24-hour movement behaviour and executive function in preschoolers: a compositional and isotemporal reallocation analysis

Bezerra, T. A., Clark, C., Neco de Souza Filho, A., de Souza Fortes, L., Mota, J., Duncan, M. & Martins, C.

Original citation & hyperlink:
Bezerra , TA, Clark, C, Neco de Souza Filho, A, de Souza Fortes, L, Mota, J, Duncan, M & Martins, C 2021, '24-hour movement behaviour and executive function in preschoolers: a compositional and isotemporal reallocation analysis', European Journal of Sport Science, vol. 21, no. 7, pp. 1064-1072.
https://dx.doi.org/10.1080/17461391.2020.1795274

DOI 10.1080/17461391.2020.1795274
ISSN 1746-1391
ESSN 1746-1391

Publisher: Taylor and Francis

24-hour movement behaviour and executive function in preschoolers: a compositional and isotemporal reallocation analysis

ABSTRACT

Adherence to healthy behaviours promotes several health benefits in preschool children, including executive function (EF). Recently, the predictive power of the 24-hour movement behaviour (24h MB) composition on health outcomes has been evidenced; however, its relationship with EF in preschoolers is unknown. Thus, the present study had two objectives: 1) to analyze the associations between the 24h MB composition and EF of preschoolers; and 2) to investigate the theoretical changes in EF when time in different movement behaviours is reallocated. This cross-sectional study was carried out with 123 preschoolers (3-to-5-years-old) of low socioeconomic status. Physical activity (PA) and sedentary behaviour were assessed using an accelerometer for 7 days, sleep time was obtained through interviews with parents, and EF was measured using the Early Tool Box battery. To verify the association between 24-h MB and EF, compositional data analysis was used, and for time reallocation, compositional isotemporal substitution analysis was utilized. It was observed that the 24h MB composition was positively associated with EF ($p < 0.0001$; $R^2 = 0.34$), and that reallocating 5, 10, 15 or 20 minutes of the time spent on sleep and light PA to moderate-to-vigorous PA, respectively, was associated with significant improvements in EF ($p < 0.05$). . These findings provide hitherto unseen insight into the relationship between 24h MB and EF in preschool children, and warrants consideration for researchers and practitioners seeking to improve EF and PA in preschool children.

Keywords: movement behaviour; executive function; composition analysis; preschoolers.

1. INTRODUCTION

Adherence to healthy movement behaviours, such as accruing adequate physical activity (PA), good quality and sufficient sleep time, and low exposure to sedentary behaviour (SB), from early childhood may promote benefits that can extend throughout life (van de Straat et al., 2020). Recent evidence suggests that in early childhood, PA is related to a healthier cardiometabolic, physical and psychosocial profile, as well as improved motor and cognitive development (Carson et al., 2017), especially in the executive function (EF).

EF is a series of cognitive processes, such as memory, inhibitory control, and cognitive flexibility, which are responsible for organizing and coordinating behaviours to perform complex tasks, especially those that escape routine (Bell and Cuevas 2012). Such components are strongly related to the inhibition to maintain the objectives of the task (Miyake et al., 2000). In early childhood, due to the prefrontal cortex immaturity, inhibitory control may represent EF (Wiebe, Espy, and Charak 2008), and improvements in this component are related to cognitive, social and emotional development (Diamond 2016)

Results from cross-sectional studies suggest a positive association between PA and EF in early childhood (Willougby, 2018). Indeed, the role of PA on angiogenesis, synaptogenesis, neurogenesis, and in the regulation of a series of neurotrophic factors is well known (Piepmeier and Etnier 2015). Moreover, during sleep, physiological mechanisms, such as synaptic compensation processes, may improve neuroplasticity, an essential phenomenon to consolidate memory skills (Tononi and Cirelli 2014), a component of EF. Conversely, SB negatively affects the brain white matter (Hutton et al. 2020), which is related to cognitive processes (Dodson et al. 2018).

Nonetheless, in early childhood, a recent systematic review demonstrates that it is still incipient to conclude the strength and direction of the association between PA and EF (Pate et al. 2019), as the existing prior results are divergent (Aggio et al. 2016; Cook et al. 2019). Similarly, there is conflicting evidence concerning sleep and EF in early ages (Reynaud, Vecchierini, Heude, Charles, & Plancoulaine, 2018; Chaput et al., 2017), and the association between SB and EF may vary according to the type of SB children perform (Carson et al. 2015).

The first years of life are a key-period for EF development, considering the upward maturation of prefrontal cortex is between three and seven years of age, and EF may be influenced by several factors, including movement behaviours (Diamond, 2016). Given that movement behaviours are interrelated, health benefits may be optimized when all components of movement behaviour are considered (Chaput et al. 2014). Indeed, recent studies have used a compositional approach in order to understand the associations between movement behaviours and health outcomes, and how reallocating time spent in these behaviours, constrained to a 24-hour period, may affect to several outcomes (Burns et al. 2019). Indeed, considering movement behaviors in an isolated manner is a flawed approach, given that movement behaviors are necessarily bound to 1440 minutes per day. All incumbent movement behaviors co-exist as a whole or composition, and thus, the time spent in one behaviour effects, and is affected by, the other behaviors during the remaining time of the day (Dumuid et al. 2019). However, to the best of author's knowledge, no study has analyzed how the composition of these behaviours is related to EF in early childhood. This information is key for children´s development, considering EF in early childhood is a predictor of academic success in subsequent school years, quality of life, physical fitness and personal fulfillment in adulthood (Moffitt et al. 2011).

Thus, the aims of this study were: 1) to analyze the associations between the 24-hour movement composition behaviours and EF of preschoolers; and 2) to investigate predicted changes in EF when time in different behaviours is reallocated. We hypothesized that the compositional 24-hour movement behaviours are more strongly associated with EF than the isolated behaviours, and that reallocating time from other behaviours to time in moderate-to-vigorous physical activity (MVPA) improves children´s EF.

2. METHODS

2.1 Setting and participants

Preschool children aged 3-to-5-year-old, of both sexes, and regularly registered in 2019 in the Child Education Reference Centers (CREIs) 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 families.

The preschool public education zone is organized in nine poles, where eighty-six CREIs are located. From those, fifty-five institutions have 3-to-5-year-old registered children, and ten institutions, located in majority low-income areas of six different poles, agreed to participate in the study. For the purpose of this study, two CREIs located in two different poles were conveniently selected. The Human Development Index (HDI) of the CREIs areas range from 0.4 to 0.5, 53.7% of the mothers or fathers were unemployed and over 39% of the mothers and 52% of the fathers had finished the 9th grade or less. All parents /registered children aged 3-to-5-year-old were invited to participate.

2.2 Measures

Movement behaviours

PA was objectively assessed using accelerometry (Actigraph, model WGT3-X, Florida). The preschool teachers and the parents/guardians received verbal and written instructions for the correct use of the accelerometer, including placement, and the correct positioning. In addition, throughout the week, parents received three phone calls to remind them about the accelerometer use. The device initialization, data reduction and analysis were performed using the ActiLife software (Version 6.13.3).

The participants were instructed to wear the accelerometer on the right hip for 7 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 11a.m for children´s bath and fastened properly after it. Accelerometers were setup to measure acceleration at a 100. Hz sampling rate and analyzed as ActiGraph counts, using a 15-s epoch length (Cliff, Reilly, and Okely 2009), and reintegrated to 60-second epochs for analysis. Periods of ≥20 min of consecutive zero counts were defined as non-wear time and removed from the analysis, and the first day of accelerometer data was omitted from analysis to avoid subject reactivity. Data with a minimum of three days (one weekend and two week days), with a minimum of 8h of wear time was considered valid. 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 PA and SB was estimated using the cut-points for vector magnitude proposed by Butte et al.(Butte et al. 2014). Light intensity was defined as 820 to 3.907 counts, moderate intensity as 3.908 to 6.111 counts, and vigorous intensity as > 6.112 counts. The amount of time spent in SB was estimated as ≤819 counts.

Parents reported children's usual daily sleep hours. Parents were asked 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?”. This approach has been recently used in similar population (Vale and Mota 2020). The questions were made separately for weekdays and weekend days and combined for analyses. A weighted average was performed for sleep time during the week and the weekend days, and calculated as follows: ((Sleep on weekdays x 5) + (Sleep on weekend days x 2))/7.

Executive Function

EF was assessed using Early Years Toolbox – EYT (Howard and Melhuish 2017), which is a battery of computerized tasks that was developed to specifically assess the EF of children aged three to five years. The battery consists of five tasks assessed from games in an app developed for Ipads: a) Mr. Ant: visual-spatial working memory; b) Not This: phonological working memory; c) Go / No Go: inhibitory control; d) Card Sorting: displacement and change; e) Expressive Vocabulary: language development. The results are computed by the number of correct answers for each task and are sent to an email previously registered.

Although there are three main EF components, at this age group, inhibitory control, working memory and cognitive flexibility are complex and difficult to dissociate, as they share common processes and are not completely dissociable (Diamond, 2013). Given that the first brain maturation peak is reached at the age of seven, it is believed that during early childhood, these components are strongly related to inhibition at the representational level and/or at the maintenance of objectives (Miyake et al. 2000). A factor analysis study carried out by Wiebe et al (2008) showed that in preschoolers, inhibitory control is able to represent EF. Moreover, previous studies have shown that the Go / No Go test can activate the entire prefrontal cortex (the brain region considered the basis of support for EF), and it is a more robust task than others to establish EF performance (Smith et al., 2017; Willoughby et al., 2012). Moreover, after conducting a pilot study with more than 50 children, it was observed that for assessing the three main domains of EF (Inhibitory control, cognitive flexibility and working memory), in our specific context conditions, the average time spent for each child would be around 45 minutes, leading many children (almost 25) to give up the protocol. So, for the purpose of this study, inhibitory control task was chosen to represent the EF construct.

Inhibitory control was indexed by an impulse control score that represents the product of the Go and No-Go accuracy, representing the strength of the prepotent response to tap whenever a no-go trial is presented, in relation to their ability to overcome this response. The Go and No-Go task consist of touching the screen and “catching the fish" and "do not catch the shark". During the task, 75 fish and sharks appear on the tablet screen randomly, into three phases. Between each phase, the aim of the task is remembered. To analyze the data, one point was assigned for each correct answer, with the score ranging from 0 to 75 points. This protocol presents satisfactory reliability values with Cronbrach's $\alpha = 0.95$ (Howard and Melhuish 2017).

Anthropometric variables

Height (cm) and weight (kg) were determined using a *Holtain* stadiometer, and by digitized weighing scales (Seca 708), while the participant was lightly dressed and barefoot, following a standardized procedure (Onnis). Body mass index (BMI) was calculated by dividing body weight with the squared height in meters (kg/m^2).

2.3 Procedures

All the schools' staff was 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. Children enrolled in CREI's were invited to participate. Trained PE teachers and graduate students conducted the study.

Assessments were conducted during a three-month period (August to October 2019). All children authorized by their parents through the consent form were evaluated. The school administration provided all socio-demographic data (children's age, birth date, parent's contact, and address). Parents were invited for a meeting at school and were interviewed individually. Sedentary behaviour and sleep time were collected during this interview. Parents were also information about the accelerometer use. During the following day, anthropometric data and EF were assessed at preschools, and the accelerometer was placed in the participating children, who used it during 7 consecutive days.

All procedures were approved by the university committee and the board of education. The Helsinki Declarations' ethical aspects were followed (Mundial 2017). The Research Ethics Committee of the Health Science Center and the local board of education approved the study.

2.4 Ethics statement

All the ethical aspects were followed. The evaluation methods and procedures were approved by the Research Ethics Committee of Health Science Center (protocol n.

2.727.698), and by the Education Board of the city.

2.5 Data analysis

Compositional data analyses, or CoDA, were conducted in R (http://cran.r-project.org) using the compositions (version 1.40-1), robCompositions (version 0.92-7) and lmtest (version 0.9-35) packages.

Standard and compositional descriptive statistics were computed for comparison; where, alternate to the standard arithmetic mean, the compositional mean is obtained by, firstly, computing the geometric mean for each individual behavior (time spent in sleep, SB, LPA [Light Physical Activity], and MVPA) and subsequently normalizing the data to the same constant as the raw data, i.e. 1. This measure is coherent with the relative and symmetrical scale of the data (Aitchison 1982), whilst univariate statistical measures of dispersion, for instance standard deviation, are not coherent with the intrinsic inter-dependent multivariable nature of compositional data. Thus, multivariate dispersion of day composition was described using pairwise log-ratio variation (Chastin, Palarea-Albaladejo, Dontje, & Skelton, 2015). The variability of the data was summarized in a variation matrix that contains all pair-wise log-ratio variances, where a value close to zero indicates that time spent in two respective behaviors are highly proportional, whilst a value close to 1 indicates the opposite.

We adopted a compositional approach based on an isometric log-ratio (ilr) data transformation, adapted from Hron (Hron, Filzmoser, and Thompson 2012) (see (Mota et al. 2020.)) to adequately adjust the models for time spent in the other behaviors. Briefly, the ilr coordinates were created using a sequential binary partition (SBP) process (Egozcue and Pawlowsky-Glahn 2005), which were obtained by partitioning the composition, where one set is designated to appear in the numerator of the first ilr coordinate, and the other in the denominator, next, one of the previously constructed sets is further partitioned into two sets, again coding the parts to be in the numerator (+1), the denominator (-1), and uninvolved parts (0). The final ilr's were constructed as normalized log ratios of the geometric mean of parts (Dumuid et al. 2019). Covariates (age, BMI, and sex) were additionally included as explanatory variables. The *ilr* multiple linear regression models were further checked for linearity, normality, homoscedasticity, and outliers to ensure assumptions were not violated. The significance of the activity behaviour 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. The ilr multiple linear regression models were used to predict differences in the outcome variables associated with the reallocation of a fixed duration of time between activity behaviors, whilst the third and fourth remained unchanged. This was achieved by systematically creating a range of new activity compositions to mimic the reallocation of 5, 10, 15, and 20 min, respectively, between all activity behavior 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 (representing a reallocation between two behaviours) were used to determine estimated differences (95% CI) in all outcomes. Predictions were repeated for pairwise reallocations of 5, 10, 15, and 20 minutes, respectively, based in previous studies (Dumuid et al. 2019; Mota et al. 2020). The rationale for starting reallocation at 5-minutes is based on the fact that the revised 2019 PA guidelines for the UK (Department of Health and Social Care 2019) and US (Services 2008) have removed the 10-minute minimum bout duration for all age groups, and specifically for children, as there is not sufficient evidence for this.

3.RESULTS

A total of 168 children were invited to participate in the study, 126 presented parental acceptance, and three did not complete the entire protocol. Thus, 123 children were assessed (50.4% female, 55.2 ± 9.2 months of age). Descriptive statistics of the proportion of time spent in the four behaviors are detailed in Table 1, indicating that the mean relative amount of time spent in MVPA is under-estimated by the arithmetic mean, with respect to the compositional alternative, by up to 2% of the day (equating to ~28 minutes)

*******Table 1*******

The variability of the data is summarized in the variation matrix (Table 2) containing all pair-wise log-ratio variances; highlighting that the highest log-ratio variance involved MVPA and sedentary time, suggesting that time spent in MVPA is the least co-dependent on sedentary time.

*******Table 2*******

Data were initially examined using linear regression, for each movement behaviour independently. Results highlighted that LPA and MVPA both significantly predicted EF scores (Table 3).

*******Table 3*******

When data were considered as a composition, adjusted for age, BMI, and sex, the composition significantly predicted EF ($P<0.0001$; $r^2=0.34$).

Moreover, results of isotemporal analysis showed EF significantly improved when reallocating 5, 10, 15, or 20-min from LPA to MVPA. However, reallocating 5, 10, 15, or 20 mins from sleep to LPA, or from MVPA to sleep, was associated with a significant reduction in EF. Substituting 15 or 20 mins from sleep to sedentary time was associated with a significant reduction in EF.

*******Table 4*******

Discussion

This study sought to investigate the association between 24-hour movement behaviours and the EF of preschoolers, in addition to discerning the effect of isotemporal substitution of movement behaviours. The main findings of this study showed that when analyzed using traditional linear regression, MVPA in isolation, was negatively associated with EF, whilst no association was seen for sleep time or SB. Nonetheless, when considering the behaviours as a 24-hour movement composition, positive significant associations were seen in such a way that they can explain 34% of the variation in the EF of preschoolers.

Evidence regarding the association between MVPA and EF in such ages are scarce and limited. A recent systematic review suggested a positive association between PA and cognitive development (Carson et al., 2016), and the authors included beneficial effects on at least one outcome of EF domain or language domain. However, six of the seven included studies were rated weak quality with a high risk of bias. In a recent cross-sectional study looking at associations between objectively measured PA and ST and preschooler's EF skills, Willoughby and colleagues (Willoughby, Wylie, and Catellier 2018) showed that MVPA was inversely related to performance (accuracy) on EF tasks ($\beta = -.28$, 95% CI = −.50 to −.06). Furthermore, the authors stated that several intervenient factors may contribute to the observed results, such as hyperactive behaviours (Willoughby et al. 2018). Cook et al., (2019) in low-income South-African preschoolers, reported that PA was not associated with inhibitory control, and reinforced that this association may be limited to the contexts and the activities performed (Diamond, 2016).

It is noteworthy to mention that the assessed children spend 10 hours/day at schools, of which 50min/day (below the recommended) are of objectively measured MVPA. Therefore, the time spent moving during awake time may not be enough for promoting cardiorespiratory fitness, which is closely related to EF in preschoolers (Nieto-López et al. 2020). However, our data showed that reallocating any time above 5 minutes of sleep or LPA to MVPA, improvements in the preschooler´s EF were evident. This finding reinforce an important issue concerning LPA at these ages, since the higher the intensity of PA, greater is the performance in different domains of EF, possibly due to the benefits provided by increased blood flow in the brain (McNeill et al. 2018).

Additionally, although a recent systematic review reported a weak positive association between sleep and EF in preschoolers (Reynaud et al. 2018), as a single behaviour, no association was seen in this study. The children assessed in this study spend ten hours per day at school, and during school hours, they have daily naps of approximately 2 hours. Lam et al., (Lam et al. 2011) demonstrated that children who nap during the day sleep less at night, and that those who slept less at night made more impulsive errors on a computerized go/no-go test. The authors hypothesized that daily napping is a marker for brain development, so that children who nap less have more mature brains and therefore perform better on neurocognitive function.

In the same way, the associations between SB and EF, or even with other variables related to cognition, are divergent, with some studies reporting a negative association (López-Vicente et al., 2017) and others, positive (Carson et al., 2015). The reallocation of over 15 minutes from sleep to SB may be harmful to the EF of preschoolers. Although in the current study we were not able to differentiate the time children are napping or awake while lying down, or even the type of activity children are doing during SB, it is known that during sleep, a synaptic compensation process occurs, which ultimately improves neuroplasticity, may be fundamental for memory consolidation (Tononi and Cirelli 2014), which is one of the main EF skills. Perhaps, for this reason, reallocating sleep time to MVPA was more important for EF than reallocating SB. Furthermore, because the activities performed during the SB may be directed towards learning, which would justify the increase in EF (Carson et al. 2015).

Furthermore, in preschool ages, SB seems to negatively affect the brain white matter (Hutton et al. 2020), which is related to cognitive processes, including EF. Considering the myelination of white matter tracts, and consequently the efficiency of signal conduction, are highly sensitive to environmental factors (Forbes and Gallo 2017) it is possible that long periods in SB may have a negative impact on children´s EF. Nonetheless, time spent in SB should be interpreted with caution. Indeed, the type of activity promoted could elicit either positive or negative effects on children´s EF (activities that promote learning, such as puzzles or thinking games may improve children´s EF) (Carson et al., 2015)

Importantly, the use of traditional linear regressions when using compositional data, such as daily PA, may yield spurious results, as it assumes no time-bounds, and may lead to incorrect inferences concerning movement behaviours and their association with EF. All 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 (Chen et al. 2019). So, when considering the behaviours as a 24-hour movement composition, it explained 34% of the variation in the EF task performed. Additionally, the largest negative change was shown when removing sleep and adding LPA, with unit changes of -1.46 at 20 minutes. Whilst the largest positive change was shown when adding MVPA, at the expense of LPA, reaching a 1.43 unit-change at 20 min of reallocation.

Although there are no previous studies that have analyzed associations between such movement composition and EF in preschoolers, we believe that the composition promoted by each behaviour may provide accumulative benefits in the children´s immature prefrontal cortex. In the early years, information´s capacity and speed, which are functionally essential for neuronal plasticity, increase. In addition, the environment plays an important role in sculpting the brain to adapt to environmental contexts (Khan and Hillman 2014). Thus, we hypothesize that the sum of healthy lifestyle behaviours in this age group, such as PA (Hillman, Erickson, and Kramer 2008), sleep (Cheng et al. 2020) and SB (Hutton et al. 2020) may be factors that potentialize brain functions.

Although this is the first study to analyze the associations between the 24-hour movement composition behaviours and EF of preschoolers, and to investigate predicted changes in EF when time in different behaviours is reallocated, our study has limitations that must be considered. Whilst we assessed the inhibitory control domain of EF. Nonetheless, it is important to highlight that high cognitive demands for a prolonged time can cause mental fatigue (Smith et al. 2019), which may impair EF, especially when the cognitive task is performed on a smartphone or tablet (Fortes et al. 2020). So, we strongly believe that the stress associated with the time spent to assess the entire protocol (5 tasks) compromises the results due to the associated mental fatigue inherent to a prolonged cognitive task (approximately 50 min in adults) (Smith et al. 2019). It is also worth mentioning that the indirect assessment of sleep time, the lack of information on the type of activity performed during the SB, the psychosocial correlates, and the direction of the observed associations are limitations that must be considered in future studies. Further, although the current study comprises specific low-income children, which may reduce its external validity, the possible mechanisms linking EF and PA are likely similar. Moreover, this study covers an under investigated sample, that can benefit from these results.

The predominant strength of this study is the use of a sensitive and statistically accurate compositional approach based on objectively and validated measurement of PA and SB to assess movement behaviours association with EF in low-income preschool children, these characteristics reinforce the internal validity of the present study. As there are no prior published studies, that the authors are aware of, which have used a compositional behaviour analysis approach, direct comparisons with other studies are not possible. However, this clearly highlights the need for further examinations in this field, where the constrained nature of PA behaviours is acutely considered.

Conclusion

The use of a compositional paradigm permits novel insight into the relationship between activity behaviours and EF in preschool children. The current study highlighted that when analyzed as a continuum, the 24-hour movement behaviour composition significantly predicted children´s EF. Moreover, increasing time spent in MVPA at the expense of LPA and sleep, was associated with positive changes in preschooler´s EF. This represents an important finding, particularly for creating and optimizing interventions with a developmental perspective, although the identification of causal relationships between these variables requires further investigation.

References

Aggio, D., L. Smith, A. Fisher, and M. Hamer. 2016. “Context-Specific Associations of Physical Activity and Sedentary Behavior With Cognition in Children.” *Am J Epidemiol* 183(12):1075–82.

Aitchison, John. 1982. “The Statistical Analysis of Compositional Data.” *Journal of the Royal Statistical Society: Series B (Methodological)* 44(2):139–60.

Bell, M. A., and K. Cuevas. 2012. “Psychobiology of Executive Function in Early Development.” in *Executive function in preschool age children: Integrating measurement, neurodevelopment and translational research*.

Burns, Ryan D., Youngwon Kim, Wonwoo Byun, and Timothy A. Brusseau. 2019. “Associations of School Day Sedentary Behavior and Physical Activity With Gross Motor Skills: Use of Compositional Data Analysis.” *Journal of Physical Activity and Health* 16(10):811–17.

Butte, N. F., W. W. Wong, J. S. Lee, A. L. Adolph, M. R. Puyau, and I. F. Zakeri. 2014. “Prediction of Energy Expenditure and Physical Activity in Preschoolers.” *Med Sci Sports Exerc* 46(6):1216–26.

Carson, V., S. Hunter, N. Kuzik, S. A. Wiebe, J. C. Spence, A. Friedman, M. S. Tremblay, L. Slater, and T. Hinkley. 2016. “Systematic Review of Physical Activity and Cognitive Development in Early Childhood.” *J Sci Med Sport* 19(7):573–78.

Carson, V., E. Y. Lee, L. Hewitt, C. Jennings, S. Hunter, N. Kuzik, J. A. Stearns, S. P. Unrau, V. J. Poitras, C. Gray, K. B. Adamo, I. Janssen, A. D. Okely, J. C. Spence, B. W. Timmons, M. Sampson, and M. S. Tremblay. 2017. “Systematic Review of the Relationships between Physical Activity and Health Indicators in the Early Years (0-4 Years).” *BMC Public Health* 17(Suppl 5):854.

Carson, Valerie, Nicholas Kuzik, Stephen Hunter, Sandra A. Wiebe, John C. Spence, Alinda Friedman, Mark S. Tremblay, Linda G. Slater, and Trina Hinkley. 2015. “Systematic Review of Sedentary Behavior and Cognitive Development in Early Childhood.” *Preventive Medicine* 78:115–22.

Chaput, Jean-Philippe, Valerie Carson, Casey E. Gray, and Mark S. Tremblay. 2014. “Importance of All Movement Behaviors in a 24 Hour Period for Overall Health.” *International Journal of Environmental Research and Public Health* 11(12):12575–81.

Chastin, Sebastien F. M., Javier Palarea-Albaladejo, Manon L. Dontje, and Dawn A. Skelton. 2015. “Combined Effects of Time Spent in Physical Activity, Sedentary Behaviors and Sleep on Obesity and Cardio-Metabolic Health Markers: A Novel Compositional Data

Analysis Approach." *PloS One* 10(10):e0139984–e0139984.

Chen, Bozhi, Jonathan Y. Bernard, Natarajan Padmapriya, Jiali Yao, Claire Goh, Kok Hian Tan, Fabian Yap, Yap-Seng Chong, Lynette Shek, Keith M. Godfrey, Shiao-Yng Chan, Johan G. Eriksson, and Falk Müller-Riemenschneider. 2019. "Socio-Demographic and Maternal Predictors of Adherence to 24-Hour Movement Guidelines in Singaporean Children." *The International Journal of Behavioral Nutrition and Physical Activity* 16(1):70.

Chen, Jiahua, and Zehua Chen. 2008. "Extended Bayesian Information Criteria for Model Selection with Large Model Spaces." *Biometrika* 95(3):759–71.

Cheng, Wei, Edmund Rolls, Weikang Gong, Jingnan Du, Jie Zhang, Xiao-Yong Zhang, Fei Li, and Jianfeng Feng. 2020. "Sleep Duration, Brain Structure, and Psychiatric and Cognitive Problems in Children." *Molecular Psychiatry*.

Cliff, Dylan P., John J. Reilly, and Anthony D. Okely. 2009. "Methodological Considerations in Using Accelerometers to Assess Habitual Physical Activity in Children Aged 0–5 Years." *Journal of Science and Medicine in Sport* 12(5):557–67.

Cook, C. J., S. J. Howard, G. Scerif, R. Twine, K. Kahn, S. A. Norris, and C. E. Draper. 2019. "Associations of Physical Activity and Gross Motor Skills with Executive Function in Preschool Children from Low-Income South African Settings." *Dev Sci* 22(5):e12820.

Department of Health and Social Care. 2019. "Guidance from the Chief Medical Officers in the UK on the Amount and Type of Physical Activity People Should Be Doing to Improve Their Health."

Diamond, A. 2013. "Executive Functions." *Annu Rev Psychol* 64:135–68.

Diamond, A. 2016. "Why Improving and Assessing Executive Functions Early in Life Is Critical." Pp. 11–43 in *Executive function in preschool-age children: Integrating measurement, neurodevelopment, and translational research*.

Dodson, Cory K., Katherine E. Travis, Lauren R. Borchers, Virginia A. Marchman, Michal Ben-Shachar, and Heidi M. Feldman. 2018. "White Matter Properties Associated with Pre-Reading Skills in 6-Year-Old Children Born Preterm and at Term." *Developmental Medicine and Child Neurology* 60(7):695–702.

Donnelly, J. E., C. H. Hillman, D. Castelli, J. L. Etnier, S. Lee, P. Tomporowski, K. Lambourne, and A. N. Szabo-Reed. 2016. "Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review." *Med Sci Sports Exerc* 48(6):1223–24.

Dumuid, Dorothea, Željko Pedišić, Tyman Everleigh Stanford, Josep-Antoni Martín-Fernández, Karel Hron, Carol A. Maher, Lucy K. Lewis, and Timothy Olds. 2019. "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." *Statistical Methods in Medical Research* 28(3):846–57.

Egozcue, Juan Jose, and Vera Pawlowsky-Glahn. 2005. "Groups of Parts and Their Balances in Compositional Data Analysis." *Mathematical Geology* 37:795–828.

Forbes, Thomas A., and Vittorio Gallo. 2017. "All Wrapped Up: Environmental Effects on Myelination." *Trends in Neurosciences* 40(9):572–87.

Fortes, Leonardo S., Dalton De Lima-Junior, Lenamar Fiorese, José R. A. Nascimento-Júnior, Arnaldo L. Mortatti, and Maria E. C. Ferreira. 2020. "The Effect of Smartphones and Playing Video Games on Decision-Making in Soccer Players: A Crossover and Randomised Study." *Journal of Sports Sciences* 1–7.

Gabel, Leigh, Heather M. Macdonald, Lindsay Nettlefold, and Heather A. McKay. 2017. "Physical Activity, Sedentary Time, and Bone Strength From Childhood to Early Adulthood: A Mixed Longitudinal HR-PQCT Study." *Journal of Bone and Mineral Research* 32(7):1525–36.

Haapala, Eero A., Juuso Väistö, Niina Lintu, Kate Westgate, Ulf Ekelund, Anna-Maija Poikkeus, Soren Brage, and Timo A. Lakka. 2017. "Physical Activity and Sedentary Time in Relation to Academic Achievement in Children." *Journal of Science and Medicine in Sport* 20(6):583–89.

Hillman, C. H., K. I. Erickson, and A. F. Kramer. 2008. "Be Smart, Exercise Your Heart: Exercise Effects on Brain and Cognition." *Nat Rev Neurosci* 9(1):58–65.

Howard, S. J., and E. Melhuish. 2017. "An Early Years Toolbox for Assessing Early Executive Function, Language, Self-Regulation, and Social Development: Validity, Reliability, and Preliminary Norms." *J Psychoeduc Assess* 35(3):255–75.

Hron, K., P. Filzmoser, and K. Thompson. 2012. "Linear Regression with Compositional Explanatory Variables." *Journal of Applied Statistics* 39(5):1115–28.

Hutton, John S., Jonathan Dudley, Tzipi Horowitz-Kraus, Tom DeWitt, and Scott K. Holland. 2020. "Associations Between Screen-Based Media Use and Brain White Matter Integrity in Preschool-Aged Children." *JAMA Pediatrics* 174(1):e193869–e193869.

Khan, N. A., and C. H. Hillman. 2014. "The Relation of Childhood Physical Activity and Aerobic Fitness to Brain Function and Cognition: A Review." *Pediatr Exerc Sci*

26(2):138–46.

Lam, Janet C., E. Mark Mahone, Thornton Mason, and Steven M. Scharf. 2011. “The Effects of Napping on Cognitive Function in Preschoolers.” *Journal of Developmental and Behavioral Pediatrics : JDBP* 32(2):90–97.

López-Vicente, Mónica, Judith Garcia-Aymerich, Jaume Torrent-Pallicer, Joan Forns, Jesús Ibarluzea, Nerea Lertxundi, Llúcia González, Desirée Valera-Gran, Maties Torrent, Payam Dadvand, Martine Vrijheid, and Jordi Sunyer. 2017. “Are Early Physical Activity and Sedentary Behaviors Related to Working Memory at 7 and 14 Years of Age?” *The Journal of Pediatrics* 188:35-41.e1.

McGregor, Duncan E., Javier Palarea-Albaladejo, Philippa M. Dall, Borja del Pozo Cruz, and Sebastien F. M. Chastin. 2019. “Compositional Analysis of the Association between Mortality and 24-Hour Movement Behaviour from NHANES.” *European Journal of Preventive Cardiology* 2047487319867783.

McNeill, J., S. J. Howard, S. A. Vella, R. Santos, and D. P. Cliff. 2018. “Physical Activity and Modified Organized Sport among Preschool Children: Associations with Cognitive and Psychosocial Health.” *Mental Health and Physical Activity* 15:45–52.

Miyake, Akira, Naomi P. Friedman, Michael J. Emerson, Alexander H. Witzki, Amy Howerter, and Tor D. Wager. 2000. “The Unity and Diversity of Executive Functions and Their Contributions to Complex ‘Frontal Lobe’ Tasks: A Latent Variable Analysis.” *Cognitive Psychology* 41(1):49–100.

Moffitt, T. E., L. Arseneault, D. Belsky, N. Dickson, R. J. Hancox, H. Harrington, R. Houts, R. Poulton, B. W. Roberts, S. Ross, M. R. Sears, W. M. Thomson, and A. Caspi. 2011. “A Gradient of Childhood Self-Control Predicts Health, Wealth, and Public Safety.” *Proc Natl Acad Sci U S A* 108(7):2693–98.

Mota, Jéssica Gomes, Cain Clark, Thaynã Alves Bezerra, Luis Filipe Gomes Barbosa Ferreira Lemos, Cézane Priscilla Reuter, Jorge Mota, Michael Duncan, and Clarice Maria de Lucena Martins. 2020. “24-Hour Movement Behaviours and Fundamental Movement Skills in Preschool Children: A Compositional and Isotemporal Substitution Analysis.” *Journal of Sports Sciences*.

Mundial, Asociacion Medica. 2017. “The World Medical Association, Inc.” (33).

Nieto-López, Marta, Mairena Sánchez-López, María E. Visier-Alfonso, Vicente Martínez-Vizcaíno, Estela Jiménez-López, and Celia Álvarez-Bueno. 2020. “Relation between Physical Fitness and Executive Function Variables in a Preschool Sample.” *Pediatric*

Research.

Pate, R. R., C. H. Hillman, K. F. Janz, P. T. Katzmarzyk, K. E. Powell, A. Torres, and M. C. Whitt-Glover. 2019. "Physical Activity and Health in Children Younger than 6 Years: A Systematic Review." *Med Sci Sports Exerc* 51(6):1282–91.

Piepmeier, Aaron T., and Jennifer L. Etnier. 2015. "Brain-Derived Neurotrophic Factor (BDNF) as a Potential Mechanism of the Effects of Acute Exercise on Cognitive Performance." *Journal of Sport and Health Science* 4(1):14–23.

Reynaud, Eve, Marie-Françoise Vecchierini, Barbara Heude, Marie-Aline Charles, and Sabine Plancoulaine. 2018. "Sleep and Its Relation to Cognition and Behaviour in Preschool-Aged Children of the General Population: A Systematic Review." *Journal of Sleep Research* 27(3):e12636.

Services, U. S. Department of Health and Human. 2008. "US Department of Health and Human Services 2008 Physical Activity Guidelines for Americans." *Hyattsville, MD: Author*.

Smith, Elizabeth, Afrouz Anderson, Audrey Thurm, Philip Shaw, Mika Maeda, Fatima Chowdhry, Victor Chernomordik, and Amir Gandjbakhche. 2017. "Prefrontal Activation During Executive Tasks Emerges Over Early Childhood: Evidence From Functional Near Infrared Spectroscopy." *Developmental Neuropsychology* 42(4):253–64.

Smith, Mitchell R., Rifai Chai, Hung T. Nguyen, Samuele M. Marcora, and Aaron J. Coutts. 2019. "Comparing the Effects of Three Cognitive Tasks on Indicators of Mental Fatigue." *The Journal of Psychology* 153(8):759–83.

van de Straat, Vera, Boris Cheval, Ralph E. Schmidt, Stefan Sieber, Delphine Courvoisier, Matthias Kliegel, Claudine Burton-Jeangros, Stéphane Cullati, and Piet Bracke. 2020. "Early Predictors of Impaired Sleep: A Study on Life Course Socioeconomic Conditions and Sleeping Problems in Older Adults." *Aging & Mental Health* 24(2):322–32.

Telama, R. 2009. "Tracking of Physical Activity from Childhood to Adulthood: A Review." *Obesity Facts* 2(3):187–95.

Tomporowski, Phillip D., Bryan McCullick, Daniel M. Pendleton, and Caterina Pesce. 2015. "Exercise and Children's Cognition: The Role of Exercise Characteristics and a Place for Metacognition." *Journal of Sport and Health Science* 4(1):47–55.

Tononi, Giulio, and Chiara Cirelli. 2014. "Sleep and the Price of Plasticity: From Synaptic and Cellular Homeostasis to Memory Consolidation and Integration." *Neuron* 81(1):12–34.

Vale, Susana, and Jorge Mota. 2020. "Adherence to 24-Hour Movement Guidelines among

Portuguese Preschool Children: The Prestyle Study.” *Journal of Sports Sciences* 1–6.

Volckaert, A. M. S., and M. P. Noël. 2015. “Training Executive Function in Preschoolers Reduce Externalizing Behaviors.” *Trends in Neuroscience and Education* 4(1–2):37–47.

Wiebe, Sandra A., Kimberly Andrews Espy, and David Charak. 2008. “Using Confirmatory Factor Analysis to Understand Executive Control in Preschool Children: I. Latent Structure.” *Developmental Psychology* 44(2):575–87.

Willoughby, M. T., A. C. Wylie, and D. J. Catellier. 2018. “Testing the Association between Physical Activity and Executive Function Skills in Early Childhood.” *Early Childhood Research Quarterly* 44:82–89.

Willoughby, Michael T., Clancy B. Blair, R. J. Wirth, and Mark Greenberg. 2012. “The Measurement of Executive Function at Age 5: Psychometric Properties and Relationship to Academic Achievement.” *Psychological Assessment* 24(1):226–39.

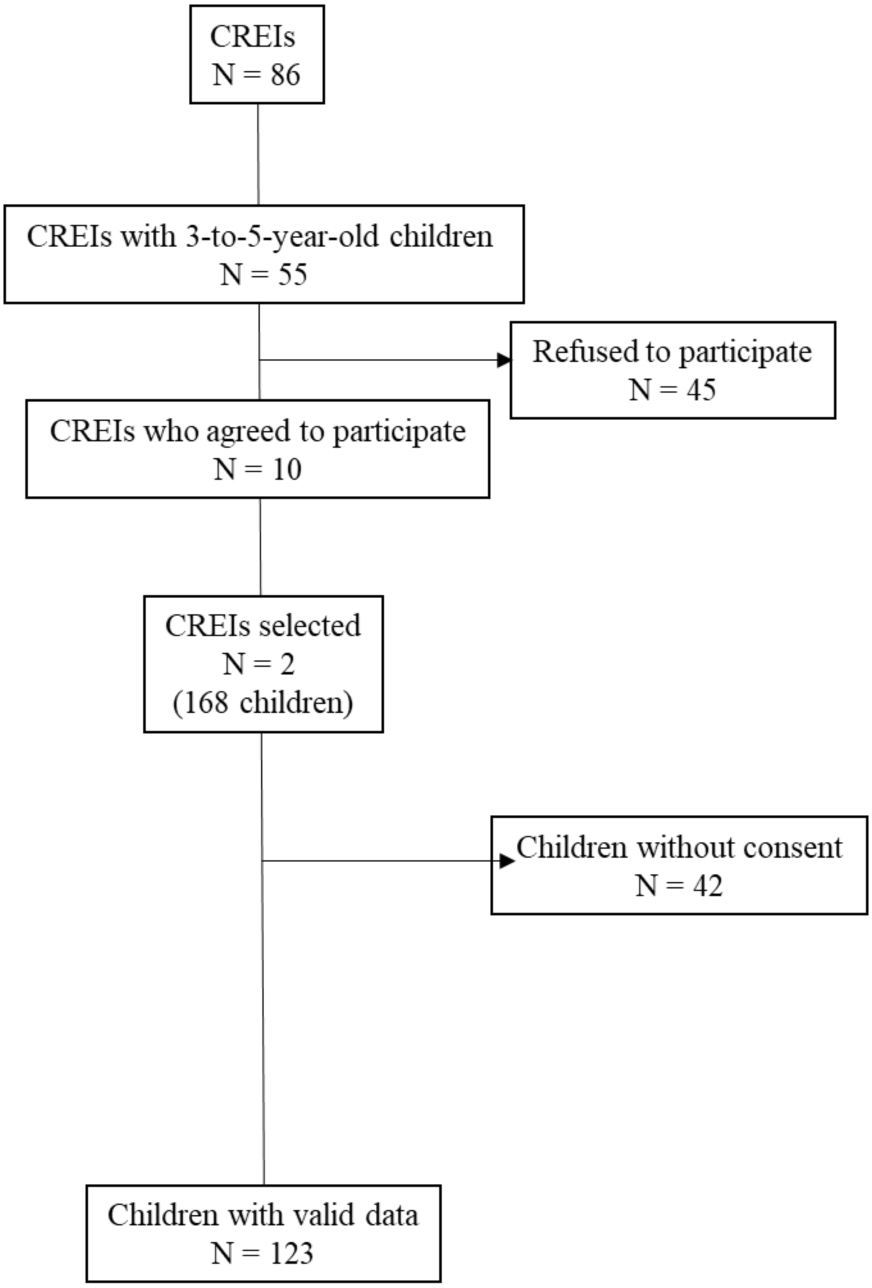

Figure 1. Study´s flowchart.

Table 1. Descriptive statistics of time in movement behaviors

	Sleep	SB	LPA	MVPA	EF
Min/day - mean	683.6 (180.5)	454.6 (147.2)	250.9 (47.3)	50.9 (23.1)	-
Arithmetic mean	0.47 (0.13) [47%]	0.31 (10) [31%]	0.18 (0.03) [18%]	0.03 (0.01) [3%]	63 (9.6)
Compositional mean	0.43 [43%]	0.32 [32%]	0.20 [20%]	0.05 [5%]	-

Min/day: minutes per day; SB: sedentary behavior; LPA: light physical activity; MVPA: moderate-to-vigorous physical activity; EF: Executive Function. Data are presented as mean (Standard Deviation (SD) [%time per day], except for *"compositional mean"*, which cannot include SD.

Table 2. Pairwise log-ratio variation matrix

	Sleep	Sedentary	LPA	MVPA
Sleep	0.00	0.18	0.09	0.19
Sedentary	0.18	0.00	0.11	0.24
LPA	0.09	0.11	0.00	0.09
MVPA	0.19	0.24	0.09	0.00

LPA: light physical activity; MVPA: moderate-to-vigorous physical activity. A value approaching "0" indicates high proportionality between pairs of behaviours, whilst a value approaching "1" indicates the opposite.

Table 3. Associations between movement behaviours and motor competence

	Sleep B [95% CI]	P value (r^2)	SB B [95% CI]	P value (r^2)	LPA B [95% CI]	P value (r^2)	MVPA B [95% CI]	P value (r^2)
Executive Function	-0.03 [-0.29, 0.23]	0.79 (0.001)	0.21 [-0.04, 0.47]	0.11 (0.04)	-0.31 [-0.55, -0.05]	**0.02 *** (0.09)	-0.21 [-0.42, -0.009]	**0.04 *** (0.04)

Note. All adjusted for age, BMI and sex. B: Beta coefficient; CI: confidence interval; SB: sedentary time; LPA: light physical activity; MVPA: moderate-to-vigorous physical activity; * significant at <0.05

Table 4. Isotemporal substitutions for 5, 10, 15, and 20-minute reallocations

		Add	Sleep	Sleep	Sleep	SB	SB	SB	LPA	LPA	LPA	MVPA	MVPA	MVPA
		Remove	SB	LPA	MVPA	LPA	MVPA	Sleep	SB	MVPA	Sleep	Sleep	SB	LPA
EF	**Total (95% CI)**	**5 min**	-0.02 -0.12, 0.08	0.19 -0.02, 0.40	**-0.17 *** -0.31, -0.03	0.02 -0.08, 0.12	-0.21 -0.43, 0.02	-0.15 -0.32, 0.02	-0.19 -0.39, 0.02	-0.21 -0.43, 0.02	**-0.36 *** -0.69, -0.03	**0.06 *** 0.03, 0.10	0.14 -0.02, 0.31	**0.35 *** 0.02, 0.68
		10 min	-0.04 -0.24, 0.16	0.39 -0.03, 0.80	**-0.35 *** -0.63, -0.06	0.03 -0.16, 0.23	-0.42 -0.87, 0.03	-0.31 -0.66, 0.01	-0.38 -0.78, 0.03	-0.41 -0.86, 0.03	**-0.72 *** -1.39, -0.05	**0.22 *** 0.05, 0.48	0.28 -0.04, 0.60	**0.70 *** 0.05, 1.36
		15 min	-0.06 -0.36, 0.25	0.58 -0.05, 1.22	**-0.53 *** -0.98 -0.09	0.05 -0.25, 0.35	-0.63 -1.32, 0.05	**-0.48 *** -1.01, -0.01	-0.56 -1.17, 0.05	-0.61 -1.28, 0.05	**-1.09 *** -2.1, -0.08	**0.36 *** 0.08, 0.75	0.41 -0.07, 0.89	**1.07 *** 0.07, 2.05
		20 min	-0.08 -0.48, 0.33	0.78 -0.07, 1.63	**-0.73 *** -1.34, -0.12	0.07 -0.33, 0.46	-0.85 -1.77, 0.06	**-0.66 *** -1.37, -0.05	-0.74 -1.55, 0.07	-0.81 -1.70, 0.07	**-1.46 *** -2.82, -0.11	**0.51 *** 0.10, 1.01	0.53 -0.09, 1.16	**1.43 *** 0.09, 2.73

Note: CI: confidence interval; SB: sedentary time; LPA: light physical activity; MVPA: moderate-to-vigorous physical activity; * significant at <0.05