Author(s): Joensuu, Laura; Kujala, Urho M.; Kankaanpää, Anna; Syväoja, Heidi; Kulmala, Janne; Hakonen, Harto; Oksanen, Hermanni; Kallio, Jouni; Tammelin, Tuija H.

Title: Physical fitness development in relation to changes in body composition and physical activity in adolescence

Year: 2021

Version: Accepted version (Final draft)

Please cite the original version:

Joensuu, L., Kujala, U. M., Kankaanpää, A., Syväoja, H., Kulmala, J., Hakonen, H., Oksanen, H., Kallio, J., & Tammelin, T. H. (2021). Physical fitness development in relation to changes in body composition and physical activity in adolescence. Scandinavian Journal of Medicine and Science in Sports, 31(2), 456-464. https://doi.org/10.1111/sms.13847

DR LAURA JOENSUU (Orcid ID : 0000-0002-9544-6552)
MR JOUNI KALLIO (Orcid ID : 0000-0002-2422-2543)

Article type : Original Article

Title Page

Physical fitness development in relation to changes in body composition and physical activity in adolescence

Original Investigation

Running title: Fat accrual detrimental for physical fitness

Laura Joensuu, MSc[1, 2], Urho M. Kujala, MD, PhD[1]; Anna Kankaanpää, MSc[2], Heidi Syväoja, PhD[2], Janne Kulmala, MSc[2], Harto Hakonen, MSc[2], Hermanni Oksanen, MSc[2], Jouni Kallio, PhD[2], Tuija H Tammelin, PhD[2]

[1]Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland; [2]LIKES Research Centre for Physical Activity and Health, Jyväskylä, Finland

Competing Interests: None declared

Corresponding author:

Laura Joensuu, MSc

Faculty of Sport and Health Sciences, University of Jyväskylä, Rautpohjankatu 8, 40700 Jyväskylä, Finland; LIKES Research Centre for Physical Activity and Health, Rautpohjankatu 8, 40700 Jyväskylä, laura.p.joensuu@jyu.fi; Tel. +358408054842, @laurajoensuu, Orcid ID: 0000-0002-9544-6552

Word count: 3430

Number of Tables: 2

Number of Figures: 2

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/sms.13847

Supporting Information: yes

Abstract

The decline in adolescents' physical fitness (PF) in recent decades has raised concerns about current population's possible future challenges with health and physical functional capacity. This study explored the associations between body composition, physical activity, maturation, and PF development in adolescents. Furthermore, PF development of adolescents with low initial PF was assessed. A 2-year observational study was conducted between spring 2013 and 2015. Nine comprehensive schools and their 10- to 13-year-old students were invited to participate in the study (1778), and a total of 971 students (54.6%) agreed. Cardiorespiratory fitness (20-metre shuttle run), muscular fitness (push-ups), fundamental movement skills (5-leaps test), body composition (bioelectrical impedance analysis), moderate-to-vigorous physical activity (accelerometer) and pubertal status (self-assessment questionnaire) were measured at 1-year intervals. Latent growth curve modeling (LGM) was used to study PF development over time. Change in fat mass had the strongest and most coherent associations with PF development during adolescence. Fat-free mass, moderate-to-vigorous physical activity and pubertal status were associated with PF development, although not systematically. Subgroup analyses showed that PF development in the low fitness group followed a similar pattern as the whole population. However, their PF remained significantly lower throughout the 2-year period. The findings suggest that fat accumulation is an essential detrimental factor for PF development during adolescence. Actions to prevent excessive fat accumulation might help to prevent future declines in functional capacity. Indications that low fitness levels sustain during adolescence highlight the relevance of detecting these individuals and providing interventions already before adolescence.

Keywords: Children, Cardiorespiratory fitness, Muscular fitness, Fundamental movement skills, Fat mass, Fat-free mass

Introduction

Physical fitness (PF) has been found to have well-established associations with health markers during adolescence and health outcomes later in life[1]. PF can be classified into cardiorespiratory, musculoskeletal and neuromotor fitness[2]. Observational data shows that especially cardiorespiratory fitness (CRF) is positively associated with a wide range of health indicators in adolescents, including cardiometabolic, bone, and mental health[3]. Similar findings have emerged for muscular fitness (MF)[4]. In the motor fitness domain, fundamental movement skills (FMS), that is, the "building blocks of movement," are considered to be essential for children's future, and previous studies have also shown associations between FMS and some health indicators[5].

The level of PF tends to track low to moderately from adolescence into adulthood[6]. Furthermore, the epidemiological data show that PF tends to degenerate gradually after adolescence[7]. These findings emphasize the importance of detecting individuals with low PF and providing interventions already during adolescence. Major societal benefits, such as in health care costs[8], might be obtained if a sufficient amount of people could be helped to reach a sustainable level of PF at the beginning of their course of life.

Field-based measures of fitness have been widely used to assess physical fitness in European adolescents[9]. The decline in adolescents' PF performance in recent decades has raised concerns about possible challenges in future health and physical functional capacity[10,11]. Although reasons for this decline are not entirely clear, changes in physical activity and obesity levels have been proposed as explanations[11]. Increases in body mass index (BMI) have been observed simultaneously with population-level declines in PF[10].

The natural development of fitness has been previously studied in adolescents. In theory, cardiorespiratory fitness, muscular fitness, and motor skills develop with age[12]. Cardiorespiratory fitness and muscle strength typically increase alongside with growth and maturation ignited morphological and neuromuscular changes[12(chaps7, 12)]. Children typically gain fundamental gross motor skills by the age of seven and further on hone these skills[12(chap4)]. Development in strength and endurance domains also improve the performance in skill-related tasks which require maximal performance[12(chap4)]. Additionally, previous findings show that exercise can significantly improve PF[1].

However, in previous research, these associations have been assessed mainly separately, leaving a research gap for studies which analyse these associations collectively. It is notable, that the processes of biological growth and behavioural development are rather simultaneous than separate in the adolescents' lives[13]. Furthermore, the fitness development in adolescents with low fitness remains underexplored. Assessment of these factors is important while striving to understand the development of healthy and adequate fitness.

This study aimed to recognize the essential factors of natural fitness development by exploring the associations of body composition, physical activity, maturational status, and physical fitness development in adolescents based on observational data. Furthermore, the aim was to explore PF development during adolescence with a special reference to adolescents with low PF. Special interest was focused on those with low level of initial fitness due to potentially higher health risks and functional capacity deficiencies in the future. This is the first study to explore these associations in both sexes utilizing objectively measured PA and BC separated into fat and fat-free mass content.

Materials and Methods

Study design and participants

Students from nine Finnish comprehensive schools were invited to a 2-year longitudinal prospective study (1778 10- to 13-year old students). Of those invited, 971 students (54.6%; 462 boys, 507 girls, 2 with no reported gender) delivered a signed written consent form and participated in the study. This study was part of a larger research entity related to the Finnish Schools on the Move programme[14]. Baseline measurements were performed in 2013, and follow-up measurements with 1-year intervals in 2014 and 2015 (between January 14, 2013 and May 20, 2015, where measurements were conducted within the same calendar week in each school throughout the study). PF, BC, and pubertal status were measured during school-day in school's gym hall. PA measurements were informed during school-day and measured in student's habitual environments. All measurements were conducted by trained research personnel. The study setting for the measurements was approved by the Ethics Committee of the University of Jyväskylä. All measurements were carried out in accordance with the Declaration of Helsinki. The detailed procedures of the measurements (excluding assessment of maturational status) are reported by Joensuu et al.[15]

Assessments

Physical fitness

PF development was measured with a 20-metre shuttle run (measurement of CRF), push-ups, (MF), and the 5-leaps test (FMS)[15]. The 20-metre shuttle run is an incremental test that involves running until maximal voluntary exhaustion. For the push-ups, participants complete as many repetitions as possible according to selected criteria within one minute. In the 5-leaps test, participants attempt to jump as far as they can in 5 leaps.

Anthropometric and body composition measurements

Body height was measured with an accuracy of 0.1 cm (Charder HM 200P scale, Issaquah, Washington, USA). BC and weight were measured in light clothing by a bioelectrical impedance analysis device (InBody 720, Biospace Co., Ltd, Seoul, Korea). Body mass index (BMI, $kg \cdot m^{-2}$) was calculated and the prevalence of normal weight, overweight, and obesity estimated using Cole's criteria[16]. Fat mass index (FMI, $kg \cdot m^{-2}$) and fat-free mass index (FFMI, $kg \cdot m^{-2}$) were used to indicate height-adjusted BC.

Physical activity

Moderate-to-vigorous PA (MVPA) was measured objectively using a hip-worn accelerometer (ActiGraph GT3X+, wGT3X+, Pensacola, Florida, USA) during waking hours for 7 consecutive days with Evenson criteria (≥ 2296 cpm)[17]. Data were collected in raw 30 Hz acceleration using normal filter and converted into 15 s epoch counts[18]. The valid amount of data was set at ≥ 500 min/day (between 7 am and 11 pm)[19], including at least 2 weekdays and 1 weekend day.

Pubertal status

Students self-assessed their biological maturation status with a questionnaire utilizing line drawings of external primary and secondary sex characteristics categorized by the Tanner scale[20,21]. Pubertal status was defined as the mean of the two questions: (1) the developmental stage of testicles/breasts and (2) pubertal hair on a scale of 1–5.

Statistical analysis

The descriptive statistics were calculated using SPSS 20.0 for Windows (IBM Corp., Armonk, New York, USA), and all the further analyses were conducted using the Mplus statistical package (7th ed., Los Angeles, California, USA)[22].

Latent growth curve modeling (LGM) was used to study PF development over time (Spring 2013, 2014 and 2015; M1, M2, and M3, respectively) among boys and girls (please see Supporting Information 1-3 for details on the modeling procedure). In the fully adjusted model, the variation in level (initial level) and slope (rate of change over time) of PF was explained by several factors, including age, pubertal status, fat and fat-free mass, and MVPA. Both the baseline measurement M1 and the absolute change between M1 and follow-up M3 (Δ) were used. Age, pubertal status, fat mass index, fat-free mass index and MVPA explained the baseline status of PF (level) and PF development (slope). Additionally, changes in fat mass index, fat-free mass index and MVPA were used to explain PF development (slope) (Figure 1). As sensitivity analyses, fully adjusted models were rerun by replacing Δ with absolute change between M1 and follow-up M2.

Finally, the students were divided into tertiles according to their result in each of the PF measurement at baseline. The lowest tertile group was named the low fit group and their PF development pattern were compared against the whole population.

Data were clustered within classes, and therefore standard errors were calculated using the sandwich estimator to take into account nonindependence of the observations. Missing data were assumed to be missing at random (MAR). Maximum likelihood with robust standard errors was used to estimate the sample correlations and the parameters of the models. The method produces unbiased parameter estimates under MAR. The level of significance was set at P=.05 and all the tests were two-sided.

Results

Descriptive statistics

At baseline participants were 12.6 (± 1.3) and 12.5 (± 1.3) years old (boys and girls, respectively). The prevalence of overweight or obesity was 15% and 14% at baseline in boys and girls, respectively. The prevalence of participants accomplishing the physical activity guidelines for children and youth (at least 60 min of MVPA per day)[23] at baseline were 34% and 20% in boys and girls, respectively. Further descriptives are presented in Table 1.

PF development during the 2-year observational period

The mean values for PF during the observational period with 95% Confidence Intervals (95% CI) are presented in Figure 2. Performance in the fitness measures (CRF, MF and FMS) increased during the 2-year observational period in boys and girls. The trend was linear in the whole population in FMS among boys, and in CRF and MF among girls. The trend was quadratic, that is, an increment following a plateau, in CRF and MF among boys, and in FMS among girls (For model fit parameters, please see Supporting Information 1 and 2). The fitness development followed similar patterns in the low fit group (those who were in the lowest PF tertile at baseline). Furthermore, the PF of the low fit group remained significantly lower throughout the observation period. Boys and girls with low initial fitness had statistically lower PF also after 1 and 2 years compared with the whole population (in M2 and M3, respectively, and no observed overlaps in the 95% CI, Figure 2).

Factors explaining PF development

The observed associations related to PF development are presented in Table 2. For more detailed results, please see Tables in Supporting Information 4 and 5.

Cardiorespiratory fitness

Of the baseline measures (FMI, FFMI, MVPA and pubertal status) only FMI showed a statistically significant association with the CRF development in boys (standardized regression coefficient -0.17, P=0.007), indicating that a high initial amount of adiposity predicted a negative development in CRF in boys (Table 2). No association between baseline measures and CRF development were observed in girls.

The change in FMI had an inverse association with CRF development in both boys and girls (-0.35, P<0.001 and -0.34, P<0.001, respectively). This association was the strongest in the model, indicating that an increase in adiposity during adolescence was considerably associated with a detrimental development in CRF (Table 2). The change in FFMI was associated with CRF development only in girls (0.15, P=0.028), and the change in MVPA only in boys (0.25, P=0.015).

Muscular fitness

Baseline pubertal status and FFMI had positive associations with MF development in boys (0.23, *P*=0.025 and 0.28, *P*=0.010, Table 2), indicating that advanced pubertal status and higher amounts of fat-free mass predicted a positive development in MF. No significant associations between baseline measures and MF development were observed in girls.

The changes in BC showed significant associations with MF development. Change in FFMI showed positive associations in boys and girls (0.25, *P*=0.004 and 0.16, *P*=0.037, respectively, Table 2), indicating that increases in fat-free mass were associated with positive MF development. The change in FMI was significantly and inversely associated only in boys (-0.36, *P*=0.001). No significant associations were observed with change in MVPA (*P*=0.80 in boys and *P*=0.061 in girls).

Fundamental movement skills

Of the baseline measures, BC had significant associations with FMS development in boys (FMI -0.24, *P*=0.001 and FFMI 0.20, *P*=0.022, Table 2), indicating that high levels of initial adiposity predicted negative FMS development and high levels of initial fat-free mass the contrary. No significant associations between baseline measures and FMS development were observed in girls.

Changes in FMI had strong and negative associations with FMS development in both boys (-0.63, *P*<0.001) and girls (-0.37, *P*<0.001, Table 2). Change in FFMI showed positive associations in boys (0.28, *P*<0.001), but not in girls. No associations were observed with change in MVPA.

Sensitivity analyses

The results of the sensitivity analyses are presented in Supporting Information 6 and 7. The interpretation of the results was mainly similar to the main analyses. As an exception, change in MVPA between M1 and M2 was positively associated with CRF development (0.22, *P*=0.043) and FMS development (0.25, *P*=0.034) in girls.

Discussion

The aim of this study was to evaluate the associations between body composition, physical activity, maturation, and PF development in adolescents. The main finding was that changes in fat mass were inversely and coherently associated with PF development. This inverse association was observed in both sexes and in all explored PF characteristics, except for MF development in girls, and the association was independent of age, pubertal status, fat-free mass and MVPA. Furthermore, the aim was to evaluate the PF development of low fit adolescents. This study showed that PF in the low fitness group remained significantly lower throughout the 2-year observational period compared to the whole population. These findings emphasize that PF, measured with weight-bearing field-tests, is strongly associated with adiposity, highlighting the importance to prevent excessive fat accumulation during adolescence. These actions have potential to support normal development of PF in adolescents and decrease the incidence of potential health risks and functional capacity deficits in later life.

The detrimental associations of excessive fat accumulation with development in PF performance during adolescence are important to recognize. These findings suggest that, from a broader perspective, increments in obesity[24] might account for observed population-level declines in functional capacity[10]. Weight-bearing field-based fitness measurements are strongly associated with adiposity[15]. Adiposity is at least partially modifiable by diet and PA. Previous studies have shown an inverse dose-response association between PA and BMI in children[25]. However, indications of a bidirectional association (i.e. increased adiposity lowering PA levels) have also been shown with indications of inherent predisposition for this association[25]. These findings highlight the biological portion of these traits, and the importance of providing interventions for people with challenges in either or both these characteristics, preferably at an early age. Additionally, tackling obesity at the population level are stated to require large, societal-scale actions[26].

There were additional but not systematic associations with PF development. Baseline pubertal status and BC predicted PF development in boys but not in girls, although not systematically. Increases in fat-free mass were positively associated with development in most PF characteristics, but not all. No associations were observed between baseline MVPA and PF development. Changes in MVPA were associated with PF development only with CRF in boys.

Although the findings of our study did not indicate systematic associations between changes in MVPA and PF development, previous data from randomized controlled trials have consistently shown that different types of exercise programs, especially at a high-intensity level, improve PF[1]. It is notable that our study used data from a longitudinal observational study. A broad interpretation of these findings might indicate that during adolescence the natural changes in PA are not significant enough to produce development in PF, at least in both genders and among a variety of PF characteristics. Therefore, exercise interventions are warranted to achieve desirable changes in PF. Additionally, PA and PF are representatives of different dimensions; they describe behavior and a status of a physical characteristic. This is reasonable to consider when performing direct comparisons, especially when PA is characterized based on one-week measurement and may not exactly describe the whole year PA behavior.

Special interest was directed at those with an initially low fitness level, due to the potential for higher health and functional capacity risks in the future. PF development followed a pattern in the low fit group similar to that in the whole population. Although PF also increased in the low fit group over the 2 years of the study, it remained significantly lower throughout the observation period compared with the whole population. This phenomenon was detectable in all PF characteristics, and in both sexes. These findings imply that low PF sustain during adolescence and indicates the importance of detecting low fit individuals already prior to adolescence. Interventions during childhood might prevent possible future health and functional capacity risks in this group.

Previous longitudinal studies on examining associations between PA, BC and PF development in children or adolescents are rare[27,28]. Augste et al., utilizing LGM, had findings similar to those in our study: self-reported baseline PA affected the level but not the slope of PF in 8-year-old children[28]. In contrast to our study, Aires et al., utilizing linear regression models, found that changes in self-reported PA index were positively associated with PF development in adolescents independent of age, gender, baseline fitness level, BMI and sedentary time[27]. Our study's findings showed that changes in accelerometer-measured MVPA were associated with PF development only in CRF in boys. Further research is needed to elucidate these associations.

Augste et al. reported no association between baseline BMI and PF development, and Aires et al. found an inverse association between change in BMI and PF development. Our study supported both of these findings: more systematic associations were observed with PF development and changes in BC than with baseline BC, especially in girls. Our study adds to current knowledge by demonstrating the separate associations of fat and fat-free mass and indicating associations independent of pubertal status.

The strengths of our study include accelerometer-based assessments of PA, BC analytics which separate fat and fat-free mass and a large subject sample. Furthermore, the observational longitudinal study design and selected data analytics provide additional insights into the studied associations.

Our study did have a number of limitations worth noting. Of the 1710 students invited to the study, only 970 students (54.6%) participated. Participants were more often girls (52% vs 40%) and had higher CRF (47 vs 42 laps) compared with their non-participating peers. Accelerometer measurements suffered from drop-out: 46.5% of the participants had information from M1 and M2 measurement points, and 29.3% from M1 and M3 (see Supporting Information 1). Furthermore, more accurate data would have been obtained with 24-h registration. Although the reliability of the PF measures is reasonable[15] and measurements were performed under the supervision of educated personnel, more accurate assessments of the characteristics might have been obtained in a laboratory setting. The authors recognize that fitness measures used in this study, e.g. the 20-m shuttle run, give an estimation of the fitness and are not direct measures of fitness[29]. Accelerometers do not record all PA (e.g., bike riding) or the quality of the PA (is it CRF, MF or FMS enhancing). Although the pubertal status assessment has been shown to be valid[21], some variation might occur between self-assessment and a clinical evaluation.

One of the methodological findings of this study was that development in PF was more difficult to explain than the status of PF. The explanatory rates of the analyses were higher for the PF level than they were for slope. The final model could explain 40-48%, 40-46% and 58-71% of the variance in the level of CRF, MF and FMS (see Tables in Supporting Information 8 and 9). Similar explanation rates were 20-24%, 13-28% and 36-46% for the change in CRF, MF and FMS, respectively. Similar findings have been reported previously[28]. A few explanations for this phenomenon were considered: 1) The phenotype is reasonably stable already during adolescence and changes are more difficult to detect than status. 2) The development of PF is confounded by the initial level of PF. The model cannot be adjusted with initial PF in the LGM. However, additional sensitivity analyses showed no robust or systematic differences in the associations with fitness level (results not shown). 3) The development of PF could be confounded by the regression to the mean phenomena. 4) The development in PF during adolescence is associated with other/additional factors not covered in this study. PF development could be influenced by, for example, societal, social, psychological and other physical factors such as heritage, which were not investigated in this study. Further research is needed to identify the most relevant factors associated with adolescent PF development.

Perspective

PF is associated with several favourable outcomes in adolescents. However, current adolescents' PF performance is notably lower than their parents'[10,11]. In the future, actions are recommended to prevent potential adverse outcomes related with declined population levels of field-based measured PF.

This study adds to previous knowledge by showing that the PF development in the low fit subgroup of adolescents followed a similar pattern to what was observed in the whole population. However, the low fit group remained to have a significantly lower PF in all characteristics throughout the observation period. Furthermore, this study demonstrated that especially fat mass accrual was considerably associated with detrimental development in PF performance. Other explored variables also had associations with PF development, but these were not systematic.

These findings emphasize the importance for actions to prevent excessive fat accumulation during adolescence. These actions might support optimal development of PF performance and decrease the incidence of potential health risks and functional capacity deficits in later life. Findings that low fitness levels sustain during adolescence indicate the importance of detecting these individuals and providing interventions already prior to adolescence.

Acknowledgements

The authors would like to thank the schools that helped facilitate this research. We would also like to thank the children and their guardians who gave their time to our study. We also want to acknowledge Kirsti Siekkinen[2] for her contribution to the coordination of data collection. [2]LIKES Research Centre for Physical Activity and Health, Jyväskylä, Finland.

The study was supported by the Finnish Ministry of Education and Culture (grant number OKM/92/626/2013), Juho Vainio Foundation (201410342), LIKES Research Centre for Physical Activity and Health and University of Jyväskylä.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes*. 2008;32(1):1-11. doi:10.1038/sj.ijo.0803774
2. Garber CE, Blissmer B, Deschenes MR, et al. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43(7):1334-1359. doi:10.1249/MSS.0b013e318213fefb
3. Lang JJ, Belanger K, Poitras V, Janssen I, Tomkinson GR, Tremblay MS. Systematic review of the relationship between 20 m shuttle run performance and health indicators among children and youth. *J Sci Med Sport*. 2017. doi:10.1016/j.jsams.2017.08.002
4. Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR. The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis. *Sport Med*. 2014;44(9):1209-1223. doi:10.1007/s40279-014-0196-4
5. Lubans D, Morgan P, Cliff D, Barnett L, Okely A. Fundamental movement skills in children and adolescents: Review of associated health benefits. *Sport Med*. 2010;40(12):1019-1035. doi:10.2165/11536850-000000000-00000
6. Beunen G, Ostyn M, Simons J, et al. Development and tracking in fitness components: Leuven longitudinal study on lifestyle, fitness and health. *Int J Sports Med*. 1997;18(Suppl 3):S171-178. doi:10.1055/s-2007-972710
7. Shvartz E, Reibold R. Aerobic fitness norms for males and females aged 6 to 75 years: a review. *Aviat Sp Env Med*. 1990;61(1):3-11.
8. Bachmann JM, DeFina LF, Franzini L, et al. Cardiorespiratory fitness in middle age and health care costs in later life. *J Am Coll Cardiol*. 2015;66(17):1876-1885. doi:10.1016/j.jacc.2015.08.030
9. Tomkinson GR, Carver KD, Atkinson F, et al. European normative values for physical fitness in children and adolescents aged 9–17 years: results from 2 779 165 Eurofit performances representing 30 countries. *Br J Sports Med*. 2017:bjsports-2017-098253. doi:10.1136/bjsports-2017-098253

10. Santtila M, Pihlainen K, Koski H, Vasankari T, Kyröläinen H. Physical fitness in young men between 1975 and 2015 with a focus on the years 2005–2015. *Med Sci Sport Exerc*. 2018;50(2):292-298. doi:10.1249/MSS.0000000000001436

11. Tomkinson GR, Lang JJ, Tremblay MS. Temporal trends in the cardiorespiratory fitness of children and adolescents representing 19 high-income and upper middle-income countries between 1981 and 2014. *Br J Sports Med*. 2017:bjsports-2017-097982. doi:10.1136/bjsports-2017-097982

12. Armstrong N, Van Mechelen W, Backx FJ, et al. *Oxford Textbook of Children's Sport and Exercise Medicine*. 3rd Edition. (Armstrong N, Van Mechelen W, eds.). Oxforf: Oxford University Press; 2017.

13. Malina RM. Top 10 research questions related to growth and maturation of relevance to physical activity, performance, and fitness. *Res Q Exerc Sport*. 2014;85:157-173. doi:10.1080/02701367.2014.897592

14. Blom A, Tammelin T, Laine K, Tolonen H. Bright spots, physical activity investments that work: the Finnish Schools on the Move programme. *Br J Sports Med*. 2017;0(0):bjsports-2017-097711. doi:10.1136/bjsports-2017-097711

15. Joensuu L, Syväoja H, Kallio J, Kulmala J, Kujala UM, Tammelin TH. Objectively measured physical activity, body composition and physical fitness: cross-sectional associations in 9 to 15-year-old children. *Eur J Sport Sci*. 2018. doi:10.1080/17461391.2018.1457081

16. Cole TJ, Lostein T. Extended international (IOTF) Body Mass indez cut-offs for thiness, overweight and obesity. *Pediatr Obes*. 2012;7(4):284-294. doi:10.1111/j.2047-6310.2012.00064.x

17. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci*. 2008;26(14):1557-1565. doi:10.1080/02640410802334196

18. Kallio J, Hakonen H, Syväoja H, et al. Changes in physical activity and sedentary time during adolescence: Gender differences during weekdays and weekend days. *Scand J Med Sci Sport*. 2020;(March):1-11. doi:10.1111/sms.13668

19. Cooper AR, Goodman A, Page AS, et al. Objectively measured physical activity and sedentary time in youth: the International children's accelerometry database (ICAD). *Int J Behav Nutr Phys Act*. 2015;12(1):113. doi:10.1186/s12966-015-0274-5

20. Tanner JM. *Growth at Adolescence. With a General Consideration of the Effects of Hereditary and Environmental Factors upon Growth and Maturation from Birth to Maturity.* 2nd ed. London: Blackwell Scientific Publications; 1962.

21. Taylor SJC, Whincup PH, Hindmarsh PC, Lampe F, Odoki K, Cook DG. Performance of a new pubertal self-assessment questionnaire: A preliminary study. *Paediatr Perinat Epidemiol*. 2001;15(1):88-94. doi:10.1046/j.1365-3016.2001.00317.x

22. Muthén LK, Muthén BO. *Mplus User's Guide*. 8th ed. Los Angeles, CA: Muthén & Muthén

23. World Health Organization. *Global Recommendations on Physical Activity for Health*. Switzerland; 2010. doi:10.1080/11026480410034349

24. Cunningham SA, Kramer MR, Narayan KMV. Incidence of Childhood Obesity in the United States. *N Engl J Med*. 2014;370(5):403-411. doi:10.1056/NEJMoa1309753

25. Richmond RC, Davey Smith G, Ness AR, den Hoed M, McMahon G, Timpson NJ. Assessing Causality in the Association between Child Adiposity and Physical Activity Levels: A Mendelian Randomization Analysis. *PLoS Med*. 2014;11(3). doi:10.1371/journal.pmed.1001618

26. Editorial. Tackling obesity seriously: the time has come. *Lancet Public Heal*. 2018;(3):e153. doi:10.1016/S2468-2667(18)30053-7

27. Aires L, Andersen LB, Mendonça D, Martins C, Silva G, Mota J. A 3-year longitudinal analysis of changes in fitness , physical activity , fatness and screen time. *Acta Pædiatrica*. 2010;99(9):140-144. doi:10.1111/j.1651-2227.2009.01536.x

28. Augste C, Lämmle L, Künzell S. Does current behaviour predict the course of children's physical fitness? *Eur J Sport Sci*. 2014;15(5):429-435. doi:10.1080/17461391.2014.948076

29. Armstrong N, Welsman J. Twenty-metre shuttle run: (mis)representation, (mis)interpretation and (mis)use. *Br J Sports Med*. 2018;0(1-2). doi:10.1136/bjsports-2018-100082

Figure legends

Figure 1. The basic structure of the latent growth curve analysis with the final multivariable model.

Footnotes: PF, physical fitness; Pube, Pubertal status at baseline, FMI, fat mass index at baseline; FFMI, fat-free mass index at baseline; MVPA, Moderate-to-vigorous physical activity at baseline; Δ, difference score between measurements in Spring 2013 and Spring 2015; M1 measurements in Spring 2013; M2, measurements in Spring 2014; M3, measurements in Spring 2015; 1 and 2, The fixed values of the factor loadings; LEVEL, latent variable of the initial level of PF; SLOPE, latent variable of the rate of change over time.

Figure 2. The 2-year physical fitness development patterns for boys and girls with 95% Confidence Intervals

Footnotes: Solid line, the average physical fitness (PF) development in the whole population; Dashed line, the average PF development in the low fit group; Dotted lines, 95% Confidence intervals; CRF, Cardiorespiratory fitness (20-m shuttle run, laps); MF, Muscular fitness (Push-up, repetitions, measurement technique differed between boys and girls); FMS, Fundamental movement skills (5-leaps test, meters). M1, measurements in Spring 2013; M2, measurements in Spring 2014; M3, measurements in Spring 2015;

Supporting Information 1. Text. Latent growth curve modeling (LGM)
Supporting Information 2. Table. Model-fit indices of the unconditional models for physical fitness.
Supporting Information 3. Table. The estimation results of unconditional latent growth models for physical fitness among boys and girls: the means and the variances of growth factors.
Supporting Information 4. Table. The results of latent growth curve modeling among boys: the associations related to physical fitness development (slope).
Supporting Information 5. Table. The results of latent growth curve modeling among girls: associations related to physical fitness development (slope).

Supporting Information 6. Table. The results of the sensitivity analyses among boys: associations related to physical fitness development (slope).

Supporting Information 7. Table. The results of the sensitivity analyses among girls: associations related to physical fitness development (slope).

Supporting Information 8. Table. The results of latent growth curve modeling among boys: associations related to physical fitness level.

Supporting Information 9. Table. The results of latent growth curve modeling among girls: associations related to physical fitness level.

Table 1. Descriptive statistics of the study sample at baseline

	Boys (n=462)	Girls (n=508)
Age (years)	12.6 ± 1.3	12.5 ± 1.3
Physical fitness		
CRF (20-m shuttle run, laps)	47.5 ± 20.3	37.0 ± 15.9
MF (Push-up, repetitions)[a]	16.7 ± 11.7	23.9 ± 13.2
FMS (5-leaps test, m)	8.5 ± 1.2	8.0 ± 1.0
Physical activity		
MVPA (min·day-1)	59.2 ± 23.7	47.5 ± 18.4
Prevalence of MVPA ≥ 60min·day^{-1} (No., %)	159 (34.4%)	101 (19.9%)
Accelerometer wear time	765.3 ± 56.1	773.6 ± 53.9
Anthropometrics, body composition and maturation		
Height (cm)	156.7 ± 11.3	155.5 ± 9.5
Weight (kg)	46.5 ± 12.7	46.5 ± 10.6
BMI (kg·m^{-2})	18.6 ± 3.3	19.1 ± 3.2
Prevalence of overweight and obesity[b] (No., %)	62 (15%)	69 (14%)
FMI (kg·m^{-2})	3.1 ± 2.3	4.2 ± 2.3
FFMI (kg·m^{-2})	15.6 ± 1.8	14.8 ± 1.4
Fat% (%)	15.3 ± 8.2	21.2 ± 7.5

Pubertal status[c]	2.7 ± 1.0	2.6 ± 0.9

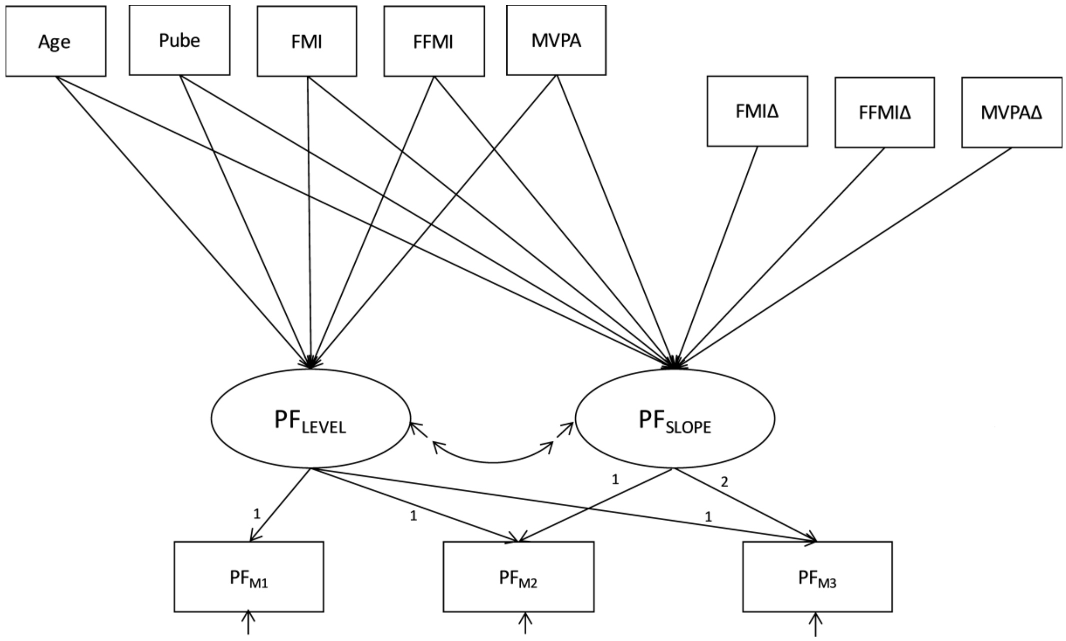
Footnotes: Units are means and standard deviations unless other mentioned; CRF, Cardiorespiratory fitness; MF, Muscular fitness; FMS, Fundamental movement skills; MVPA, Moderate-to-vigorous physical activity; BMI, Body mass index; FMI, Fat mass index; FFMI, Fat-free mass index; a, The measurement technique differed between boys and girls; b, Classification is based on Cole's thresholds; c, Classification is based on self-assessment questionnaire and Tanner's scale.

Table 2. The associations of explored variables with physical fitness development (slope) in boys and girls.

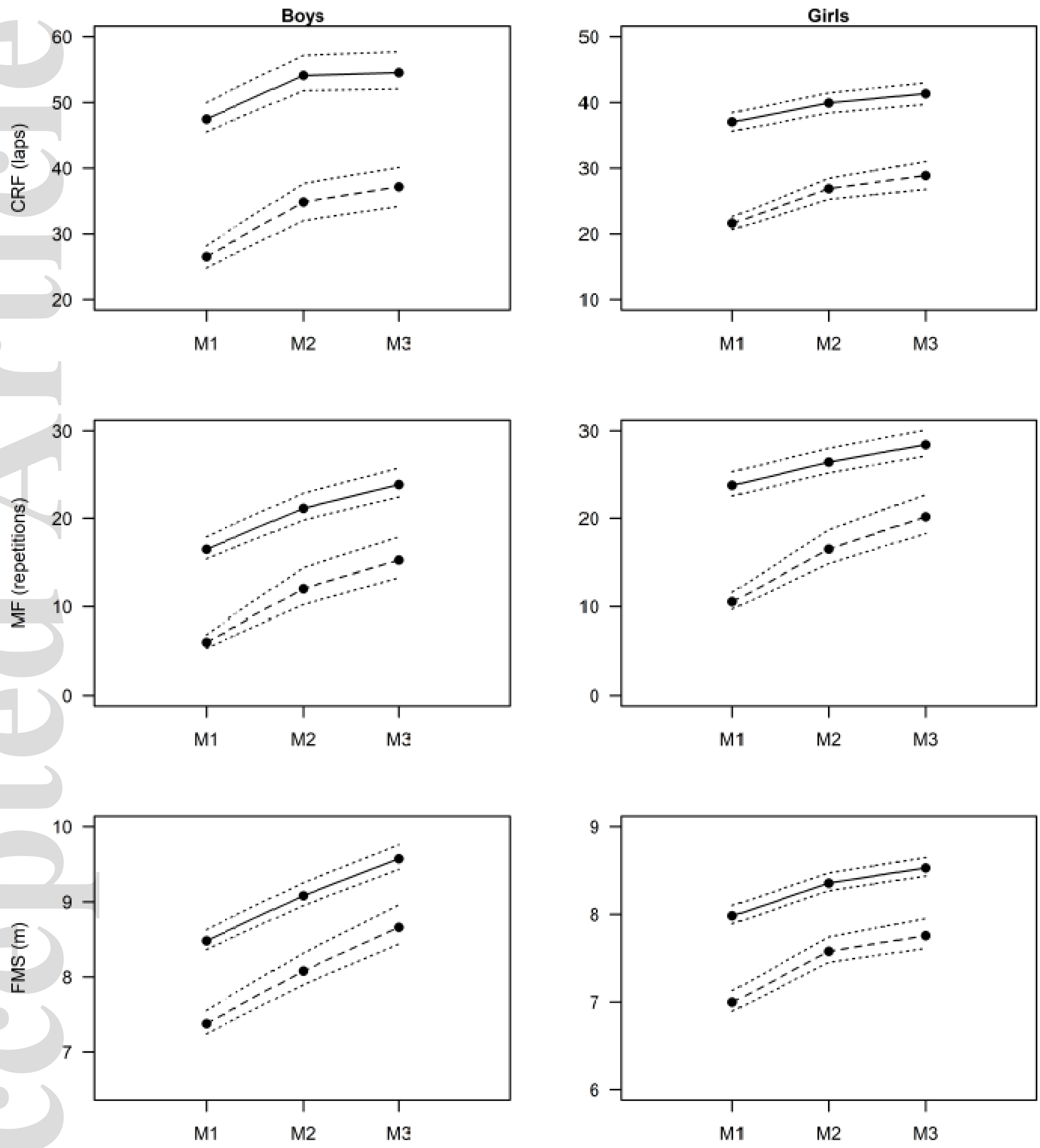
	Boys		**Girls**	
CRF slope	B (SE)	P value	B (SE)	P value
Pube	0.12 (0.09)	0.19	-0.04 (0.10)	0.72
FMI	-0.17 (0.06)	0.007	-0.07 (0.08)	0.39
ΔFMI	-0.35 (0.07)	<0.001	-0.34 (0.10)	<0.001
FFMI	0.08 (0.10)	0.42	0.08 (0.08)	0.30
ΔFFMI	0.11 (0.07)	0.12	0.15 (0.07)	0.028
MVPA	0.09 (0.09)	0.28	0.14 (0.11)	0.18
ΔMVPA	0.25 (0.10)	0.015	0.17 (0.12)	0.18
R^2	0.20		0.24	
MF slope	B (SE)	P value	B (SE)	P value
Pube	0.23 (0.10)	0.025	0.09 (0.11)	0.40
FMI	-0.17 (0.09)	0.074	0.06 (0.07)	0.38
ΔFMI	-0.36 (0.11)	0.001	-0.12 (0.08)	0.13
FFMI	0.28 (0.11)	0.010	-0.10 (0.09)	0.26
ΔFFMI	0.25 (0.09)	0.004	0.16 (0.07)	0.037
MVPA	0.07 (0.15)	0.63	0.11 (0.09)	0.20
ΔMVPA	0.05 (0.20)	0.80	0.24 (0.13)	0.061
R^2	0.28		0.13	

FMS slope	B (SE)	P value	B (SE)	P value
Pube	0.12 (0.11)	0.25	-0.18 (0.10)	0.057
FMI	-0.24 (0.07)	0.001	-0.10 (0.08)	0.19
ΔFMI	-0.63 (0.11)	<0.001	-0.37 (0.10)	<0.001
FFMI	0.20 (0.09)	0.022	0.12 (0.10)	0.20
ΔFFMI	0.28 (0.07)	<0.001	0.16 (0.10)	0.096
MVPA	-0.05 (0.12)	0.68	0.04 (0.11)	0.70
ΔMVPA	-0.13 (0.19)	0.49	0.00 (0.13)	0.99
R^2	0.46		0.36	

Footnotes: All models were adjusted for age; CRF, Cardiorespiratory fitness; MF, Muscular fitness; FMS, Fundamental movement skills; Slope, Latent variable of the rate of change over time; Pube, Pubertal status; FMI, Fat mass index; FFMI, Fat-free mass index; MVPA, Moderate-to-vigorous physical activity; Δ, difference score between measurements in Spring 2013 and Spring 2015; B, Standardized regression coefficient; SE, Standard error; R^2, Coefficient of determination



sms_13847_f1.tif



sms_13847_f2.tif