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Effects of the Summer Holiday on Physical Fitness in Danish Adolescents: An Exploratory Longitudinal Person-Centred Approach

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Abstract

Background: Physical fitness is an important determinant of adolescent health, yet how physical fitness changes over the summer holiday period relative to the school year remains unclear, particularly in adolescent populations. This study examined changes in physical fitness across three measurement occasions spanning a school year and summer holiday in Danish adolescents.

Methods: A longitudinal observational study was conducted with 162 Danish adolescents (mean age: 13.6 years; 58 males, 55 females). Measurements were taken at three occasions: t1 (August 2024, start of school year, baseline), t2 (June 2025, end of school year, before summer), and t3 (August 2025, after summer holiday). Primary outcomes were cardiorespiratory fitness, blood pressure, and resting heart rate. Secondary outcomes included agility, balance, handgrip strength, standing long jump, and body composition. Linear mixed models were used to assess the changes in the outcome scores over the school year and the summer holidays, and latent transition analysis was used to investigate fitness profiles and profile membership over time.

Results: Cardiorespiratory fitness, measured as distance covered by the Yo-Yo Intermittent Recovery Test, declined by ~162 m across the school year, with no summer recovery. Diastolic blood pressure fell across the school year and returned toward baseline over the summer, while systolic pressure, resting heart rate, and BMI were unchanged. Girls showed disproportionate school-year declines in agility, handgrip strength, and standing long jump (all sex × timepoint interactions significant), whereas boys remained stable or improved. Body fat decreased slightly over the summer, and muscle mass rose across both periods. Three latent fitness profiles (low, average, high) were largely stable, but girls were four times more likely than boys to transition to a lower-fitness profile during the school year.

Conclusions: Danish adolescent fitness declined across the school year rather than the summer holiday, with girls being disproportionately affected across cardiorespiratory, strength, and neuromotor domains, and adolescents in the lowest-fitness profile being locked into that status across both periods. These findings suggest that the school year does not protect adolescent fitness and highlight the need for sex-responsive physical education and targeted strategies for the least-fit adolescents.

Currently 6,018 words

Background

Physical fitness during childhood and adolescence has been identified as a strong marker of current and future health [1]. Comprehensive systematic reviews and meta-analyses have shown that cardiorespiratory fitness (CRF) and muscular strength in youth track into adulthood and are prospectively associated with a lower risk of cardiovascular disease, adverse cardiometabolic risk-factor profiles, adiposity, poorer mental health, and all-cause mortality [1–3]. Conversely, low fitness levels in adolescence predict elevated risk for chronic disease decades later [3,4]. Longitudinal prospective studies have shown that individuals in higher aerobic fitness profiles had lower risk of death from any cause compared to those in lower aerobic fitness profiles [4]. As a modifiable determinant of health across the life course, adolescent fitness is, therefore, a legitimate and increasingly urgent public health target.

Global surveillance data indicate that adolescents do not move enough and do not meet global physical activity (PA) guidelines. More than 80% of adolescents worldwide fail to accumulate the 60 minutes of daily moderate-to-vigorous PA recommended by the World Health Organization [5,6]. This trend is also present in Denmark, where the percentage of young people meeting PA guidelines declines with age: 46% of 11-year-olds, 33% of 13-year-olds, and 23% of 15-year-olds [7]. This shortfall generates the declines and subsequent stagnation in both cardiorespiratory and muscular fitness among children and adolescents [8,9]. A systematic review on trends of endurance and muscular strength in children and adolescents showed that endurance and, to some extent muscular levels, have been declining since 1990, a trend that appears to have been amplified during the COVID-19 pandemic [10]. Because the adolescent years overlap with critical windows for maturation, motor competence acquisition, and the formation of activity habits, deficits accumulated during this period may persist in later years [11]. These deficits may contribute to a lifelong disadvantage [11,12] and increase the risk of developing chronic disease [4].

Against this backdrop, the school context has been positioned as a central setting for promoting adolescent fitness. Compulsory attendance, curricular physical education (PE), organised break-time activity, and the presence of adults enforcing routines create structured

days where students can be active and develop health PA habits. The Structured Days Hypothesis (SDH) formalises this observation, suggesting that children's obesogenic behaviours, such as insufficient PA, prolonged screen time, poor diet, and inadequate sleep, are more favourably regulated on structured days than on unstructured ones [13]. In this context, researchers have argued that the loss of structure during summer holidays may accelerates unhealthy weight gain and erodes fitness gains achieved during the school year [13,14]. Empirical support for the SDH has come primarily from studies of primary-school children, in whom summer holidays have been associated with accelerated body mass index (BMI) increases, reduced moderate-to-vigorous PA, and increased screen time [13–17]. Whether the same pattern applies to adolescents remains largely untested. Moreover, the SDH literature has focused overwhelmingly on adiposity and behaviour [13–17] rather than on directly measured physical fitness, leaving a gap in understanding how the school-year and summer-holiday contexts differentially shape CRF, muscular, and neuromotor capacities during the adolescent decade.

Furthermore, in the context of PA and physical fitness literature, girls are consistently reported to be less active and fit than boys [5], to experience steeper declines in moderate-to-vigorous PA across adolescence, and to disengage more rapidly from organised sport [18,19]. Recent large-scale evidence also documents sex-specific patterns of fitness decline. Specifically, girls tend to show larger relative reductions in CRF, whereas boys show more pronounced declines in speed and power components [20]. These divergences reflect an interplay of pubertal timing, differential increase of fat-free mass, and social and cultural norms shaping girls' access to PA [20,21]. Whether these disparities are exacerbated or attenuated when adolescents move from the structured school context to the unstructured summer holiday is not currently known but has clear implications for the design and timing of equity-focused interventions.

While examining the effects of summer holidays on adolescents' physical fitness, researchers have extensively used variable-centred approaches (e.g., linear mixed models, LMM) to estimate average changes and quantify the magnitude and direction of period effects. These approaches, however, assume a common underlying trajectory and may obscure heterogeneity in how subgroups of adolescents move through the same environments [22]. Person-centred approaches, such as latent profile analysis and its longitudinal extension, latent transition analysis (LTA), complement this by identifying qualitatively distinct profiles and quantifying the

probability that adolescents shift between profiles across time [23]. Previous research has profiled adolescents on PA, sedentary behaviours, and digital screen time and results revealed that behavioural typologies are largely stable and that the small amount of movement that does occur tends to be towards less favourable profiles [23]. Whether analogous stability characterises fitness profiles, and whether such stability differs between the school-year and summer-holiday periods, has, to our knowledge, not previously been examined.

The present study addresses these gaps using a three-occasion longitudinal design that brackets both a full school year (August 2024 to June 2025) and the subsequent summer holiday (June 2025 to August 2025) in a sample of Danish adolescents. Summer holidays in Denmark span across six summer weeks, from end of June to mid-August. Our aims were threefold. First, we sought to quantify period-specific changes in CRF, blood pressure, resting heart rate (RHR), muscular strength, agility, balance, and body composition, and to test whether these changes differed between boys and girls. Second, using LTA, we sought to identify empirically derived fitness profiles and to characterise the stability of, and transitions between, these profiles across the school-year and summer-holiday periods. Third, we examined whether sex and age predicted the direction of profile transitions during each period to identify subgroups at greater risk of downward mobility in fitness. The aims of present study were not pre-specified in the trial protocol [24] of the main study and, therefore, this study should be considered as exploratory rather than confirmatory.

Methods

Study Design and Timeline

This study was part of a larger cluster randomised controlled trial project, which investigated the effects of a PE intervention (FIT FIRST Teen) on Danish adolescents' physical fitness and mental health. The main study was registered at clinicaltrials.gov (NCT06615791) on the 13th of September 2024. A longitudinal observational design was employed with three measurement occasions: t1 (August 2024), start of the school year and baseline measurement; t2 (June 2025), end of the school year, before the summer holiday; and t3 (August 2025), after the summer holiday, follow-up measurement.

Participants and Setting

In the main FIT FIRST Teen project, 22 schools (ten in the intervention arm and 12 in the control arm) were tested at the beginning (August 2024) and at the end (June 2025) of the school year. Schools were asked to participate with their 7th, 8th, and 9th graders, including students aged 13 to 16. This present study adopted a convenience sampling method and followed the *Strengthening The Reporting of Observational studies in Epidemiology* (STROBE) guidelines [25]. Two schools were purposely selected from the schools allocated to the control arm, and they were asked to be further tested at the beginning of the following school year (August 2025). These schools participated in the main project with 7 classes, resulting in a total of 162 participants. Supplementary Table S1 shows the number of participants tested in each measure at each timepoint. Given the exploratory nature of this study, power calculation was not conducted. To address potential sources of bias, participants were tested in a standardised order (non-physical assessments before progressive physical assessments) and by trained research staff following a consistent protocol across all schools and timepoints.

Measures

CRF was measured by the performance (total distance in metres) in the Yo-Yo Intermittent Recovery Level 1 test for children and adolescents (YYIR1C) [26]. Blood pressure (systolic and diastolic) and RHR were measured with the OMRON M6 HEM-7223-E blood pressure monitor. After an initial 8-minute supine rest, three readings were taken at 1-minute intervals with the blood pressure monitor positioned on the skin of the left upper arm. Body composition (weight, body fat percentage, and muscle mass) was measured using the InBody270 and BMI was retrieved by using the formula kg/m^2. Upper- and lower-limb muscular strength was assessed using the hand grip dynamometer and the standing long jump, respectively. Balance was measured using the Stork Balance Test. Finally, agility was assessed using the Arrowhead Agility Test. Details for all measures are reported in Supplementary Material 1. Further information regarding the testing procedure for the primary and secondary outcomes is also reported elsewhere [27].

Testing procedures

Testing followed a standardised protocol. Participants were asked to avoid vigorous PA the evening before and to fast for one hour before data collection. Non-physical assessments

(blood pressure, RHR, and body composition) were conducted first, followed by the physical assessments (balance, handgrip strength, long jump, agility, and YYIR1C). This sequence ensured baseline cardiovascular and anthropometric measurements were obtained in a rested state. Food intake was permitted between assessment phases, but not prior to the non-physical assessments. No restrictions were placed on caffeine consumption.

Ethical Approval

Ethics approval was obtained from the Regional Committees on Health Research Ethics for Southern Denmark (reference: S-20210099) at the beginning of the project. Informed consent to participate was sent via email to parents/guardians, who were given the option to opt out their children from the study. Research staff introduced the project to the students at the beginning of every test day and reassured them that they could withdraw from participation at any moment and/or from any of the tests. Oral assent was obtained from participants on each day of testing. Given the minimal-risk nature of this school-based, non-pharmacological project, a formal Data Safety Monitoring Board was not convened. Participant safety was monitored through continuous observation by research and school staff during testing, in accordance with institutional ethics and safeguarding procedures. All procedures were conducted in accordance with the Declaration of Helsinki.

Statistical Analysis

Linear mixed models. All analyses were conducted in R [28]. Descriptive statistics are presented as mean and standard deviation (SD). Missing data were quantified overall and by sex and timepoint, and Little's Missing Completely at Random (MCAR) test was used to evaluate the missing data mechanism. Linear mixed-effects models were fitted using restricted maximum likelihood (REML), with participant ID included as a random intercept to account for repeated measurements. Three nested models were examined: Model 1 included timepoint as a fixed effect; Model 2 additionally adjusted for centred age, centred baseline height, centred baseline weight, and sex; and Model 3 further included a sex × timepoint interaction. Continuous covariates (age, baseline height, and baseline weight) were grand-mean centred prior to analysis to improve interpretability of model coefficients. For BMI, weight and height were not included in the models. To investigate the changes during the school year and the summer holidays, t2 (June 2025) was set as a reference category in the all the models (0 = June 2025, 1 = August

2024, and 2 = August 2025). Therefore, when interpreting the results about the changes over the school year (t1 → t2), positive estimates indicate declines in the outcome variable estimates (August 2024 minus June 2025), and vice versa. When interpreting the results regarding the summer holidays period (t2 → t3), positive results indicated an increase in the outcome variable estimates (August 2025 minus June 2025), and vice versa. Fixed-effect estimates, standard errors, t-statistics, and p-values were extracted for each model, and Benjamini-Hochberg correction was applied to control the false discovery rate across fixed-effect tests [29]. Estimated marginal means (EMMs) and pairwise contrasts were calculated using the *emmeans* package [30]. Overall timepoint effects were derived from Model 2 to avoid confounding by the sex × timepoint interaction, whereas sex-specific timepoint effects and interaction contrasts were derived from Model 3. Intraclass correlation coefficients (ICCs) were calculated to quantify the proportion of variance attributable to between-participant differences. As a sensitivity analysis, missing outcome data were imputed using multiple imputation by chained equations (MICE; 25 imputations, predictive mean matching) [31]. Estimates were pooled according to Rubin's rules and compared with the primary complete-case analyses to assess the robustness of findings to missing data assumptions. Results of MICE are reported in the supplementary material.

Latent transition analysis. LTA was performed using the *depmixS4* package [32]. Adolescents' physical fitness was profiled using five indicators: YYIR1C (metres), standing long jump, (centimetres), agility (seconds), balance (seconds), and grip strength (kilograms). Because lower agility times denote better performance, agility scores were reversed prior to analysis so that, for every indicator, higher values represented better fitness. All indicators were standardised (z-scored) against the pooled grand mean and standard deviation across the three measurement occasions, placing them on a common scale. A single latent transition model was fitted across the three measurement occasions (August 2024, June 2025, and August 2025), with the measurement model constrained to be invariant across time so that profiles retained a consistent meaning on each occasion. This specification permitted estimation of two distinct transitions: from t1 to t2, spanning the school year, and from t2 to t3, spanning the summer holiday. Models with two to six latent statuses were estimated, each using 20 random starts to reduce the risk of convergence on local maxima [33]. The number of profiles was selected by considering the Akaike and Bayesian information criteria (AIC, BIC) through the elbow plot (lower values representing better model fit), entropy, profile interpretability in relation to external variables

(see below), and adequacy of profile sizes [34]. Each participant was assigned to their most likely profile on each occasion based on membership probabilities. Transitions between profiles were then examined separately for the school-year period (t1→t2) and the summer-holiday period (t2→t3). Only participants with a valid profile assignment at all relevant occasions contributed to each transition.

External validation. To evaluate whether the derived profiles reflected meaningful differences in physical fitness, we compared them on three body-composition variables that were not used to construct the profiles: muscle mass (kg), body fat (%), and BMI. Validation was conducted at baseline (t1) only, using each participant's baseline profile membership. For each variable, a one-way analysis of variance (ANOVA) tested for overall differences among the three profiles. Homogeneity of variance was assessed with Levene's test, and Welch's ANOVA was reported. Pairwise differences between profiles were estimated using estimated marginal means, with p-values adjusted for multiple comparisons using the Benjamini–Hochberg false discovery rate procedure.

*Predictors of profile transitions***.** To examine whether sex and age predicted the direction of adolescents' movement between fitness profiles, we conducted multinomial logistic regressions using each participant's most likely profile membership from the latent transition model. Because the profiles were ordered by fitness level (low < average < high), each participant's change between consecutive occasions was classified as a downward transition (to a lower-fitness profile), no change (remaining in the same profile), or an upward transition (to a higher-fitness profile). This three-category variable served as the outcome, with "no change" as the reference category, so that the model estimated the odds of moving to a worse or better profile relative to remaining stable. Separate models were fitted for the school year (t1–t2) and the summer holiday (t2–t3), each including sex and age as predictors, measured at the start of the respective period. Odds ratios with 95% confidence intervals were derived from the model coefficients, and the overall contribution of each predictor was assessed using likelihood-ratio tests. Analyses were conducted in R using the *nnet* package [35]. Owing to the small number of transitions towards better profiles, estimates for the better-versus-stay comparison were unstable and are not interpreted. These analyses should therefore be regarded as exploratory.

Results

Participant Characteristics

A total of 162 adolescents were enrolled at t1. Of these, 79 were male and 83 were female. Mean age at t1 was 13.6 years (SD = 0.6). Participants' baseline characteristics are reported in Table 1. The number of participants tested in each measure at each timepoint is reported in Supplementary Material 1. Non-participation at each measurement occasion was primarily attributable to school absence, injury preventing completion of physical tests, and unwillingness to take part on the day of testing or in a specific assessment.

Table 1. Participants baseline characteristics.

Categorical variable	**n**	**%**
Sex		
Male	79	48.8
Female	83	51.2
Continuous variables	**n**	**Mean (SD)**
Age (years)	113	13.60 (0.59)
Height (cm)	113	165 (8.1)
Weight (kg)	113	55 (12.3)
Yo-Yo IR1 (m)	106	828 (559)
Agility (s)	111	10.14 (0.94)
Standing long jump (cm)	110	131.8 (21.6)
Flamingo balance (s)	113	6.23 (4.63)
Handgrip (kg)	115	23.93 (5.23)
Muscle mass (kg)	113	23.55 (4.71)
Body fat (%)	113	20.58 (9.28)
BMI (kg/m^2)	113	20.09 (3.53)

Notes. cm = centimetres, kg = kilograms, m = metres.

Linear mixed models

Primary outcomes. Figures 1 and 2 show the timepoint effect and the Sex × Timepoint interaction effects for the primary outcomes, respectively. All the models' results are reported in Supplementary Material 1. A significant overall timepoint effect emerged for the YYIRC1 for the school-year comparison (B = 162.13, SE = 52.84, p = .0.004), indicating a decline in the performance across the school year (August 2024 to June 2025) of ~162m. No significant overall timepoint effect was observed for the summer period, and the Sex × Timepoint interaction was

non-significant at both timepoints. In relation to the diastolic blood pressure, significant overall timepoint effects were found for the school year (B = 2.4, SE = 0.87, p = .018) and the summer holidays (B = 2.04, SE = 0.93, p = .041). These results indicated that during the school year, the diastolic blood pressure declined by ~2.4mmHg, but it returned to almost baseline values after the summer holiday, increasing by ~2.0mmHg from June 2025 to August 2025. These changes were mainly driven by a significant Sex × Timepoint interaction (B = 4.62, SE = 1.72, p = .036), which showed that, relative to boys, girls demonstrated a greater decrease in diastolic blood pressure across the school-year period (from 62.59 to 57.72 mmHg in girls, versus a stable 58.29 to 58.05 mmHg in boys). Finally, no significant overall timepoint effects and no significant Sex × Timepoint interactions were observed for the systolic blood pressure and resting heart rate.

[INSERT FIGURE 1 HERE]

[INSERT FIGURE 2 HERE]

Secondary outcomes. Tables and Figures regarding the secondary outcomes are reported in Supplementary Material 1. Regarding the agility, results showed a significant timepoint effect during the school year (B = -0.42, SE = 0.10, p < .001), indicating an increase in the agility test performance of ~0.42s. Furthermore, a significant Sex × Timepoint interaction emerged for the school-year comparison (B = −0.72, SE = 0.20, p = .001). Specifically, relative to boys, girls showed a greater increase in agility time across the school-year period (August 2024 to June 2025), reflecting a greater decline in agility performance (from 10.45 to 11.26 seconds in girls, versus 9.82 to 9.91 s in boys). Regarding the handgrip strength, results showed significant timepoints effects both for the school year (B = 0.76, SE = 0.37, p = .042), and the summer period (B = 0.89, SE = 0.39, p = .034), indicating a decline during the school period of ~0.8kg, followed by an increase during the summer holidays of ~0.9kg. These results were mainly driven by the significant Sex × Timepoint interaction for the school-year comparison (B = 1.99, SE = 0.73, p = .012), which demonstrated that girls showed a greater decrease in handgrip strength

across the school-year period (August 2024 to June 2025; from 22.71 to 20.89 kg in girls, versus a stable 24.98 to 25.15 kg in boys). The interaction for the summer period was not significant. Results of the standing long jump revealed no timepoint effect. However, a significant Sex × Timepoint interaction emerged for the school-year comparison (B = 17.01, SE = 3.89, p < .001). Specifically, girls showed a greater decrease in jump distance across the school-year period (from 122.66 to 112.81 cm) compared to boys, whose performance increased (from 141.54 to 148.68 cm). Neither the timepoint effect nor the interaction was significant for the summer period. A significant timepoint effect was shown for the summer comparison in relation to the body fat percentage (B = −0.99, SE = 0.47, p = .043), indicating a decrease in body fat across the summer-holiday period of ~1%. However, no significant Sex × Timepoint interactions were observed. Results regarding the muscle mass revealed significant timepoint effects for the school year (B = −1.55, SE = 0.20, p < .001) and the summer holidays (B = 0.71, SE = 0.22, p = .001), showing that a constant increase in the muscle mass. Further, significant Sex × Timepoint interactions were found for the school year (B = 1.71, SE = 0.37, p < .001), indicating that from August 2024 to June 2025 boys increased their muscle mass more compared to girls (from 24.60 to 26.94 kg for boys, and from 22.39 to 23.02 kg in girls). No significant Sex × Timepoint interactions were found for the summer holidays period. Finally, no significant results were found for the balance and the BMI.

ICC and Sensitivity Analysis

The ICCs for the primary outcomes indicated small-to-moderate between-participant clustering, supporting the inclusion of a participant-level random intercept: YYIR1C ICC = 0.544, resting heart rate ICC = 0.451, diastolic blood pressure ICC = 0.373, and systolic blood pressure ICC = 0.132. Sensitivity analyses using MICE yielded estimates that were directionally consistent with the complete-case models for all four primary outcomes. The sex × timepoint interaction for diastolic blood pressure across the school year was, however, attenuated after pooling (B = 2.52, SE = 2.09, p_BH = 0.681), whereas the same effect reached statistical significance in the complete-case analysis. This sex-specific school-year decline in diastolic blood pressure should, therefore, be interpreted with some caution. Systolic blood pressure and resting heart rate remained null under both analyses.

Latent Transition Analysis

The fit indices of the LTA are reported in Supplementary Material 2. BIC kept decreasing until the k=4 and AIC reached the lowest value at k = 6. Entropy had the highest value at k = 5. Although the model indices and the elbow plot suggested a four-profile solution, one profile approached the recommended minimum class size threshold of approximately 5% (Supplementary Material 2), below which latent classes may be unstable and difficult to interpret meaningfully [34,36]. Therefore, we opted for the three-profile solution with the profiles being (from best to worst in terms of fitness scores): *high-fit*, *average-fit*, and *low-fit*. Figures 3 and 4 show the proportion of students in each profile at each timepoint and the standardised z-scores for each profile, respectively.

[INSERT FIGURE 3 HERE]

The first profile (*low fit*) consisted of 17.3% (28 students) at t1, and 23.5% (38 students) at t2, and 26.5% (43 students) at t3. Participants in this profile were characterised by below-average scores (standardised) on the five indicators, with values ranging from -0.54 (balance) to -1.10 (agility). The second profile (*average fit*) was the largest each timepoint: 58.0% (94 students) at t1; 54.9% (89 students) at t2; and 53.3% (88 students) at t3. Participants in this profile had values on the five indicators that were around the standardised mean, ranging from -0.29 (YYIRC1) to 0.02 (hand grip strength). Finally, the third profile (*high fit*) was characterised by participants having standardised scores in the indicators well above average, ranging from 0.53 (hand grip strength) to 1.10 (YYIRC1). This profile consisted of 24.0% (40) students at t1, 21.6% (35) students at t2, and 19,1% (31) students at t3.

[INSERT FIGURE 4 HERE]

The ANOVA provided evidence of external validity of the three-profile solution by comparing baseline scores on body composition (muscle mass, body fat percentage, and BMI) of the three profiles. Table 2 shows the raw scores of the body composition measures at baseline across the profiles. Pairwise comparisons (Benjamini-Hochberg) confirmed significant differences between adjacent profiles for most of the body composition domain, as shown in Supplementary Material 2, confirming that the three-profile solution yielded meaningfully distinct profiles. Adding a fourth profile to the solution resulted in fewer significant differences between adjacent profiles, suggesting the four-profile solution not yielding meaningful distinct profiles (Supplementary Material 2).

Table 2. Means, standard deviations, and sample size of the external validation variables across the three profiles at baseline.

Variable	Profile	N	Mean	SD
BMI	Low fit	21	21.85	4.02
	Average fit	56	20.09	3.74
	High fit	36	19.06	2.38
Body fat %	Low fit	21	29.81	9.7
	Average fit	56	20.48	8.2
	High fit	36	15.36	6.06
Muscle mass	Low fit	21	21.52	3.36
	Average fit	56	23.51	4.81
	High fit	36	24.81	4.9

Notes. BMI = Body Mass Index, SD = standard deviation.

Profile transitions across timepoints

Results regarding the stability and change in profile membership between t1 and t2 (school year) are reported in Figure 5. Specifically, 100% of participants who started the school year in the *low fit* profile stayed in the same profile at the end of the school year. Eighty-eight per cent of the students who started the school year in the *average fit* profile remained in the same profile. And eighty-two per cent of the students who started the school year in the *high fit* profile remained in the same profile. Notably, 10% of the students who started the year in the *average fit* profile moved to the *low fit* profile, and 2% of those who started in the *high fit* profile moved

towards the *low fit* by the end of the school year. Finally, 15% of students who started in the *high fit* profile at the beginning of the school year transitioned to the *average fit* profile.

[INSERT FIGURE 5 HERE]

Figure 6 shows the stability and change in profile membership between t2 and t3 (summer holiday). Results show similar transition patterns, with the majority of students who finished the school year in a specific profile retaining such membership over the summer period:100% for *low fit*, 93% for *average fit*, and 86% for *high fit*. Similar to the school year patterns, 14% of students who finished the school year in the *high fit* profile moved towards the *average fit* profile over the summer period. Notably, 6% of students who were in the *average fit* profile in June 2025 moved towards the *low fit* profile in August 2025, and 1% moved from *average fit* to *high fit*.

[INSERT FIGURE 6 HERE]

Multinomial logistic regression

Considering that during the school year, most adolescents remained in their baseline fitness profile, while a minority moved to a lower-fitness profile and only two moved to a better one, upward transitions were too infrequent to yield stable estimates and, therefore, are not interpreted (Table 3). For the downward-versus-stable comparisons, sex was a significant predictor. Specifically, girls were more likely than boys to move to a lower-fitness profile rather than remain stable (OR = 4.42, 95% CI [1.15, 16.93], p = .030). Age was not a significant predictor of downward transition (OR = 0.33, 95% CI [0.09, 1.19], p = .089). Over the summer holiday, neither predictor was significantly associated with downward transition (sex: OR = 0.14, 95% CI [0.02, 1.20], p = .073; age: OR = 0.44, 95% CI [0.10, 1.90], p = .271). Notably, the association with sex was in the opposite direction to that observed during the school year,

suggesting that the greater likelihood of girls declining in fitness profile was specific to the school-year period rather than a general tendency.

Table 3. Multinomial logistic regression predicting profile transitions (Worse / Better vs. Stay) from sex and age, by period.

Period	Transition	Predictor	OR	95% CI	p
School year (t1→t2)	Worse vs. Stay	Female (vs. male)	4.42	[1.15, 16.83]	**.030**
	Worse vs. Stay	Age	0.33	[0.09, 1.19]	.089
	Better vs. Stay	Female (vs. male)	—	—	—
	Better vs. Stay	Age	—	—	—
Summer holiday (t2→t3)	Worse vs. Stay	Female (vs. male)	0.14	[0.02, 1.20]	.073
	Worse vs. Stay	Age	1.44	[0.10, 1.90]	.271
	Better vs. Stay	Female (vs. male)	—	—	—
	Better vs. Stay	Age	—	—	—

Note. OR = odds ratio; CI = confidence interval.
Reference outcome category = "Stay" (remained in the same fitness profile). Profiles were ordered by fitness level (low < average < high); "Worse" and "Better" denote transitions to a lower- or higher-fitness profile, respectively. Sex reference category = male. Age was measured at the start of each period. Upward ("Better") transitions were too infrequent (n = 2, school year; n ≈ 2, summer) to yield stable estimates and are not reported (—). Highlighted row indicates statistical significance ($p < .05$). n = 113 (school year); n = [insert] (summer).

Discussion

The aim of this longitudinal study was to examine how Danish adolescents' physical fitness and body composition changed across a full school year and the subsequent summer holiday and used LTA to characterise stability and change in fitness profiles. Results indicated that, across a range of fitness indicators (CRF, agility, standing long jump, and handgrip strength) average performance declined, or in some cases stagnated, over the school year rather than during the summer holiday. Second, the majority of adolescents remained in the same latent fitness profile across all three occasions. The small amount of profile transition that occurred was mainly towards worse profiles, and girls were more likely than boys to transition to a lower-fitness profile during the school year.

In relation to our primary outcomes, diastolic blood pressure declined by ~2.4 mmHg across the school year and rose by ~2.0 mmHg across the summer, indicating that the summer

increase represented a return towards baseline, and supporting the argument that structured days may counter physical fitness declines compared to unstructured days. Even though a 2-mmHg shift in diastolic blood pressure is small at the individual level, population-based studies have found that a 2 mmHg lower usual diastolic blood pressure is associated with meaningful reductions in stroke and ischaemic heart disease mortality in adults [37]. Considering that adolescent blood pressure tracks moderately into adulthood [38], our results should prompt further investigation in relation to the effects of summer holidays on adolescents' blood pressure. These results, however, should also be interpreted with caution. On the one hand, given that MICE attenuated the effect, these patterns may be best interpreted as short-term environmental sensitivity around an individual set-point rather than a durable elevation. On the other hand, the sex-stratified analyses attribute most of the school-year decline to girls (from 62.6 to 57.7 mmHg), whose values returned toward those of boys over the summer. In this cohort, however, the oscillation did not accumulate into a durable net change and remained well below adolescent hypertension thresholds throughout. CRF, measured by YYIR1C, declined by approximately 162 metres across the school year, with no compensatory recovery over the summer. Because maturation would be expected to raise YYIR1C distance at this age [11,12], this change may be interpreted as a net deficit relative to the maturational trajectory rather than a plateau. Our findings are consistent with previous evidence that showed declines in adolescent CRF trajectories [8,9,39,40] and with the well-documented drop in moderate-to-vigorous PA between ages 13 and 16 as sedentary academic demands and organised-sport dropout accumulate [5,18,41]. That the summer holiday did not produce a rebound suggests that neither of the two annual periods (school year and summer holiday) currently provides an adequate aerobic stimulus. Finally, systolic blood pressure and RHR showed no significant change across either period. Both variables are relatively insensitive short-term indices, so small seasonal effects may be obscured by measurement noise. Combined with limited statistical power to detect ~1–2 bpm or mmHg changes, these null findings should not be over-interpreted as evidence that the cardiovascular system was unaffected by the seasonal shifts. As shown, diastolic blood pressure, as the most environmentally sensitive of the three, may have captured the small decline in adolescents' cardiovascular system. Future research should incorporate device-based measures of PA and sedentary behaviour to clarify whether the school year itself, rather than the broader academic-year context, drives the aerobic deficit observed here.

Results of the secondary outcomes revealed that muscle mass increased across both periods, but the school-year increase was significantly larger in boys than in girls, whereas the summer-holiday increase did not differ by sex. This pattern reflects pubertal fat-free mass growth. Specifically, testosterone-driven gains in skeletal muscle are steeper in boys and cluster in the mid-adolescent window, while girls' fat-free mass rises more modestly and earlier [42,43]. In this sense, the muscle mass results can be interpreted as a maturational trace rather than as an environmental effect of the school year versus the summer holiday. Body fat percentage, by contrast, decreased by ~1% across the summer holiday, with the change directionally driven by boys although the sex × timepoint interaction did not reach statistical significance. These findings contrast with the accumulating body of evidence from primary-school-aged cohorts, in which the summer holiday is associated with accelerated fat gain rather than fat loss [17,44,45]. In a most recent multi-year observational cohort, for example, children achieved 93% of their annual body-fat gain during the summer months [45]. Two non-exclusive explanations should be considered. First, adolescents differ meaningfully from primary-school children in the autonomy, sport participation, and outdoor exposure that characterise their summer, and Nordic summers in particular offer extended daylight and outdoor opportunity that may partly offset the loss of school-day structure [17]. Second, the composition and direction of change observed here (muscle mass rising while fat percentage falls) points to a favourable, activity-consistent body-composition shift over the summer that is at odds with the "summer weight gain" narrative developed in younger, geographically, and climatically distinct samples. Finally, BMI showed no significant change across either period. This null finding is expected rather than surprising: because BMI cannot distinguish fat mass from fat-free mass, the concurrent rise in muscle mass and small decline in fat percentage cancel each other at the whole-body-weight level, and BMI is a well-recognised insensitive short-term indicator of body-composition change in growing adolescents [46]. The convergent interpretation across the three body-composition outcomes is, therefore, that our sample experienced a modest but favourable composition shift over the summer holiday, invisible to BMI but detectable in its constituent components. Future research should examine whether the favourable summer body-composition shift observed here generalises to other adolescent cohorts and climates, and should directly measure physical activity, diet, and sleep during the summer holiday to identify which behaviours drive the divergence from the primary-school-aged "summer weight gain" pattern.

Finally, agility, handgrip strength, and standing long jump showed convergent patterns. The school-year change was unfavourable for girls (agility time 10.45 → 11.26 s; handgrip 22.71 → 20.89 kg; standing long jump 122.66 → 112.81 cm), while boys remained stable or improved. Each outcome returned a significant sex × timepoint interaction for the school year but none for the summer. The 13–16-year window coincides with the sharpest widening of male–female differences in strength and power, with female grip strength falling to ~65% of male values by age 16 [43,47], so part of the divergence reflects normal maturation. This pattern is difficult to reconcile with biology alone and is more consistent with the current PE and school-day environment providing an insufficient strength, power, and agility stimulus for adolescent girls, allowing maturity divergence to proceed unopposed [48]. Moreover, this divergence can also be explained by the fact that girls tend to drop from leisure-time sport participation. A recent cross-sectional study conducted in Danish adolescents observed a significant drop out of sports from the previous to the current year among girls, but not among boys [19]. Future research should investigate the extent to which, and at what age, declining leisure-time sport participation contributes to the sex-specific decline in strength, power, and agility observed here, and whether school-based interventions targeting girls' retention in organised sport can offset this trend.

Our novel approach to profile adolescents' fitness using LTA showed patterns of profile stability. Across the school year, 100% of adolescents classified as *low fit* at baseline remained *low fit* at the end of the school year, and the same was true over the summer holiday. Only two participants transitioned to a higher-fitness profile across the entire study, precluding meaningful modelling of upward mobility. This is arguably the most important finding of the study. The subgroup of adolescents most in need of fitness gains (namely those already at the lower end of the multivariate fitness distribution and, based on baseline external validation, those with the highest BMI and body fat and the lowest muscle mass) were also the least likely to experience improvement. In other words, neither the school year nor the summer holiday appears to offer them a meaningful pathway to catch up. Combined with the observation that downward transitions from *average*- to *low-fit* profiles occurred in ~10% of adolescents during the school year and 6% during the summer, this suggests a slow but consistent expansion of the low-fitness group and a hardening of within-cohort fitness inequalities across the adolescent decade. This distributional pattern is aligned with recent large-scale surveillance evidence showing that declines in adolescent fitness are concentrated in the lower portion of the distribution, while the

highest-fit minority remain stable or improve. As Nevill and colleagues framed it: “fitness declining for the majority but not for a fit minority” [48]. Out results align with a 34-year Chinese cohort in which adolescents with low CRF continued to decline while those with high CRF stabilised over time [40]. The multinomial regression added a second layer to this picture. Specifically, girls were four times more likely than boys to transition to a lower-fitness profile during the school year, whereas no such effect was observed over the summer. This converges with the sex-specific school-year declines identified by the LMM in agility, handgrip strength, and standing long jump, and provides internally consistent, cross-analytic evidence that the current school-year environment does not equally serve adolescent boys and girls, with girls being disproportionately at risk of both mean-level fitness loss and downward mobility between empirically defined fitness profiles. These findings should prompt future researchers to examine whether targeted, intensive interventions can shift adolescents out of the low-fit profile.

Our study has several implications. First, the assumption that being at school is sufficient to protect adolescent fitness should be reconsidered. Curricular PE, as currently delivered, may not provide the frequency, intensity, or engagement required to offset accumulating sedentary demands in this age group [49]. Whole-school approaches that combine higher-intensity PE with active breaks, active travel, and reductions in in-class sitting have a stronger evidence base and warrant scaling [49,50]. Second, sex-responsive design is not optional. Given that girls’ disproportionate school-year decline is now demonstrable across variable- and person-centred analyses, PE curricula and school PA policies should be co-designed with adolescent girls and evaluated with a specific focus on inclusion, autonomy, and enjoyment [18,51]. Third, the stability of the low-fit profile calls for targeted, rather than universal, intervention strategies for adolescents at the bottom of the fitness distribution. Universal school-based programmes may lift the average without meaningfully changing the trajectories of those most at risk, thereby maintaining or widening inequalities.

Strengths and limitations

This study has several strengths. First, the longitudinal design included both a full school year and the subsequent summer holiday within the same participants, allowing within-person estimation of period-specific change rather than the between-cohort comparisons that dominate much of the summer-effect literature. Second, all outcomes were directly measured using

standardised, field-validated protocols spanning CRF, upper- and lower-limb muscular strength, agility, balance, resting cardiovascular function, and body composition, providing a broader and more objective phenotypic characterisation than is typical in this literature. Third, the complementary use of variable- and person-centred analytic approaches allowed the same underlying pattern to be identified independently by the LMM and by the multinomial regression built on LTA profile assignments. Finally, sensitivity analyses using multiple imputations by chained equations produced estimates directionally consistent with the primary complete-case models, indicating that the substantive conclusions are unlikely to be driven by the pattern of missingness.

Several limitations should, however, be acknowledged. First, the convenience sample comprised 162 adolescents drawn from two schools in the control arm of a cluster RCT limited the statistical power (particularly for the LTA-based multinomial regression) and constrained generalisability to the wider Danish and European adolescent population. Second, missing data at some timepoints and outcomes were not fully at random, and although the pattern of results was largely consistent with the multiply imputed sensitivity analyses, residual bias cannot be excluded. Third, we did not directly measure PA, sedentary time, sleep, diet, or screen use, which limits our ability to attribute the observed period effects to specific behavioural mechanisms proposed by the SDH. Forth, pubertal and maturation statuses were not assessed, which is a particular limitation given the sex-specific findings. Finally, upward transitions between fitness profiles were too rare to yield stable estimates, and the multinomial model comparing “better versus stay” should be regarded as exploratory only.

Conclusions

In this Danish adolescent sample, physical fitness declined across a full school year, with CRF, agility, standing long jump, and handgrip strength all showing unfavourable change. Girls carried a disproportionate share of this decline and were more than four times more likely than boys to transition to a lower-fitness profile during the school year. The summer holiday, contrary to the predictions of the Structured Days Hypothesis, was associated with partial recovery in several outcomes and no sex-specific decline. Person-centred analyses revealed that adolescents in the lowest-fitness profile were essentially locked into that status across both periods, signalling a within-cohort fitness inequality that neither school nor summer currently addresses.

Public health strategies to protect adolescent fitness should therefore reconsider the assumed protective role of the school year, prioritise sex-responsive PE and PA policies, and design targeted supports for the subgroup of adolescents least likely to experience spontaneous improvement.

List of Abbreviations

CRF, Cardiorespiratory Fitness

PA, Physical Activity

PE, Physical Education

SDH, Structured Days Hypothesis

BMI, Body Mass Index

LMM, Linear Mixed Models

LTA, Latent Transition Analysis

RHR, Resting Heart Rate

YYIRC1, Yo-Yo Intermitted Recovery for Children

SD, Standard Deviation

MCAR, Missing Completely at Random

REML, Restricted Maximus Likelihood

MICE, Multiple Imputation by Chained Equations

AIC, Akaike Information Criteria

BIC, Bayesian Information Criteria

EMM, Estimated Marginal Means

ICC, Interclass Correlation Coefficient

ANOVA, Analysis of Variance

Figure Captions

Figure 1. Adjusted means for the primary outcomes across the three timepoints.

Legend. Values are estimated marginal means from the linear mixed model including age, baseline height, baseline weight, and sex as covariates, with a random intercept for participant. Shading represents the 95% confidence interval. ΔSchool denotes the change across the school-year period (August 2024 to June 2025) and ΔSummer the change across the summer holiday (June 2025 to August 2025); *p*-values are Benjamini–Hochberg corrected. YoYo = Yo-Yo Intermittent Recovery for Children; SYS = Systolic blood pressure; DIA = Diastolic blood pressure; RHR = Resting heart rate.

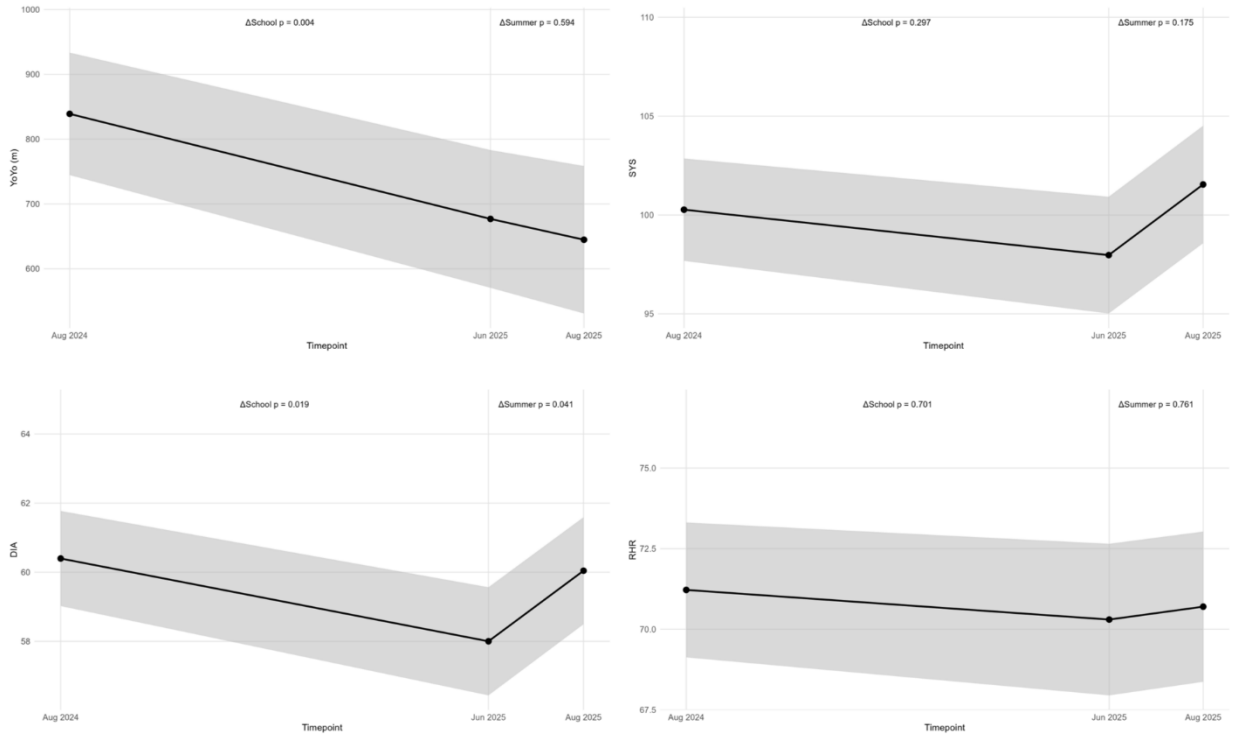


Figure 2. Adjusted means for the primary outcomes across the three timepoints, stratifies by sex.

Legend. Values are estimated marginal means from the linear mixed model including age, baseline height, and baseline weight as covariates and a Sex × Timepoint interaction, with a random intercept for participant. Shading represents 95% confidence intervals. Asterisks indicate significant differences between boys and girls at each timepoint (*$p < .05$, **$p < .01$, ***$p < .001$). ΔSchool and ΔSummer *p*-values refer to the Sex × Timepoint interaction terms, testing whether the change across each period differed between boys and girls. All *p*-values are Benjamini–Hochberg corrected. YoYo = Yo-Yo Intermittent Recovery for Children; SYS = Systolic blood pressure; DIA = Diastolic blood pressure; RHR = Resting heart rate.

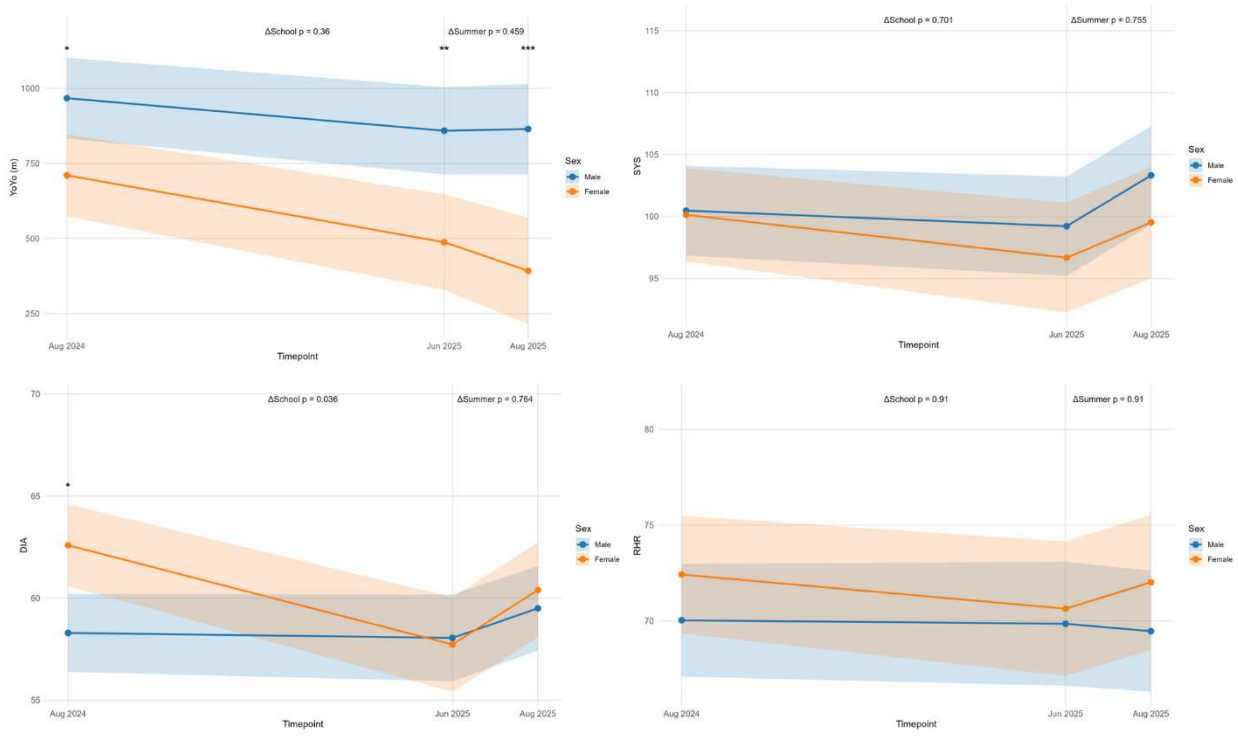


Figure 3. Percentage of students in each profile at each timepoint.

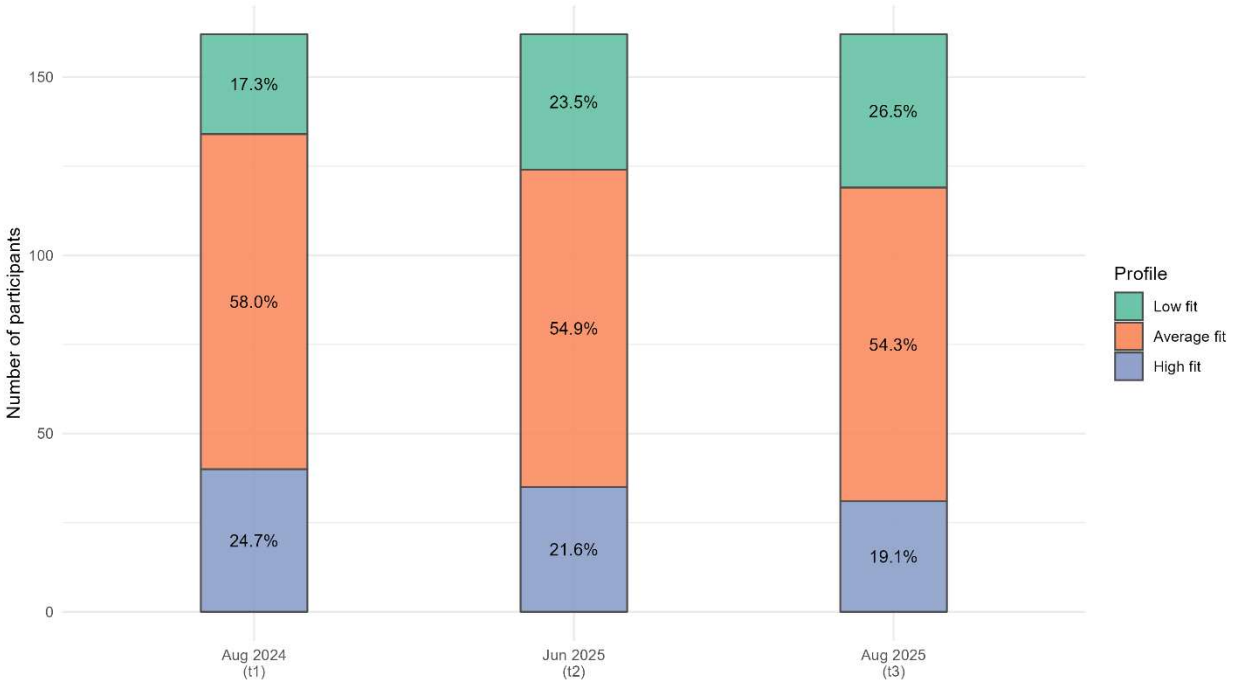


Figure 4. Standardised fitness profiles (K = 3) derived from latent transition analysis.

Legend. Bars represent z-scores for each fitness indicator across three distinct profiles. The green colour represents scores above the mean and the red colour represents scores below the mean. Agility scores were reversed so that higher values indicate better performance across all measures.

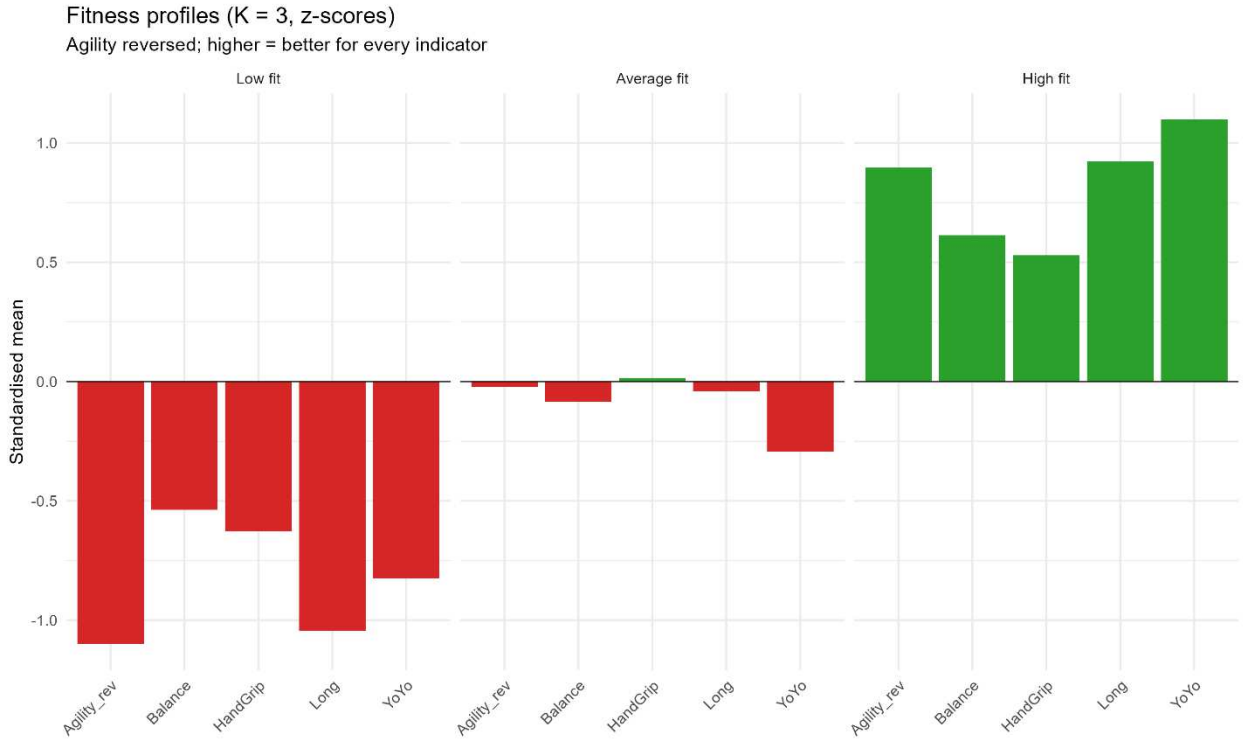


Figure 5. Transition probability matrix between fitness profiles across school year (August 2024 to June 2025).

Legend. Values represent the probability of transitioning from each profile at t1 (vertical axis) to each profile at t2 (horizontal axis). Colour intensity corresponds to probability magnitude (darker = higher probability).

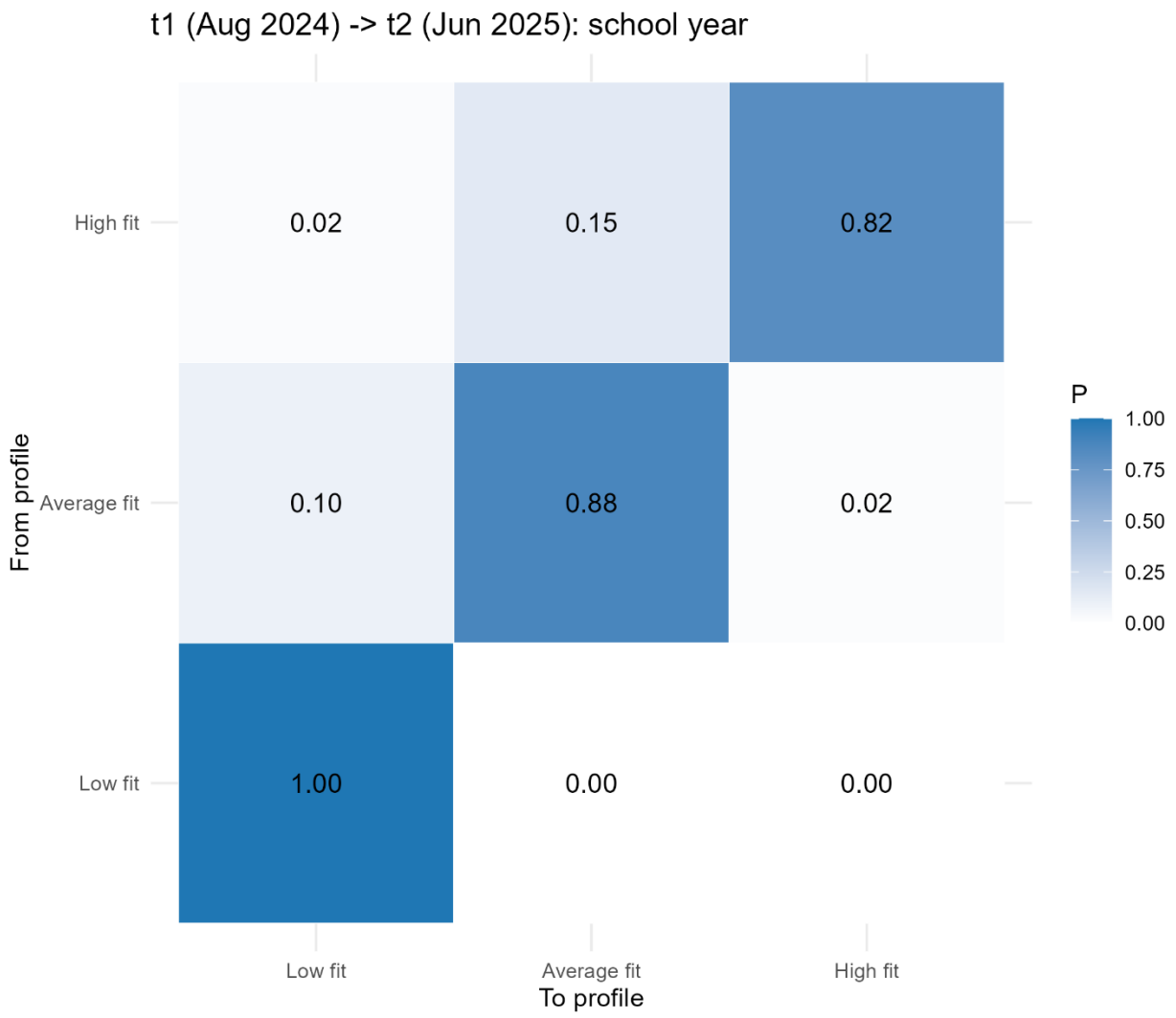
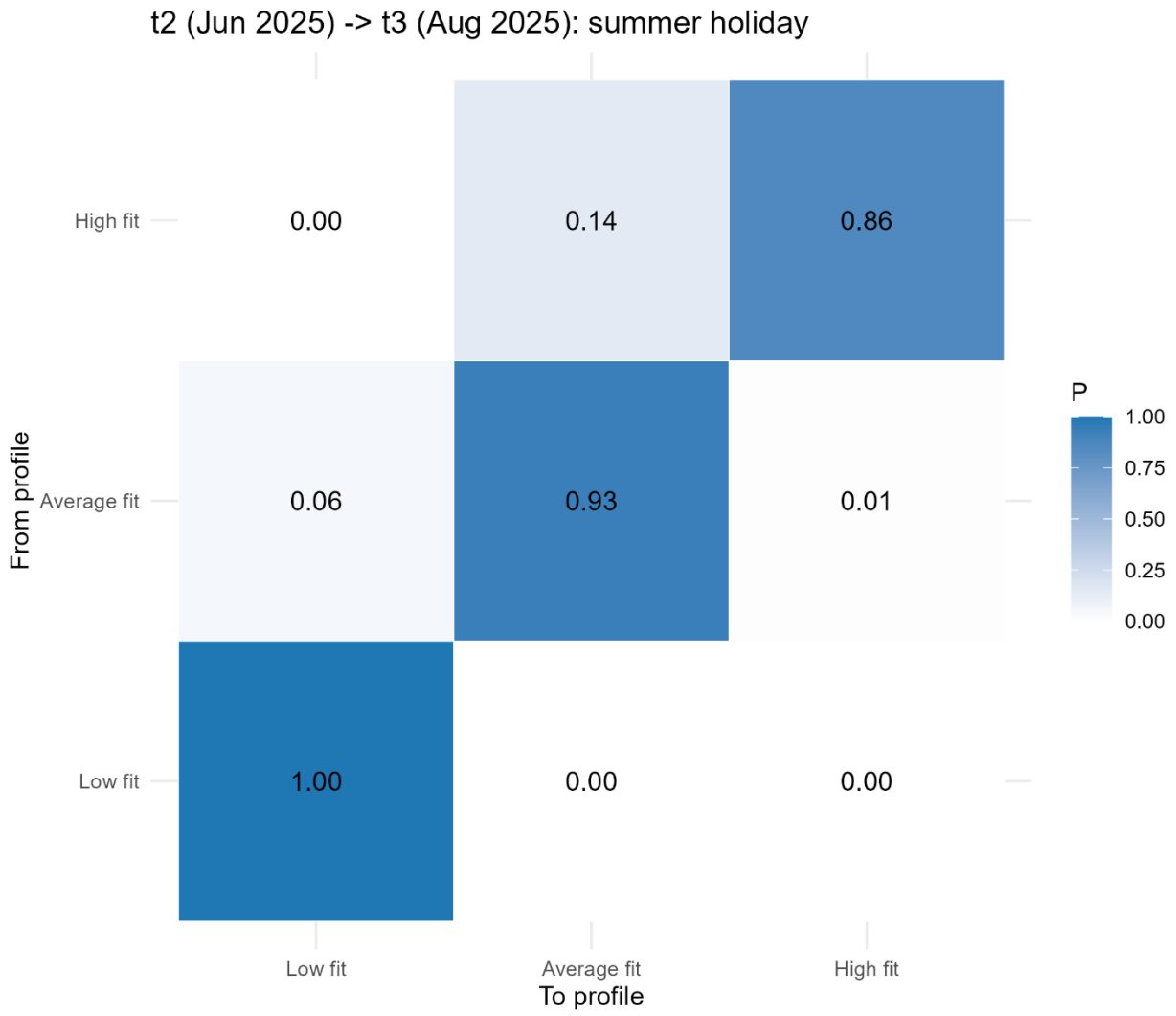


Figure 6. Transition probability matrix between fitness profiles across summer holiday (June 2025 to August 2025).

Legend. Values represent the probability of transitioning from each profile at t1 (vertical axis) to each profile at t2 (horizontal axis). Colour intensity corresponds to probability magnitude (darker = higher probability).


t2 (Jun 2025) -> t3 (Aug 2025): summer holiday
High fit
Average fit
Low fit
0.00
0.14
0.86
0.06
0.93
0.01
1.00
0.00
0.00
From profile
Low fit
Average fit
High fit
To profile
P
1.00
0.75
0.50
0.25
0.00

Declarations

Ethics approval and consent to participate

Ethics approval was obtained from the Regional Committees on Health Research Ethics for Southern Denmark (reference: S-20210099). Informed consent to participate was sent via email to parents/guardians, who were given the option to opt out their children from the study; oral assent was obtained from participants on each testing day, who were reassured they could withdraw at any time. The consent statement (and its English translation) is provided in the supplementary material.

Consent for publication

Not applicable.

Clinical trial number

Not applicable.

Availability of data and materials

The data that support the findings of this study are available from University of Southern Denmark RIO (Research and Innovation Organisation. Data are stored in a SharePoint, and restrictions apply to the availability of these data. The datasets used and/or analysed during the current study, however, are also available from the corresponding author on reasonable request.

Competing interests

The authors declare no competing interests.

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Authors' contributions

PK and MNL secured the funding. GT, PK, SK and MNL designed the study. GT, MGC, CC, MNL, SK, and PK collected the data. GT, MGC, and CC handled the data. GT performed the

statistical analysis and wrote the first draft of the manuscript. All the authors revised and approved the final version of the manuscript.

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