults had greater childhood (at age 10–11 years) physical fitness level compared with inactive peers. More specifically, Dennison et al.[14] demonstrated that the risk of physical inactivity in young adulthood was related to the number of low scores on aerobic fitness and abdominal muscular fitness tests. In Finland, Huotari et al[15] recognized that physical fitness (composite score; muscular fitness, agility and aerobic capacity) at the age of 12 to 18 predicted male's subsequent self-reported PA engagement 25 years later (no relationship among females). Overall, the longitudinal relationship between health-related fitness and PA has been mixed, with some of the studies not showing statistically significant relationships. [16,18] It has been suggested that although there is evidence that objectively measured PA has low-to-moderate relationship with $VO2_{PEAK}$ in childhood and adolescence[17], the association between PA engagement and aerobic fitness remains controversial within youth because of different rate in children's growth and maturation.[18]

This study extends existing literature by investigating the associations among objectively measured motor competence, cardiorespiratory fitness, muscular fitness, and MVPA engagement in late childhood through a longitudinal study setting. Previous longitudinal studies in the area did not measure all variables included in this study[8,19] or used self-reports to collect MVPA engagement.[9,12] Thus, the aim of this study was to analyze cross-lagged associations between stability, locomotor and manipulative skills, cardiorespiratory fitness, muscular fitness and objectively measured moderate-to-vigorous PA engagement across one year. In addition, the moderating effect of sex on the associations was investigated.

2. Methods

Participants of this 1-year follow-up study included 491 (216 boys and 275 girls; mean age at the first measurement point = 11.36, SD = .33) Finnish physical education students from South and Middle Finland. Characteristics of subjects at the baseline and follow-up measures are presented in Table 1. Both measurements were collected between the middle of August and the end of September, baseline in 2017 and the follow-up in 2018. The same researchers collected all physical performance data during physical education classes in both time points. Accelerometers were given to students in classrooms. Additionally, a letter about the use of accelerometers were given to parents and teachers. Students' guardians were informed on study protocol and their written consent for the participation was obtained. The study protocol was approved by the ethics committee of the local university.

Accelerometer-based MVPA was measured by accelerometers (Actigraph GT3X+). Students were asked to continuously wear an accelerometer on the right hip during waking hours for seven consecutive days, except while bathing or doing other water-based activities. Data were collected as raw acceleration in 30 Hz frequency, standardly filtered and converted into 15s epoch counts. A customized Visual Basic macro for Excel software was used for data reduction. The valid monitoring period included measured values ≥500 min/day for at least two weekdays and one weekend day between 7:00 and 23:00. Periods of 30 min of consecutive zero counts were defined as non-wearing time, and values over 20,000 counts per minute (cpm) were ruled out as spurious accelerations.[20] Evenson et al's[21] cut-points were used to calculate MVPA (≥2296 cpm).

Cardiorespiratory fitness was analyzed by a 20-meter shuttle run test[22]. In the test a participant runs continuously between two lines 20 meters apart in time of recorded beeps from the tape. The result was the number of shuttles reached before participant is unable to keep on pace.

Muscular fitness was measured by curl-up test (abdominal muscles)[23] and push-up test[23]. In the curl-up test a participant; 1) lies on their back, 2) keep heels on mat and curls up slowly, 3) while curling up they slide across the measuring tape until fingertips reach the other side of tape, and 4) after curl-up they curl back down until head touches the floor. Performance rhythm comes from the tape. Push-up test has different versions for the boys and the girls. In the boys' starting position their hands and toes touch floor, whereas in the girls' version their hands and knees touch floor. Otherwise the test protocol is the same for both sex groups; 1) body and legs are in a straight line, 2) both feet are together, 3) arms are at shoulder width apart, 4) body is lowered down until there is a 90-degree angle in elbows with the upper arms parallel to the floor, and 5) keeping back and knees straight while pushing up until the arms are straight. The result was the number of correctly completed push-ups (max. 60 repetitions). Before data analyses test results of curl-up and push-up tests were first standardized using Z-scores and summed to create a composite muscular fitness score.

Motor competence was assessed by; 1) two-legged jumping from side to side test[24], 2) throwing-catching combination test[23] and 3) 5-leaps test[23]. These tests are representative of students' stability, manipulative and locomotor movement skill. Students' stability skills were measured by two-legged jumping from side to side test[24]. A participant keeps legs parallel and consecutively jumps 15 seconds over a small wooden beam from one side to another. The test is conducted twice, and the result is the sum successful jumps over the beam of these attempts. The throwing-catching combination test was used to measure students' manipulative skills.[23] A participant throws a tennis ball at a target area situated on the wall (1.5 meters x 1.5 meters; 90 centimeters above the floor level). Students had 20 attempts to throw the ball from behind the marked line, hit the target area and catch the ball after one bounce. The throwing distances were 7 meters for the girls and 8 meters for the boys. The result of the test is the number of successfully performed throwing-catching combinations. Before data analyses test results were standardized by using Z-scores because throwing distance varied between sex groups. Students locomotor skills were measured by 5-leaps test[24]. A participant completes five leaps, beginning with both legs, and finishing with legs in parallel position. The result is the length of five leaps in centimeters measured from the heel of the leg furthest back upon the landing phase.

All measures of cardiorespiratory and muscular fitness and motor competence have been used extensively in Finnish sport science research and these tests have demonstrated satisfactory reliability and validity in children and adolescents.[23,24]

Statistical analyses. Normal distribution, outliers, and missing values, and descriptive statistics of the study variables were calculated. Muscular fitness variable was created by calculating the sum of standardized scores of push-up and sit-up tests. To examine the associations between study variables, a cross-lagged model was implemented. The equality of means between measurements at T0 and T1 was tested using the Wald's test of parameter equality. The Chi-square test was used to analyze the equality of means, variances, and variable loadings between girls and boys.[25] The preliminary data analyses were performed using SPSS Version 22.0 and structural equation models using Mplus Version 8.2.

The data were approximately normally distributed, and no significant outliers were detected. The data matrix included 11.74% of missing values (807 out of 6874), because some students did not provide motor competence, muscular fitness, or MVPA scores at T1. Missing Completely at Random -

test (c2 = 723.16, df = 640, p < .05) indicated that missing values were missing at random (MAR).[26] Thus, the missing values were estimated using Full Information Maximum Likelihood procedures, which has been shown to produce unbiased parameter estimates and standard errors under MAR conditions.[27]

3. Results

Correlation coefficients, means, standard deviations, and mean differences between T0 and T1 were examined (Table 2). The results indicated that stability, manipulative, and locomotor skills, and cardiovascular fitness improved over time in both girls and boys. In contrast, muscular fitness scores improved in boys but declined in girls, whereas overall MVPA decreased in both groups over time.

To examine the appropriateness of the theorized model including stability, manipulative, and locomotor skills, muscular and cardiovascular fitness, and MVPA at T0 and T1, both girls and boys were included in the same model as one group. The theorized model revealed an excellent model fit ($\chi^2(17) = 23.51$, $p = .134$, *CFI* = 1.00, *TLI* = .99, *RMSEA* = .028, *90% CI* [.00, .05], *SRMR* = .016), when non-significant associations between the following variables were removed: stability, manipulative, locomotor skills, muscular fitness T0 > MVPA T1; MVPA, manipulative skills T0 > stability T1; MVPA, stability, manipulative, muscular fitness T0 > locomotor skills T1; cardiovascular, muscular fitness T0 > manipulative skills T1; stability, manipulative, muscular fitness T0 > cardiovascular fitness T1; MVPA, manipulative skills T0 > muscular fitness T1.

To examine sex related associations between stability, manipulative, and locomotor skills, muscular and cardiovascular fitness, and MVPA at T0 and T1, a two-group model including girls and boys was implemented. The model showed an excellent model fit for the data ($\chi^2(34) = 43.34$, $p = .131$, *CFI* = 1.00, *TLI* = .98, *RMSEA* = .033, *90% CI* [.00, .06], *SRMR* = .023). The significant associations between study variables in both girls and boys are presented in Figure 1.

To test the differences in variable loadings between of girls and boys, loadings were fixed to be equal one by one in both groups. A series of Chi-square tests showed a difference between girls and boys in the loadings between cardiovascular fitness T0 and MVPA T1 ($\chi^2(1) = 4.22$, $p < .05$), cardiovascular fitness T1 and locomotor skills T1 ($\chi^2(1) = 4.01$, $p < .05$), stability skills T1 and manipulative skills T1 ($\chi^2(1) = 7.08$, $p < .01$), cardiovascular fitness T0 and manipulative skills T0 ($\chi^2(1) = 4.59$, $p < .05$), and cardiovascular fitness T0 and stability skills T0 ($\chi^2(1) = 6.42$, $p < .05$), with boys having stronger loadings than girls.

Similarly, means and variances were fixed to be equal one by one in girls and boys to identify significant mean and variance differences between groups. Boys had higher scores in cardiovascular fitness T0 ($\chi^2(1) = 20.11$, $p < .001$), manipulative skills T0 ($\chi^2(1) = 38.28$, $p < .001$), stability skills T0 ($\chi^2(1) = 10.71$, $p < .001$), muscular fitness T0 ($\chi^2(1) = 31.29$, $p < .001$), and MVPA T0 ($\chi^2(1) = 16.48$, $p < .001$). The significant differences in variances were found in cardiovascular fitness T0 ($\chi^2(1) = 25.36$, $p < .001$) and T1 ($\chi^2(1) = 104.05$, $p < .001$). Finally, squared multiple correlations (R^2) showed that the model explained 28% to 63% of the variability of study variables in girls and 38% to 63% in boys.

4. Discussion

This study aimed to investigate cross-lagged associations among stability, locomotor and manipulative skills, cardiorespiratory fitness, muscular fitness and objectively measured MVPA engagement from Grade 5 to Grade 6 within Finnish children. The main findings of the study were the following: 1) cardiorespiratory fitness measured at Grade 5 was the only significant predictor of later MVPA and this association appeared only in the boys' group, 2) MVPA assessed at Grade 5 significantly predicted cardiorespiratory fitness at Grade 6 in the girls' group, 3) cardiorespiratory fitness collected at Grade 5 associated with muscular fitness, locomotor and stability skills at Grade 6 in both sex groups, and 4) locomotor skills measured at Grade 5 predicted significantly muscular fitness, locomotor and manipulative skills at Grade 6 in both sex groups, and also stability skills in the boys' group.

Results of this study demonstrated that boys' cardiorespiratory fitness was related to their MVPA engagement across time. Association between these variables is in line with previous longitudinal studies.[14,15] These findings suggest that elementary school years represent an important period to develop students' cardiorespiratory fitness by providing children intensive physical activities which increase their breathing and heart rate. According to this study, these activities may improve boys' cardiorespiratory fitness and subsequently increase their later probability for health-enhancing

PA engagement. Results of this study also demonstrated that girls who collected relatively high intensity PA at Grade 5, had better cardiorespiratory fitness one year later. This is a significant result knowing that cardiorespiratory fitness in childhood and adolescence lowers future cardiovascular risk.[28] Although relationships between cardiorespiratory fitness and MVPA engagement across time were different for the boys than the girls, it should be recognized that these variables are closely related with each other. Physical activities which develop cardiorespiratory fitness in late childhood include MVPA, and vice versa. This suggests that physical activities increasing children's heart rate and breathing are strongly encouraged during elementary school years. Communing to/from school by bicycle/feet, active recess, physical education, children's intensive leisure time and sport club activities are possible contexts to contribute MVPA as well as cardiorespiratory fitness. The role of physical education is remarkable. For example, study by Salin et al[29] demonstrated that Finnish students collected almost one third of their MVPA during physical education classes.

This study revealed many cross-lagged associations among cardiorespiratory fitness, muscular fitness and components of motor competence. These findings suggest that 11 – 12 -years old children develop many aspects of their physical performance if they are involved in PA. This is an important finding because previous studies have indicated that cardiorespiratory fitness[28], muscular fitness[30] and motor competence[4] have many health-related benefits but through different mechanisms. Unfortunately, many children do not meet PA recommendations[2,3] and therefore do not develop their cardiorespiratory fitness, muscular fitness and motor competence to gain versatile health benefits.

It was unexpected finding that motor competence was not related to MVPA across time because previous studies have demonstrated such an association from childhood to adolescence.[8,9] According to the motor development literature, the most children have developed their motor competencies by age 10-11.[31] Thus, children of this study sample may have reached their motor competence capacity but have not got experiences of quality motor skills-oriented practice after the end of development. However, it should be recognized that the time period in the current research design was only one year. It may be that the development of motor competence and its' subsequent association with MVPA engagement takes more time. Another reason for nonsignificant associations between motor competence and MVPA may be that product-oriented measures used in this study are not the most valid assessments to represent motor competencies of children today.

Strengths of this study were relatively large sample size, longitudinal design and the use of objective measures to evaluate participants' motor competence, health-related fitness and MVPA. The first and major limitation of this study is that we only used product-oriented measures to analyze children's motor competence. Another limitation is that we did not assessed children's' level of growth and maturation. For example, previous studies have revealed that the association between PA engagement and cardiorespiratory fitness remains controversial within youth because of different rate in growth and maturation.[18] The third limitation of this study is that due to the high collinearity among different PA intensities in accelerometer data we were not able to include other PA intensities in the structural equation model. Future studies should analyze associations among motor competence, health-related fitness and MVPA in longer designs. Additionally, future studies could benefit from including process-oriented measures of motor competence, Subsequently, future studies could add to the literature by investigating if health-related fitness and motor competence are related to other intensities of PA than MVPA.

5. Conclusion

Our findings demonstrate that boys' cardiorespiratory fitness measured at Grade 5 was a significant predictor of later MVPA. Similarly, girls' MVPA assessed at Grade 5 significantly predicted their later cardiorespiratory fitness. These findings suggest that elementary school years are important period to provide intensive physical activities. Additionally, this study showed that cardiorespiratory fitness collected at Grade 5 associated with later muscular fitness, and locomotor and stability skills in both sex groups. These findings are important because: a) muscular fitness in youth has several health-related benefits, and b) motor competence in childhood and adolescence has positive association with later PA engagement.

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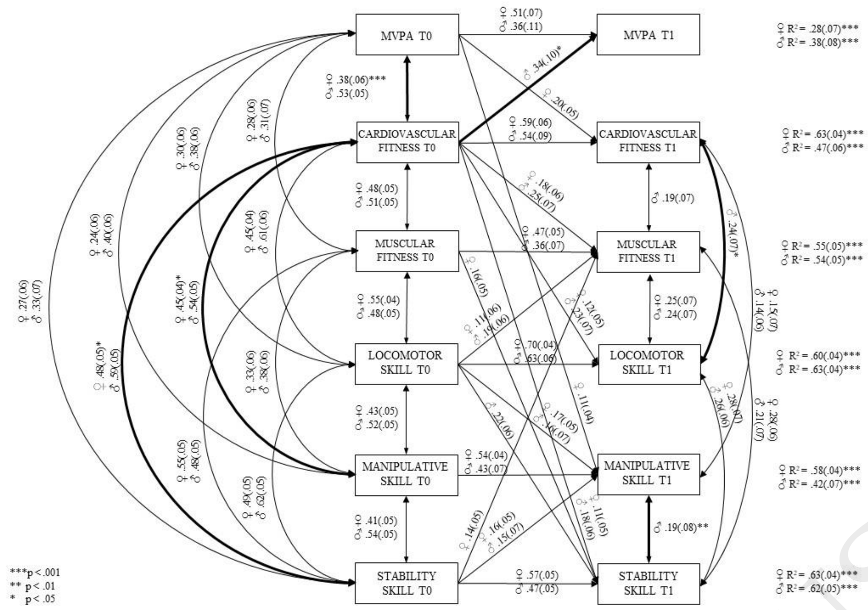
Figure 1. The standardized parameter estimates of the multi-group model including both girls (n = 275) and boys (n = 216). All paths are significant at p < .05 level.



The differences in variable loadings between of girls and boys are presented using bold arrows and p-values.

Table 1. Characteristics of subjects at the baseline and follow-up measures.

Variable	Girls (n = 275)		Boys (n = 216)		Total sample (N = 491)	
	Baseline mean (SD)	Follow-up mean (SD)	Baseline mean (SD)	Follow-up mean (SD)	Baseline mean (SD)	Follow-up mean (SD)
Age (years)	11.26 (.33)	12.26 (.33)	11.27 (.33)	12.27 (.33)	11.26 (.33)	12.26 (.33)
Height (cm)	148.07 (7.18)	154.38 (7.46)	148.49 (6.36)	154.59 (7.09)	148.35 (6.83)	154.47 (7.29)
Weight (kg)	41.34 (8.57)	46.51 (10.13)	42.03 (9.40)	47.24 (10.34)	41.64 (8.94)	46.83 (10.22)
BMI (kg/m2)	18.74 (2.96)	19.38 (3.22)	18.92 (3.19)	19.66 (3.48)	18.82 (3.06)	19.50 (3.34)

Table 2. Correlations, means, standard deviations, and mean differences between T0 and T1 of the study variables.

	1	2	3	4	5	6	7	8	9	10	11	12	M	SD	W_T
1 Stability T0	-	.75***	.41***	.47***	.49***	.44***	.55***	.53***	.49***	.42***	.26***	.23**	38.50	6.45	29.52(3.69)***
2 Stability T1	.72***	-	.39***	.40***	.51***	.56***	.57***	.63***	.48***	.42***	.15*	.24**	41.65	7.11	
3 Manipulative T0	.53***	.51***	-	.69***	.43***	.43***	.33***	.36***	.45***	.36***	.24***	.17*	9.63	5.04	14.38(1.69)***
4 Manipulative T1	.48***	.52***	.59***	-	.51***	.47***	.36***	.40***	.47***	.47***	.30***	.20*	12.69	4.64	
5 Locomotor T0	.61***	.64***	.51***	.47***	-	.77***	.56***	.52***	.60***	.56***	.28***	.23**	7.72	.91	5.52(.38)***
6 Locomotor T1	.51***	.64***	.42***	.45***	.77***	-	.48***	.56***	.51***	.54***	.22***	.29***	8.24	.96	
7 Muscular fitness T0 Push-up Sit-up	.48***	.45***	.36***	.32***	.47***	.44***	-	.69***	.49***	.42***	.29***	.23**	- 27.24 41.28	- 11.54 23.34	3.99(.82)***
8 Muscular fitness T1 Push-up Sit-up	.51***	.59***	.30***	.33***	.57***	.60***	.61***	-	.52***	.47***	.27***	.33***	- 24.31 39.76	- 11.94 21.40	
9 Cardio fitness T0	.58***	.58***	.55***	.44***	.61***	.60***	.50***	.58***	-	.77***	.37***	.28***	33.12	15.61	51.32(7.08)***
10 Cardio fitness T1	.40***	.50***	.33***	.38***	.49***	.57***	.33***	.52***	.67***	-	.46***	.39***	38.69	18.02	
11 MVPA T0	.33***	.43***	.41***	.34***	.39***	.42***	.31***	.47***	.53***	.48***	-	.55***	54.90	21.05	30.38(4.23)***
12 MVPA T1	.26**	.38***	.29***	.21*	.41***	.43***	.28**	.36***	.50***	.35***	.53***	-	51.89	19.20	
M	36.57	40.43	12.56	14.31	7.76	8.37	- 18.14 38.16	- 18.10 40.69	40.58	42.94	63.22	58.71			
SD	6.50	7.08	4.81	4.26	.89	1.07	- 11.66 21.78	- 13.69 22.28	19.91	22.91	23.11	21.32			
W_T	31.16(3.28)***		13.25(2.28)***		5.79(.59)***		4.30(.86)***		55.51(13.05)***		40.83(5.93)***				

Note 1. Correlations for girls (n = 275) are presented above and for boys (n = 216) below the diagonal.
Note 2. Means (M), standard deviations (SD), and mean differences between two measurements (W_T = Wald's test) for girls are presented in vertical and for boys in horizontal columns (standard errors in the parentheses). Note 3. ***p < .001, **p < .01, *p < .05.