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Association between daily movement behaviors and optimal physical fitness of university students: a compositional data analysis

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Abstract

Objective This study investigates the relationship between movement behaviors and physical fitness (PF) in university students, and based on the top 5% of model-predicted outcomes for PF to determine the optimal movement behaviors balance.

Methods A total of 463 university students aged 15–24 years from Jinhua City wore accelerometers to measure moderate-to-vigorous physical activity (MVPA), light-intensity physical activity (LPA), and sedentary behavior (SB). Sleep (SLP) was self-reported. The body mass index (BMI), forced vital capacity (FVC), 50-meter dash, standing long jump, sit-and-reach, sit-ups (female), pull-ups (male), 800-meter run (female), and 1000-meter run (male) were used as indicators to assess the physical fitness of university students. Regression analysis was used to examine the relationship between movement behaviors and PF. All possible movement component combinations were investigated to determine the best correlation (top 5%) with each outcome.

Results For males, SB ($\beta = 5.05$, $p < 0.05$) was significantly correlated with an increase in BMI. MVPA was significantly correlated with improvements in BMI (β = -1.75, $p < 0.05$), FVC ($\beta = 494.21$, $p < 0.05$), and endurance qualities (β = -25.77, $p < 0.05$). For females, MVPA was significantly correlated with improvements in BMI (β = -1.03, $p < 0.05$), FVC ($\beta = 176.05$, $p < 0.05$), speed capability (β = -0.26, $p < 0.05$), and endurance qualities (β = -16.38, $p < 0.05$). LPA was associated with improvements in endurance qualities (β = -24.10, $p < 0.05$). SB was significantly correlated with a decline in endurance qualities ($\beta = 24.25$, $p < 0.05$). The average (range) optimal combination of time use was as follows: For males, MVPA = 142 min/day, SB = 534 min/day, LPA = 295 min/day, and SLP = 469 min/day. For females, MVPA = 115 min/day, SB = 536 min/day, LPA = 306 min/day, and SLP = 482 min/day.

Conclusion For both males and females, increased MVPA and reduced sedentary time were associated with improved endurance and strength, while optimal sleep duration contributed to overall fitness. These findings highlight the importance of a balanced daily movement schedule for university students.

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Keywords Movement behaviors, Physical fitness, Isotemporal substitution, Compositional data analysis, Students

Introduction

Physical fitness (PF) consists of five main components: body composition, aerobic capacity, muscular strength, flexibility, and speed. It serves as a key indicator of an individual's physical health level. High physical fitness not only enhances bodily functions but also improves mental health, fosters social interactions, and boosts work performance [1]. Despite its importance, physical fitness of college students has been steadily declining worldwide [2]. Longitudinal studies have also reported consistent declines in physical fitness indicators among university students [3, 4]. A systematic review highlighted a significant reduction in standing long jump performance in high- and upper-middle-income countries, while performance in sit-ups and cardiorespiratory fitness either stabilized or showed minor declines [5, 6]. Another study spanning 16 low- and high-income countries found that endurance, strength, and flexibility in youth also declined with age [7].

Physical activity (PA) is strongly linked to physical fitness. Moderate to vigorous physical activity (MVPA) has been shown to prevent obesity, increase strength, and enhance aerobic capacity [8]. Meanwhile, excessive sedentary behavior (SB) resulting from insufficient PA has been found to negatively affect health-related fitness. Research also indicates that university students with poor sleep quality or shorter sleep durations are more likely to have lower levels of muscular endurance, flexibility, and cardiorespiratory fitness (CRF) [9, 10]. Recent meta-analyses further demonstrate that meeting WHO-recommended MVPA levels (≥150 min/week) alone explains only 12–18% of variance in PF outcomes among adolescents, underscoring the need to examine synergistic effects of 24-hour behaviors [11]. Behaviorally, movement behaviors can be grouped into sleep (SLP), SB, and PA, all of which are interrelated and mutually influencing. A change in one inevitably affects the others [12]. While cross-sectional studies have established independent associations between MVPA and CRF or SB with obesity, these approaches fail to account for the compositional nature of daily time allocation [13, 14].

Given the interdependent nature of movement behaviors, it is essential to adopt a theoretical framework that accounts for their combined effects on physical fitness. The 24-hour Movement Framework posits that physical activity, sedentary behavior, and sleep function as an integrated system, jointly influencing health outcomes [15]. This approach highlights the need to analyze daily time-use patterns holistically rather than in isolation. Additionally, the Behavioral Epidemiology Model underscores the importance of understanding how modifiable lifestyle behaviors—such as physical activity and sedentary time—contribute to long-term health benefits [16]. Compositional data analysis (CoDA) provides a comprehensive view by examining the combined effects of PA, SB, and SLP on PF, rather than isolating each behavior [11]. Previous research has mostly focused on whether individuals meet the recommended levels of MVPA, offering limited and incomplete insights into other 24-hour behaviors [17]. A study in Japan assessed the relationship between 24-hour movement behaviors and PF (handgrip strength, sit-ups, trunk flexion, and the 20-meter shuttle run) in elementary school students [13]. The findings indicated that meeting MVPA recommendations correlated with better aerobic fitness and muscular endurance. However, previous studies have focused on children and adolescents, leaving a research gap when it comes to university students. Additionally, the relationship between different types and amounts of activity remains unclear in this population.

To address these gaps, we apply CoDA to university students—a cohort at high risk of declining PA during the transition to adulthood [18]. Our study uniquely quantifies how time reallocations between behaviors (e.g., replacing SB with MVPA) synergistically optimize PF, rather than isolating individual behaviors. Furthermore, we explored the optimal combination of movement behaviors, time reallocation, and PA indicators to achieve maximum benefits, aiming to provide recommendations for tailored interventions that can accelerate improvements in the PA of university students. Based on this rationale, we propose the following hypotheses (i) Time reallocations from SB to MVPA will show the strongest association with improved physical fitness in university students; (ii) The top 5% of model-based predictions of optimal physical fitness are characterized by more MVPA, less SB, and appropriate sleep and (iii) Sex-specific movement behavior compositions will differentially predict physical fitness outcomes.

Methods

Participants

This study is a cross-sectional research design. Participants were recruited from a university in Jinhua, Zhejiang Province. Stratified sampling was conducted by selecting two random classes from each faculty. Eligible participants had to meet the following inclusion criteria: (1) aged between 17 and 24 years, (2) free of any serious chronic or acute illnesses, and (3) without restrictions on physical activity. A total of 500 full-time students were initially selected, of which 463 agreed to participate (response rate 92.6%). After screening for eligibility, 342 qualified university students were invited to complete the data collection process.

This study adhered to the Declaration of Helsinki. Ethical approval for this study was obtained from the Ethics Committee of Zhejiang Normal University. All participants were required to sign a written informed consent form before undergoing the tests (Fig. 1).

Measurement of movement behaviors

MVPA, LPA, and SB were measured using the ActiGraph wGT3X-BT accelerometer. Participants were instructed to wear the accelerometer on their right hip for seven consecutive days, except during activities such as bathing or swimming. The device was set to record data in 60-second intervals. After the monitoring period, the collected data were processed and analyzed using the ActiLife 6.0 software for validity. Activity intensity was categorized as follows: SB (0–99 counts per minute), LPA (100–1951 counts per minute), MVPA (1952 or higher) [19]. Non-wear time was defined as 60 or more consecutive minutes of zero counts per minute. A valid day was considered as one where participants wore the accelerometer for at least 10 waking hours. Data from participants with at least three valid days (including two weekdays and one weekend day) were considered valid for analysis. Additionally, sleep duration was estimated using a combination of accelerometer data and self-reported sleep logs. The daily duration of MVPA, LPA, SB, and SLP time were used as the movement behaviors data for analysis.

Measurement of physical fitness

The PF of participants was assessed and evaluated according to the *National Student Physical Fitness Standards* (CNSPFT) issued by the Ministry of Education of China (Supplement file 1). Based on the CNSPFT, the following indicators were used to assess speed, muscular strength, flexibility, endurance, and other physical attributes in university students: body mass index (BMI), forced vital capacity (FVC), 50-meter dash, standing long jump, sit-and-reach, sit-ups (for females), pull-ups (for males), 800-meter run (for females), and 1000-meter run (for males). Among these, BMI was used as an indicator of body composition. BMI was calculated using the formula: BMI = weight (kg) / height^2 (m). Participants' weight (measured to the nearest 0.1 kg) and height (measured to the nearest 0.1 cm) were recorded. FVC was used as a measure of physical function. For the FVC test, participants held the spirometer and inhaled as deeply as possible. Endurance was assessed through the 800-meter run (for females) and the 1000-meter run (for males) [20]. Participants started in a standing position and completed the test in pairs. Scores were recorded in minutes and seconds, and verified by two research assistants. Speed capability was tested through the 50-meter dash [21]. Explosive leg power (muscular power) was assessed using the standing long jump [22] (Qaili & Iseni, 2020). Participants started behind a marked line on the ground, taking off with both feet and landing stably. Flexibility of the lower back and hamstrings was evaluated using the sit-and-reach test [23] (Mier & Sport, 2011). Participants

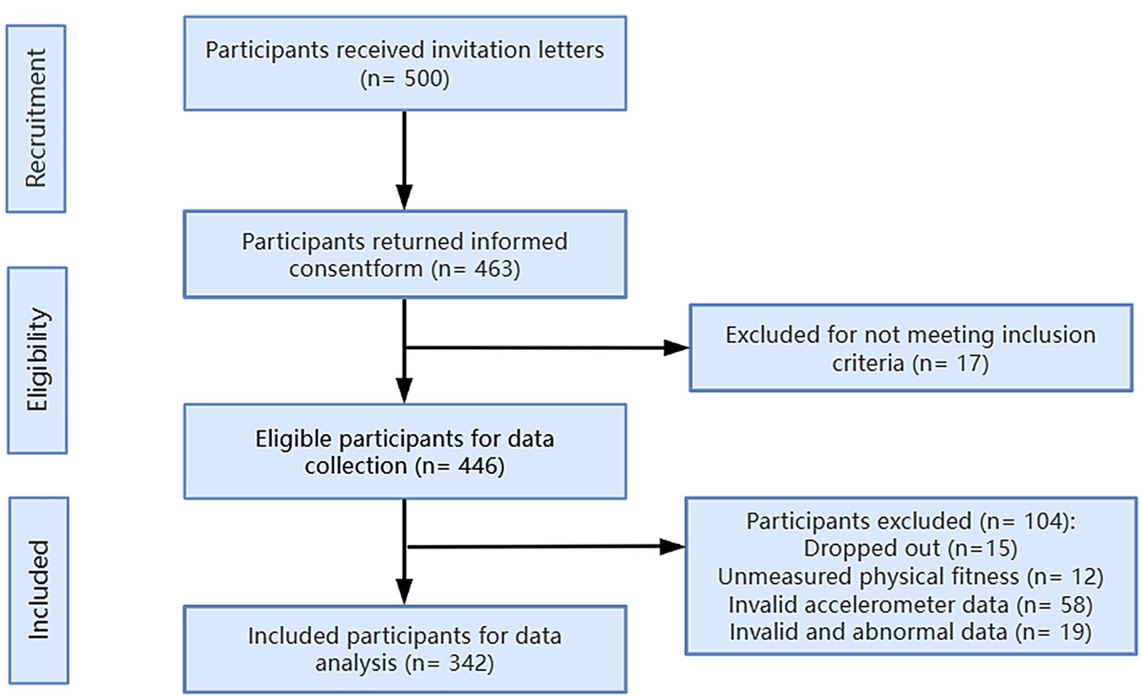

Fig. 1 Flowchart of participants selection

were barefoot and required to sit on the testing apparatus with their legs fully extended and reach forward as far as possible while maintaining straight legs. Pull-ups and sit-ups were used to assess localized muscular strength in males and females, respectively [24]. For the pull-ups, participants used an underhand grip (palms facing toward the body) or overhand grip (palms facing away from the body) to grasp the bar overhead with arms fully extended. The participant then pulled their body up until their chin passed the top of the bar before lowering themselves back down to a fully extended position. The total number of pull-ups was recorded. For the sit-ups, participants lay on their backs with knees bent at a 90-degree angle, arms crossed over the chest with hands on opposite shoulders. When instructed to begin, a timer was started, and participants performed as many repetitions as possible in one minute. Each test was performed twice, with the best result used for analysis.

Covariates

Researchers selected several variables based on previous studies [9, 25], including age, socioeconomic status, current smoking habits, and alcohol consumption. Future studies should incorporate additional covariates, such as dietary intake and stress levels, to provide a more comprehensive understanding of factors influencing physical fitness.

Data analysis

Following the CoDA methods proposed by Dumuid [18], statistical analyses were conducted using R Studio with the "Compositions" and "Robcompositions" packages. CoDA was chosen as the primary analytical approach because movement behaviors are compositional in nature, meaning they exist as interdependent parts of a fixed 24-hour period. By using CoDA, we ensure that changes in one behavior (e.g., increasing MVPA) are interpreted relative to compensatory changes in others (e.g., decreasing SB or sleep), reducing confounding and enhancing the interpretability of results.

First, the geometric mean, which contains relative information among components, was used to describe the central tendency of the data. The variation matrix was employed to represent the dispersion of compositional data, with elements of the variation matrix closer to 0 indicating a smaller log-ratio variance between the corresponding two components, signifying a stronger interdependence between the proportions of those components. Next, compositional data were transformed using isometric log-ratio (*ilr*) coordinates, constructed through Sequential Binary Partition (SBP). In this method, the data composition is divided into two parts, with one part forming the numerator of the respective *ilr* coordinate and the remaining part serving as the denominator. The subsequent set is then further divided into two parts, and this process continues for *D-1* steps. The transformation formula is as follows:

$$ilr_1 = \sqrt{\frac{3}{4}}\ln\frac{sleep}{\sqrt[3]{SED\times\ LPA\times\ MVPA}}$$

$$ilr_2 = \sqrt{\frac{2}{3}}\ln\frac{SED}{\sqrt[3]{LPA\times\ MVPA}}$$

$$ilr_3 = \sqrt{\frac{1}{2}}\ln\frac{LPA}{\sqrt[3]{MVPA}}$$

After the ilr transformation, the *D*-dimensional data is represented by *D-1 ilr* coordinates. By rearranging the position of each component such that every behavior appears in the first position once, the corresponding ilr_1 coordinate is obtained. Under the control of covariates, a compositional multivariate linear regression model is then constructed, with all ilr coordinates for each behavior serving as independent variables:

$$\widehat{y} = \beta_0 + \widehat{\boldsymbol{\beta}}^T ilr\left(\overline{Sleep}, \overline{ST}, \overline{LPA}, \overline{MVPA}\right) + Covariates$$

Subsequently, based on the fitted compositional multivariate linear regression model, compositional isotemporal substitution analysis was applied to predict the average change in physical fitness outcomes following a 30-minute reallocation of time. The model is expressed as:

$$\widehat{y}_{(+30,-30,0,0)} = \beta_0 + \widehat{\beta}^T ilr\left(\overline{Sleep_{+30}}, \overline{ST_{-30}}, \overline{LPA}, \overline{MVPA}\right) + Covariates$$

This analysis was repeated by incrementally increasing the reallocation by 5-minute intervals, up to 60 min, to explore the "dose-response" relationship between movement behaviors and PF. Following standard practices in compositional data analysis, β coefficients and p-values were reported to illustrate the relative impact of time reallocations on physical fitness outcomes.

To predict the optimal time balance of MVPA, LPA, SB, and SLP for improving PF indicators, we developed incremental models with 5-minute adjustments. The optimal movement behavior compositions were identified based on the top 5% of model-predicted outcomes for physical fitness. This approach ranks all possible time-use combinations and selects those yielding the highest predicted fitness improvements [26]. To ensure the feasibility of these time reallocations within the realistic range of participants' behaviors, each time component was

Table 1 Characteristics of participants

Variables	Overall	Boys	Girls	*p*-value
	Mean (SD)/*N* (%)	Mean (SD)/*N* (%)	Mean (SD)/*N* (%)	
Age (yr.)	19.28 (1.05)	19.03 (1.40)	19.31 (1.06)	0.442
Drinking alcohol status, n, %				0.010
Never	142 (43.4)	41 (33.1)	101 (49.8)	
Sometimes (≤ 2 times/month)	180 (55.1)	80 (64.5)	100 (49.3)	
Often (1 ≥ times/week)	5 (1.5)	3 (2.4)	2 (1.0)	
Smoking status, n (%)				0.005
Yes	25 (7.6)	16 (12.9)	9 (4.4)	
No	302 (92.4)	108 (87.1)	194 (95.6)	
Fitness				
BMI	20.98 (3.32)	21.20 (4.05)	20.90 (2.87)	0.044
FVC	2948 (1133)	4303 (1063.00)	2739 (706.50)	< 0.001
50 m dash	8.70 (1.80)	7.30 (0.70)	9.3 (1.00)	0.007
Sit-and-reach	18.25 (11.55)	16.7 (10.70)	20.10 (11.10)	< 0.001
Standing long jump	180.00 (43.00)	226.00 (32.00)	171.00 (22.50)	< 0.001
Body muscle strength	29 (27.75)	2.00 (3.00)	33.00 (10.50)	/
Endurance running	242.00 (35.75)	247.00 (39.00)	240 (31.00)	/
Movement behavior				
SLP min (%) [a]	515.25 (35.8)	505.97 (35.1)	520.93 (36.2)	/
SBr min (%) [a]	678.29 (47.1)	677.98 (47.1)	675.50 (46.9)	/
LPA min (%) [a]	196.16 (13.6)	194.41 (13.5)	198.15 (13.8)	/
MVPA min (%) [a]	50.29 (3.5)	61.63 (4,3)	45.42 (3.1)	/

Note Values are arithmetic mean (SD) unless stated otherwise. a, Geometric mean normalized to 100% of time

Table 2 Compositional variation matrix of proportions of time spent in sleep, sedentary behavior, and physical activity

	SLP	SB	LPA	MVPA
SLP	0	0.050	0.106	0.414
SB	0.050	0	0.097	0.412
LPA	0.106	0.097	0	0.461
MVPA	0.414	0.412	0.461	0

Note SLP, sleep; SB, sedentary behavior; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity

constrained within three standard deviations (SD) of its mean. This approach prevents the inclusion of unrealistic values that could bias the predictions. We then ranked all possible time use combinations from best to worst based on the predicted outcomes.

Results

Descriptive statistics

A total of 342 participants were included in the analysis. The participants' ages ranged from 17 to 23 years, with a mean age of 19.28 years. Females comprised 62.1% of the sample. The study revealed (Table 1) that participants spent most of their time in SB, averaging 678.29 min per day (47.1%), followed by SLP, which accounted for 515.25 min per day (35.8%), and LPA, which averaged 196.16 min per day (13.6%). The least amount of time was allocated to moderate to MVPA, with an average of 50.29 min per day (3.5%). Significant statistical differences were observed among participants in terms of smoking, alcohol consumption, and PF ($P < 0.05$). The variation matrix (Table 2) indicated that the log-ratio variances between the components of the compositional data were all greater than zero, suggesting varying degrees of dependency between the components. The log-ratio variance between SB and sleep was the smallest (ln(sleep/SB) = 0.050), indicating a high level of interdependence between these two behaviors, making them the most likely to be substituted for one another. In contrast, MVPA had a relatively higher log-ratio variance with the other three components (>0.400), suggesting that MVPA time was more stable and less likely to be reallocated compared to other behaviors.

Relationship between movement behaviors and physical fitness

Table 3 presents the results of the compositional regression analysis, which examined the relationship between all movement behaviors and PF indicators. For males, the analysis indicated that SB ($\beta = 5.05$, $p < 0.05$) was significantly associated with an increase in BMI compared to other behaviors. MVPA was significantly associated with improvements in BMI (β = -1.75, $p < 0.05$), FVC ($\beta = 494.21$, $p < 0.05$), and endurance qualities (β = -25.77, $p < 0.05$). For females, the results showed that MVPA was significantly associated with improvements in BMI (β = -1.03, $p < 0.05$), increases in FVC ($\beta = 176.05$, $p < 0.05$), enhancements in speed (β = -0.26, $p < 0.05$), and improvements in endurance qualities (β = -16.38, $p < 0.05$). LPA

Table 3 Compositional regression analysis of associations between movement behaviors and fitness

Regression models	Boy					Girl				
	β	SE	*p*-value	Model fit		*β*	SE	*p*-value	Model fit	
				R^2	*p*-value				R^2	*p*-value
BMI										
ilr1-SLP/(SB*LPA*MVPA)	-3.62	2.69	0.183	**0.15**	0.031	-0.72	1.14	0.526	**0.23**	0.021
ilr1-SB/(SLP*LPA*MVPA)	**5.05**	**2.56**	**0.054**			2.17	1.34	0.108		
ilr1-LPA/(SLP*SB*MVPA)	0.67	1.48	0.658			-0.54	0.90	0.550		
ilr1-MVPA/(SLP*SB*LPA)	**-1.75**	**0.82**	**0.039**			**-1.03**	**0.41**	**0.012**		
FVC										
ilr1-SLP/(SB*LPA*MVPA)	-1225.32	686.74	0.080	**0.21**	0.039	-345.22	234.02	0.142	**0.21**	0.039
ilr1-SB/(SLP*LPA*MVPA)	458.45	661.87	0.491			179.28	271.47	0.510		
ilr1-LPA/(SLP*SB*MVPA)	272.64	380.24	0.476			-10.12	201.24	0.959		
ilr1-MVPA/(SLP*SB*LPA)	**494.21**	**213.50**	**0.024**			**176.05**	**87.46**	**0.046**		
50 m dash										
ilr1-SLP/(SB*LPA*MVPA)	-0.27	0.39	0.492	0.18	0.372	0.46	0.30	0.121	**0.14**	0.025
ilr1-SB/(SLP*LPA*MVPA)	0.58	0.38	0.131			0.10	0.34	0.774		
ilr1-LPA/(SLP*SB*MVPA)	-0.13	0.21	0.547			-0.30	0.25	0.241		
ilr1-MVPA/(SLP*SB*LPA)	-0.17	0.12	0.154			**-0.26**	**0.11**	**0.019**		
Sit-and-reach										
ilr1-SLP/(SB*LPA*MVPA)	-14.19	8.60	0.105	0.26	0.266	-2.96	3.22	0.359	0.19	0.312
ilr1-SB/(SLP*LPA*MVPA)	6.93	8.29	0.406			-0.60	3.74	0.871		
ilr1-LPA/(SLP*SB*MVPA)	-8.16	4.76	0.092			2.39	2.77	0.390		
ilr1-MVPA/(SLP*SB*LPA)	-0.90	2.67	0.737			1.17	1.20	0.330		
Standing long jump										
ilr1-SLP/(SB*LPA*MVPA)	-38.23	21.01	0.074	0.09	0.305	-6.19	8.44	0.464	0.27	0.216
ilr1-SB/(SLP*LPA*MVPA)	23.77	20.29	0.246			-9.82	9.80	0.318		
ilr1-LPA/(SLP*SB*MVPA)	23.86	20.25	0.244			11.93	7.26	0.102		
ilr1-MVPA/(SLP*SB*LPA)	4.05	6.53	0.537			4.08	3.15	0.198		
Body muscle strength										
ilr1-SLP/(SB*LPA*MVPA)	5.40	4.03	0.186	0.19	0.412	-2.53	3.81	0.507	0.22	0.322
ilr1-SB/(SLP*LPA*MVPA)	-3.93	3.88	0.316			-3.05	4.42	0.491		
ilr1-LPA/(SLP*SB*MVPA)	-1.66	2.23	0.489			3.23	3.27	0.325		
ilr1-MVPA/(SLP*SB*LPA)	0.19	1.25	0.875			2.35	1.42	0.101		
Endurance running										
ilr1-SLP/(SB*LPA*MVPA)	25.70	32.26	0.429	0.15	0.031	**24.25**	**11.61**	**0.036**	**0.25**	**0.018**
ilr1-SB/(SLP*LPA*MVPA)	1.57	31.09	0.959			10.94	13.47	0.418		
ilr1-LPA/(SLP*SB*MVPA)	-1.49	17.82	0.933			**-24.10**	**9.98**	**0.017**		
ilr1-MVPA/(SLP*SB*LPA)	**-25.77**	**10.03**	**0.013**			**-16.38**	**4.34**	**0.009**		

Note The *β* value refers to the strength of the association between the change in a given behavior relative to other behaviors and PF. For example, ilr1-MVPA/(SLP*SB*LPA) refers to the strength of the association between PF and the time spent in MVPA as the first coordinate, relative to the time spent in SLP, SB, and LPA. SE refers to the standard error. All models have been adjusted for factors such as age, sex, BMI, smoking and alcohol status

was significantly associated with improvements in endurance (β = -24.10, $p < 0.05$). However, SLP was significantly associated with a decline in endurance qualities (β = 24.25, $p < 0.05$). These findings highlight the significant role of MVPA in improving various PF components, while prolonged SB and insufficient LPA and SLP may have adverse effects on fitness outcomes.

Predicted changes in PF due to substitution of one behavior for another

Table 4 lists the estimated differences in PF outcomes resulting from reallocating 30 min between various movement behaviors. For males, the analysis showed that substituting time from MVPA to SB was significantly associated with improvements in BMI (β = -0.78, $p < 0.05$), FVC (β = 151.76, $p < 0.05$), and endurance (β = -8.63, $p < 0.05$). Conversely, increasing SB at the expense of MVPA was significantly associated with an increase in BMI (β = 1.19, $p < 0.05$), a decrease in FVC (β = -268.25, $p < 0.05$), and a decline in endurance qualities (β = 14.74, $p < 0.05$). Increasing MVPA at the expense of SLP was associated with increases in FVC (β = 234.59, $p < 0.05$) and improvements in endurance (β = -10.93, $p < 0.05$). Conversely, increasing SLP at the expense of MVPA

Table 4 Reallocations of 30 min from one movement behavior to another

	Reallocation		BMI	FVC	50 m dash	Sit-and-reach	Standing long jump	Body muscle strength	Endurance running
	Add	Remove							
Boy	SLP	SB	-0.36 (-0.82,0.09)	-79.09 (-195.57, 37.39)	-0.03 (-0.10, 0.03)	-0.97 (-2.43, 0.47)	-2.86 (-6.44, 0.71)	0.31 (-0.37, 1.00)	2.17 (-3.29, 7.65)
	SLP	LPA	-0.27 (-0.83, 0.27)	-100.69 (-241.37, 39.97)	0.01 (-0.07, 0.18)	**-1.89 (-3.65, -0.12)**	-3.51 (-7.86, 0.82)	0.43 (-0.40, 1.27)	2.33 (-4.30, 8.97)
	SLP	MVPA	0.83 (-0.22, 1.88)	**-346.57 (-618.98, -74.16)**	0.08 (-0.06, 0.24)	-0.18 (-3.60, 3.22)	-4.19 (-12.47, 4.08)	0.02 (-1.57, 1.62)	**16.90 (4.25, 29.55)**
	SB	SLP	0.36 (-0.09, 0.83)	82.05 (-36.38, 200.49)	0.03 (-0.03, 0.01)	1.01 (-0.47, 2.49)	2.94 (-0.70, 6.58)	-0.32 (-1.02, 0.38)	-2.28 (-7.85, 3.29)
	SB	LPA	0.08 (-0.43, 0.59)	-22.38 (-155.58, 110.81)	0.04 (-0.03, 0.01)	-0.92 (-2.59, 0.74)	-0.69 (-4.75, 3.36)	0.12 (-0.66, 0.90)	0.17 (-6.03, 6.37)
	SB	MVPA	**1.19 (0.23, 2.14)**	**-268.25 (-514.27, -22.24)**	0.12 (-0.01, 0.26)	0.78 (-2.30, 3.86)	-1.36 (-8.87, 6.13)	-0.28 (-1.73, 1.16)	**14.74 (3.27, 26.20)**
	LPA	SB	-0.10 (-0.56, 0.36)	15.91 (-104.01, 135.84)	-0.03 (-0.10, 0.02)	0.74 (-0.76, 2.24)	0.42 (-3.22, 4.08)	-0.08 (-0.79, 0.62)	-0.08 (-5.67, 5.49)
	LPA	SLP	0.27 (-0.23, 0.78)	98.74 (-31.07, 228.56)	-0.01 (-0.07, 0.07)	**1.76 (0.13, 3.39)**	3.41 (-0.60, 7.42)	-0.41 (-1.18, 0.36)	-2.38 (-8.51, 3.75)
	LPA	MVPA	1.09 (-0.05, 2.24)	-251.56 (-546.59, 43.46)	0.08 (-0.08, 0.25)	1.53(-2.16, 5.23)	-0.90 (-9.89, 8.08)	-0.37 (-2.11, 1.36)	14.63 (0.90, 28.37)
	MVPA	SLP	-0.41 (-1.10, 0.28)	**234.59 (55.25, 413.93)**	-0.04 (-0.14, 0.05)	0.44 (-1.80, 2.68)	3.39 (-2.05, 8.85)	-0.10 (-1.16, 0.94)	**-10.93 (-19.26, -2.59)**
	MVPA	LPA	-0.69 (-1.52, 0.13)	130.15 (-83.34, 343.66)	-0.04 (-0.14, 0.08)	-1.49 (-4.16, 1.18)	-0.24 (-6.75, 6.27)	0.33 (-0.92, 1.59)	-8.48 9-18.43, 1.47)
	MVPA	SB	**-0.78 (-1.37, -0.20)**	**151.76 (2.22, 301.30)**	-0.08 (-0.16, 0.01)	-0.58 (-2.45, 1.29)	0.41 (-4.15, 4.98)	0.21 (-0.66, 1.10)	**-8.63 (-15.62, -1.64)**
Girl	SLP	SB	-0.12 (-0.31, 0.06)	-23.79 (-63.41, 15.82)	0.01 (-0.03, 0.06)	-0.11 (-0.66, 0.42)	0.08 (-1.34, 1.51)	-0.01 (-0.64, 0.64)	0.76 (-1.20, 2.72)
	SLP	LPA	0.0 (-0.26, 0.35)	-15.30 (-80.38, 49.78)	0.06 (-0.01, 0.14)	-0.48 (-1.38, 0.41)	-1.99 (-4.34, 0.35)	-0.58 (-1.64, 0.47)	**4.61 (1.38, 7.84)**
	SLP	MVPA	**0.90 (0.14, 1.66)**	**-181.45 (-348.89, -14.01)**	**0.27 (0.05, 0.48)**	-1.24 (-3.55, 1.06)	-4.12 (-10.16, 1.92)	-2.32 (-5.04, 0.40)	**11.84 (3.53, 20.15)**
	SB	SLP	0.12 (-0.06, 0.31)	24.48 (-15.53, 64.49)	0.02 (-0.07, 0.03)	0.12 (-0.42, 0.68)	-0.05 (-1.49, 1.39)	0.01 (-0.63, 0.66)	-0.84 (-2.83, 1.13)
	SB	LPA	0.16 (-0.14, 0.47)	8.18 (-61.48, 77.85)	0.04 (-0.04, 0.13)	-0.36 (-1.32, 0.59)	-2.06 (-4.58, 0.44)	-0.57 (-1.70, 0.55)	**3.83 (0.38, 7.29)**
	SB	MVPA	**1.02 (0.26, 1.79)**	-157.96 (-323.49, 7.56)	**0.25 (0.03, 0.46)**	-1.12 (-3.40, 1.15)	-4.18 (-10.16, 1.78)	-2.31 (-5.01, 0.38)	**11.06 (2.84, 19.28)**
	LPA	SB	-0.15 (-0.43, 0.12)	-8.28 (-70.92, 54.34)	-0.04 (-0.12, 0.03)	0.31 (-0.54, 1.17)	1.84 (-0.41, 4.10)	0.51 (-0.50, 1.53)	**-3.37 (-6.48, -0.26)**
	LPA	SLP	-0.02 (-0.30, 0.24)	16.49 (-41.88, 74.87)	-0.06 (-0.13, 0.01)	0.44 (-0.36, 1.24)	1.77 (-0.33, 3.88)	0.52 (-0.42, 1.47)	**-4.20 (-7.10, -1.30)**
	LPA	MVPA	0.87 (-0.01, 1.63)	-165.95(-338.23, 6.33)	0.21(-0.01, 0.43)	-0.80 (-3.18, 1.56)	-2.36 (-8.58, 3.85)	-1.80 (-4.61, 0.99)	7.71 (-0.84, 16.26)
	MVPA	SLP	**-0.41 (-0.79, -0.02)**	**95.05 (11.42, 178.68)**	**-0.14 (-0.24, -0.03)**	0.66 (-0.48, 1.82)	2.11 (-0.90, 5.13)	1.16 (-0.19, 2.52)	**-6.26 (-10.41, -2.11)**
	MVPA	LPA	-0.37 (-0.79, 0.05)	78.75 (-19.12, 176.63)	-0.07 (-0.19, 0.05)	0.17 (-1.17, 1.52)	0.09 (-3.43, 3.62)	0.57 (-1.02, 2.16)	-1.57 (-6.43, 3.28)
	MVPA	SB	**-0.53 (-0.92, -0.15)**	70.26(-10.97, 151.51)	**-0.12 (-0.22, -0.01)**	0.54 (-0.57,1.66)	2.17 (-0.75, 5.11)	1.15 (-0.16, 2.47)	**-5.43 (-9.46, -1.39)**

Note *, $p < 0.05$; β: standardized regression coefficient estimate; SLP: sleep; SB: sedentary behavior; LPA: light physical activity; MVPA: moderate-to-vigorous physical activity

All models have been adjusted for factors such as age, sex, BMI, smoking and alcohol status was significantly associated with a decrease in FVC (β = -346.57, $p < 0.05$) and a decline in endurance (β = 16.90, $p < 0.05$). The study also found significant changes in flexibility due to the substitution between SLP and LPA. Figure 2 illustrates the dose-response relationships for PF indicators with incremental 5-minute increases up to 60 min of time reallocation. This visualization highlights how varying time allocations across movement activities affect PF outcomes.

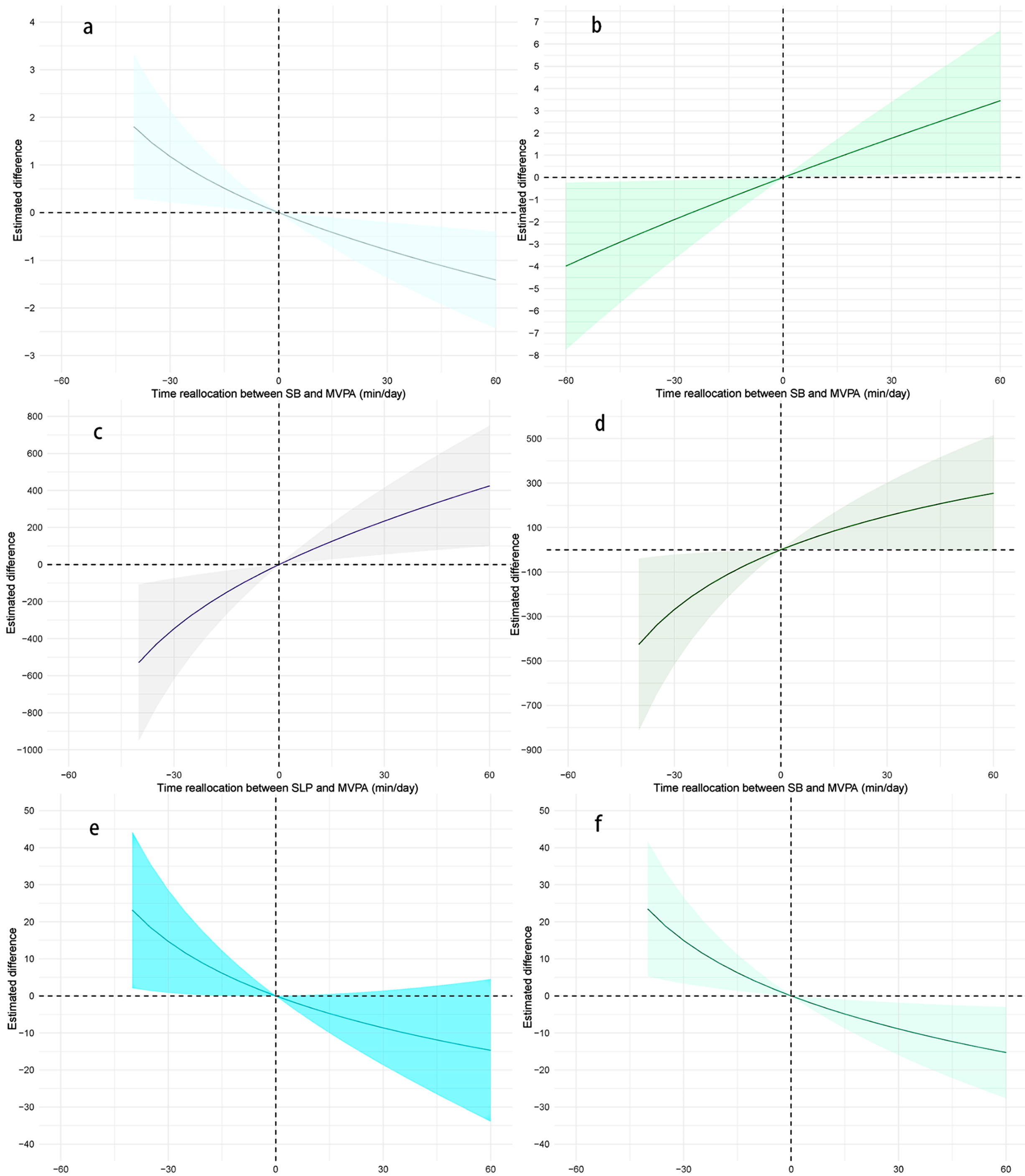

Fig. 2 The dose-response relationship between substitution of movement behaviors on PF in boy. **a** Effect of time reallocation between SB and MVPA on BMI; **b** Effect of time reallocation between SB and MVPA on Sit-and-reach; **c** Effect of time reallocation between SLP and MVPA on FVC; **d** Effect of time reallocation between SB and MVPA on FVC; **e** Effect of time reallocation between SB and MVPA on Endurance running; **f** Effect of time reallocation between SB and LPA on Endurance running

Table 4 for females shows that substituting time from MVPA to SB was significantly associated with improvements in BMI (β = -0.53, $p<0.05$), 50-meter sprint speed (β = -0.12, $p<0.05$), and endurance (β = -5.43, $p<0.05$). Conversely, increasing SB at the expense of MVPA was significantly associated with an increase in BMI (β = 1.02, $p<0.05$), a decrease in 50-meter sprint speed (β = 0.25, $p<0.05$), and a decline in endurance (β = 11.06, $p<0.05$). Increasing MVPA at the expense of SLP was associated with improvements in BMI (β = -0.41, $p<0.05$), FVC (β = 95.05, $p<0.05$), 50-meter sprint speed (β = -0.14, $p<0.05$), and endurance qualities (β = -6.26, $p<0.05$). In contrast, increasing SLP at the expense of MVPA was significantly associated with an increase in BMI (β = 0.90, $p<0.05$), a decrease in FVC (β = -181.45, $p<0.05$), a reduction in 50-meter sprint speed (β = 0.27, $p<0.05$), and a decline in endurance (β = 11.84, $p<0.05$). The study also found significant changes in endurance due to substitutions between SLP, SB, and LPA. Figure 3 illustrates the dose-response relationships for PF indicators with incremental 5-minute increases up to 60 min of time reallocation. This figure demonstrates how varying time allocations among movement activities affect PF outcomes.

Optimal time use for PF

Table 5 identify the ideal daily time allocations for PF. For males, the best combination is 142 min of MVPA (range: 90–150 min), 534 min of SB (range: 450–670 min), 295 min of LPA (range: 110–330 min), and 469 min of SLP (range: 350–510 min). For females, the optimal amounts are 115 min of MVPA (range: 60–140 min), 536 min of SB (range: 450–680 min), 306 min of LPA (range: 220–320 min), and 482 min of SLP (range:

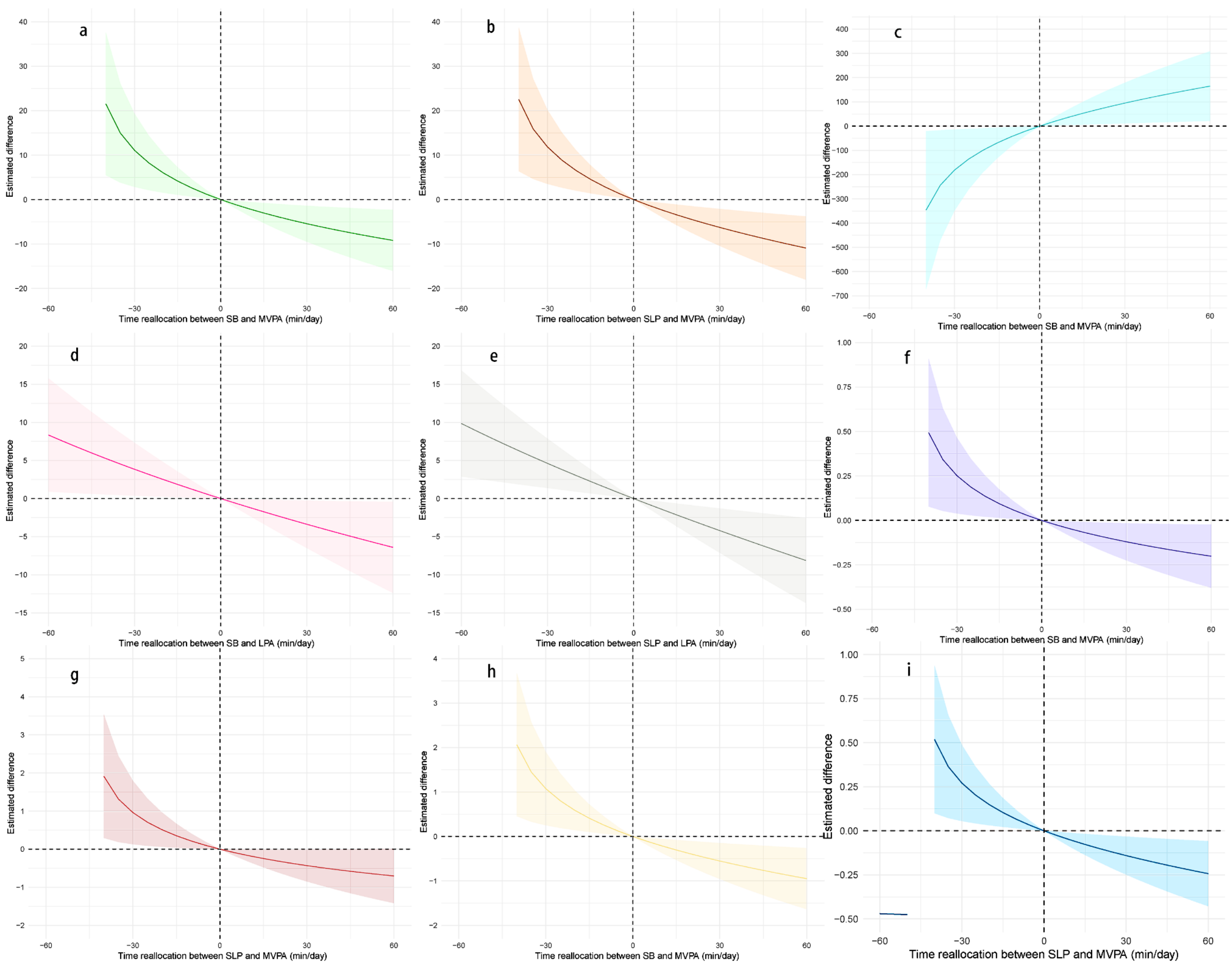

Fig. 3 The dose-response relationship between substitution of movement behaviors on PF in girl. **a** Effect of time reallocation between SB and MVPA on Endurance running; **b** Effect of time reallocation between SLP and MVPA on Endurance running; **c** Effect of time reallocation between SB and MVPA on FVC; **d** Effect of time reallocation between SB and LPA on Endurance running; **e** Effect of time reallocation between SLP and LPA on Endurance running; **f** Effect of time reallocation between SB and MVPA on 50 m dash; **g** Effect of time reallocation between SLP and MVPA on BMI; **h** Effect of time reallocation between SB and MVPA on BMI; i: Effect of time reallocation between SLP and MVPA on 50 m dash

Table 5 Movement behavior time use associated with the most-optimum levels of fitness(boy)

	Outcomes	Movement behavior			
		SLP	**SB**	**LPA**	**MVPA**
Boy	BMI	497 (400, 510)	531 (450, 670)	273 (110, 330)	139 (100,150)
	FVC	438 (350, 510)	546 (450, 650)	311 (270, 330)	145 (130, 150)
	50 m dash	486 (420 510)	516 (450, 550)	303 (230, 330)	135 (90, 150)
	Sit-and-reach	485 (380, 510)	598 (450, 710)	319 (260, 330)	109 (20, 150)
	Standing long jump	356 (350, 360)	694 (600, 750)	284 (190, 330)	104 (40, 150)
	Body muscle strength	510 (460, 510)	649 (450, 750)	148 (90,330)	132 (70,150)
	Endurance running	445 (350, 510)	548 (450, 660)	299 (230, 330)	148 (130, 150)
	Overlap optimal zone	469 (350,510)	534 (450, 670)	295 (110, 330)	142 (90, 150)
Girl	BMI	509 (430, 540)	520 (450, 570)	290 (210, 320)	120 (90,130)
	FVC	523 (470, 540)	515 (450, 550)	293 (230, 320)	109 (60, 130)
	50 m dash	442 (340, 540)	565 (450, 680)	314 (290, 320)	120 (100, 130)
	Sit-and-reach	506 (410, 540)	518 (440, 580)	307 (260, 320)	109 (60, 130)
	Standing long jump	520 (450, 540)	536 (450, 640)	317 (290, 320)	67 (40, 130)
	Body muscle strength	464 (340, 540)	546 (450, 670)	309 (270,320)	122 (90,130)
	Endurance running	384 (340, 520)	634 (470, 720)	305 (260, 320)	117 (80, 130)
	Overlap optimal zone	482 (340,540)	536 (450, 680)	306 (220, 320)	115 (60, 140)

Note Data are presented as min (range); SLP: sleep; SB: sedentary behavior; LPA: light physical activity; MVPA: moderate-to-vigorous physical activity. All models have been adjusted for factors such as age, sex, BMI, smoking, and alcohol status

340–540 min). The top 5% of model-based predictions were characterized by higher MVPA, lower sedentary time, and adequate sleep duration, reinforcing established recommendations for balanced movement behavior distributions.

Discussion

This study investigated the relationship between movement activity behaviors and PF among Chinese university students, with a particular focus on the effects of substituting various behaviors. Substituting different behaviors was found to impact BMI, FVC, endurance, and speed, with notable gender differences. For males, replacing SLP with LPA significantly affected flexibility. In females, changes in sleep, SB, and LPA had marked effects on endurance. A dose-response analysis revealed that substitutions between MVPA and either SB or SLP had asymmetric effects on FVC and muscular strength in males. In contrast, for females, replacing MVPA with SB or SLP, as well as switching between LPA and SLP, asymmetrically influenced BMI and 50-meter dash performance. The optimal time allocation for physical fitness was determined to be 142 min/day of MVPA, 534 min/day of SB, 295 min/day of LPA, and 469 min/day of SLP for males, while for females, the ideal distribution was 115 min/day of MVPA, 536 min/day of SB, 306 min/day of LPA, and 482 min/day of SLP.

The results demonstrate that increasing MVPA while reducing SB significantly enhances endurance and FVC in university students. Common MVPA activities, including jogging, basketball, weightlifting, resistance training, cycling, swimming, and high-intensity interval training, are widely practiced on and off campus. MVPA promotes muscle hypertrophy and remodeling by activating the mTOR pathway, thereby boosting protein synthesis [27]. Neural adaptations that improve muscle fiber recruitment efficiency further enhance endurance [28]. Reducing SB helps prevent muscle catabolism, maintains hormonal balance, and supports muscle growth [29]. Our study also confirms that increasing MVPA and reducing SB can improve FVC through multiple mechanisms. A three-year follow-up study found that these activities strengthen respiratory muscles, enhance lung elasticity and compliance, increase blood oxygen delivery, and optimize breathing frequency and depth [30]. MVPA improves airway patency and facilitates the clearance of metabolic waste, leading to better lung efficiency and increased FVC, ultimately enhancing both respiratory function and endurance [31]. Additionally, a longitudinal study reported that overall SB and MVPA frequency are strongly related to PF in adolescents [32]. Current PA guidelines recommend 150–300 min of moderate-intensity aerobic exercise or 75–150 min of vigorous-intensity aerobic exercise per week for significant health benefits [33]. These findings underscore the importance of promoting MVPA and minimizing SB in daily life, as such behavioral changes can have lasting positive effects on endurance and muscular strength. Moreover, MVPA is consistently associated with better health outcomes in adolescents, with sedentary bouts of less than 30 min positively influencing overall health [34]. Another longitudinal study demonstrated that replacing 30 min/day of SB with high-intensity physical activity significantly lowers overall and cardiovascular mortality risks [35]. Using compositional and isotemporal substitution analyses, our study highlights the critical role of encouraging MVPA and reducing SB to improve PF performance.

This study found that reallocating time from LPA and SLP significantly improved flexibility in males. Stretching and flexibility exercises, such as yoga and Pilates, enhance hamstring and lower back flexibility while increasing the range of motion in the hips and spine [36–38]. Long-term increases in PA have also been shown to alleviate muscle tension and stiffness, leading to greater flexibility [39–41]. Furthermore, LPA has been found to improve metabolic health, aid in muscle recovery, and boost flexibility in young individuals [42–44]. However, while increasing PA generally enhances flexibility, reducing sleep simultaneously may diminish some of these benefits [45]. Sleep deprivation can cause fatigue, hinder recovery, and result in muscle stiffness, potentially limiting gains in flexibility [46]. Therefore, replacing sleep with LPA is not advisable. To maximize flexibility improvements, it is recommended to maintain adequate sleep while increasing PA.

The study indicates that transitioning from prolonged SB to LPA has a significant impact on endurance qualities in female college students. Female students generally have a slightly weaker cardiovascular adaptation compared to males [47]. However, regular LPA, such as walking or light exercise, can effectively improve heart function and vascular health, enhancing the heart's pumping capacity and vascular elasticity, and improving cardiorespiratory endurance [48]. Typically, females have a lower basal metabolic rate, and increasing LPA helps boost metabolism and fat metabolism, reducing fat accumulation and thus improving energy utilization [49]. These changes collectively enhance endurance qualities and performance in endurance running. Although LPA has a lower intensity, research shows its long-term benefits in gradually improving cardiorespiratory function and overall physical fitness in female college students [50], supporting more efficient endurance running performance. Moreover, LPA, with its lighter load, is more suitable for long-term adherence and is a preferred exercise choice for most female college students [51].

The study found no significant correlation between the standing long jump (a test of explosive strength and coordination) and movement behaviors among college students. This result contrasts with Zhang's findings, which indicated that substituting MVPA for SB or LPA positively affected PF composite scores and explosive strength [52]. The discrepancy might be due to the standing long jump's specific requirements—technique, muscle strength, core stability, body posture control, and coordination between the lower and upper limbs—which may not be adequately addressed by the types and intensities of muscle contractions typical of daily activities. This limitation could explain why no significant improvement in standing long jump performance was observed. Additionally, the relationship between explosive strength, muscle endurance, and PA might not be fully captured within a short timeframe. Previous research suggests that the connection between exercise and PF becomes more pronounced over time [53]. Therefore, longitudinal studies are needed to further investigate how explosive strength, muscle endurance, and PA behavior interact over extended periods.

Interestingly, the average (range) best combinations used when referring to time are as follows. For boys, the optimal PF schedule includes 142 min per day of MVPA, with a recommended range of 90–150 min, and 295 min per day of light LPA, within a range of 110–330 min. For girls, the optimal regimen comprises 115 min per day of MVPA, with a range of 60–140 min, and 306 min per day of LPA, within a range of 220–320 min. These findings align with World Health Organization guidelines, which recommend that children and adolescents 5–17 engage in at least 60 min of MVPA daily, while those 18 and older should aim for 150–300 min of moderate-intensity or 75–150 min of vigorous-intensity activity per week, or an equivalent combination [54]. The slight differences in optimal MVPA and LPA durations between boys and girls may reflect physiological, metabolic, and exercise preference variations between genders [55]. Young men, typically having higher muscle mass and strength, often favor high-energy activities such as weight training or running. Conversely, women may lean towards lower-intensity activities due to factors like bone density concerns and physiological considerations, such as the menstrual cycle, to avoid excessive strain [56]. Additionally, both genders' optimal sleep durations align with current guidelines recommending at least 7 h of sleep per night [57].

Strengths and limitations

The main strengths of this study are its use of accelerometers to collect comprehensive movement behavior data and the application of objective measurements and compositional isotemporal substitution methods to assess the relationship between PA and PF among Chinese university students. This research provides insights into the optimal movement behavior combinations and their gender-specific relationships with PF, which could inform future updates to physical activity guidelines. Current guidelines suggest 150 min of MVPA per week, no more than 8 h of SB per day, and 7–9 h of SLP [54]. However, guidance on effectively replacing sedentary behavior is sparse, and the benefits of short periods of SB time, moderate SLP, and high PA are not well-defined. Further research is needed to determine minimum PA requirements, maximum sedentary limits, and the balance between healthy and unhealthy behaviors. Additionally, while the minimum sleep threshold is recognized, its role in the optimal activity mix needs more investigation. Emphasizing the feasibility and sustainability of 24-hour movement behaviors patterns is crucial, as long-term adherence is key. Thus, developing activity patterns that people can realistically maintain, taking into account physiological, psychological, and sociological factors, represents the true optimal approach.

However, this study has several limitations. As with other cross-sectional studies, it cannot establish causality. Additionally, the effects of intermittent sitting or brief periods of activity on PF were not examined. Future research should investigate the potential benefits of intermittent sitting combined with multiple short bouts of activity versus continuous exercise. Moreover, while the study controlled for confounding variables such as parental education level, being an only child, and diet, there may still be unknown or unmeasured confounders affecting the results. Lastly, although sleep duration was estimated using both accelerometer data and sleep logs, potential inaccuracies may still arise due to participant reporting errors and device limitations in distinguishing between sleep and prolonged sedentary periods.

Conclusion

This study found that movement behaviors were strongly associated with PF in college students. Higher PA and lower SB were linked to better PF indicators, suggesting that targeted movement strategies may enhance fitness outcomes. Additionally, we provided recommendations for optimal 24-hour time allocation to maximize PF. A daily activity composition characterized by higher levels of MVPA and LPA, reduced SB, and adequate SLP was associated with more favorable BMI, FVC, and endurance in college students. To promote better physical fitness, universities and policymakers should encourage structured PA programs, integrate movement breaks into daily routines, and utilize digital tools for behavior tracking.

Abbreviations

PF	Physical fitness
MVPA	Moderate-to-vigorous physical activity
LPA	Light-intensity physical activity
SB	Sedentary behavior
SLP	Sleep
BMI	Body mass index
FVC	Forced vital capacity
CoDA	Compositional data analysis
CI	Confidence interval
MD	Mean difference
SD	Standard deviation

Supplementary Information

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Supplementary Material 1

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Author contributions

JYL: Writing—Original Draft, Formal Analysis, Data Curation, Visualization. ZDL: Formal Analysis, Data Curation, Visualization. MTZ: Formal Analysis, Data Curation, Visualization. XF: Writing-Review and Editing, Formal Analysis, Data Curation, Visualization. YYL: Conceptualization, Methodology, Data Curation, Supervision. All authors read and approved the final manuscript.

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Data availability

All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the Ethics Committee of Zhejiang Normal University. All participants provided written informed consent.

Consent for publication

This manuscript does not contain an individual person's data; therefore, consent for publication is not required.

Competing interests

The authors declare no competing interests.

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