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

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Original research

Developmental associations of accelerometer measured moderate-to-vigorous physical activity and sedentary time with cardiorespiratory fitness in schoolchildren

Arto Gråstén [a,b,*], Mikko Huhtiniemi [a], Iiris Kolunsarka [a], Timo Jaakkola [a]

[a] *Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland*
[b] *College of Education, United Arab Emirates University, Al Ain, United Arab Emirates*

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ABSTRACT

Objectives: This study examined the developmental associations of accelerometer-based moderate-to-vigorous physical activity (MVPA) and sedentary time (ST) with cardiorespiratory fitness (CRF) in schoolchildren.
Design: A three-year follow-up study.
Methods: Participants were 446 (girls 57 %) Finnish children (M = 11.26 ± 0.32 years) from 17 randomly selected public schools in Finland. Accelerometer-based MVPA and ST were assessed using waist-worn activity monitors and CRF using the 20 m shuttle run test at four measurement points from 2017 to 2020. The developmental associations were tested using the Random Intercept Cross-Lagged Panel Model (RI-CLPM) reflecting MVPA, CRF, and ST overall levels and repeated measures over time.
Results: The key findings were 1) MVPA was positively associated with CRF, whereas ST was negatively associated with CRF; 2) associations between repeated measures of MVPA and ST with CRF were found only at the final time point; 3) CRF was lower in girls than boys, CRF and MVPA were lower in children with higher BMI, and vice versa; and 4) CRF was higher in children who were still experiencing or had already passed their peak growth spurt than children whose growth spurts had not yet begun.
Conclusions: The results contribute to the growing evidence of a positive developmental association between MVPA engagement and CRF. Furthermore, the inverse association between ST and CRF calls for the avoidance of excessive sedentary behaviour. More effort should be made to promote physically active lifestyles in children and youth.

Practical Implications

- Accelerometer-measured MVPA level was positively associated with CRF level and ST level negatively associated with CRF level.
- Repeated measures of MVPA and ST were associated with CRF only at the final time point.
- Half of the participants accumulated negligible or little vigorous intensity activity.
- Awareness of the importance of extensive physical activity and avoidance of ST should be raised.

1. Introduction

Cardiorespiratory fitness (CRF) is an indicator of population health in children and youth.[1,2] While CRF in school-aged children has decreased in the middle- and high-income countries over the past 30 years, the underlying reasons for this remain unclear.[3] Insufficient moderate-to-vigorous physical activity (MVPA) and excessive sedentary time (ST) are believed to be significant contributors to the decline on CRF.[3] It has been widely shown that MVPA is associated with CRF in children,[4] while the association between CRF and ST, however, is less well established.[5,6]

According to the latest Global Physical Activity Report Card, only 30 % of children and youth meet the current physical activity guidelines (60 min of MVPA per day) and 35 % the sedentary guidelines (<2 h of recreational screen time per day), and only 40 % of children have healthy CRF.[7] Comparing population health across countries based on total MVPA is hampered by the heterogeneity of the self-report or objective data on physical activity used in different studies.[7]

* Corresponding author.
E-mail addresses: agrasten@uaeu.ac.ae (A. Gråstén), mikko.huhtiniemi@jyu.fi (M. Huhtiniemi), iiris.a.kolunsarka@jyu.fi (I. Kolunsarka), timo.jaakkola@jyu.fi (T. Jaakkola).

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In contrast, CRF assessments present an alternative measure of health behaviour,[2] as CRF can be tracked over time and population comparisons are possible.[3] The 20 m shuttle run test (20mSRT) is a reasonable CRF test that can universally be performed in, for example, school physical education settings.[2] Welsman and Armstrong[8] concluded that the results of the 20mSRT reflected fatness rather than CRF in a sample of 76 boys aged 11–14 years, and that it is therefore important to consider adiposity measures such as the body mass index (BMI) along with shuttle run performance in children and youth. Specifically, carrying additional fat mass increases the work required to complete each shuttle and thus may influence test performance. In addition, cognitive (e.g., motivation) and affective (e.g., self-efficacy) factors appear to influence 20mSRT performance.[9] Moreover, while laboratory tests of VO_2 can be considered the most accurate at the individual level, field tests such as 20mSRT, a measure of the individual's ability to perform continuous large-muscle group physical activity, provide alternative methods to administer such tests to large populations at minimal cost.[9]

The extensive international review by Lang et al.[1] showed that CRF measured with the 20mSRT was positively associated with cardiometabolic health (e.g., lipids, insulin resistance, blood pressure). Ruiz et al.,[10] using sex- and age-specific 20mSRT cut points, found that to reduce risk of developing cardiovascular disease, a girl aged 12 should be able to complete stage one (7 shuttles) and a boy stage four (32 shuttles), and that lower levels of performance should be considered alarming. The most influential determinants of CRF are age (i.e., maturity), sex, and engagement in vigorous physical activity.[2] First, owing to maturation, CRF tends to increase with age.[11] Second, because the tempo and timing of the biological maturity of same-age children may vary by sex, the use of sex-specific measure of maturation is necessary in studies involving children and adolescents.[12] One such method is the measure of peak height velocity (PHV). PHV refers to the period of rapid growth known as the growth spurt, which lasts from 12 to 18 months and varies widely between individuals.[12] Girls typically have lower VO_2 max capacity than boys.[3] Third, although physically active children and youth have often been assumed to have higher CRF, vigorous physical activity levels in children rarely correspond in intensity or duration to the increases in their CRF.[2]

A review of the literature on the topic highlighted the following research gaps. Given that several international studies have shown a declining trend in MVPA[13] and CRF[3] and an increasing trend in ST in children and youth,[7] the concurrent developmental associations of CRF with MVPA and ST warrant further study.[2,11,14] The association between CRF and ST is especially in need of additional investigation, owing to the inconsistency of previous findings.[5,6] Since the measurement of CRF using the 20mSRT in schoolchildren calls for the rigorous monitoring of developmental change, it has been suggested that the associations of CRF with MVPA and ST should be studied using multilevel modeling at both the within level, capturing changes in the repeated measures, and the between level, reflecting the overall levels.[11,14] To extend previous research by also including development at the within and between levels, this study examined the concurrent associations of objective CRF with MVPA and ST over a three-year follow-up.

Specifically, the aims were 1) to examine the three-year developmental associations of accelerometer based MVPA and ST with CRF levels and repeated measures using the 20mSRT in a sample of schoolchildren, and 2) to analyze whether sex, maturity, and adiposity are associated with CRF, MVPA, and ST. Based on previously established associations, CRF was expected to be positively associated with MVPA engagement[4] and negatively with ST.[5] The covariates of sex, PHV and BMI were expected to be associated with CRF and MVPA,[2,8,12] with boys and matured children showing higher scores. CRF[3] and participation in MVPA were expected to decline[13] and ST to increase[7] over time.

2. Methods

The total sample comprised 446 (girls 256, boys 190) Finnish children aged 11 to 13 years ($M = 11.26 \pm 0.32$ years at baseline) from 17 randomly selected public schools across Finland. The schools were Finnish speaking, typically taught 300 to 500 students, and followed the national core curriculum. All fifth graders were invited to participate through their school principals. The children were in elementary school from T0 (time point) to T1 and middle school from T2 to T3. No students with disabilities or special needs were involved.

Data were collected following the same procedures at four timepoints (August to September) from 2017 to 2020 (T0 to T3). Participants were informed about the study protocol and their right to terminate their participation at any time without consequences. Parental consents were obtained from the participants' parents or legal guardians. The Human Sciences Ethics Committee of the affiliated university approved the study protocols before the study commenced.

CRF was assessed using the 20mSRT test.[15] Children were asked to run continuously along the 20-meter track between two lines marked on the gym floor. The shuttle runs were performed by following the structured pace of recorded beeps. Running velocity was 8.5 km/h for the first minute, with an incremental increase of 0.5 km/h in each successive minute. The test finished when the participant was no longer able to keep the pace with the beeps. The CRF score was the number of completed shuttles.

Accelerometer-based MVPA and ST were measured using Actigraph GT3X+ waist-worn activity monitors for seven consecutive days at each measurement point. Participants were asked to wear the monitor during waking hours (07–23), excluding bathing and water-based activities. The raw data at the frequency of 30 Hz were collected and converted to 15-second epoch counts. Only days for which valid data (≥500 min) were obtained, including a minimum of two weekdays and one weekend day, were accepted for analysis. Periods of ≥30 min of consecutive zero counts were deemed on-wear time, and spurious scores (>20,000 cpm) were rejected.[16] The cut-points provided by Evenson et al.[17] were used to determine MVPA (≥2296 cpm) and ST (≤100 cpm). The final scores (min/day) were the average time spent in MVPA and ST at each measurement point.

PHV was identified following the procedures of Moore et al.[12] The maturity offset for girls and boys was calculated using the equation with documented age and height from T0 to T3. The maturity offset is the number of years the child is from arriving at PHV. A negative offset value means that the child was not yet reached PHV, and a positive offset value of >1.5 indicates that PHV has already occurred. A positive value of <1.5 indicates that the child is still undergoing PHV.

BMI was calculated using the standard height and weight formula (kg/m^2). Height and weight were measured at T0 to T3. BMI categories were determined based on the cut points suggested by Cole and Lobstein.[18]

Normality, outliers, missing values, correlations, means, and standard deviations of the observed variables were examined. Standardized mean difference effect sizes were computed to analyze changes over time. Random Intercept Cross-Lagged Panel models (RI-CLPM) were applied to answer the research questions.[19] The within- and between-level variables were estimated based on the observed variables. Specifically, the repeated measures were the person-centred variables comprising each participant's within-unit fluctuations over time. The between-level variables were the random intercepts representing the overall levels between participants across the whole sample. The Chi-square (χ^2) test was used to test the overall goodness-of-fit of the estimated models. A non-significant *p*-value between the observed distribution and theoretical distribution indicated acceptable fit to the data, although significant values are common, because of the high sensitivity of the test. Model fit was examined with the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Squared Residual (SRMR). CFI and TLI values >0.95 indicate excellent model fit while a RMSEA value below 0.05 and SRMR value below 0.08 are generally considered to indicate acceptable model fit.[20] The covariate of BMI reflected the level of adiposity including BMI measures T0 to T3. PHV was calculated separately for each year. The differences in loadings between paths were analyzed using independent *t*-tests. Preliminary analysis was performed using SPSS 26.0 and RI-CLPM using Mplus 8.4.

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

	N	Min	Max	M	SD	Skewness	Kurtosis	%
MVPA T0	446	11	150	58.78	22.96	0.28	−0.54	45
MVPA T1	245	17	131	55.44	21.01	0.99	1.67	38
MVPA T2	177	10	113	52.97	21.74	0.67	1.05	36
MVPA T3	114	17	159	56.52	26.07	1.62	3.06	35
ST T0	446	502	834	682.75	53.56	−0.47	0.06	–
ST T1	245	500	818	686.27	55.20	−0.44	−0.18	–
ST T2	177	560	829	704.04	56.55	−0.56	0.44	–
ST T3	114	524	842	723.06	65.61	−0.63	0.12	–
CRF T0	416	1	85	36.67	18.04	−0.09	−0.31	80
CRF T1	370	3	97	40.83	20.21	0.25	−0.27	72
CRF T2	319	0	103	40.26	19.88	0.72	−0.16	71
CRF T3	288	0	101	44.90	22.36	0.54	−0.34	61
BMI T0	446	13.54	33.79	18.82	3.07	1.44	3.41	5/75/16/4
BMI T1	413	13.87	34.54	19.50	3.34	1.36	2.61	6/73/17/4
BMI T2	345	15.01	35.95	20.20	3.24	1.31	2.42	4/75/18/3
BMI T3	249	15.17	33.48	20.90	3.14	1.00	1.30	4/74/19/3
PHV T0	403	−1	0	−0.97	0.18	5.17	24.86	97/3/0
PHV T1	408	−1	1	−0.58	0.49	0.38	−1.71	58/42/0
PHV T2	336	−1	1	−0.16	0.66	0.18	−0.71	31/55/14
PHV T3	245	−1	1	0.51	0.55	−0.49	−0.89	2/44/54

% children meeting the guidelines; % BMI = thinness/normal weight/overweight/obesity; % PHV = not reached PHV/inside PHV/occurred PHV.

3. Results

Descriptive statistics (Table 1) and correlation coefficients (Appendix 1) were examined. The observed variables were approximately normally distributed, and a graphical display and standardized values showed no significant outliers. Missing values occurred due to the decrease in sample size over time, especially at T3. The Missing Completely at Random test ($X^2 = 528.80$, df = 485, $p = 0.083$) indicated that the data matrices with and without missing values were similar, and thus, no further data modifications were required. The sample was considered large enough to tolerate possible loss of data, as the sample size calculation with the confidence level of 95 % and a margin error of $p < 0.05$ showed that a minimum of 207 participants were needed at T0. The standardized mean difference effect sizes showed no statistically significant changes in the observed MVPA ($\beta = 0.37$, SE = 0.27, $p = 0.163$) and ST ($\beta = 1.34$, SE = 1.25, $p = 0.282$) over time, whereas the observed CRF increased between T0 and T3 ($\beta = 0.22$, SE = 0.07, $p = 0.002$). The proportion of children meeting the current MVPA and CRF guidelines remained relatively stable over time (Table 1). The proportion of children meeting the recreational screen time guidelines was not calculated, as the accelerometers only recorded total ST minutes. On average, 35 % (range 4 % to 67 %) of MVPA consisted of vigorous intensity activities over time. About 50 % of the participants accumulated <20 min of daily vigorous activity, with individual accumulations ranging from 0 to 86 min. Most children were identified having normal weight. In addition, most children had not yet reached PHV at T0, while more than half of the sample had passed the growth spurt at T3.

RI-CLPM models were applied to examine the three-year developmental associations of CRF with MVPA and ST including the covariate effects of sex, BMI, and PHV. The first model examined the associations between CRF and MVPA levels and repeated measures (Fig. 1). The model fit for the data was good (X^2 (41) = 67.90, $p < 0.01$, CFI = 0.98,

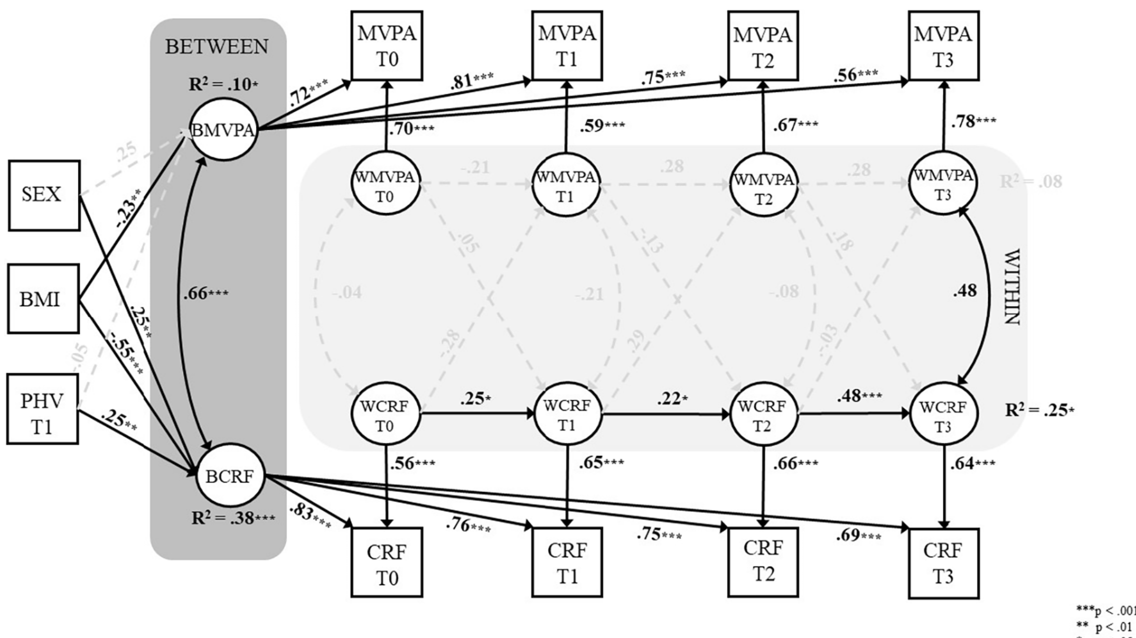

Fig. 1. Model for the developmental associations of MVPA and CRF over three years.

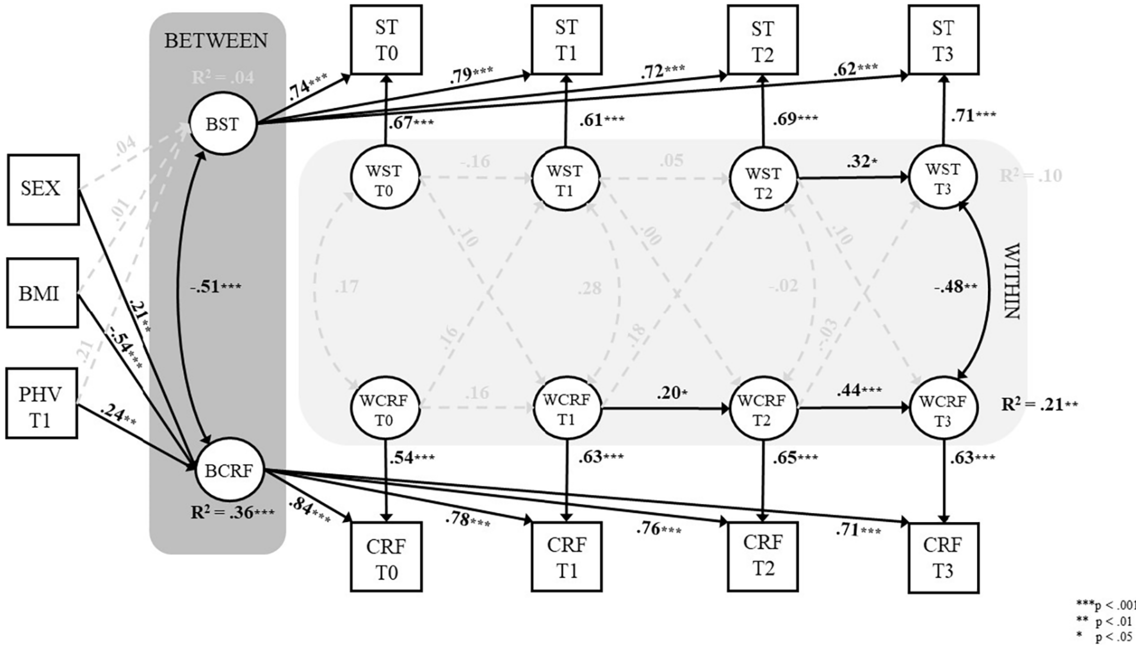

Fig. 2. Model for the developmental associations of ST and CRF over three years.

TLI = 0.96, RMSEA = 0.037, CI 90 % [0.02, 0.05], SRMR = 0.047). At the between level, the standardized results showed a strong positive association between CRF and MVPA engagement, indicating that the higher the 20 m shuttle run scores, the higher the total MVPA. Closer examination showed that the association was reciprocal, as the paths from MVPA to CRF ($\beta = 0.43$, SE = 0.08, $p < 0.001$) and from CRF to MVPA ($\beta = 1.18$, SE = 0.55, $p < 0.001$) were equal ($t(966) = 1.35$, $p = 0.178$). Boys had higher CRF than girls and children with higher BMI had lower CRF than vice versa. Only PHV at T1 (Grade 5) was significantly associated with CRF level. Children who were still experiencing PHV or in whom PHV had already occurred had higher CRF than children who had not yet reached PHV. The squared multiple correlations (R^2) showed that the model explained 38 % of the variability of CRF and 10 % of the variability of MVPA at the between level. At the within level, no associations between MVPA engagement measures were found, whereas CRF between T0 and T1, T1 and T2, and T2 and T3 were significantly associated. The model explained 25 % of the variability in CRF at T3.

The second model examined the associations between CRF and ST levels and repeated measures (Fig. 2). The model fit for the data was acceptable (X^2 (41) = 74.80, $p < 0.001$, CFI = 0.98, TLI = 0.95, RMSEA = 0.041, CI 90 % [0.02, 0.06], SRMR = 0.050). At the between level, the standardized results revealed a moderate negative association between ST and CRF, indicating that the higher the ST, the lower the 20 m shuttle run scores. The association was reciprocal, as the paths from ST to CRF ($\beta = -0.37$, SE = 0.09, $p < 0.001$) and from CRF to ST ($\beta = -0.66$, SE = 0.17, $p < 0.001$) were equal ($t(966) = 1.51$, $p = 0.132$). Boys showed higher CRF levels than girls. As in the previous model, children with higher BMI had lower CRF than children with lower BMI. PHV at T1 was significantly associated with CRF level. The model explained 36 % of the variance of CRF at the between level. At the within level, the repeated measures of ST at T2 and T3 were positively associated and CRF at T1 and T2 and at T2 and T3 were significantly associated. The model explained 21 % of the within-level variability in CRF at T3.

4. Discussion

This study examined whether the development of accelerometer-measured MVPA and ST were associated with corresponding CRF measures in schoolchildren. The key findings were 1) MVPA was positively associated with CRF and ST negatively associated with CRF; 2) associations between the repeated measures of MVPA and ST with CRF were found only at the final time point; 3) CRF was lower in girls than boys, CRF and MVPA were lower in children with higher BMI, and vice versa; and 4) CRF was higher in children who were still experiencing or had already passed PHV than in those who had not yet reached that stage.

As expected, CRF measured using the 20mSRT was associated positively with MVPA[4] and negatively with ST[5] at the between level over the three-year follow-up. Gralla et al.[21] found that an increase in CRF, a potential indicator of past physical activity, mostly benefits from vigorous compared to lower intensity physical activities. Furthermore, physically fitter school-aged children are more likely to be physically active for longer periods of time, a factor that may positively influence their CRF development, and vice versa.[22,23] This is important, as past physical activity follow-up studies have shown that that school-age physical activity appears to influence adult physical activity.[24] Similarly, young people with high levels of ST are also likely to show the high levels of ST later in their lives.[25] Enhancing high intensity physical activities that substantially increase the heart rate and induce rapid breathing[21] and limiting ST, especially recreational screen time, in children and adolescents[2] would be of great value in promoting positive development in CRF, and more broadly in public health.

Both repeated measures of MVPA and ST were associated with CRF only at the final measurement point. An explanation for this may lie in the measurement methods used. Armstrong and Welsman[11] for example found that when measured using rigorous methods, studies have consistently demonstrated no significant relationship between peak oxygen uptake and objectively measured physical activity in youth. They pointed out that it is crucial to differentiate between habitual physical activity and exercise training, as young people rarely experience the intensity and duration of physical activity necessary to increase their CRF. In the current sample, 50 % of the participants accumulated negligible or little vigorous intensity activity. Hence, the lack of a significant association between habitual physical activity in the first three measurement points, as measured in this study, and CRF was not surprising. Despite some evidence that Finnish elementary school-age children's habitual MVPA is improving at the population level,[26] the lack of vigorous intensity activity and high ST behaviour at the individual level remains a concern.

A somewhat conflicting finding in the current sample was that a clear majority of the children met the minimum criterion for healthy CRF.[10] It can thus be questioned whether the age- and sex-related lower cut points for adequate cardiovascular health in combination with extensive ST are up to date. The results may at least partly be explained by the fact that most of the children in the current sample were of normal weight. The prevalence of children with overweight or obesity was similar as in the latest Finnish national study using ISO-BMI standards in 2020.[27] It may be that ST behaviour should be considered on an equality with 20mSRT performance when formulating future cut points for sufficient CRF. Although, as called for the Finland's Report Card 2022 on Physical Activity for Children and Youth[26] the least physically active adolescents require special attention, high intensity activities to improve CRF in children and youth generally should be promoted.

Children who were experiencing or had passed their growth spurt had higher CRF than children who had not yet entered their period of rapid physical growth. Specifically, PHV correlated with CRF only in the fifth grade, when more than half of children had not reached PHV. This supported the earlier findings as children's CRF increases along with age-related physiological changes in growth and maturation,[11] although its timing and tempo vary greatly between individuals.[28] Thus, CRF is at least partly determined by genotype, it can be improved with systematic training[29] or with everyday physical activities, especially high intensity activities such as interval-type training.[30]

Because girls showed lower CRF than boys, the findings suggest that more attention should be paid to increasing girls' physical activity behaviours. Girls' participation in active play outside school and in organised sports decreases, especially after age 12.[26] While school physical education has the potential to improve girls' physical activity behaviour, actions could be also taken to improve girls' unorganised physical activity participation. First, the common barriers to physical activity that teenage girls may encounter should be identified. Many girls reject an overly competitive teaching climate, even when capable and physically active, and prefer individual or cooperative activities.[31] According to Finland's Report Card 2022, traditional actions such as focusing school recess time activities on promoting physical activity rarely work on the most inactive children and adolescents.[26] Given this situation, alternative ways to shed traditional structures and promote physical activity participation in girls would be highly welcome.

Finally, an interesting result was that both MVPA and ST remained stable over the measurement period. In Finland, the site of this study, children's overall physical activity has shown some positive developments in the 2000s, as the proportion of children meeting the physical activity recommendations of daily 60 min of MVPA has risen and the proportion of the physically least active has fallen.[26] This may be a result of the additional recess time activities introduced in schools since 2009.[32] In the schools involved in this government-based action plan, children are provided with a variety of physical activities during the school day and have less sedentary time. Children are encouraged to participate in activities during breaks, and active travel to school and after school activities are supported. Schools implement these activities in the best ways they can, given their local facilities and resources. Thus, the stable MVPA and ST development identified in the current sample may indicate an ongoing process of positive change.

The strengths of this study were the use of direct measures of the main variables at the between and within levels and the three-year follow-up period. However, the study is not free of limitations. As in many similar voluntary-based follow-up studies, the proportions of participants decreased over time. It is possible that only the most active children participated in the follow-up measurements. Moreover, the commonly used minimum requirement of acceptable MVPA and ST data for only two weekdays and one weekend day may leave out a significant amount of weekly activity. Finally, it must be considered that the 20 m shuttle run test used in this study may be influenced by other confounding factors such as motivation and body composition, and thus the results cannot be directly compared to those of more rigorous VO_2 max tests. With these limitations in mind, future studies could attempt to measure MVPA and ST using a more rigorous protocol that takes seasonal differences in physical activity behaviour into account. It could also be highly beneficial to study the associations between ST and CRF using person-oriented methods, such as latent class analysis, to identify and compare differences between CRF profiles over time. It would also be important to clarify what levels of MVPA and ST support healthy CRF development.

5. Conclusion

The results contribute to the growing evidence of a positive developmental association between MVPA and CRF. Furthermore, the inverse association between ST and CRF calls for the avoidance of excessive sedentary behaviour. These results clearly support raising awareness of the importance of increasing the CRF of schoolchildren through a physically active lifestyle, including extensive physical activity and limiting ST. More effort should be made to promote physically active lifestyles in children and youth.

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Declaration of Interest Statement

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

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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Appendix 1

Correlation coefficients of the observed variables at each time point.

	MVPA T0	MVPA T1	MVPA T2	MVPA T3	SED T0	SED T1	SED T2	SED T3	CRF T0	CRF T1	CRF T2	CRF T3
MVPA T0	1	0.55***	0.49***	0.53***	−0.74***	−0.42***	−0.44***	−0.48***	0.48***	0.46***	0.42***	0.39***
MVPA T1		1	0.64***	0.46***	−0.41***	−0.69***	−0.47***	−0.50***	0.39***	0.39***	0.35***	0.40***
MVPA T2			1	0.58***	−0.44***	−0.49***	−0.69***	−0.58***	0.38***	0.43***	0.38***	0.46***
MVPA T3				1	−0.44***	−0.34**	−0.37***	−0.77***	0.49***	0.48***	0.51***	0.54***
SED T0					1	0.54***	0.59***	0.50***	−0.29***	−0.31***	−0.23***	−0.32***
SED T1						1	0.69***	0.58***	−0.32***	−0.29***	−0.23**	−0.31***

(*continued*)

	MVPA T0	MVPA T1	MVPA T2	MVPA T3	SED T0	SED T1	SED T2	SED T3	CRF T0	CRF T1	CRF T2	CRF T3
SED T2							1	0.67***	−0.35***	−0.29***	−0.32***	−0.35***
SED T3								1	−0.50***	−0.40***	−0.49***	−0.51***
CRF T0									1	0.71***	0.70***	0.67***
CRF T1										1	0.70***	0.67***
CRF T2											1	0.78***
CRF T3												1

*** $p < 0.001$.
** $p < 0.01$.

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