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Temporal and bi-directional associations between sleep duration and physical activity/sedentary time in children: An international comparison

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ABSTRACT

The purpose of this multinational and cross-sectional study was to investigate whether nighttime sleep duration was associated with physical activity (PA) and sedentary time (SED) the following day, whether daytime PA/SED were associated with sleep duration the subsequent night, and whether the associations were modified by sex and study sites. Data from 5779 children aged 9–11 years were analyzed. A waist-worn Actigraph GT3X + accelerometer was used to assess children's 24-h movement behaviours for 7 days, i.e. sleep duration, total SED, light-intensity physical activity (LPA), and moderate- to vigorous-intensity physical activity (MVPA). Multilevel linear regression models were used to account for the repeated measures nested within participants (there were up to 7 sleep → PA/SED and PA/SED → sleep pairings per participant) and schools, and adjusted for covariates. To facilitate interpretation, all sleep and PA/SED variables were standardized. Results showed that the relationship between sleep and PA/SED is bi-directional in this international sample of children. Specifically, for each one standard deviation (SD) unit increase in sleep duration, SED the following day decreased by 0.04 SD units, while LPA and MVPA increased by 0.04 and 0.02 SD units, respectively. Sleep duration decreased by 0.02 SD units and increased by 0.04 SD units for each one SD unit increase in SED and MVPA, respectively. Sleep duration was not affected by changes in LPA. These associations differed across sex and study sites in both directions. However, since the observed effect sizes are subtle, public health initiatives should consider the clinical and practical relevance of these findings.

1. Introduction

Recently, the Canadian 24-Hour Movement Guidelines for Children and Youth provided evidence-informed recommendations for a healthy day, comprising an integration of sleep, physical activity (PA) and sedentary time (SED) (Tremblay et al., 2016). For instance, longer sleep duration is associated with an array of positive health outcomes among school-aged children, such as lower adiposity indicators, better emotional regulation, academic achievement and quality of life/well-being (Chaput et al., 2016). Sufficient PA, including light-intensity physical activity (LPA) and moderate- to vigorous-intensity physical activity (MVPA), is also associated with better mental and physical health outcomes (Janssen and LeBlanc, 2010; Biddle and Asare, 2011; Kwon et al., 2011); while excess SED is associated with unfavorable health

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indicators (Biddle and Asare, 2011; Carson et al., 2016). However, in recent decades, there has been declines in sleep duration and PA levels, and increases in SED among children worldwide (Matricciani et al., 2012; Dollman et al., 2005; Hallal et al., 2012).

There is a growing interest to determine whether there is a virtuous/vicious cycle between children's nighttime sleep duration and daytime PA/SED in the context of the 24-hour lifestyle recommendations. Thus far, research examining the possible bi-directional connection between sleep duration and PA/SED within the pediatric population has produced inconsistent findings. Studies have reported that nighttime sleep duration positively (Hart et al., 2016), negatively (Sorić et al., 2015; Pesonen et al., 2011), or did not (Ekstedt et al., 2013; Vincent et al., 2017) predict the next day's PA. Similarly, studies have reported that PA/SED during the day positively (Nixon et al., 2008), negatively (Pesonen et al., 2011), or did not (Ekstedt et al., 2013; Vincent et al., 2017; Nixon et al., 2008; Dworak et al., 2008) predict the subsequent night's sleep duration. Reasons for these inconsistency remain unclear. Also, research surrounding the association between sleep duration and SED is limited to only one study (Nixon et al., 2008). More epidemiological inquiry is clearly needed based on the available equivocal evidence.

Furthermore, existing research has been mainly conducted in developed countries (Sorić et al., 2015; Pesonen et al., 2011; Ekstedt et al., 2013; Vincent et al., 2017; Nixon et al., 2008; Nixon et al., 2009), with only one study from a developing country (Sorić et al., 2015). The role of higher-order environmental correlates of children's daily lifestyle behaviours are not well understood due to the limited socio-cultural variability. The present multinational study is unique in its international diversity and provides an opportunity to determine whether the relationships of interest differ across countries and socio-cultural settings. Such information is key to informing the development of interventions that can be culturally adapted for implementation around the world.

The objective of this study was to examine the temporal and bi-directional associations between sleep duration and PA/SED in children from 12 countries representing a wide range of geographic and social contexts. Specifically, this study examined whether sleep duration the preceding night was associated with total SED/LPA/MVPA accumulated the following day, and whether SED/LPA/MVPA during the day were associated with sleep duration the subsequent night. We hypothesized that longer sleep duration would be temporally and bi-directionally associated with less SED and more LPA/MVPA. Based on the available evidence, we also hypothesized that the associations of interest would differ across sex (Sorić et al., 2015; Pesonen et al., 2011) and study sites (Sorić et al., 2015; Pesonen et al., 2011; Vincent et al., 2017).

2. Methods

2.1. Study design and setting

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) is a cross-sectional, multinational study designed to determine the relationships between lifestyle behaviours and obesity in 12 study sites located in Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, UK and USA. These countries represent a wide range of economic development (low to high income) (Katzmarzyk et al., 2013). By design, the within-site samples were not intended to be nationally representative. Rather, the primary sampling frame was urban/suburban schools, which were typically stratified by an indicator of socioeconomic status to maximize variability within sites (Katzmarzyk et al., 2013). A standardized protocol was used to collect data across all sites, and all study personnel underwent rigorous training and certification to ensure the data quality (Katzmarzyk et al., 2013). The Institutional Review Board at the Pennington Biomedical Research Center in Baton Rouge, USA (coordinating center) approved the ISCOLE protocol, and the Ethics Review Boards at each participating institution also approved the local protocol. Written informed consent was obtained from parents or legal guardians, and children before participation in the study. Data were collected during the school year at each study site between September 2011 and December 2013.

2.2. Participants

The sample included 9–11-year-old children from the 12 ISCOLE sites. A total of 7372 children participated in ISCOLE, of which 5779 remained in the present analytical sample. Participants without any valid sleep/PA/SED data were excluded ($n = 1214$). Participants without covariate information were also excluded, including diet ($n = 129$), parental education ($n = 247$), and body mass index (BMI) z-score ($n = 3$). Participants who were excluded due to missing data consisted of more males, with significantly higher BMI z-scores, but did not differ in age (data not shown). Within the 5779 participants, several nights and days were removed because of insufficient (invalid) data to determine sleep and/or PA/SED. The final number of pairings were $n = 31,019$ for the analyses where nighttime sleep duration predicted the subsequent day's PA/SED and $n = 31,408$ for the analyses where daytime PA/SED predicted the subsequent night's sleep duration.

2.3. Measurements

Sleep duration, SED, LPA and MVPA were all objectively assessed using 24-h accelerometry. An Actigraph GT3X + accelerometer (ActiGraph LLC, Pensacola, FL, USA) was worn at the waist on an elasticized belt at the right mid-axillary line. Participants were encouraged to wear the accelerometer 24 h per day (removing only for water-based activities) for at least 7 consecutive days, including 2 weekend days. The minimal amount of daytime data considered acceptable for inclusion in the sample was at least 10 h of wake wear time per day. Data were collected at a sampling rate of 80 Hz, downloaded in 1-s epochs with the low frequency extension filter using the ActiLife software version 5.6 or higher (ActiGraph LLC, Pensacola, FL, USA), and later reintegrated to 15-s and 60-s epochs for the different analyses. Nocturnal sleep duration (h/night) was estimated from the accelerometry data using 60-s epochs and a fully automated algorithm for 24-hour waist-worn accelerometers that was developed and validated for ISCOLE (Tudor-locke et al., 2014; Barreira et al., 2015). Sleep data were considered valid if daily total sleep period time was ≥ 160 min/night and $> 90\%$ estimated wear time. After exclusion of total sleep period time and awake non-wear time (any sequence of ≥ 20 consecutive minutes of 0 activity counts), SED was defined as all movement ≤ 25 counts per 15-s, LPA between 26 and 573 counts, and MVPA ≥ 574 counts (Barreira et al., 2015), which is consistent with the widely used Evenson cut-offs (Evenson et al., 2008). Daily values of sleep duration, SED, LPA and MVPA were exported into datasets with multiple observations for each participant (e.g., one row per day), with each participant having up to 7 repeated sleep duration and SED/LPA/MVPA measures.

2.4. Covariates

Age, sex, parental education, BMI z-score, unhealthy dietary pattern, daily awake wear time of accelerometer, and type of day (weekday or weekend day) were included as covariates in statistical models. Age was computed from birth and observation dates and sex was self-reported on a questionnaire. Parental education was coded into three categories based on the highest level of education attained by either parent: “did not complete high school”, “completed high school or some college”, or “completed bachelor's or postgraduate degree”. Body mass was measured using a portable Tanita SC-240 Body Composition Analyzer (Arlington Heights, IL) without outer clothing, heavy pocket