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# Associations between 24-h movement behaviours and BMI in Chinese primary- and middle- school students

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ABSTRACT

*Purposes:* This cross-sectional study aimed to examine the associations between the 24-h movement behaviours and body mass index (BMI) of students from China by using compositional data analysis.
*Methods:* A total of 389 students aged 6–16 years participated in this study. Accelerometers were used to measure moderate-to-vigorous physical activity (MVPA), light-intensity physical activity (LPA), sedentary behaviour (SED), and sleep. Weight and height were objectively measured. The association between 24-h movement and BMI was analyzed by using compositional data analysis.
*Results:* Time reallocation using minutes and proportions created major differences to the results. Reallocating 10 min from other movement behaviours to MVPA was associated with decreased BMI z-score of 1.372 to 0.158 among primary-school students. Reallocating 10 min from sleep and SED to MVPA, and from sleep and SED to LPA were associated with decreased BMI z-score of 0.505 to 0.017 among middle-school students. Reallocating 10% of time from all other components to SED and sleep were associated with a higher BMI z-score by 0.148 (95%CI: 0.020; 0.276) and 0.125 (95%CI: 0.046; 0.204), while reallocating time to MVPA was associated with a decrease in BMI z-scores of 0.132 (95%CI: -0.193; −0.070) among primary-school students. Reallocating 10% of time from all other components to SED was associated with a higher BMI z-score of 0.254 (95%CI: 0.165; 0.345), whereas reallocating time to MVPA and LPA was associated with a decrease in BMI z-scores of 0.039 (95%CI: -0.073; −0.005) and 0.093 (95%CI: -0.153; −0.033) among middle-school students.
*Conclusion:* Research results of 10-min one-to-one reallocation may be treated cautiously due to uneven distribution of time in 24-h movement behaviours. Based on the results of 10% one-to-remaining reallocation, replacing SED with MVPA may be an appropriate target for adiposity intervention in primary-school students, while increasing MVPA or LPA at the expense of SED may be effective in controlling adiposity of middle-school students in China.


## 1. Introduction

The prevalence of overweight and obesity in children and adolescents aged 6–17 years rapidly increased from 1.3% in 1985 to 19% in 2020 in China.[1] Adiposity persists into adulthood and may lead to numerous physical and psychological health problems throughout the lifespan.[2–4] Moderate-to-vigorous-intensity physical activity (MVPA), light-intensity physical activity (LPA), sedentary behaviour (SED), and sleep have been shown to independently relate to weight status among children and adolescents.[5,6] These four movement behaviours are called 24-h movement behaviours because they collectively account for the entire 24-h period from no movement to high movement.[7] Due to the finite nature of the 24-h window, the four movement behaviours are co-dependent, that is, an increase of time spent in one behaviour naturally decreases time spent in the others. Therefore, the movement behaviours across the 24-h day constitute “compositional” data, which are made up of mutually exclusive and exhaustive parts (time spent in MVPA, LPA, SED, and sleep) of a whole (24-h movement).[8,9]

However, the usual statistical practice (e.g. multiple linear regression) fails to analyze the “compositional” data.[10,11] Time spent in different movement behaviours are intrinsically collinear

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and codependent for the fixed 24-h period.[8,9,12] Correlation coefficients using traditional statistics may obscure the real relationships of these variables.[13] In addition, movement behaviours are mutually exclusive parts of the overall 24-h day. Thus, they should be analyzed and interpreted with relative information rather than absolute information.[9] Consequently, an alternative approach for analyzing daily behaviours, called compositional data analysis (CoDA), was suggested by Aitchison[14] and were introduced for movement behaviour data.[8,12] This analytical approach utilizes log-ratio transformational techniques and expresses movement behaviours as a set of ratios to determine the effect of relative time spent in each movement behaviour as a proportion of the 24-h period, by which it overcomes the multicollinearity problems of traditional statistics.

Until recently, a group of studies used CoDA to examine the relative relationship between accelerometer-measured 24-h movement and body mass index (BMI) and estimate the differences in BMI z-score when time in 24-h movement was reallocated among children and adolescents.[15–29] Most studies found that participants with a greater amount of MVPA time, relative to other behaviours, tend to have lower adiposity measures[15,16,19,23,24,27,28] and participants with a greater amount of SED time, relative to other behaviours, tend to have higher adiposity measures.[15,16,22,24,26] Findings from most compositional isotemporal substitution studies suggested that lower adiposity was estimated when time was reallocated from a fixed duration of sleep, SED, and LPA to an equivalent duration of MVPA and from SED or LPA to sleep, whereas higher obesity was observed for opposite reallocation.[15,18–21,24]

Estimates of the relationship between 24-h movement and BMI z-score have generally been presented in terms of reallocation of a set block of minutes (e.g., 10 min).[21,23,25] However, the distribution of 24-h movement is uneven, for example, MVPA is a small proportion while sleep is a large proportion of the day. The increase or decrease of the same number of minutes results in a different change in one behaviour (e.g., large change in MVPA) with others (e.g., small change in SED or sleep). This uneven distribution can be overlooked when conducting compositional analysis using minutes.[30] Moreover, researchers suggested that one-to-one substitution without impacting other components has to be performed in a more controlled environment (such as replacing sitting with standing in class time) and substitution of time from one behaviour to all others proportionally may be more realistic.[28,30] There is a need to present and compare how these two substitutions affect associations with BMI z-score.

Although the relative and substitutional relationships between 24-h movement behaviours and adiposity among children and adolescents was investigated in Western countries, no study used CoDA to examine these relationships of children and adolescents in China, which has different cultural and educational systems. Influenced by Confucian heritage culture and familial educational expectations, students in China are under greater academic burden and thus own different 24-h behavioural pattern from Western counterparts,[31] which may result in different relationships between 24-h movement and their BMI. Moreover, children and adolescents are in various developmental and learning stages (e.g., primary and middle schools). Previous studies found that BMI increases with age and school levels[32,33] and 24-h movement behaviours vary between primary- and middle-school students.[34] However, evidence regarding the differential association between these two variables among children and adolescents at different school levels is lacking. Therefore, the current study focused on primary- and middle-school students in China and aimed to use CoDA 1) to examine the relationships between accelerometer-measured 24-h movement behaviours (MVPA, LPA, SED, and sleep relative to all other components) and BMI z-scores by school levels; 2) to estimate differences in BMI z-score when the time presented using proportions was reallocated from one component to all others; and 3) to estimate the predicted differences in BMI when time presented using minutes was reallocated from one movement behaviour to another by school levels. The findings of this cross-sectional study may provide evidence in China to support the 24-h movement behaviour guidelines and could be used to inform the effective and tailored interventions to prevent adiposity of primary- and middle-school students.

## 2. Research method

### 2.1. Participants

Multistage cluster random sampling was used to select participants from two elementary schools and two middle schools located in two districts in Shanghai, a city in the eastern part of China. Elementary and middle schools in Shanghai have five (i.e., grades 1–5 with students aged 6–11 years) and four (i.e., grades 6–9 with students aged 12–16 years) grades, respectively. One class was randomly selected from each grade, and all 688 students from 18 classes were invited to participate in the survey. Consent forms were sent to the students and their parents or guardians, and 603 students volunteered to participate (87.65% response rate). Seven students were excluded because of their serious physical disability or psychological dysfunction, and accordingly 596 students participated in the present study. An initial inspection of the raw data showed that five participants had missing data because of accelerometer malfunction or loss, 183 students provided invalid accelerometer data because they did not cover one valid weekend day and two valid weekdays, and 19 students provided data that were out of normal range in sleep and SED which were defined as the standardized z scores of the observation beyond the limit of $\pm 4.00$ in the dataset with a large sample size ($n \geq 80$).[35] Removing these data resulted in a total of 389 students that were included as the final analysis sample (64.51% of the initial sample). No significant differences were found in the general characteristics between excluded ($n = 201$) and included participants ($n = 389$).

### 2.2. Data collection

The university's Ethics Committee and relevant school authorities approved the study. Data were collected by the first author and two research assistants who are postgraduates majoring in physical activity. The participants were required to follow their normal daily routines during the monitoring period and return the accelerometers after 8 days to ensure 7 days for complete data collection. Thereafter, the weight (kg) and height (m) of the participants with valid accelerometer data were measured, and the students were asked to report their age and sex.

### 2.3. Measure

#### 2.3.1. Twenty-four-h movement behaviours

MVPA, LPA, SED, and sleep were measured using the triaxial accelerometer (ActiGraph wGT3X-BT). The participants were instructed to wear the accelerometer fastened by an elastic belt on their right hipbone for 24 h per day for 7 consecutive days and only remove it for bathing or swimming. The sampling interval (epoch) in this study was set at 15-s epochs.[36] After the test was conducted, Actigraph data were processed with the ActiLife software version 6.13.3 (ActiGraph Corp., Pensacola, FL, USA) with the cutoffs by Evenson et al.[36] to determine the activity-level thresholds. A total of 10 h of recorded accelerometer data per day (excluding strings of zeros for 20 min or longer) or more during awaking time were considered valid. The accelerometer data were included in the final analysis if they contained at least one valid weekend day and two valid weekdays.[37] A sleep detection algorithm developed by van Hees and colleagues[38] was used to define sleep onset and offset and collapsed into 60-s epochs. The average daily total sleep duration was calculated using only days when valid sleep was recorded (total sleep period ≥200 min) and only for participants with at least four nights of valid sleep, including one weekend night. Finally, the average minutes spent (minutes per day) engaged in SED, LPA, MVPA, and sleep were weighed at 5:2 for weekdays and weekend days and linearly adjusted to collectively sum to 24 h.

#### 2.3.2. BMI

The height and weight of adolescents were measured by a portable instrument (GMCS-IV; Jianmin, Beijing, China). The adolescents' BMI was calculated as weight in kilograms divided by height in meters squared ($kg/m^2$). Age- and sex-specific BMI z-scores were calculated on the basis of the World Health Organization growth reference, and the participants were categorized into underweight (BMI z-scores $< -2$), normal weight ($-2 \le$ BMI z-scores $\le 1$), overweight ($1 <$ BMI z-scores $\le 2$), and obesity (BMI z-scores $>2$).[39]

### 2.4. Data analysis

Analyses were performed using R studio 3.2.4 (R Studio, Boston, Massachusetts, USA) with the "compositions", "robCompositions" and lme4 packages and IBM SPSS Statistics 24 (IBM Crop., Armonk, NY, USA). All analyses followed the published guidelines for conducting compositional data analysis,[8,9] and they were performed separately for primary- and middle-school students.

Compositional descriptive statistics, including geometric mean and pairwise log-ratio variation matrix, were calculated for daily composition of 24-h movement behaviours. The compositional geometric mean measures central tendency, and it was derived by calculating the geometric mean of the time spent in each movement behaviour after they were linearly adjusted to collectively sum to 1440 min.[8] The variance matrix is a measure of dispersion, and it was derived by calculating the variances of the logarithms of all possible pair-wise ratios [e.g., variance of In (SED/MVPA)]. Values close to one showed lower codependence, and those closer to zero indicated higher codependence.[8]

Four mixed-effects multivariable linear regression models were used to examine the associations between 24-h movement behaviours and BMI z-score in primary- and middle-school students, respectively. Covariates (sex and age) were included in the models as fixed effects, and grade and class were added as random effects to account for the grouping effect of class, nested in grade. The four movement behaviour compositions were expressed as four sets of three isometric log ratios (ilr) coordinates, and they entered the regression models as explanatory variables. Regression coefficients for the first ilr coordinate, standard errors (SE) and *P*-values were calculated to determine if the individual movement behaviour was significantly associated with BMI z-score relative to other movement behaviours. The distributional properties of each variable suggested that the assumptions of linearity, normality, and homoscedasticity required by models were met. The model parameter VIF values ranged from 1.01 to 1.42, indicating no multicollinearity.

Compositional isotemporal substitution models were established to examine the estimated changes in BMI z-scores of both reallocating 10% time spent in one component proportionally to all others and reallocating 10 min between pairs of behaviour sets. The estimated changes in BMI z-scores were calculated using the differences between predictions from the mean composition and the new composition. All regression models were adjusted for age and sex.

## 3. Result

### 3.1. Descriptive statistics

A total of 389 students (194 males and 195 females, 182 primary- and 207 middle-school students) participated in the study. The characteristics of primary- and middle-school students and the total samples are tabulated in Table 1.

The variability of the data for primary- and middle-school students was summarized in the variation matrix (Table 2). The highest pairwise log-ratio variances were observed for SED and MVPA among primary-school students (0.177) and middle-school students (0.247), indicating that the time spent in SED had the least co-dependence on MVPA. The smallest variances were observed for LPA and sleep among primary-school students (0.054) and middle-school students (0.074), indicating high co-dependence between this pair of variables.

### 3.2. Compositional regression analysis

The results from the mixed-effects multivariable linear regression models for the associations between four movement behaviour compositions and BMI z-scores among primary- and middle-school students were summarized (Table 3). Participants with a greater amount of MVPA time, relative to the other behaviours, tended to have lower BMI z-scores among primary- ($\beta = -1.552$, $P < 0.001$) and middle-school students ($\beta = -0.465$, $P = 0.024$). Participants with a greater amount of LPA time, relative to the other behaviours, tended to have lower BMI z-scores among middle-school students ($\beta = -0.889$, $P = 0.002$) but it was not significantly related to BMI z-scores among primary-school students ($P = 0.339$). However, participants with a higher amount of SED, relative to the other behaviours, tended to have higher BMI z-scores among primary- ($\beta = 1.068$, $P = 0.024$) and middle-school students ($\beta = 1.625$, $P < 0.001$) respectively. Participants with a higher amount of sleep, relative to the other behaviours, tended to have higher BMI z-scores among primary- ($\beta = 0.983$, $P = 0.002$) but it was not significantly related to BMI z-score of middle-school students ($P = 0.498$).

### 3.3. Estimates of reallocations to one component from all others in terms of proportion

The 4th column in Table 3 reports the estimated difference in BMI z-score for reallocating 10% of the mean time of one behaviour to all others. Results show that the relationship between SED and BMI z-scores is strongest among primary- and middle-school students. Reallocating 10% more time (on average of 48 min in primary-school students and 65 min in middle-school students) to SED, with a time reduction of all other components, was associated with a higher BMI z-score by 0.148 (95%CI: 0.020; 0.276) and 0.254 (95%CI: 0.165; 0.345) among primary- and middle-school students, respectively. Conversely, a 10% increase in MVPA (on average of 4 min in primary-school students and 3 min in middle-school students), reallocated from all other movement behaviours, is associated with a decrease in BMI z-scores of 0.132 (95%CI: -0.193; −0.070) and 0.039 (95%CI: -0.073; −0.005) among primary- and middle-school students, respectively. Reallocating 10% more time to sleep from all other components was only associated with a higher BMI z-score by 0.125 (95%CI: 0.046; 0.204) among primary-school students. Reallocating 10% more time to LPA, with a time reduction of all other components, was only associated with a lower BMI z-score by 0.093 (95%CI: -0.153; −0.033) among middle-school students.

**Table 1**
Descriptive statistics of primary, middle school students and total samples.

| Variable | Total (n = 389) | Primary-school students (n = 182) | Middle-school students (n = 207) |
|---|---|---|---|
| Age (years, M±SD) | 6–16 years<br>11.89 ± 2.09 | 6–12 years<br>10.22 ± 1.50 | 11–16 years<br>13.37 ± 1.25 |
| **Sex, n (%)** | | | |
| Boys | 194 (49.87) | 92 (50.5) | 102 (49.3) |
| Girls | 195 (50.13) | 90 (49.5) | 105 (50.7) |
| Height (cm, M±SD) | 1.53 ± 0.14 | 140.70 ± 7.83 | 163.54 ± 8.54 |
| Weight (kg, M±SD) | 45.98 ± 14.06 | 34.97 ± 8.39 | 55.65 ± 10.57 |
| BMI (kg/m$^2$, M±SD) | 19.22 ± 3.45 | 17.54 ± 3.21 | 20.69 ± 2.94 |
| BMI z-score | 0.34 ± 1.23 | −0.10 ± 1.37 | 0.55 ± 1.05 |
| **Weight status, n (%)** | | | |
| Underweight | 13 (3.3) | 9 (4.9) | 4 (1.9) |
| Normal weight | 253 (65.0) | 125 (68.7) | 128 (61.8) |
| Overweight | 97 (24.9) | 33 (18.1) | 64 (30.9) |
| Obesity | 26 (6.7) | 15 (8.2) | 11 (5.3) |
| Accelerometer wear time | 1435.88 (8.70) | 1436.58 (9.06) | 1435.27 (8.36) |
| **Activity behaviours: composition mean[a] (%)** | | | |
| MVPA/minutes | 35 (2.46) | 39 (2.71) | 32 (2.23) |
| LPA/minutes | 317 (22.04) | 365 (25.36) | 277 (19.22) |
| SED/minutes | 570 (39.55) | 482 (33.50) | 650 (45.13) |
| sleep/minutes | 518 (35.95) | 554 (38.44) | 481 (33.42) |
| **Activity behaviours: arithmetic mean (SD)** | | | |
| MVPA/minutes | 37 (13.05) | 44 (12.09) | 34 (13.24) |
| LPA/minutes | 319 (74.72) | 365 (64.13) | 279 (58.77) |
| SED/minutes | 572 (131.77) | 486 (102.79) | 647 (105.44) |
| sleep/minutes | 513 (84.52) | 550 (78.06) | 479 (75.98) |

Note: a. Movement behaviours are presented as composition means, adjusted to sum 1440 min/day. Abbreviations: BMI, body mass index; BMI z-score, body mass index z-score; MVPA, moderate-to vigorous-intensity physical activity; LPA, light-intensity physical activity; SED, sedentary behaviour.

**Table 2**
Pairwise log-ratio variation matrix for movement behaviour compositions.

| | Primary-school students | | | | Middle-school students | | | |
|---|---|---|---|---|---|---|---|---|
| | MVPA | LPA | SED | sleep | MVPA | LPA | SED | sleep |
| MVPA | 0 | 0.076 | 0.177 | 0.102 | 0 | 0.152 | 0.247 | 0.140 |
| LPA | 0.076 | 0 | 0.122 | 0.054 | 0.152 | 0 | 0.130 | 0.074 |
| SED | 0.177 | 0.122 | 0 | 0.113 | 0.247 | 0.130 | 0 | 0.098 |
| Sleep | 0.102 | 0.054 | 0.113 | 0 | 0.140 | 0.074 | 0.098 | 0 |

Note: Abbreviations: LPA, light-intensity physical activity; MVPA, moderate-to vigorous-intensity physical activity; SED, sedentary behaviour.

### *3.4. Estimates of reallocations of time from one component to another in terms of minutes*

Table 4 displays the predicted difference in BMI z-scores when 10 min was reallocated from one behaviour to another behaviour, keeping the remaining behaviours constant. Among primary-school students, reallocating 10 min from sleep, SED, and LPA to MVPA was associated with a decreased BMI z-score by 0.323 (95% CI: −0.478; −0.167), 0.326 (95% CI: −0.485; −0.167), and 0.299 (95% CI: −0.470; −0.128), respectively. Meanwhile, the opposite time reallocation from MVPA to sleep, SED and LPA were associated with an increased BMI z-score by 0.414 (95% CI: 0.212; 0.616), 0.418 (95% CI: 0.213; 0.623), and 0.391 (95% CI: 0.175; 0.607), respectively. No significant difference in BMI z-score was found for the replacement between sleep and SED or LPA and between SED and LPA.

Among middle-school students, the results showed that reallocating 10 min from sleep and SED to MVPA was associated with a decreased BMI z-score by 0.111 (95% CI: −0.213; −0.008) and 0.121 (95% CI: −0.217; −0.024), respectively, whereas the opposite reallocation from MVPA to sleep and SED was associated with an increased BMI z-score by 0.150 (95% CI: 0.012; 0.289) and 0.161 (95% CI: 0.028; 0.294), respectively. Meanwhile, reallocating time from sleep to LPA (−0.033, 95% CI: −0.061, −0.006) and from SED to LPA (−0.044, 95% CI: −0.065; −0.022) was associated with a

**Table 3**
Relationships between 24-h movement behaviours and BMI z-score presented using raw regression coefficients and reallocation of 10% time between one component and all others.

| Component | Regression coefficient (SE)[a] | 10% relative difference in minutes | Difference[b] in BMI z-score associated with 10% more time in component | Difference[b] in BMI z-score associated with 10% less time in component | P-value |
|---|---|---|---|---|---|
| Primary-school students | | | | | |
| MVPA | −1.552 (0.371) | 4 | −0.132 (−0.193; −0.070) | 0.145 (0.077; 0.213) | <0.001 |
| LPA | −0.500 (0.523) | 37 | −0.056 (−0.172; 0.059) | 0.060 (−0.063; 0.183) | 0.339 |
| SED | 1.068 (0.473) | 48 | 0.148 (0.020; 0.276) | −0.154 (−0.287; −0.020) | 0.024 |
| Sleep | 0.983 (0.315) | 55 | 0.125 (0.046; 0.204) | −0.132 (−0.214; −0.049) | 0.002 |
| Middle-school students | | | | | |
| MVPA | −0.465 (0.205) | 3 | −0.039 (−0.073; −0.005) | 0.043 (0.005; 0.081) | 0.024 |
| LPA | −0.899 (0.296) | 28 | −0.093 (−0.153; −0.033) | 0.100 (0.036; 0.165) | 0.002 |
| SED | 1.625 (0.292) | 65 | 0.254 (0.165; 0.345) | −0.259 (−0.351; −0.168) | <0.001 |
| Sleep | −0.260 (0.384) | 48 | −0.033 (−0.129; 0.063) | 0.035 (−0.066; 0.135) | 0.498 |

Abbreviations: LPA, light-intensity physical activity; MVPA, moderate-to vigorous-intensity physical activity; SED, sedentary behaviour.
Note: [a] Coefficient for the first isometric log ratio (ilr) co-ordinate, which is proportional to the log ratio of the behaviour and the geometric mean of the remaining behaviours.
[b] Difference in BMI z-score if the composition of the 24-h day is changed whereby 10% more (or less) time is spent in one behaviour and proportionally less (or more) time spent in all other behaviours.

**Table 4**
Estimated differences in BMI z-scores for one-to-one reallocation of 10 min from one behaviour to another.

| | Primary-school students Δ′ (95%CI) | P | Middle-school students Δ′ (95%CI) | P |
|---|---|---|---|---|
| SED to sleep | −0.004 (−0.019; 0.027) | 0.774 | 0.010 (−0.028; 0.007) | 0.241 |
| LPA to sleep | 0.027 (−0.010; 0.064) | 0.159 | 0.034 (0.006; 0.062) | 0.016 |
| MVPA to sleep | 0.414 (0.212; 0.616) | <0.001 | 0.150 (0.012; 0.289) | 0.033 |
| sleep to SED | −0.004 (−0.027; 0.019) | 0.735 | 0.010 (−0.007; 0.028) | 0.261 |
| LPA to SED | 0.023 (0.008; 0.055) | 0.150 | 0.045 (0.023; 0.066) | <0.001 |
| MVPA to SED | 0.418 (0.213; 0.623) | <0.001 | 0.161 (0.028; 0.294) | 0.018 |
| sleep to LPA | −0.027 (−0.064; 0.010) | 0.152 | −0.033 (−0.061; −0.006) | 0.017 |
| SED to LPA | −0.023 (−0.054; −0.008) | 0.142 | −0.044 (−0.065; −0.022) | <0.001 |
| MVPA to LPA | 0.391 (0.175; 0.607) | <0.001 | 0.117 (−0.022; 0.256) | 0.100 |
| sleep to MVPA | −0.323 (−0.478; −0.167) | <0.001 | −0.111 (−0.213; −0.008) | 0.034 |
| SED to MVPA | −0.326 (−0.485; −0.167) | <0.001 | −0.121 (−0.217; −0.024) | 0.014 |
| LPA to MVPA | −0.299 (−0.470; −0.128) | 0.001 | −0.076 (−0.180; 0.028) | 0.150 |

Note: Δ′ predicted differences in BMI z-score; 95% CI stands for 95% Confidence Interval. a. 10 min are reallocated from sedentary behaviour to sleep. Analysis adjusted for age, sex. Abbreviations: LPA, light-intensity physical activity; MVPA, moderate-to vigorous-intensity physical activity; SED, sedentary behaviour.

decreased BMI z-score, whereas increased BMI z-scores were associated with the opposite reallocation from LPA to SED (0.045, 95% CI:0.023; 0.066) and to sleep (0.034, 95% CI: 0.006, 0.062). No significant difference in BMI z-score was found for the replacement between sleep and SED and between MVPA and LPA (Table 4).

## 4. Discussion

This study used CoDA to examine the relationships between four movement behaviour compositions and BMI z-scores among primary- and middle-school students. Compositional isotemporal substitution analysis indicated that reallocating 10 min from other movement behaviours to MVPA was associated with decreased BMI z-score of primary school students. Among middle school students, reallocating 10 min from sleep and SED to LPA and from sleep and SED to MVPA were associated with BMI z-score. Similar findings were achieved by previous studies.[18,19,24,26] Therefore, increasing MVPA and decreasing other movement behaviours appears to be an appropriate target for adiposity intervention in primary-school students. Promoting MVPA and LPA and reducing sleep and SED may be particularly meaningful for middle-school students.

However, the results from the one-to-remaining reallocation of 10% time show that SED is most strongly associated with BMI z-scores of primary- and middle-school students. This is inconsistent with the results of substitution analysis in terms of 10 min which indicated that MVPA is the most strongly associated variable (i.e., the reallocations between MVPA and other movement behaviours produced the largest difference in BMI z-score in Table 4). These mixed messages come about because of the uneven time distribution of 24-h movement behaviours. MVPA only accounted for 2.71% and 2.23% of a 24-h day for primary- and middle-school students and a small change of MVPA minutes may bring a large effect. Haszard et al. (2020) also reported that imbalance in time across the day is a key problem with using one-to-one reallocation in terms of minutes. Thus, findings for a one-to-one reallocation in terms of minutes may need careful interpretation.[28,30,40] More appropriate recommendation may be based on the results of the one-to-remaining reallocation of 10% time, which is increasing MVPA at the expense of SED and sleep for BMI outcomes of primary school students and increasing MVPA and LPA at the expense of SED for BMI outcomes of middle school students.

This finding is important for students in China because they are physically inactive and spend much time sitting to study.[41,42] The descriptive results of this study also confirmed that primary- and middle-school students spent 38 and 32 min in MVPA and 482 and 649 min in SED, respectively. These values did not meet the WHO[43] recommendation of at least 60 min MVPA per day. SED time of middle school students is also beyond the SED range (from 309 to 646 min/day) of children and adolescents from an international review.[44] Therefore, these results implied that increasing MVPA and decreasing SED may be beneficial to control adiposity.

However, it is notable that the sleep duration of students in China is reported to be insufficient due to the high academic burden.[45,46] The descriptive results of the current study also confirmed that the average sleep duration of primary- and middle-school students (553 min and 481 min, respectively) only reached the lower limit of the sleep duration recommendation (sleep durations of 9–11 and 8–10 h per night for children aged 6–13 years and adolescents aged 14–17 years, respectively) by the U.S. National Sleep Foundation.[47,48] Maintaining and extending sleep time is needed for the health of students in China. Moreover, the cross-sectional data of the current study preclude the causal inference on the relationship of the reallocation between MVPA and sleep to BMI z-scores. Due to these reasons, although results showed that reallocating 10% more time from sleep to all other components was associated with a lower BMI z-score of primary-school students, this result should be treated cautiously.

Differential adiposity associations for the movement behaviour compositions existed between primary- and middle-school students. Reallocating time from all other behaviours to LPA was associated with predicted decrease of BMI z-scores among middle-school students, whereas no significant change in primary-school students. This finding is aligned with the other study by Gaba et al. (2020). It is not difficult to understand because LPA requires higher energy expenditure than SED and sleep, thus reducing BMI level. The relationship is significant for middle school students instead of primary school students, which may be related to their different physiological characteristics and academic burden. On the one hand, a number of physiological changes including rapid increases in physical size, hormonal fluctuations, and marked changes in body composition occur when entering puberty,[49] which may bring more BMI variability of middle-school students. Therefore, BMI is easier to be influenced by the time reallocation between LPA and remaining behaviours among middle school students than primary school students. On the other hand, upon entering middle schools, students encounter challenges in the entrance examination to high school in China. They have to study harder than elementary-school students to obtain academic achievements, which results in less PA participation.[50] The descriptive findings of this study also confirmed that the LPA time of middle-school students (279 min) was shorter than that of primary students (365 min). Therefore, the increase or decrease in LPA time yielded more significant changes in the BMI z-scores among middle-school students than among primary-school students.

Based on these results, interventions to control weight may focus on the difference between primary- and middle-school students. In particular, adiposity intervention strategies may target at increasing MVPA at the expense of SED for primary school students. More opportunities may be provided for primary school students to increase MVPA time in physical education classes in schools or engage in more MVPA out of school (e.g., during afterschool programs, on the weekends with family). Interventions to increase LPA at the expense of SED may be provided to middle-school students to control their adiposity. For instance, students should be encouraged to reduce sitting time and replace it with standing and light ambulation during recess. Meanwhile, teachers may provide classroom-based active breaks to interrupt students' prolonged sitting. After school, parents may incorporate family walks or active games with their kids into the family daily routine.

### *4.1. Strength and limitations*

To date, this study was the first to use compositional isotemporal substitution analysis to examine the relationships between 24-h movement behaviours and adiposity among Chinese school students. In addition, the accelerometer-based measures of 24-h movement behaviours provided objective and reliable data. However, this study has limitations. First, the study design was cross-sectional and causal conclusions about the associations between time-use composition and BMI z-score could not established. Second, the models provide only theoretical estimates of differences in adiposity. Therefore, the findings should be interpreted with caution and confirmed by longitudinal and interventional studies. Thirdly, BMI does not account for body fat percentage or body fat distribution, which limits the ability to capture real body composition of students. Other measures (e.g., fat mass) should be adopted to assess weight status in future studies. Fourth, puberty status is an important factor which may influence body composition.[51] Although age was adjusted in the regression analysis, the current study is limited by not adjusting puberty as a covariate. Future studies should account for this variable. Finally, the present study only focused on the volume and intensity of the movement behaviours and ignored the different effects of patterns and types of the behaviours. Future research may explore whether the associations differ when taking patterns and types of SED (e.g., long SED bouts and short SED bouts, recreational screen time vs. classroom SED time) and other movement behaviours into consideration.

## 5. Conclusions

In conclusion, when investigating the association of 24-h movement behaviours with BMI with CoDA, time reallocation using minutes and proportions created major differences to the results. Presentations in terms of 10 min one-to-one reallocation may need careful interpretation because of the uneven distribution of time in each component. Based on the results of 10% of time reallocation from one behaviour to all others, the increase in MVPA at the expense of SED appears to be an appropriate target for adiposity intervention in primary-school students. Promoting MVPA or LPA and reducing SED may be particularly meaningful for middle-school students. These findings would facilitate the development of more effective interventions to prevent and control obesity among school students in China.

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## Author statement

All authors agree with the content of the manuscript and approve of its submission to the Journal of Exercise Science & Fitness (JESF). We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere

## Availability of data and materials

The dataset analyzed during the current study are available from the corresponding author on reasonable request.

## Declaration of conflicting interests

The author(s) declared no potential conflicts of interest.

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