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24-hour movement behaviours and fitness in preschoolers: a compositional and isotemporal reallocation analysis

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Abstract

This study aimed to analyze the associations between the 24-hour movement composition behaviours and fitness in preschoolers; and to investigate predicted changes in fitness when time in active behaviours are isotemporally reallocated. This cross-sectional study was carried out with 270 preschoolers (132 boys, means age = 3.97 ± 0.80). Physical activity (PA) and sedentary behaviour (SB) were verified using an accelerometer for 7 days. Sleep time was obtained through interviews with parents. Components of physical fitness (cardiorespiratory fitness - CRF, speed-agility, and lower body muscular strength) were assessed using the PREFIT Battery. To verify the association between 24-hour movement behaviours and physical fitness, the compositional analysis was used, and for the time reallocation, the compositional isotemporal substitution analysis was used for active behaviours (light and moderate-to-vigorous PA).The daily time-use composition, adjusted for body mass index, sex, and age, was significantly associated with CRF (P=0.007; r^2=0.29), speed-agility (P<0.001; r^2=0.14), and lower body muscular strength (P=0.01; r^2=0.07), respectively. For CRF, the addition of moderate-to-vigorous PA, at the expense of any other behaviour, was associated with significant improvements. For speed-agility and lower body muscular strength, only reallocations between Sleep and light PA yielded significant associations. The variation in CRF, speed-agility, and lower body muscular strength were associated with the 24h movement composition, and reallocating 5, 10 or 15 minutes of SB or sleep for MVPA was significantly positive for CRF (P<0.05). The present findings highlight the relevance of decreasing SB and increasing PA practice, particularly at high intensities, to promote a better CRF profile for preschoolers.

Keywords: preschoolers, compositional analysis, physical fitness

1.Introduction

Physical fitness refers to the ability to engage in daily physical activity (PA), without excessive fatigue, to respond to environmental demands, and to maintain and improve health [1]. ~~Moreover, in preschool children, physical fitness has been characterized as a combination of cardiorespiratory, musculoskeletal, and motor fitness, and regarded as an important marker of children´s present and future health [2,3].~~ Although previous cross-sectional and longitudinal studies [2,4] have reported that individual PA behaviours, e.g. moderate-to-vigorous physical activity (MVPA), are positively associated with physical fitness in preschoolers, the composition of a 24-h day comprises various co-dependent movement behaviours, such as, PA, sedentary behavior (SB), and sleep, that must be appropriately considered. Indeed, physical fitness is only partly genetically determined, and is greatly influenced by environmental factors [2], such as movement behaviours.

There is a growing interest in public health research and practice related to PA, SB, and sleep time throughout the day, as contemporary research has showcased that these combined behaviors are significantly related to health [5]. Moreover, when considering behaviours compositionally, positive health changes have been shown to be achievable by reallocating time between these behaviours among youth, adults, and the elderly. The new 24-Hour

Guidelines on Movement Behaviours for the Early Years, proposed by the World Health Organization (WHO) [6], recommends that, for preschoolers up to 4 years-old, a healthy 24-h during includes: i) ≥180 minutes of PA, including at least 60 minutes of MVPA, ii) ≤1 hour of sedentary behaviour based on screen time, and iii) between 10 and 13 hours of good quality sleep. Whilst for 5 years-old children, Tremblay et al., [7] stated that besides PA, a healthy 24-h day should include less than 2 hours of screen time, and between 9 and 11 hours of good quality sleep. Although the importance of these movement behaviours for health is evident, reports from several countries worldwide have shown that less than 15% of preschool aged-children are compliant with the three recommendations of the WHO guidelines [8-10], and in Brazilian preschoolers, this adherence is markedly lower [11], and may compromise children´s short and long-term health.

A recent systematic review on the relationship between movement behaviours and health outcomes in young children reported that, across observational and experimental study designs, SB and PA patterns concordant with international guidelines were favorably associated with fitness among preschool-aged children [12], and when theoretically replacing time in SB at the expense of different PA intensities, additional time spent in vigorous physical activity (VPA) was associated with a better physical fitness profile. Nonetheless, it is important to highlight that information concerning fitness measures was based in the results of only one cross-sectional study [13], which provided a low-to-very low degree of evidence. Consequently, it is vital that research on this topic be conducted, to elucidate the possible associations between movement behaviours and fitness in preschool children, and appropriately considering the compositional nature of daily time-use. Thus, this study sought to, 1) analyze the associations between the 24-hour movement composition behaviours and fitness in preschoolers; and 2) investigate predicted changes in fitness when time in active behaviours (LPA and MVPA) are isotemporally reallocated.

2. Methods

2.1 Setting and Population Characteristics

For this cross-sectional study, preschool children aged 3- to 5-year-old, of both sexes, and registered in early education childhood centers (EECC) of João Pessoa were eligible. João Pessoa is a large seaside city in the northeast of Brazil, with a mixture of low to middle income, and formal, as well as informal housing. The preschool public education zone is organized in nine districts, where eighty-six EECC are located, and six districts have 3-to-5 years old children registered. For the purpose of this study, one school in each district was randomly selected, totalizing 573 registered preschoolers of varying ages. All children aged 3 to 5 years-old (322) were invited for assessments. From those, 13 did not return the informed consent form, 14 children were absent on assessment days, 4 refused to participate or gave up during the assessments, and 21 did not validate accelerometer data. A total of 270 eligible children aged 3-to-5 years provided valid accelerometer data, sleep/screen time information, and participated in the fitness assessments. From those children, the majority of mothers or fathers (64.5%) were unemployed. Over 47% of the mothers and 46% of the fathers had finished the 9th grade or less. The Human Development Index (HDI) for the EECC´s areas range from 0.4 to 0.5 (low).

2.2. Procedures

All the preschools' staff and parents were informed about the research's goals, protocols, and procedures in meetings with the project coordinator (one session in each school) and agreed to participate in the present study. Trained physical education teachers and graduate students conducted the assessments. The school administration provided all socio-demographic data (children's age, birth date, parent's contact, and address). Parents / caregivers were invited for a meeting at school and were interviewed individually. The interview was conducted with different children´s caregivers (5.4% fathers, 76.2% mothers, 2.0% older brothers, 8.8% grandparents, 2.2% uncle, 5.4% others). Demographic information, and screen and sleep time were collected during this interview.

Assessments were conducted during a four-month period (November / December, 2019, and February / March, 2020). Anthropometric data were assessed at preschools, and the accelerometer was placed on the participating children, who wore the monitor for 7 consecutive days.

2.3. Measurements

2.3.1. Anthropometric Measures

Height (cm) and body mass (kg) were assessed using a *Holtain* stadiometer, and weighting scale (Seca 708, Germany), while the participant was lightly dressed and barefoot. Two measures were taken, if they differed, the average value was adopted. BMI was calculated by dividing body weight with the squared height in meters (kg/m^2) [14], and children were classified according to the WHO cut-offs [15].

2.3.2. Physical Activity

PA was objectively assessed using accelerometry (Actigraph, model WGT3-X, Florida), a valid instrument for measuring PA in preschoolers. The preschool teachers received training (verbal and written instructions) for the correct use of the accelerometer, including placement, and the proper positioning. The participants were instructed to wear the accelerometer on the right hip for seven consecutive days (Wednesday morning to Tuesday afternoon). Children were allowed to remove the device during water-based activities and while sleeping (at night). During preschool time, accelerometers were removed by teachers around 11 am for children´s bath and attached properly after it. Parents were also instructed to remove the belt during night and attach when children woke up.

The device initialization, data reduction, and analysis were performed using the ActiLife software (Version 6.13.3). Data were registered using a sampling frequency of 90Hz, processed using normal filter, and analyzed as ActiGraph counts considering vector magnitude. A 15-s epoch length was used, and data were reintegrated in 60-s epochs for analysis. Periods of ≥ 20 min of consecutive zero counts were defined as non-wear time and removed from the analysis. The first day of accelerometer data was omitted from analysis to avoid subject reactivity [17]. Valid data were considered for a minimum of 8 h of wear time, during at least three days (one weekend day and two weekdays). The mean wear time was 10.9 hours (SD ± 1.4h of wear time between children).

Time spent in the commonly defined intensity domains light, moderate and vigorous was estimated using the cut-points proposed by Butte et al. [18] for vector magnitude, with light-intensity defined as 820 to 3.907 counts, moderate-intensity defined as 3.908 to 6.111 counts and vigorous-intensity as ≥ 6.112 counts. The cut-point used for sedentary time was set at 819 counts. For the statistical analysis, sedentary time, Light physical activity (LPA), and MVPA weres considered.

2.3.3. Sleep Time

Parents reported children’s usual daily sleep hours. Parents were asked, in a face-to-face interview, to recall the total average hours their child sleep as follows: “On weekdays, how many hours of sleep does your child usually have during the night?” and “On weekend days, how many hours of sleep does your child usually have during the night?”. Separate questions were asked for weekdays and weekend days and were subsequently merged for analysis. Overall sleep hours were calculated as follows: ((Sleep on weekdays x 5) + (Sleep on weekend days x 2))/7. The results were multiplied by 60 to represent minutes per day. This approach has been previously used in a similar population [19], and has been validated against estimates from sleep logs and objective actigraphy in young children [20].

2.3.4. Physical fitness

The protocol included reliable and feasible assessments of three health-related fitness tests from the PREFIT Battery [14], as follow:

a) Cardiorespiratory fitness (CRF) was measured using the PREFIT 20-m shuttle run test [21]. Participants completed PREFIT 20-m shuttle run keeping in time with an audible "bleep" signal. The frequency of the sound signals was increased every minute, by 0.5 km/h, increasing the intensity of the test, and youth were encouraged to run to exhaustion. Some adaptations of the original test were made by decreasing the initial speed (i.e. 6.5km/h instead of the original 8.5km/h). Evidence for the acceptable reliability and validity of the PREFIT 20-m shuttle run test for preschoolers has been previously provided [21].
b) Speed-agility (shuttle-run test 4x10m) consisted in running and turning as fast as possible between two parallel lines (10 m apart), covering a distance of 40 m. The best of two attempts was recorded (seconds). The test has provided a good correlation in boys and girls (r = 0.86) [14] .
c) Lower-body muscular strength was assessed by the standing long jump. From a parallel standing position and with arms hanging loose to the side, participants were instructed to jump twice as far as possible in horizontal direction and to land on both feet. The test score (best of two trials) was the distance in centimeters, measured form the starting line to the point where the back of the heel landed on the floor, as previously proposed [14].

2.4. Statistical procedures

Compositional data analyses were conducted in R (http://cran.r-project.org) using the compositions (version 1.40-1), robCompositions (version 0.92-7) [22,23], and lmtest (version 0.9-35) packages. The time-use composition (daily time spent in sleep, SB, LPA, and MVPA) was referred to in terms of central tendency, i.e. the geometric mean of time spent in each component, linearly adjusted so that all components summed to the total day, which for purposes of this study, was bound to 1,440 minutes. Multivariate dispersion of the daily composition was described using pairwise log-ratio variation [5,24].

Multiple linear regression models were used to investigate the relationship between the time-use composition (explanatory variable) and each health-related fitness parameter (dependent variable). Prior to inclusion in the regression model, the composition was expressed as a set of three isometric log ratio (*ilr*) co-ordinates. Covariates (age, BMI, and sex) were additionally included as explanatory variables. The outcome variables were CRF (PREFIT 20-m shuttle run), speed-agility (4x10m), and lower-body muscular strength (standing long jump), respectively. The *ilr* multiple linear regression models were further checked for linearity, normality, homoscedasticity, and outlying observations to ensure assumptions were not violated. The significance of the time-use composition (i.e., the set of *ilr* coordinates) was examined with the '*car::Anova()*' function, which uses Wald Chi squared to calculate Type II tests, according to the principle of marginality, testing each covariate after all others [25]. The aforementioned *ilr* multiple linear regression models were subsequently used to predict differences in the outcome variables associated with the reallocation of a fixed duration of time (5 mins) between two activity behaviours, whilst the third and fourth remain unchanged. This was achieved by systematically creating a range of new activity compositions to mimic the reallocation of 5 min between all activity behaviour pairs, using the mean composition of the sample as the baseline, or starting composition. The new compositions were expressed as ilr coordinate sets, and each subtracted from the mean composition ilr coordinates, to generate ilr differences. These ilr differences (each representing a 5-minute reallocation between two behaviours) were used in the linear models to determine estimated differences (95% CI) in all outcomes. Predictions were repeated for pairwise reallocations of 5, 10, and 15 minutes, respectively. The decision was made to only go up to 15 minutes reallocation so as to reflect the viability of real or actual change in MVPA. Beyond 15 minutes, there is relatively high proportion of MVPA being reallocated, and thus, any inferences from reallocating such a high proportion of overall MVPA may yield distorted or unrealistic outputs.

3. Results

Descriptive statistics of the proportion of time spent in the four behaviours, fitness measures and participants characteristics (132 boys, means age = 3.97 ± 0.80) are displayed in Table 1. The most obvious difference is found with the mean relative amount of time spent in MVPA, which is under-estimated by the arithmetic mean with respect to the compositional alternative by ~ 4% of the day.

****************** **Insert table 1** *******************

The variability of the data was explored in a variation matrix (Table 2) containing all pair-wise log-ratio variances. A value approaching zero indicates that the time spent in the two respective behaviors are highly proportional. In this study, for example, the variance of log (Sleep/LPA) is 0.086, which reflects the (proportional) relationship or co-dependence between the two behaviors. Conversely, the highest log-ratio variance involved MVPA and sedentary behaviour (0.208).

****************** **Insert table 2** *******************

****************** **Insert figure 1** *******************

The daily time-use composition, adjusted for BMI, sex, and age, was significantly associated with CRF ($P=0.007$; $r^2=0.29$), speed-agility ($P<0.001$; $r^2=0.14$), and lower-body muscular strength ($P=0.01$; $r^2=0.07$), respectively.

Thereafter, we conducted isotemporal substitution between movement behaviour-pairs, in time increments of 5-mins (ranging from 5-mins to 15-mins). Accordingly, we found that for CRF, the addition of MVPA at the expense of any other behaviour was associated with significant improvements ($P<0.05$). However, for speed-agility and lower-body muscular strength, only reallocations between Sleep and light physical activity (LPA) yielded significant associations ($P<0.05$), and reallocations to MVPA elicited no significant alterations (Table 3).

****************** **Insert table 3** *******************

4. Discussion

This study sought to investigate the association between 24-hour movement behaviours and health-related fitness of preschoolers, in addition to discerning the effect of isotemporal substitution among active (LPA and MVPA) behaviours. The main findings of this study showed that when considering the behaviours as a 24h movement composition, positive significant associations were seen in such a way that they could explain 29%, 14%, and 7%, of the variation in CRF, speed-agility, and lower-body muscular strength, respectively.

Additionally, we found that reallocation of the individual components of the daily time-use composition were differentially associated with changes in, CRF, speed-agility, and lower-body muscular strength.

Studies linking PA to health-related fitness in preschoolers have largely focused on CRF assessments as indicator of overall fitness. Indeed, CRF improvements throughout life are essential, and especially in youth, CRF may be associated with maintaining health parameters in later life [26]. In a longitudinal study assessing the associations between PA and fitness in the transition from preschool to school, Reisberg et al. [27] reported that VPA at 6.6 years was positively associated with CRF at 7.6 years, whilst greater baseline VPA or MVPA predicted greater upper body strength a year later. Our results are concordant with Reisberg et al. [27], such that, for CRF, increasing MVPA, at the expense of any non-active behaviour (SB and sleep), yielded significant and positive outcomes. Indeed, from an ecological point of view, CRF will likely be engaged in during games/play. Thus, association with MVPA is to be expected, and promoting higher-intensity PA and reducing SB in children´s lives may have long-term beneficial effects on their CRF.

However, when substituting SB and sleep for LPA, there was no apparent influence on physical fitness. Therefore, it seems that meaningful effects on physical fitness might only achieved through high intensities of PA, which is supported by a systematic review in preschoolers, that showed an association between multiple health indicators, including physical fitness, with MVPA and VPA, only [28]. A longitudinal study indicated that substituting LPA for VPA at the age of 4.5 tended to be related with a better CRF at 5.5 years of age [29]. Another aspect that should be considered is that habitual PA levels in early childhood rarely achieve the duration and intensity to promote an improvement on CRF [30]. Therefore, even if there is no effect on this variable when reallocating SB and sleep for LPA, reducing these behaviors and increasing PA practice, even in low intensities, may enhance motor competence in this age group, which may exert positive effects in the physical fitness levels throughout life. Indeed, fundamental motor skill competence is an important predictor of MVPA and physical fitness in children [31].

Concerning lower-body muscular strength, reallocation results were abstruse. For instance, only reallocation of SB and sleep appeared to confer any significant positive changes. Similarly, ambiguous results were seen for speed-agility assessments, when reallocating LPA and sleep. It is well-known that musculoskeletal fitness is an important indicator of health in childhood [2] and is particularly relevant in early childhood, owing to the short, intermittent nature of their activity [32]. It is also important to consider that for tests such as speed/agility and standing long jump, there is likely greater variability in movement patterns for preschoolers, as their neuromuscular system is less well developed. This may create instability in assessments, making it more difficult to accurately determine a pattern. However, such a pattern may become more obvious for older children. A recent longitudinal study [32] across early childhood showed consistency in the strength of the association between motor competence and fitness, suggesting that these variables will continue to be associated over a longer follow-up period, and may only become strongly associated once children reach middle to late childhood. In this sense, the results of this paper need to be considered respective to the population that is examined.

Intervention programs usually focus on increasing PA, to consequently improve CRF levels, mainly through structured play [33]. In addition, it has been shown that providing structured activities during recess periods, including activities such as running, jumping, and stretching, facilitated by a fitness instructor may increase the amount of PA in preschool children [34]. Therefore, structured activities, that are not necessarily intense, may be considered as a pragmatic opportunity to promote PA, and in turn, to improve physical fitness. Nonetheless, the role of partially free-play, especially in this age group, must also be considered as a strategy to promote PA increments and motor skills development. Tortella et al [35] reported that preschool children (4-5y) who engaged in partly structured play presented higher PA levels compared to those engaged in unstructured play.

The abovementioned is highly relevant if we consider a gap in VPA engagement as children get older [36]. Children with higher motor competence tend to demonstrate a greater increase in VPA over time; indeed, children regarded as being motorically competent tend to participate more physically engaging activities and sports as they get older [37]. Conversely, children with motor difficulties may begin to withdraw more and more from active pursuits. Thus, a reciprocal association between PA and motor competence is assumed [38]. Furthermore, it is physical activities at high intensities that appears to be associated with positive health outcomes, including health-related fitness, with emerging evidence that vigorous activities provide additional benefits [39,40].

Thus, understanding and accounting for the compositional nature of time-use behaviour is useful, but must be interpreted in the context of its complexity, especially when mixing behaviours (PA/SB/Sleep) with abilities (fitness) that are a consequence of engaging in these behaviours. Moreover, in preschoolers, fitness assessment will likely be more variable and the consequences of small shifts in behaviour may not show a very marked change in fitness at this age, at least compared to adults. Nonetheless, the cumulative impact of such small 5-to-15 min changes over time must be considered.

The principal strength of this study was the novel approach to discerning the association between movement behaviours and components of fitness. Moreover, to the authors knowledge, this represents the first work to have examined compositional data analysis and isotemporal substitution in the context of pre-school children's fitness characteristics. However, notwithstanding the novelty of the present study, some limitations should be highlighted. The compositional data analytic approach used does not discriminate between the type of activity children were performing during sedentary behaviours. Indeed, there is evidence in that specific forms of sedentary behaviour might be better/worse than others, e.g. reading, puzzles, vs. screen-time. Thus, the exploration of sedentary patterns and activities and its relationship with fitness, holistically, could be considered an area for further exploration. Moreover, although we exemplified the importance of higher intensity PA, moderate and vigorous intensities were bound, thus reducing the granularity of our interpretations. An additional limitation, that should be considered in the interpretation of our findings, is that we were unable to utilize objective measures to record sleep. Indeed, particularly in young children, ensuring adherence to accelerometer wear at night is difficult, and sometimes infeasible [20]. Nevertheless, to ameliorate this issue, we utilized an approach previously advocated in this population [19], and that has been validated against estimates from sleep logs and objective actigraphy, where it was shown to be clinically useful and efficacious for screening of sleep in typically developing children at young ages [20]. Finally, the variability in the fitness assessments in this age group hinders our ability to glean detailed insight into certain constructs, i.e. speed/agility and lower body muscular strength. Therefore, we advocate longitudinal investigations accordingly.

In conclusion, this study showed that the variation in physical fitness was associated with the 24h movement composition, in which CRF was the most affected variable (29%), followed by speed-agility (14%), and lower-body muscular strength (7%). When considering isotemporal substitution, reallocating SB and sleep for MVPA was significantly positive for CRF, whereas for speed-agility and muscular strength reallocations to MVPA were equivocal. The present findings highlight the relevance of decreasing SB and increasing PA practice, particularly at high intensities, in order to promote a better CRF profile, while results concerning speed-agility and muscular strength must be cautiously interpreted due to the high variability in movement patterns for preschoolers.

5. Perspective

The present study showed that physical fitness components variation could be explained by the daily movements' composition preschoolers are engaged in. Considering each movement behaviour in an isolated manner is a flawed approach, given that movement behaviours co-exist as a whole or composition, and thus, the time spent in one behaviour effects, and is affected by the other behaviours during the remaining time of the day. Accordingly, we demonstrated that, following isotemporal reallocation of time between SB and sleep for MVPA, significantly positive associations were seen for CRF, whereas for speed-agility and muscular strength reallocations to MVPA were equivocal and must be cautiously interpreted due to the high variability in movement patterns for preschoolers. Thus, it is evident that achieving adequate balance between movement behaviours over 24 hours, and its' relationship with physical fitness should be further investigated in early childhood.

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