Lu *et al. BMC Public Health* (2024) 24:2823
https://doi.org/10.1186/s12889-024-20290-6

BMC Public Health

RESEARCH Open Access

Reallocation of time to moderate-to-vigorous physical activity and estimated changes in physical fitness among preschoolers: a compositional data analysis

Zhaoxu Lu[1], Jin Guo[1], Chuanhe Liu[2], Jian Wu[3], Chuo Zhao[4], Fang Wang[1], Yihua Bao[1], Haowen Zhang[3], Bing Qi[5], Xiuhe Li[6], Hongyan Guan[1,7*], Jianxin Wu[1,8*] and Ting Zhang[1*]

Abstract

Background Previous research has examined the associations of preschoolers' 24-h movement behaviours, including light and moderate-to-vigorous physical activity (LPA and MVPA), sedentary behaviour (SB), sleep, with physical fitness in isolation, ignoring intrinsically compositional nature of movement data while increasing the risk of collinearity. Thus, this study investigated the associations of preschoolers' 24-h Movement behaviours composition with physical fitness, estimated changes in physical fitness when time was reallocated between movement behaviours composition, and determined whether associations differ between different genders, using compositional data analysis.

Methods In the cross-sectional study, a total of 275 preschoolers (3 ~ 6 y) from China were included. SB, LPA and MVPA times were objectively monitored with an ActiGraph GT9X accelerometer for 7 consecutive days. Sleep duration was obtained using parental reports. Physical fitness parameters, including upper and lower limb strength, static balance, speed-agility, and cardiorespiratory fitness (CRF), were determined with the PREFIT battery. The associations of 24-h movement behaviours composition with each physical fitness parameter were examined employing compositional multivariable linear regression models. The changes following time reallocation among behaviours were estimated employing compositional isotemporal substitution analyses.

Results Greater MVPA, but not LPA, was significantly related to better upper and lower limb strength, speed-agility, and CRF. Reallocating time from LPA or SB to MVPA was related to better physical fitness. The associations were non-symmetrical: the estimated detriments to physical fitness from replacing MVPA with LPA or SB were larger than the estimated benefits associated with adding MVPA of the same magnitude. The aforementioned associations with lower limb strength, CRF, and speed-agility were observed in boys, while associations with upper and lower limb strength were noted in girls.

---

*Correspondence:
Hongyan Guan
hongyanguan@126.com
Jianxin Wu
cipbiolab@163.com
Ting Zhang
zhangtingcv@126.com

Full list of author information is available at the end of the article

Conclusion Our findings reinforce the importance of physical activity (PA) intensity for the development of physical fitness in preschoolers. Replacing LPA or SB time with MVPA may be an appropriate strategy for enhancing preschoolers' physical fitness.

Keywords Preschoolers, Compositional data analysis, 24-h movement behaviours, Physical fitness, MVPA

Background

Physical fitness is a capability to conduct daily physical activity (PA) [1], including upper and lower limb strength, cardiorespiratory fitness (CRF), static balance, and speed-agility [2]. The preschool period is a critical stage for the development and enhancement of physical fitness [1]. Physical fitness is recognized as a robust indicator of both current and future health in preschoolers [3]. However, in recent decades, preschoolers' physical fitness has shown a declining trend [4]. Therefore, knowledge about preschoolers' physical fitness and the factors that affect it are especially crucial.

It is well accepted that physical fitness is only partly determined by non-modifiable factors (e.g. gene) and is significantly shaped by environmental factors, including daily movement behaviours [5]. From the perspective of movement behaviours, the daily 24-h cycle consists of a continuum of movement behaviour intensity, including sleep, sedentary behaviour (SB), light and moderate-to-vigorous physical activity (LPA and MVPA) [6]. Previous studies indicated that increased MVPA time leads to acute physiological changes (i.e., increases in ventilation, blood pressure, heart rate, and energy expenditure). When these acute changes are followed by adequate recovery, they can result in long-term changes in metabolism, which contribute to enhancing CRF and muscle strength [7, 8]. Besides, a growing body of research has found that reducing lower-intensity activities (e.g., SB) while simultaneously increasing MVPA time is positively associated with fat-free mass [3, 9]. This increase in fat-free mass may, in turn, enhance physical fitness in preschoolers [10]. Adequate sleep duration may enhance physical fitness levels by increasing fat-free mass and decreasing fat mass through the maintenance of metabolic homeostasis and energy balance [10, 11]. Conversely, SB may negatively affect physical fitness through increasing body fat percentage [10, 12]. Therefore, to ensure the health of preschoolers, the WHO has released daily activity guidelines for preschoolers, recommending that they engage in ≥180 min/d of PA (including≥60 min/d of MVPA), ≤ 60 min/d of SB screen time, and 10–13 h/d of sleep [13]. However, a recent review reported that only 5-24% of preschoolers met daily activity guidelines [14]. Understanding how to balance daily movement behaviours is crucial for enhancing physical fitness in preschoolers.

In the past decade, pediatric movement behaviours studies have focused on the health effects of MVPA, defined as PA conducted at ≥4 METs (i.e., ≥ 4 times the intensity of rest) [13]. The cross-sectional and longitudinal studies indicated that speed-agility, CRF, and muscular strength were positively associated with MVPA in preschoolers [9, 15]. Yet studies that investigate the association of SB, sleep, and LPA with physical fitness among children are scarce and findings are mixed [8, 9, 16–18], which may be attributed to data analyses challenges [19]. Until recently, previous research has typically used traditional linear regression analysis to investigate the relationships of movement behaviours with physical fitness in isolation [7, 8, 17, 18], ignoring the interplay between behaviours and potentially leading to pseudo-correlation [20]. However, 24-h movement data is inherently compositional, featuring perfect collinearity and co-dependence among behaviours [19]. That is, an increase in the time dedicated to one behaviour would necessitate compensation by reducing the time allocated to at least one of the others, whereby it is crucial to analyze the relationships of time reallocation among behaviours with physical fitness [21]. WHO guidelines on 24-h movement for preschoolers also highlight the importance of integrating each movement behaviour of the whole day for optimal health [13]. This means investigating the health associations of a single behavior in isolation is unreasonable and can produce unreliable results [22]. Pearson cautioned that associations may appear spurious and inconsistent when employing the traditional linear regression analysis to directly handle data with perfect collinearity [23]. Thus, traditional linear regression analysis cannot be used to analyze 24-h movement data. In contrast, compositional data analysis (CoDA) recognizes the inherent compositional nature of 24-h movement data, which account for co-dependence among behaviours and lower the risk of collinearity [24]. CoDA has been recommended to explore the associations of movement behaviours with health outcomes by capturing the relative time spent in different behaviours and estimate changes in health outcomes following time reallocation between behaviours [21, 25].

A growing evidence supported the use of CoDA in studies of physical fitness in adults [26], children and adolescents [8, 27, 28], indicating that better physical fitness (e.g., CRF) was associated with time reallocation from any of other behaviours (e.g., SB) to MVPA. However, CoDA-based evidence in preschoolers is scarce and mixed. Until now, only two studies has employed CoDA to investigate the associations of 24-h movement behaviours with preschoolers' physical fitness [4, 5]. Lemos et al. observed that substituting SB or sleep with MVPA was significantly associated with better CRF, while the reallocation results for lower limb strength and speed-agility were inconclusive [5]. However, Song et al. observed substituting SB or sleep with MVPA was significantly associated with better upper limb strength and speed-agility, and the reallocation results for CRF were not significant [4]. Given the inconsistent findings from the limited studies, further investigation is important to understand how preschoolers' 24-h movement behaviours related to physical fitness. Additionally, the existing studies revealed that 24-h movement behaviours pattern [29, 30] and physical fitness indicators [31] are different in boys and girls. Given the gender differences of these indicators, previous research has emphasized the necessity of employing CoDA to examine the associations between daily time-use composition and physical fitness across different genders [19]. However, to the authors' knowledge, there is currently no gender-specific associations' evidence.

Thus, to fill evidence gaps, this study aimed to investigate the associations of preschoolers' 24-h movement behaviours composition with physical fitness, to estimate the changes in physical fitness when time is reallocated between movement behaviours composition, and to determine whether associations differ between different genders. Our overall hypotheses were that 24-h movement behaviours composition would be associated with physical fitness, the time reallocation from other behaviours to MVPA would be favourably related to physical fitness regardless of gender.

Methods

Participants

During August and October 2022, this cross-sectional study was conducted in Beijing. Preschoolers (3–6 years) of both genders were recruited from urban and suburban kindergartens using convenience sampling. Ethical approval was obtained from the Ethics Committee of the Capital Institute of Pediatrics (NO. SHERLL2021069), aligning with the principles delineated in the Declaration of Helsinki. Informed consent was gained for all participants from their parents or guardians.

For inclusion, participants had to meet the following criteria: (1) no recent onset of seasonal illnesses (e.g., cold or fever); (2) no chronic diseases (e.g., arrhythmia or hypertension); (3) absence of overweight and obesity; (4) no physical, mental, or behavioral impairments; (5) no disorders interfering with PA. Overall, 355 preschoolers were enrolled. Participants without sufficient valid accelerometer data, with a minimum of 480 min/d for at least 4 days (including at least 1 weekend day and 3 weekdays), or those lacking sleep data, covariate (i.e., age, gender, zBMI), or physical fitness variables were excluded, leaving data from 275 preschoolers was included in the analysis.

Procedures

All kindergarten staff, as well as parents/guardians, received comprehensive information about the study's objectives, protocols and procedures, and provided consent for their children. In accordance with standard operating procedures [31], each included child was assessed by experienced researchers. Parents/guardians completed a questionnaire to gather information on children's gender, birth date, age, disease status, and sleep report. Participants underwent anthropometric measurements and physical fitness testing at preschools, and then they wore the accelerometer for 7 consecutive days. During the accelerometer wear period, the kindergarten staff and parents/guardians were requested to write a diary to track sleep and the status of accelerometer wear.

Measurements

Anthropometry

Following a standardized procedure [32], weight and height were measured with participants wearing light dressing and bare feet utilizing a portable electronic Seca 899 scale and Seca 217 stadiometer, respectively. Measurements were recorded with a precision of one decimal place. All anthropometry variables were each measured twice. A third measurement was taken when there was a difference of more than 0.25 kg in weight and 0.5 cm in height between two consecutive measurements. The mean of the two nearest measurements was used for subsequent analyses. The calculation of Body mass index (BMI) and the associated BMI z-scores (zBMI) was performed utilizing the anthro and anthroplus packages in R 4.1.3.

Movement behaviours

Habitual PA and SB were objectively monitored with the ActiGraph GT9X accelerometer, a device well-recognized for its established validity and reliability in preschoolers [33–35]. Children's teachers and parents/guardians received detailed instructions on how to correctly place/remove the accelerometer. To ensure the correct use of device, during the monitoring period, teachers and parents/guardians were contacted daily through WeChat, and were asked to register bed and wake times, and times/reasons for monitor non-wear on an activity diary.

Each enrolled child was given instructions to wear a hip-worn accelerometer, sampling at 30 Hz, continuously throughout waking hours for 7 consecutive days, with the exception of water-based activities and sleep. The raw data from the device was re-integrated into 1-s epochs [30]. The Choi algorithm [36] was employed to identify non-wear times, which was then excluded from the accelerometer data analysis. Accelerometer data was considered valid if waking wear time was at least 4 days (including at least 1 weekend day and 3 weekdays) with ≥480 min/d [37–39]. Standard count-per-minute (CPM) thresholds were employed to classify valid data as SB (≤100 CPM) [40], LPA (101–1679 CPM), and MVPA (≥1680 CPM), which has been validated and widely used in preschoolers [33, 40]. We calculated the daily durations of SB, LPA, and MVPA (min/d) by dividing the accumulated time of corresponding intensity behaviour over total valid days. To initialize device, download, and analyze accelerometer data, we used the ActiLife 6.13.3.

Children's sleep duration, including both nighttime sleep and naps, was obtained using parental reports. Based on their child's sleep patterns during the most typical week of the past month, parents were instructed to answer the questions: "How many hours of sleep does your child typically have within a 24-hour day on weekdays?" and "How many hours of sleep does your child typically have within a 24-hour day on weekends?". This method of assessing daily sleep has been validated and widely used in young children [41, 42]. For the subsequent analysis, the daily average minutes spent in sleep were weighted at a ratio of 5:2 for weekdays and weekends.

Physical fitness

PREFIT fitness test battery, a tool with established reliability, feasibility, and practical recommendations, was widely used to assess preschoolers' physical fitness [5, 31, 43]. Previous research has described the details of the physical fitness measurements [31]. Briefly, upper limb strength was measured utilizing the grip strength test with Jamar Plus+dynamometer. The best value (kg) for both hands (non-consecutive test twice with each hand) were averaged. Lower limb strength was determined using the standing long jump. The longest jump (cm) from two tests was recorded. The one-leg stance test was used to measure static balance. The average time for the left and right leg (one attempt per leg) was registered in seconds. The 4×10 m shuttle run test was used to measure speed-agility, instructing each child to sprint back and forth between two lines spaced 10 m apart. The test value was the running time in seconds. As the last test, CRF was determined with the 20 m shuttle run test, which instructed each child to run back and forth between two lines spaced 20 m apart. The shuttle run tests were conducted only once. The total laps completed was registered as the final score of CRF. A larger number indicates a better performance, except for speed-agility that is poorer performance with a longer time.

Statistical analysis

R software 4.1.3 was used to conduct all analyses. CoDA was performed with the 'Compositions' and 'robCompositions' packages. This approach represents a mature statistics field applied to multivariable proportion-type data, such as movement behaviour compositions [5].

The arithmetic means and standard deviations were calculated for describing all continuous variables, except for movement behaviours. These variables are roughly normally distributed (skewness<1.5 [44]). Boys were compared with girls using the independent-samples ***t*** tests for these variables. 24-h movement behaviour compositions were referred to in terms of centrality [geometric mean of each movement part (LPA, MVPA, sleep, and SB), and then normalized to collectively sum to the whole day (i.e., 1440 min)] and dispersion (variation matrix) [5, 25]. Boys were compared with girls using compositional multivariate analysis of variance (MANOVA) for movement behaviours. The correlations between different compositions of movement behaviours were investigated using Pearson correlation.

The associations of habitual movement behaviours composition (explanatory variables) with each physical fitness parameter (dependent variable) were examined employing compositional multivariable linear regression models (the method is detailed in Additional file 1). Before being integrated into the models, each movement part was represented by a set of 3 isometric log ratio (ILR) coordinates [45, 46]. To capture aggregated relative influence of each part, 4 regression models were conducted for each physical fitness parameter [45, 46]. The gamma (γ) coefficient of the first ILR coordinate was used to determine the strength and direction of associations, encompassing all the information regarding the composition of the first movement behaviour relative to the other parts [6, 45]. The coefficient of determination ($\boldsymbol{R^2}$) was used to examine model fit and interpret the effect size for the associations following the cutoffs defined by Cohen [47]. To safeguard against assumption violations, we scrutinized the models for linearity, normality, homoscedasticity, and outliers.

Following the methodologies introduced by Dumuid and colleagues [48], we utilized compositional isotemporal substitution to investigate the relationships between reallocating time from one behaviour to another and physical fitness. Specifically, the aforementioned linear models were employed to predict physical fitness at a starting composition (i.e., mean movement behaviours composition), and at new compositions resulting from time reallocation among behaviours. For instance, the new composition representing the substitution of 25 min of SB with 25 min of MVPA was calculated as follows: MVPA=mean MVPA+25 min; SB=mean SB – 25 min; sleep=mean sleep; LPA=mean LPA. The predicted

Table 1 Descriptive characteristics

	Overall ($n=275$)	Boys ($n=149$)	Girls ($n=126$)	*p*
Age (y), mean ± SD	4.98 ± 0.76	5.05 ± 0.72	4.88 ± 0.80	0.06
Height (cm), mean ± SD	110.55 ± 7.07	111.31 ± 7.23	109.65 ± 6.80	0.05
Weight (kg), mean ± SD	19.16 ± 3.61	19.47 ± 3.86	18.78 ± 3.26	0.11
BMI (kg/m^2), mean ± SD	15.57 ± 1.65	15.59 ± 1.72	15.54 ± 1.58	0.78
zBMI, mean ± SD	0.12 ± 1.07	0.13 ± 1.15	0.10 ± 0.98	0.81
Wearing time (min/d), mean ± SD	683.08 ± 49.35	681.24 ± 45.57	685.25 ± 53.57	0.50
Valid days (d), mean ± SD	6.41 ± 1.06	6.42 ± 1.05	6.40 ± 1.09	0.88
Upper limb strength (kg), mean ± SD	5.58 ± 1.83	5.93 ± 1.92	5.18 ± 1.64	**< 0.01**
Lower limb strength (cm), mean ± SD	90.53 ± 18.25	92.39 ± 19.55	88.35 ± 16.41	0.06
Static balance (s), mean ± SD	14.11 ± 13.48	13.05 ± 12.41	15.37 ± 14.60	0.16
Speed-agility (s), mean ± SD	17.24 ± 2.83	17.04 ± 2.88	17.48 ± 2.76	0.20
CRF (laps), mean ± SD	10.32 ± 5.11	10.85 ± 5.73	9.70 ± 4.19	0.06

Note: Bold and denotes statistical significance

Abbreviations: BMI, body mass index; CRF, cardiorespiratory fitness; zBMI, body mass index z-score

absolute changes of physical fitness for the 25 min reallocation were derived by calculating the difference between the two estimated physical fitness. Predictions were repeated for various new compositions using the aforementioned procedure, involving pairwise reallocations in 5-min increments (up to 30 min) based on previous study [25]. Besides, using MVPA as an example, predicted changes in physical fitness across the continuum of reallocations of 0 to 30 min were graphically illustrated. All models for the overall sample were adjusted age, gender and zBMI. All models were stratified by gender, and these models were adjusted age, and zBMI. When $p<0.05$ or the 95% confidence interval (95% CI) does not include 0, statistical significance is considered.

Sample size and power calculation

G*Power 3.1.9.7 was used to calculate sample size and power [49]. Based on recent CoDA-based studies, the smallest effect size for the association between reallocating time from other behaviours to MVPA and physical fitness was 0.07 [4, 5]. With a power of 0.80, an alpha of 0.05, an effect size of 0.07, and dropout rate of 30%, the sample size calculation indicated that at least 246 preschoolers are required. A post hoc power analysis was also conducted to assess the statistical power of the study based on the final sample size, and an alpha of 0.05. The effect sizes for physical fitness parameters ranged from 0.30 to 0.52. Post hoc power analysis indicated that the statistical power of the study was 100%.

Results

Among the initially eligible cohort of 355 participants, complete datasets with the indicators of interest were available for 275 individuals. Descriptive characteristics are summarized in Table 1. Boys had higher levels of upper limb strength than girls ($p<0.05$).

Table 2 Geometric means for each movement behaviour in minutes/day

	Overall ($n=275$)	Boys ($n=149$)	Girls ($n=126$)	*p*
Sleep	677.95	**680.41****	**674.49**	**< 0.01**
SB	568.11	**555.08**	**583.43****	
LPA	112.39	**116.85****	**107.25**	
MVPA	81.55	**87.65****	**74.83**	

Note: Bold and denotes statistical significance. ** $p<0.01$. Physical behaviours have been adjusted to sum to 1440 $\text{min}\cdot\text{day}^{-1}$

Abbreviations: MVPA, moderate-to-vigorous physical activity; LPA, light physical activity; SB, sedentary behaviour

Table 3 Compositional variation matrix for movement behabiours for the overall sample

	Sleep	SB	LPA	MVPA
Sleep	0.000			
SB	0.017	0.000		
LPA	0.032	0.039	0.000	
MVPA	0.070	0.083	0.037	0.000

Note: Values approaching zero represent higher co-dependence between movement behaviour compositions

Abbreviations: MVPA, moderate-to-vigorous physical activity; LPA, light physical activity; SB, sedentary behaviour

The geometric means for movement behaviours are detailed in Table 2. Geometric means of the overall sample revealed that the majority of the 24-h period was devoted to sleep (47.08%), followed by SB (39.45%), LPA (7.81%), and MVPA (5.66%). Gender differences in mean movement behaviours composition were found ($p<0.05$). Boys had higher sleep, LPA and MVPA time than girls, lower SB time ($p<0.05$).

Table 3 communicates the variation matrix for the overall sample. The variance between sleep and SB (0.017) was the lowest, demonstrating the highest co-dependence among the two behaviours. The variance between SB and MVPA (0.083) was the largest, demonstrating the highest independence among the two behaviours. Table S1 presents the variation matrices of both genders. The correlation coefficients between different compositions of movement behaviours are shown in Table S2.

The results of variance analysis of regression parameters are displayed in Table S3. In the overall sample, 24-h movement behaviours composition was significantly related to upper and lower limb strength, speed-agility, and CRF ($p<0.05$). The R^2 values, ranging from 0.30 to 0.52, were above 0.25 for all significant models, indicating large effect sizes [47]. The pattern of association with physical fitness was similar among boys, with the exception of upper limb strength. Only the association with muscular strength demonstrated statistical significance among girls.

The compositional multiple linear regression analyses results for the overall sample are summarized in Table 4. MVPA time relative to other composition parts was positively related to muscular strength and CRF, and negatively related to speed-agility (favorable). SB time relative to other composition parts was negatively related to upper limb strength. LPA time relative to other composition parts was negatively related to lower limb strength and CRF, and positively related to speed-agility (unfavorable). The pattern of associations with physical fitness was similar when CoDA was conducted using 24-h movement behaviours composition for both genders (Table S4).

Table 4 Multiple linear regression analyses of the relationship between ilr coordinates and physical fitness in the overall sample

ilr Regression models	γ-coefficient (95% CI)	*p*
Upper limb strength		
Sleep	0.84 (-0.93, 2.61)	0.35
SB	**-2.13 (-3.76, -0.50)**	**0.01**
LPA	0.01 (-1.61, 1.63)	0.99
MVPA	**1.28 (0.12, 2.45)**	**0.03**
Lower limb strength		
Sleep	13.15 (-3.28, 29.58)	0.12
SB	-13.06 (-28.24, 2.11)	0.09
LPA	**-22.06 (-37.03, -7.10)**	**<0.01**
MVPA	**21.97 (11.19, 32.75)**	**<0.01**
Static balance		
Sleep	1.29 (-13.53, 16.11)	0.86
SB	−0.99 (-14.61, 12.63)	0.89
LPA	1.75 (-11.78, 15.28)	0.80
MVPA	−2.05 (-11.77, 7.66)	0.68
Speed-agility		
Sleep	-1.30 (-3.67, 1.07)	0.28
SB	1.06 (-1.12, 3.24)	0.34
LPA	**2.36 (0.20, 4.53)**	**0.03**
MVPA	**-2.12 (-3.68, -0.57)**	**0.01**
CRF		
Sleep	-3.45 (-8.63, 1.75)	0.19
SB	4.17 (-0.59, 8.94)	0.09
LPA	**-6.27 (-11.01, -1.53)**	**0.01**
MVPA	**5.53 (2.13, 8.93)**	**<0.01**

Note: Analyses adjusted for age, gender, and zBMI. Bold and denotes statistical significance

Abbreviations: MVPA, moderate-to-vigorous physical activity; LPA, light physical activity; SB, sedentary behaviour; γ-coefficient, gamma coefficients; ilr, isometric log ratio; CRF, cardiorespiratory fitness; 95% CI, 95% confidence interval

For all fitness parameters that exhibited a significant association with daily movement behaviours, we performed compositional isotemporal substitution. The predicted changes in upper and lower limb strength, speed-agility, and CRF for the overall sample and according to gender, following reallocation of 30 min among behaviours, are detailed in Tables 5 and 6, respectively.

From Table 5, in the overall sample, when 30 min of SB was substituted with 30 min of MVPA, upper limb strength was estimated to be 0.448 kg higher than the mean upper limb strength. Substituting 30 min of LPA, SB, or sleep with 30 min of MVPA led to significantly higher predicted changes in lower limb strength (11.894, 6.575 and 5.446 cm, respectively) and CRF (3.186, 1.305 and 1.635 laps, respectively), and lower predicted changes in speed-agility (-1.212, -0.626 and −0.525 s, respectively) [favorable] than the predicted mean. These associations were reversed, with the substitution of 30 min in the reverse order (higher LPA, SB, and sleep and lower MVPA) predicting worse physical fitness (lower muscular strength, lower CRF and higher speed-agility [unfavorable]). However, these associations were non-symmetrical. For instance, predicted CRF exhibited a smaller increase when adding 30 min of MVPA (1.305 to 3.186 laps), compared to the decrease in CRF predicted with a reduction of 30 min in MVPA (−3.482 to −2.011 laps).

From Table 6, for girls, reallocating 30 min to MVPA or sleep from SB were related to significantly higher predicted change in upper limb strength than the predicted mean upper limb strength. For both genders, reallocating 30 min to MVPA from other behaviours were related to significantly higher predicted change in lower limb strength, and for boys, significantly higher predicted changes in CRF and lower predicted changes in speed-agility (favorable). These relationships were also opposite and non-symmetrical.

For reallocations of 5 –25 min, predicted changes in upper and lower limb strength, speed-agility, and CRF are communicated in Tables S5, S6, S7 and S8, respectively.

Figure 1 depicts how the regression parameters from the compositional isotemporal substitution can be visualized and interpreted, to inspect the magnitude and asymmetry of a predicted changes in all fitness variables for the overall sample, through reallocating different time to/from MVPA. Visual representations for all fitness variables for boys and girls are available in the Fig. S1 and Fig. S2 respectively.

Table 5 L predicted changes in physical fitness following 30-min reallocation between movement behaviours in the overall sample

	Sleep (95% CI)	**SB (95% CI)**	**LPA (95% CI)**	**MVPA (95% CI)**
Upper limb strength				
Sleep		0.131 (−0.002, 0.265)	0.029 (−0.425, 0.483)	-0.479 (-0.955, 0.002)
SB	-0.128 (-0.260, 0.005)		-0.097 (−0.557, 0.363)	**-0.605** **(-1.062, -0.147)**
LPA	-0.031 (-0.384, 0.322)	0.102 (−0.258, 0.462)		-0.508 (-1.233, 0.216)
MVPA	0.316 (-0.018, 0.649)	**0.448** **(0.134, 0.763)**	0.346 (−0.340, 1.032)	
Lower limb strength				
Sleep		1.107 (−0.136, 2.350)	**6.426** **(2.222, 10.630)**	**-8.235** **(-12.658, -3.812)**
SB	-1.098 (-2.332, 0.137)		**5.351** **(1.091, 9.610)**	**-9.310** **(-13.568, -5.053)**
LPA	**-5.036** **(-8.306, -1.766)**	**-3.907** **(-7.240, -0.574)**		**-13.249** **(-19.961, -6.536)**
MVPA	**5.446** **(2.351, 8.540)**	**6.575** **(3.645, 9.504)**	**11.894** **(5.548, 18.240)**	
Speed-agility				
Sleep		-0.099 (−0.278, 0.081)	**-0.685** **(-1.293, -0.076)**	**0.795** **(0.156, 1.434)**
SB	0.098 (-0.080, 0.276)		-0.589 (-1.205, 0.028)	**0.891** **(0.278, 1.505)**
LPA	**0.535** **(0.062, 1.009)**	0.435 (-0.048, 0.917)		**1.328** **(0.357, 2.300)**
CRF MVPA	**-0.525** **(-0.972, -0.079)**	**-0.626** **(-1.048, -0.205)**	**-1.212** **(-2.131, -0.293)**	
Sleep		-0.325 (-0.717, 0.067)	**1.557** **(0.226, 2.887)**	**-2.326** **(-3.723, -0.930)**
SB	0.321 (-0.068, 0.710)		**1.871** **(0.523, 3.220)**	**-2.011** **(-3.353, -0.670)**
LPA	**-1.149** **(-2.185, -0.114)**	**-1.480** **(-2.535, -0.426)**		**-3.482** **(-5.606, -1.358)**
MVPA	**1.635** **(0.658, 2.613)**	**1.305** **(0.383, 2.227)**	**3.186** **(1.177, 5.195)**	

Note: Analyses adjusted for age, gender, and zBMI. Bold and denotes statistical significance. Values represent estimation of change (95% CI) in physical fitness when time is reallocated from the behaviours in the columns to the behaviours in the rows

Abbreviations: MVPA, moderate-to-vigorous physical activity; LPA, light physical activity; SB, sedentary behaviour; CRF, cardiorespiratory fitness; 95% CI, 95% confidence interval

Discussion

To our knowledge, this is one of the first studies to use CoDA to understand how preschoolers' 24-h movement behaviours related to physical fitness. This is also the first study to use CoDA to investigate these associations across different genders. We found that daily movement behaviours composition, and MVPA in particular, were significantly associated with muscular strength, speed-agility, and CRF. The results of compositional isotemporal substitution consistently highlighted that reallocating time from LPA or SB to MVPA was related to better these physical fitness parameters. The greatest predicted improvements in physical fitness parameters were observed when time of LPA or SB was substituted with time of MVPA. The associations were non-symmetrical: the estimated detriments to physical fitness from replacing MVPA with LPA or SB were larger than the estimated benefits associated with adding MVPA of the same magnitude. Furthermore, the directions of these associations related to physical fitness are similar across different genders. Replacing other behaviours with MVPA was positively associated with upper and lower limb strength in girls, and with lower limb strength, speed-agility, and CRF in boys.

For upper limb strength, we observed that reallocating time to MVPA from SB was related to higher upper limb strength. These findings are in accordance with the only 24-h movement behaviours study related to upper limb strength based on CoDA [4] and a quasi-experimental study [50]. Song et al. [4] reported replacing SB

Table 6 Predicted changes in physical fitness following 30-min reallocation between movement behaviours according to gender

	Sleep **(95% CI)**	**SB** **(95% CI)**	**LPA** **(95% CI)**	**MVPA** **(95% CI)**
Girls				
Upper limb strength				
Sleep		**0.238** **(0.039, 0.438)**	0.167 (-0.521, 0.856)	-0.638 (-1.491, 0.214)
SB	**-0.234** **(-0.433, -0.035)**		-0.063 (-0.752, 0.625)	**-0.869** **(-1.702, -0.035)**
LPA	-0.149 (-0.678, 0.379)	0.093 (-0.436, 0.622)		-0.784 (-2.016, 0.448)
MVPA	0.389 (-0.183, 0.961)	**0.631** **(0.077, 1.184)**	0.559 (-0.555, 1.674)	
Lower limb strength				
Sleep		1.052 (-0.668, 2.772)	5.640 (-0.286, 11.566)	**-8.067** **(-15.405, -0.729)**
SB	-1.043 (-2.754, 0.669)		4.618 (-1.306, 10.542)	**-9.089** **(-16.266, -1.912)**
LPA	-4.374 (-8.922, 0.175)	-3.301 (-7.852, 1.251)		**-12.420** **(-23.025, -1.815)**
MVPA	**5.131** **(0.207, 10.056)**	**6.204** **(1.441, 10.967)**	**10.792** **(1.197, 20.387)**	
Boys				
Lower limb strength				
Sleep		1.101 (-0.701, 2.902)	**6.707** **(0.600, 12.814)**	**-7.363** **(-13.091, -1.635)**
SB	-1.094 (-2.880, 0.691)		5.637 (-0.607, 11.880)	**-8.433** **(-13.897, -2.970)**
LPA	**-5.311** **(-10.110, -0.512)**	-4.187 (-9.138, 0.765)		**-12.650** **(-21.717, -3.583)**
MVPA	**4.992** **(0.863, 9.121)**	**6.116** **(2.247, 9.986)**	**11.723** **(2.898, 20.548)**	
Speed-agility				
Sleep		-0.076 (-0.325, 0.174)	-0.718 (-1.569, 0.133)	0.802 (0.003, 1.601)
SB	0.076 (-0.172, 0.323)		-0.644 (-1.514, 0.226)	**0.876** **(0.117, 1.635)**
LPA	0.564 (-0.105, 1.233)	0.486 (-0.203, 1.176)		**1.364** **(0.098, 2.631)**
MVPA	-0.550 (-1.126, 0.026)	**-0.628** **(-1.165, -0.091)**	**-1.270** **(-2.503, -0.037)**	
CRF				
Sleep		-0.549 (-1.143, 0.045)	**2.103** **(0.074, 4.131)**	**-2.870** **(-4.773, -0.966)**
SB	0.540 (-0.049, 1.129)		**2.633** **(0.561, 4.706)**	**-2.339** **(-4.149, -0.530)**
LPA	-1.563 (-3.157, 0.031)	**-2.121** **(-3.764, -0.478)**		**-4.442** **(-7.460, -1.424)**
MVPA	**2.087** **(0.714, 3.459)**	**1.529** **(0.249, 2.808)**	**4.180** **(1.243, 7.118)**	

Note: Analyses adjusted for age, and zBMI. Bold and denotes statistical significance. Values represent estimation of change (95% CI) in physical fitness when time is reallocated from the behaviours in the columns to the behaviours in the rows

Abbreviations: MVPA, moderate-to-vigorous physical activity; LPA, light physical activity; SB, sedentary behaviour; CRF, cardiorespiratory fitness; 95% CI, 95% confidence interval

by MVPA was associated with better upper limb strength in preschoolers. Popović et al. [50] found that a nine-month structured multisport program at moderate to vigorous intensity led to enhancing upper limb strength. For lower limb strength, we also observed that replacing SB or LPA by MVPA was related to better lower limb strength. Although the only 24-h movement behaviours study related to lower limb strength based on CoDA

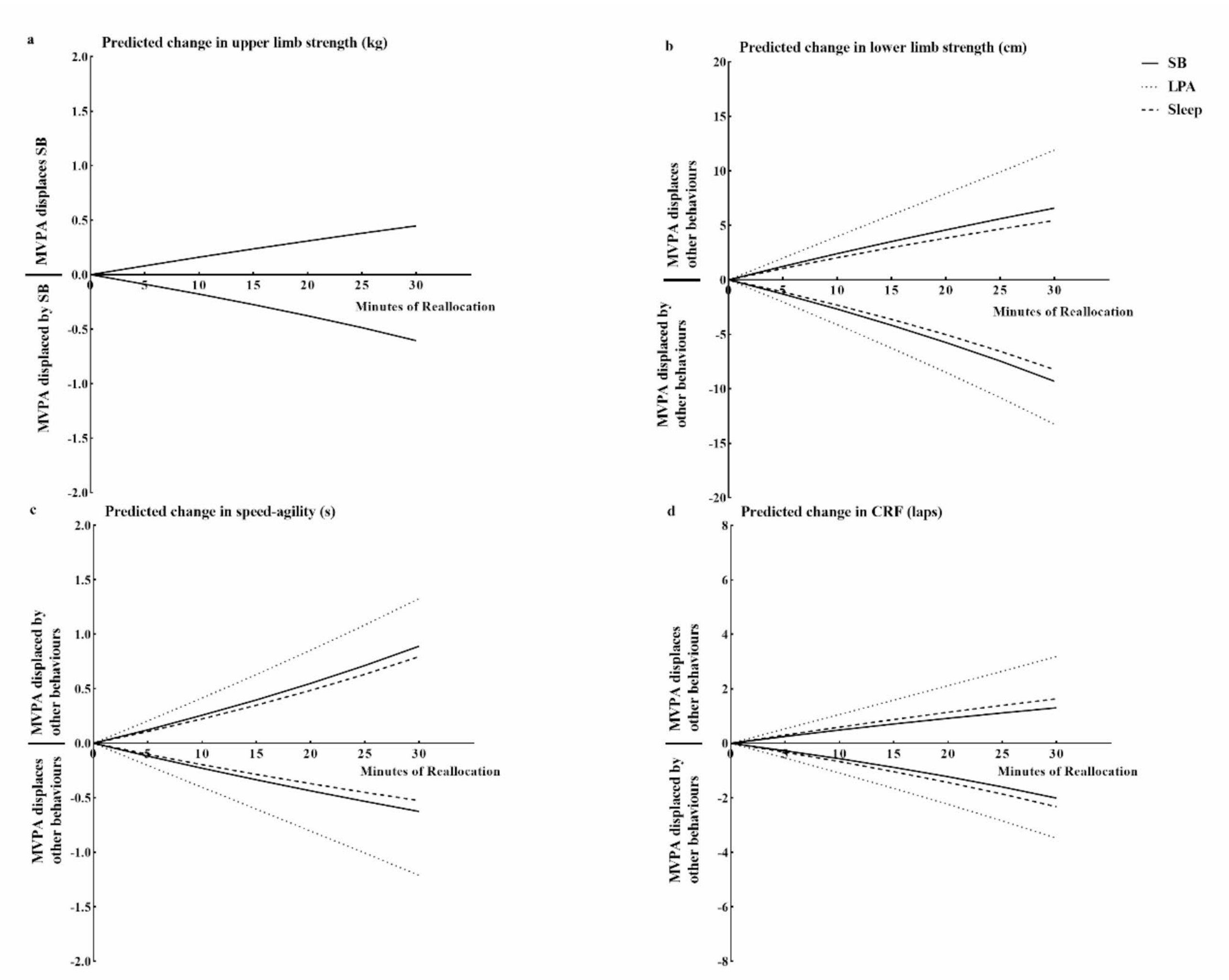

Fig. 1 Asymmetry of predicted changes in physical fitness with the reallocation of time to and from MVPA time in the overall sample. (**a**) Asymmetry of predicted changes in upper limb strength. (**b**) Asymmetry of predicted changes in lower limb strength. (**c**) Asymmetry of predicted changes in speed-agility. (d) Asymmetry of predicted changes in CRF

didn't observe significant associations between reallocating time to MVPA from other behaviours and lower limb strength at cross-sectional level [5], our findings generally align with a quasi-experimental study [50] and a meta-analysis of randomized controlled trials (RCTs) [51]. Current evidence reveals that engaging in more MVPA can place a greater demand on the cardiorespiratory system, potentially contributing to enhancing muscle strength [8]. Besides, growing studies suggested that decreasing lower intensities, while simultaneously increasing MVPA time, was related to better fat-free mass in preschoolers, potentially benefiting muscle strength [3, 9, 10, 31]. These would explain our findings. This is suggestive that reallocating time to MVPA from LPA or SB may be an effective intervention for enhancing muscle strength in preschoolers.

Concerning speed-agility, reallocation results observed an enhanced performance in speed-agility when SB or LPA was replaced with MVPA. This is broadly similar to the only waking movement behaviours study based on CoDA [3] and a meta-analysis of randomized controlled trials (RCTs) [51]. Garcia-Hermoso et al. suggested that MVPA interventions favored improvement in speed-agility in preschoolers [51]. However, previous 24-h movement behaviours studies based on CoDA did not find any significant relationships between reallocating time to MVPA from SB or LPA and speed-agility [4, 5]. There are two plausible explanations for these inconsistent results. Firstly, as recommended for preschoolers, we used shorter epochs, which contribute to capturing PA more closely [9]. Secondly, differences in activities cut-points contribute to the somewhat different results [27]. Nonetheless, given the robust support from high-quality RCTs for our findings [51], we can still hypothesize that performance in speed-agility would be improved when SB or LPA was replaced with MVPA.

CRF is considered one of the most crucial indicators of physical fitness and may link to maintaining health parameters in the later stages of life [5]. Lifelong improvement of CRF is therefore essential. Previous CoDA-based studies observed that MVPA was the leading behaviour within the daily time-use composition that is beneficially related to physical fitness, including CRF [5, 52, 53]. Full movement spectrum CoDA-based study reported substituting SB with MVPA predicted higher CRF in preschoolers [5]. Alternatively, Migueles et al. observed substituting any SB or LPA with MVPA was related to better CRF in preschoolers [3]. A meta-analysis of RCTs supports that MVPA interventions contribute to enhancing CRF in preschoolers [51]. These findings supports our results regarding CRF. One plausible explanation is that more MVPA time leads to acute changes (i.e., increasing in ventilation, blood pressure, heart rate, and energy expenditure), which in combination with adequate recovery will result in long-term changes in metabolism, and thus higher CRF [7].

The associations of daily movement behaviours composition with static balance were not observed, which is broadly similar to a recent non-CoDA based study [54]. There are several plausible explanations for this result. Firstly, the nature of preschoolers' activity, characterized by short bursts of MVPA and intermittency, may not always be sufficient to promote better static balance. Indeed, daily movement behaviours of preschoolers may not comprehensively target al.l dimensions of physical fitness. Previous evidence also supports this speculation, indicating that targeted exercise training (e.g., soccer training) may be necessary to achieve significant improvement in static balance [55]. Secondly, the associations between daily time-use composition and static balance might only become significantly associated in middle to late childhood. Previous research has suggested that the association of movement behaviours with physical fitness increases with children's age [56]. However, the results concerning static balance must be cautiously interpreted, and these associations should be confirmed by future research in preschoolers.

In addition, we found the predicted improvement in speed-agility, lower limb strength, and CRF when substituting sleep with MVPA. Our findings are less consistent with previous studies. A recent review of CoDA studies indicated that reallocating sleep towards MVPA was not associated with physical fitness [53]. The full movement spectrum CoDA-based study by Lemos et al. observed that reallocating sleep towards MVPA was positively associated with CRF but not with speed-agility or lower limb strength [5]. However, another full movement spectrum CoDA-based study observed that reallocating sleep towards MVPA was positively associated with upper limb strength and speed-agility, but not with CRF [4]. The inconsistent results may be attributed to methodological differences in accelerometry measurements, such as variations in epoch lengths and cut-points, as well as differences in baseline time-use compositions and populations [52]. It is noteworthy that these findings are derived from cross-sectional studies that involve theoretical (rather than actual) reallocations of time. Therefore, these findings must be cautiously interpreted. Considering the important role of sufficient sleep in the early development, more research is warranted to identify the optimal combination of sleep and MVPA for maximizing preschoolers' physical fitness.

To our knowledge, no study has conducted a comprehensive examination of the associations between physical fitness and the full movement spectrum based on gender. We bridged this gap using CoDA and observed that MVPA, and not lower intensities, was the leading behaviour within the daily movement behaviours composition beneficially related to physical fitness parameters for both genders. For upper limb strength, we observed a significant association only in girls. Further analysis showed that replacing SB with MVPA or sleep was related to higher upper limb strength. Due to lacking previously published evidence using CoDA, direct comparison with other studies is difficult. Further investigations are warranted to validate these findings and determine the reasons for this occurrence. For lower limb strength, we found that replacing other behaviours by MVPA predicted higher lower limb strength regardless of gender, which is in line with a recent non-CoDA study [56]. One plausible explanation is that the popular types of MVPA (e.g., running) for preschoolers may predominantly target the lower-limb muscles, thereby enhancing lower limb strength [9]. Additionally, we also observed that replacing other behaviours with MVPA was related to better CRF and speed-agility, but only in boys. Direct comparison with previously published research is not feasible due to the absence of CoDA evidence. However, our findings are partly similar to the research of Zhang et al. [57], which observed a positive association between higher intensity PA and CRF only in boys. One plausible explanation for our results is that the MVPA boys accumulated is a higher average intensity than that of girls. Therefore, an absolute amount of time may have a stronger relationship with improved health in boys. Taken collectively, our findings support that MVPA, and not lower intensities, is an effective accelerator of preschoolers' physical fitness regardless of gender.

In accordance with a recent review of CoDA studies [52], the predicted changes observed for the reallocation of time were non-symmetrical regardless of gender. In particular, increasing MVPA above the mean may result in a lower estimated benefit to physical fitness parameters than the estimated detriment following an equivalent magnitude decrease below the mean. The non-symmetrical relationships have been attributed, in part, to the relative contributions of each movement behaviour to the 24-h day [25, 27]. For instance, taking 10 min from MVPA (12.3% change in MVPA) represents a more significant relative change than it does in SB (1.8% change in SB in our sample). Furthermore, detraining and reversibility, such as engaging in more SB, are likely to rapidly induce a more significant negative impact on health, in contrast, overloading exercise capacity, such as engaging in more MVPA, slowly induces physiological adaptations, thereby yielding lower returns [25, 27].

Our results have significant public health implications in prompting physical fitness. They reinforce that the synergy of daily movement behaviours may achieve the maximum health and endorse the recently updated PA guidelines, which advocate for MVPA as the preferred intensity for maximizing health benefits [13]. Therefore, caregivers, early childhood development professionals, and policymakers should recognize the significance of creating opportunities that facilitate the transition of preschoolers' time-use composition from lower intensities to MVPA, especially in the context of the small proportion meeting MVPA guideline [58]. The feasibility of this shift largely depends on the movement settings and contexts [27]. Preschools create various discretionary, such as recess games, and mandatory opportunities, such as organized aerobics class, to promote MVPA in preschoolers. Integrated PA Promotion plans in Schools are acknowledged as validated strategies to expand, extend, and enhance these opportunities [27]. However, MVPA levels after school have significantly decreased and are significantly influenced by parents and peers [27]. In community and home settings, enhancing opportunities for MVPA, with a particular emphasis on acknowledging the pivotal roles of caregivers, can be recognized as a complementary strategy to more structured promotional efforts in schools.

This study exhibits several strengths. Firstly, this study uses CoDA to examine the associations of daily movement behaviours with physical fitness parameters. Our findings contribute to the current understanding of these associations in both the general population and within specific subgroups, and lay the groundwork for future research in this area. Secondly, SB and PA were objectively monitored using an ActiGraph GT9X accelerometer, reducing risk of recall bias. Finally, physical fitness parameters were accurately determined using PREFIT battery [31], allowing comparison with other studies. Nonetheless, our research is not without limitations. Firstly, an important limitation of any cross-sectional setting is that causation cannot be determined. Secondly, sleep duration is collected using parental reports, which has known reporting bias. Furthermore, accelerometers cannot discriminate completely SB type and may not detect some types of movement (e.g., swimming and cycling). Although we have considered some sociodemographic confounders in our analyses, residual confounding (e.g., dietary factors) remains possible. Another limitation of this study is the exclusion of children with overweight and obesity. However, a previous study showed that the estimated benefits to physical fitness from replacing MVPA with other behaviours in overweight/obese schoolchildren were greater than the benefits associated with adding an equivalent amount of MVPA in schoolchildren of normal weight [27]. This suggests that our findings may also be applicable to overweight/obese preschoolers, and that the strength of this association could be greater in these populations. Finally, participants were recruited from urban and suburban kindergartens using convenience sampling, which may limit our findings' generalizability. Future research, using a larger and more representative sample in longitudinal studies and RCTs, is warranted to establish the causation and generalizability of results.

Conclusion

This study observed that greater MVPA, but not LPA, was significantly related to better upper and lower limb strength, speed-agility, and CRF. Replacing LPA or SB with MVPA was related to better physical fitness. The estimated changes were non-symmetrical when LPA or SB substituted MVPA. These relationships varied with gender. Broadly, these findings reinforce the importance of PA intensity for promoting physical fitness development in the early stage. Replacing LPA or SB time with MVPA may be an appropriate strategy for better physical fitness in preschoolers.

Abbreviations

BMI	Body mass index
CoDA	Compositional data analysis
CRF	Cardiorespiratory fitness
CPM	Count-per-minute
ILR	Isometric log ratio
LPA	Light physical activity
MVPA	Moderate-to-vigorous physical activity
PA	Physical activity
SB	sedentary behaviour
95% CI	95% confidence interval
γ-coefficient	Gamma coefficient

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-20290-6.

Supplementary Material 1

Supplementary Material 2

Acknowledgements

We would like to sincerely thank the contributions of all the participants and research staff of the study.

Author contributions

TZ, JXW, HYG, and ZXL designed the research; ZXL, HWZ, JG, CZ, FW, YHB, BQ, and XHL conducted the study; TZ, JXW, CHL, JW, and ZXL conceptualized and designed the analysis; TZ, JXW and ZXL accessed and verified the underlying data reported in the manuscript; ZXL performed the analysis and wrote the manuscript; TZ and JXW critically revised the manuscript. All authors read and approved the final manuscript.

Funding

This study was supported by Beijing Finance Bureau (CIP2024-0040), The Special Fund of the Pediatric Medical Coordinated Development Center of Beijing Hospitals Authority (XTZD20180402), and Public service development and reform pilot project of Beijing Medical Research Institute (BMR2021-3). The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Data availability

The datasets generated during and/or analysed during the current study are obtainable from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the Ethics Committee of the Capital Institute of Pediatrics (NO. SHERLL2021069). Informed consent was gained for all participants from their parents or guardians.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Beijing Municipal Key Laboratory of Child Development and Nutriomics, Capital Institute of Pediatrics, Beijing, China
[2]Department of Allergy, Children's Hospital of Capital Institute of Pediatrics, Beijing, China
[3]School of Kinesiology and Health, Capital University of Physical Education and Sports, Beijing, China
[4]School of Public Health, Hebei University, Baoding, China
[5]Jinding Street Kindergarten, Shougang Preschool Education Center, Beijing, China
[6]Child Growth Data Center, Beijing Economic and Technological Development Zone Froebel (Fu Wa) Kindergarten, Beijing, China
[7]Nurturing Care Research and Guidance Center, Child Healthcare Center, Capital Institute of Pediatrics, Beijing, China
[8]Beijing Tongren Hospital, Capital Medical University, Beijing, China

Received: 3 July 2024 / Accepted: 4 October 2024

References

1. Zou R, Wang K, Li D, Liu Y, Zhang T, Wei X. Study on the relationship and related factors between physical fitness and health behavior of preschool children in southwest China. BMC Public Health. 2024;24(1):1759.
2. Martinez-Tellez B, Sanchez-Delgado G, Cadenas-Sanchez C, Mora-Gonzalez J, Martin-Matillas M, Lof M, Ortega FB, Ruiz JR. Health-related physical fitness is associated with total and central body fat in preschool children aged 3 to 5 years. Pediatr Obes. 2016;11(6):468–74.
3. Migueles JH, Delisle Nystrom C, Leppanen MH, Henriksson P, Lof M. Revisiting the cross-sectional and prospective association of physical activity with body composition and physical fitness in preschoolers: a compositional data approach. Pediatr Obes. 2022;17(8):e12909.
4. Song H, Lau PWC, Wang J, Liu Y, Song Y, Shi L. 24-H movement behaviors and physical fitness in preschoolers: a compositional and isotemporal reallocation analysis. J Exerc Sci Fit. 2024;22(3):187–93.
5. Lemos L, Clark C, Brand C, Pessoa ML, Gaya A, Mota J, Duncan M, Martins C. 24-hour movement behaviors and fitness in preschoolers: a compositional and isotemporal reallocation analysis. Scand J Med Sci Sports. 2021;31(6):1371–9.
6. Powell C, Browne LD, Carson BP, Dowd KP, Perry IJ, Kearney PM, Harrington JM, Donnelly AE. Use of Compositional Data Analysis to show estimated changes in Cardiometabolic Health by reallocating time to light-intensity physical activity in older adults. Sports Med. 2020;50(1):205–17.
7. Ketels M, Rasmussen CL, Korshøj M, Gupta N, De Bacquer D, Holtermann A, Clays E. The relation between Domain-Specific Physical Behaviour and Cardiorespiratory Fitness: a cross-sectional compositional data analysis on the physical activity Health Paradox using accelerometer-assessed data. Int J Environ Res Public Health 2020;17(21).
8. Dumuid D, Wake M, Burgner D, Tremblay MS, Okely AD, Edwards B, Dwyer T, Olds T. Balancing time use for children's fitness and adiposity: evidence to inform 24-hour guidelines for sleep, sedentary time and physical activity. PLoS ONE. 2021;16(1):e0245501.
9. Leppänen MH, Nyström CD, Henriksson P, Pomeroy J, Ruiz JR, Ortega FB, Cadenas-Sánchez C, Löf M. Physical activity intensity, sedentary behavior, body composition and physical fitness in 4-year-old children: results from the ministop trial. Int J Obes (Lond). 2016;40(7):1126–33.
10. Henriksson P, Cadenas-Sanchez C, Leppanen MH, Delisle Nystrom C, Ortega FB, Pomeroy J, Ruiz JR, Lof M. Associations of Fat Mass and Fat-Free Mass with Physical Fitness in 4-Year-old children: results from the MINISTOP Trial. Nutrients 2016;8(8).
11. Wyszynska J, Matlosz P, Asif M, Szybisty A, Lenik P, Deren K, Mazur A, Herbert J. Association between objectively measured body composition, sleep parameters and physical activity in preschool children: a cross-sectional study. BMJ Open. 2021;11(1):e042669.
12. Fu J, Sun S, Zhu S, Wang R, Chen D, Chen R, Xue R, Lv W, Zhang Y, Huang T et al. Relationship between 24-h activity behavior and body fat percentage in preschool children: based on compositional data and isotemporal substitution analysis. BMC Public Health 2024;24(1).
13. WHO. WHO Guidelines on Physical Activity, Sedentary Behaviour and Sleep for Children Under 5 Years of Age. In.; 2019.
14. Rollo S, Antsygina O, Tremblay MS. The whole day matters: understanding 24-hour movement guideline adherence and relationships with health indicators across the lifespan. J Sport Health Sci. 2020;9(6):493–510.
15. Leppänen MH, Henriksson P, Delisle Nyström C, Henriksson H, Ortega FB, Pomeroy J, Ruiz JR, Cadenas-Sanchez C, Löf M. Longitudinal physical activity, body composition, and physical fitness in preschoolers. Med Sci Sports Exerc. 2017;49(10):2078–85.
16. Leppanen MH, Henriksson P, Delisle Nystrom C, Henriksson H, Ortega FB, Pomeroy J, Ruiz JR, Cadenas-Sanchez C, Lof M. Longitudinal physical activity, body composition, and physical fitness in preschoolers. Med Sci Sports Exerc. 2017;49(10):2078–85.
17. Poitras VJ, Gray CE, Janssen X, Aubert S, Carson V, Faulkner G, Goldfield GS, Reilly JJ, Sampson M, Tremblay MS. Systematic review of the relationships between sedentary behaviour and health indicators in the early years (0–4 years). BMC Public Health. 2017;17(Suppl 5):868.
18. Poitras VJ, Gray CE, Borghese MM, Carson V, Chaput JP, Janssen I, Katzmarzyk PT, Pate RR, Connor Gorber S, Kho ME, et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. Appl Physiol Nutr Metab. 2016;41(6 Suppl 3):S197–239.
19. Carson V, Tremblay MS, Chaput JP, Chastin SF. Associations between sleep duration, sedentary time, physical activity, and health indicators among Canadian children and youth using compositional analyses. Appl Physiol Nutr Metab. 2016;41(6 Suppl 3):S294–302.
20. Dumuid D, Pedisic Z, Stanford TE, Martin-Fernandez JA, Hron K, Maher CA, Lewis LK, Olds T. The compositional isotemporal substitution model: a method for estimating changes in a health outcome for reallocation of time between sleep, physical activity and sedentary behaviour. Stat Methods Med Res. 2019;28(3):846–57.
21. Walmsley R, Chan S, Smith-Byrne K, Ramakrishnan R, Woodward M, Rahimi K, Dwyer T, Bennett D, Doherty A. Reallocation of time between device-measured movement behaviours and risk of incident cardiovascular disease. Br J Sports Med 2021.
22. Pelclová J, Štefelová N, Dumuid D, Pedišić Ž, Hron K, Gába A, Olds T, Pechová J, Zając-Gawlak I, Tlučáková L. Are longitudinal reallocations of time between movement behaviours associated with adiposity among elderly women?

A compositional isotemporal substitution analysis. Int J Obes (Lond). 2020;44(4):857–64.
23. Pearson P K. Mathematical contributions to the theory of evolution.—On a form of spurious correlation which may arise when indices are used in the measurement of organs. Proc Royal Soc Lond. 1897;60(359–367):489–98.
24. Migueles JH, Delisle Nyström C, Dumuid D, Leppänen MH, Henriksson P, Löf M. Longitudinal associations of movement behaviours with body composition and physical fitness from 4 to 9 years of age: structural equation and mediation analysis with compositional data. Int J Behav Nutr Phys Activity 2023;20(1).
25. Lu Z, Qu X, Chang J, Xu M, Song G, Wang X, Okely AD, Zhang T, Guan H, Wu J. Reallocation of time between preschoolers' 24-h movement behaviours and executive functions: a compositional data analysis. J Sports Sci. 2023;41(12):1187–95.
26. Dumuid D, Lewis LK, Olds TS, Maher C, Bondarenko C, Norton L. Relationships between older adults' use of time and cardio-respiratory fitness, obesity and cardio-metabolic risk: a compositional isotemporal substitution analysis. Maturitas. 2018;110:104–10.
27. Fairclough SJ, Dumuid D, Taylor S, Curry W, McGrane B, Stratton G, Maher C, Olds T. Fitness, fatness and the reallocation of time between children's daily movement behaviours: an analysis of compositional data. Int J Behav Nutr Phys Act. 2017;14(1):64.
28. Zhang T, Li H, Li C, Zhang L, Zhang Z. Relationship between 24-hour Movement Behaviour & Physical Fitness among Adolescents Using Compositional Data Analysis. Med Sci Sports Exerc. 2021;53(8S):250–250.
29. Leppanen MH, Ray C, Wennman H, Alexandrou C, Saaksjarvi K, Koivusilta L, Erkkola M, Roos E. Compliance with the 24-h movement guidelines and the relationship with anthropometry in Finnish preschoolers: the DAGIS study. BMC Public Health. 2019;19(1):1618.
30. Quan M, Zhang H, Zhang J, Zhou T, Zhang J, Zhao G, Fang H, Sun S, Wang R, Chen P. Are preschool children active enough in Shanghai: an accelerometer-based cross-sectional study. BMJ Open. 2019;9(4):e024090.
31. Cadenas-Sanchez C, Intemann T, Labayen I, Peinado AB, Vidal-Conti J, Sanchis-Moysi J, Moliner-Urdiales D, Rodriguez Perez MA, Canete Garcia-Prieto J, Fernandez-Santos JDR, et al. Physical fitness reference standards for preschool children: the PREFIT project. J Sci Med Sport. 2019;22(4):430–7.
32. WHO Child Growth Standards. Dev Med Child Neurol. 2009;51(12):1002–1002.
33. Pate RR, Almeida MJ, McIver KL, Pfeiffer KA, Dowda M. Validation and calibration of an accelerometer in preschool children. Obes (Silver Spring). 2006;14(11):2000–6.
34. Pate RR, O'Neill JR, Brown WH, Pfeiffer KA, Dowda M, Addy CL. Prevalence of compliance with a New Physical Activity Guideline for Preschool-Age Children. Child Obes. 2015;11(4):415–20.
35. Guan H, Zhang Z, Wang B, Okely AD, Tong M, Wu J, Zhang T. Proportion of kindergarten children meeting the WHO guidelines on physical activity, sedentary behaviour and sleep and associations with adiposity in urban Beijing. BMC Pediatr. 2020;20(1):70.
36. Choi L, Liu Z, Matthews CE, Buchowski MS. Validation of accelerometer wear and nonwear time classification algorithm. Med Sci Sports Exerc. 2011;43(2):357–64.
37. Addy CL, Trilk JL, Dowda M, Byun W, Pate RR. Assessing preschool children's physical activity: how many days of accelerometry measurement. Pediatr Exerc Sci. 2014;26(1):103–9.
38. Byun W, Beets MW, Pate RR. Sedentary behavior in preschoolers: how many days of Accelerometer Monitoring is needed? Int J Environ Res Public Health. 2015;12(10):13148–61.
39. Bisson M, Tremblay F, Pronovost E, Julien AS, Marc I. Accelerometry to measure physical activity in toddlers: determination of wear time requirements for a reliable estimate of physical activity. J Sports Sci. 2019;37(3):298–305.
40. Trost SG, Fees BS, Haar SJ, Murray AD, Crowe LK. Identification and validity of accelerometer cut-points for toddlers. Obes (Silver Spring Md). 2012;20(11):2317–9.
41. Mota JG, Clark CCT, Bezerra TA, Lemos L, Reuter CP, Mota J, Duncan MJ, Martins CML. Twenty-four-hour movement behaviours and fundamental movement skills in preschool children: a compositional and isotemporal substitution analysis. J Sports Sci. 2020;38(18):2071–9.
42. Bezerra TA, Clark CCT, Souza Filho AN, Fortes LS, Mota J, Duncan MJ, Martins CML. 24-hour movement behaviour and executive function in preschoolers: a compositional and isotemporal reallocation analysis. Eur J Sport Sci. 2021;21(7):1064–72.
43. Cadenas-Sanchez C, Martinez-Tellez B, Sanchez-Delgado G, Mora-Gonzalez J, Castro-Pinero J, Lof M, Ruiz JR, Ortega FB. Assessing physical fitness in preschool children: feasibility, reliability and practical recommendations for the PREFIT battery. J Sci Med Sport. 2016;19(11):910–5.
44. Bourke M, Vanderloo LM, Irwin JD, Burke SM, Johnson AM, Driediger M, Timmons BW, Tucker P. Association between childcare movement behaviour compositions with health and development among preschoolers: finding the optimal combinations of physical activities and sedentary time. J Sports Sci 2022;1–10.
45. Kim Y, Burns RD, Lee DC, Welk GJ. Associations of movement behaviors and body mass index: comparison between a report-based and monitor-based method using Compositional Data Analysis. Int J Obes (Lond). 2021;45(1):266–75.
46. Aitchison J. The Statistical Analysis of Compositional Data. J Roy Stat Soc: Ser B (Methodol). 1982;44(2):139–60.
47. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, N.J: L. Erlbaum Associates; 1988.
48. Dumuid D, Stanford TE, Martin-Fernandez JA, Pedisic Z, Maher CA, Lewis LK, Hron K, Katzmarzyk PT, Chaput JP, Fogelholm M, et al. Compositional data analysis for physical activity, sedentary time and sleep research. Stat Methods Med Res. 2018;27(12):3726–38.
49. Kang H. Sample size determination and power analysis using the G*Power software. J Educ Eval Health Prof. 2021;18:17.
50. Popović B, Cvetković M, Mačak D, Šćepanović T, Čokorilo N, Belić A, Trajković N, Andrašić S, Bogataj Š. Nine months of a structured Multisport Program improve physical fitness in Preschool children: a quasi-experimental study. Int J Environ Res Public Health 2020;17(14).
51. Garcia-Hermoso A, Alonso-Martinez AM, Ramirez-Velez R, Izquierdo M. Effects of Exercise intervention on Health-related physical fitness and blood pressure in Preschool children: a systematic review and Meta-analysis of Randomized controlled trials. Sports Med. 2020;50(1):187–203.
52. Miatke A, Olds T, Maher C, Fraysse F, Mellow ML, Smith AE, Pedisic Z, Grgic J, Dumuid D. The association between reallocations of time and health using compositional data analysis: a systematic scoping review with an interactive data exploration interface. Int J Behav Nutr Phys Activity. 2023;20(1):127.
53. Zahran S, Visser C, Ross-White A, Janssen I. A systematic review of compositional analysis studies examining the associations between sleep, sedentary behaviour, and physical activity with health indicators in early childhood. J Activity Sedentary Sleep Behav. 2023;2(1):1.
54. Nilsen AKO, Anderssen SA, Loftesnes JM, Johannessen K, Ylvisaaker E, Aadland E. The multivariate physical activity signature associated with fundamental motor skills in preschoolers. J Sports Sci. 2020;38(3):264–72.
55. Shen K, Liu Y. Effects of Soccer Exercise on Balance ability and Kinesthesia of the lower limb joints in children aged 5–6 years. Motor Control. 2022;26(2):213–25.
56. Serrano-Gallen G, Arias-Palencia NM, Gonzalez-Villora S, Gil-Lopez V, Solera-Martinez M. The relationship between physical activity, physical fitness and fatness in 3–6 years old boys and girls: a cross-sectional study. Transl Pediatr. 2022;11(7):1095–104.
57. Zhang L, Li H, Zhang Z. Association of 24-hour activity behaviors and cardiorespiratory fitness in Chinese adolescents: Compositional Data Analysis. Med Sci Sports Exerc. 2022;54(9S):506–506.
58. Gao W, Zhang Y, Wu D, Dong Y, Liu N, Wang H. Compliance with Health-related behaviors guidelines and its relationship with multiple factors in Preschool Children aged 3–6 years: a National Cross-sectional Survey in China. Int J Environ Res Public Health 2022;19(3).

Publisher's note