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Executive function mediates prospective relationships between sleep duration and sedentary behavior in children

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ABSTRACT

Childhood sedentary behavior has been linked to increased obesity risk. Prior work has identified associations between sedentary behavior, executive function (EF), and sleep. This study tested the hypothesis that reduced sleep duration may adversely impact EF and lead to increased childhood sedentary behavior. Southern California schoolchildren participating in the school-based health promotion program *Pathways to Health* (N = 709) were assessed annually from 4th through 6th grades (2010 − 2013) on self-report measures of sedentary behavior, sleep duration, and executive function. A series of path models were specified treating average nightly sleep duration and weekend wake/bed-time shift at 4th grade as predictors of 6th grade sedentary behavior. Four EF subdomains were tested as potential mediators of longitudinal associations at 5th grade. Significant associations between average nightly sleep duration, EF and sedentary behavior were identified ($p < 0.05$), adjusting for participant gender, physical activity, SES, ethnicity, program group assignment, and the presence/absence of parental screen time rules. Fifth grade overall EF ($p < 0.05$)—and in particular the subdomains of inhibitory control ($p < 0.05$) and organization of materials ($p < 0.01$)—significantly mediated the relationship between 4th grade sleep duration and 6th grade sedentary behavior ($p < 0.05$). Furthermore, delay of weekend bed- or wake-times relative to weekdays was prospectively associated with decreased overall EF ($p < 0.05$), but not increased sedentary behavior ($p = 0.35$ for bed-time delay; $p = 0.64$ for wake-time delay), irrespective of average nightly sleep duration. Findings suggest that sleep promotion efforts may reduce children's sedentary behavior both directly and indirectly through changes in EF.

1. Background

Compared to previous generations, today's youth increasingly engage in sedentary activities such as computer use, video games and viewing other electronic media—frequently characterized as *screen time* (Rideout et al., 2010). For example from 2000 to 2010 the average US child's screen time–including television, movies, videogames and computer use—increased by more than 2.5 h/day (Rideout et al., 2010). Data from the CDC's Youth Risk Behavior Surveys in 2011 (2)–2013 (3) suggest that video gaming and non-school-related computer use have increased particularly sharply in recent years. Moreover, growing use of internet-enabled mobile phones and tablets is likely to result in further screen time increases as these devices become increasingly incorporated into children's lives.

Sedentary behavior has been defined as *"any waking activity characterized by an energy expenditure <= 1.5 metabolic equivalents and a sitting or reclining posture"* (Cart, 2012), and is associated with increased risk of childhood obesity (Wong and Leatherdale, 2009; Anderson et al., 2008), hypertension (Pardee et al., 2007) and numerous psychosocial outcomes (Strasburger et al., 2010; Russ et al., 2009). A recent Danish study found that long-term sedentary behavior was related to greater reduction of quality adjusted life years (7 years) than either obesity (3–6 years) or high rates of alcohol consumption (3–5 years) (Bronnum-Hansen et al., 2007). This suggests that sedentary behavior constitutes an important target for health promotion interventions, independent of physical activity. Within the home environment, previous work has found that the establishment of parental rules governing screen time within the household can lead to significantly reduced sedentary behavior in children (Ramirez et al., 2011).

One behavior which has been found to be inversely associated with sedentary behavior is sleep (Cain and Gradisar, 2010; Costigan et al., 2013). A longitudinal British study found screen time to be associated with increased sleep problems (e.g. daytime fatigue) though nightly sleep duration was not assessed (Viner and Cole, 2006). Two cross-sectional studies found high levels of internet use and computer game playing to be positively associated with self-reported insufficient sleep (Van den Bulck, 2004; Belanger et al., 2011). Furthermore, a recent longitudinal birth cohort study of television viewing and sleep in children found that not only did children who watched more television sleep

Abbreviations: EF, Executive Function; BRIEF-SR, Behavioral Rating Inventory of Executive Function-Self-Report; SES, Socioeconomic status.

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less, but that changes in TV viewing patterns were negatively associated with changes in sleep duration across time (Marinelli et al., 2014). While each study suggested that efforts to cap children's screen time would lead to improved sleep, none explored the possibility that sleeping less might increase sedentary behavior.

A recent systematic review examining relationships between sleep and sedentary behavior suggested that—beyond the direct metabolic effects of sleep—there are two indirect pathways through which sleeping less may lead to increased sedentary behavior (Must and Parisi, 2009). The first is that sleep deprivation may lead to fatigue, rendering children less likely to engage in physical activity and more likely to engage in sedentary activities. The second is that time children spend asleep may simply displace time that would otherwise be spent in obesogenic environments, which promote sedentary behavior. While these pathways are plausible, a novel third, cognitive pathway may provide a useful framework to link sleep and sedentary behavior. In this latter framework, it may be that children with the cognitive capacity to better plan their behavior in a goal-directed manner, organize their environments, and inhibit the tendency to engage in default, obesogenic behaviors (e.g. TV watching), will be less sedentary than children lacking these complex cognitive skills. In support of this possibility, a recent study utilizing polysomnography found that television viewing and computer game playing adversely impacted both children's sleep efficiency and their verbal cognitive performance (Dworak et al., 2007)—implying a link between sleep, cognition and sedentary behaviors in school-aged children.

An important set of cognitive processes that may relate to both sedentary behavior and sleep is executive function (EF). EF refers to a cluster of cognitive processes such as inhibitory control and working memory, which play a significant role in the planning and execution of decision-making, self-regulatory, and goal-directed behaviors (Diamond, 2013). Deficits in EF have been found to predict sedentary behavior in elementary schoolchildren (Riggs et al., 2012a) and have been associated with decreased sleep duration among adolescents (Anderson et al., 2009). Although EF has been found to be relatively stable during late childhood-early adolescence (Harms et al., 2014), studies have identified links between insufficient sleep and EF impairment (Chuah et al., 2006; Durmer and Dinges, 2005; Killgore, 2010). Such work has found acute sleep deprivation to substantially impair inhibitory control (Chuah et al., 2006; Drummond et al., 2006), working memory (Lim and Dinges, 2010), and integration of emotional cues into complex decision-making (Killgore et al., 2006).

Research has also identified associations between delaying weekend wake-times relative to school nights and multiple health risk behaviors (O'Brien and Mindell, 2005). Such changes in sleep patterns may be particularly detrimental during adolescence since circadian rhythms governing sleep during this developmental period adapt more readily to delayed bedtimes than advanced wake-times (Dahl and Lewin, 2002). However, little is known about inter-relationships between sleep, EF, and sedentary behavior. The present study tested the longitudinal impact of total weekly sleep duration, as well as delay of weekend wake- or bed-times on sedentary behavior among elementary schoolchildren, hypothesizing that EF would mediate these prospective relationships.

2. Methods

2.1. Background

Data were taken from the 4th (2010 baseline), 5th, and 6th grade assessment waves of *Pathways to Health*, a randomized controlled trial for prevention of obesity and substance use in children in 24 Southern California elementary schools (Sakuma et al., 2012). This program translated evidence-based social-emotional learning and substance use interventions (Riggs et al., 2006a) into a health promotion curriculum focused on improving health behavior decision-making.

2.2. Participants

Participants were 1005 4th grade assented students with full active parent consent to participate in the study, and who constituted a panel that was followed from grades four through six. Of these, 709 had complete data for all three years and constituted the analytic sample. Of the 296 participants who were not retained, participant attrition was due to the following: 185 (63%) to families moving, 18 (6%) to students, parents and/or administrators declining participation, 29 (10%) to student absences on days of assessment, and 64 (22%) to school closures. When compared to the 709 study participants the 296 participants lost to follow-up were more likely to be Hispanic (33% vs. 26%; $p < 0.05$) and low socioeconomic status (SES) (35% vs. 21%; $p < 0.001$). The final analytic sample was 50% female, 26% Hispanic and 21% low SES. These students represent 75 classrooms and 24 Southern California schools. Human subjects procedures were approved by the relevant Institutional Review Board.

2.3. Measures

Data for the study were drawn from a self-report survey administered in one 45-min classroom period. The survey was administered verbally by a trained data collector.

2.3.1. Sleep

Average nightly sleep duration was calculated using four survey items asking participants: "*On an average school day what time do you go to bed/wake up?" and "On an average weekend day what time do you go to bed/wake up?"* These items were adapted from the Sleep Habits Survey, which was developed and validated for use in adolescents (Wolfson et al., 2003). Numerous studies have employed similar self-report measures of sleep duration in comparable populations (Nuutinen et al., 2013; Appelhans et al., 2014; Hoedlmoser et al., 2010). An estimate of participants' average nightly sleep hours was calculated as the weighted mean of weekday and weekend sleep duration. To estimate how much participants shifted their wake/bed times on weekends relative to school nights, self-reported weekend wake/bed times were subtracted from self-reported weekday wake/bed times, creating variables indicating the number of hours that children "slept in", and "stayed up" on weekends, respectively.

2.3.2. Executive function

Items from the following four of eight clinical sub-scales of the Behavioral Rating Inventory of Executive Function-Self-Report (BRIEF-SR) were used to assess EF (Guy et al., 2004): inhibitory control, emotional control, working memory and organization of materials. These four scales were selected by investigators to reflect the subdomains of EF hypothesized to be more relevant to the observable and modifiable health behaviors targeted by the Pathways intervention. To abbreviate the scales, factor analyses were conducted on each subscale and items demonstrating factor loadings <0.45 were dropped. Each BRIEF-SR item asks participants: "How often each of the following has been a problem in the last month?" Response choices are: 1 = Never, 2 = Sometimes, 3 = Often. An example item from the inhibitory sub-scale is "I do things without thinking first," and for the working memory sub-scale is "I forget what I'm doing in the middle of things". Subscale means and total mean scores were reverse-coded so higher scores reflect greater EF competency. The BRIEF was designed to be an appropriate and ecologically valid measure of EF skills associated with goals and actions in everyday problem solving situations encountered by school-age children, rather than an indicator of laboratory or structured task performance (Guy et al., 2004; Toplak et al., 2013). Over 400 peer-reviewed manuscripts report the reliability, validity and clinical utility of the BRIEF (Roth et al., 2015). Our decision to abbreviate the BRIEF-SR measure was motivated by time-constraints imposed by partner schools for in-class survey administration. Previous work found these