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Replacing sedentary time with sleep, light, or moderate-to-vigorous physical activity: Effects on self-regulation and executive functioning

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Abstract

Introduction—Recent attention has highlighted the importance of reducing sedentary time for maintaining health and quality of life. However, it is unclear how changing sedentary behavior may influence executive functions and self-regulatory strategy use, which are vital for the long-term maintenance of a health behavior regimen. The purpose of this cross-sectional study is to examine the estimated self-regulatory and executive functioning effects of substituting 30 minutes of sedentary behavior with 30 minutes of light activity, moderate-to-vigorous physical activity (MVPA), or sleep in a sample of older adults.

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Compliance with Ethical Standards

Ethical Approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Conflict of Interest:
Jason Fanning declares that he has no conflict of interest.
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Methods—This study reports baseline data collected from low-active healthy older adults (N = 247, mean age 65.4±4.6 years) recruited to participate in a six month randomized controlled exercise trial examining the effects of various modes of exercise on brain health and function. Each participant completed assessments of physical activity self-regulatory strategy use (i.e., self-monitoring, goal-setting, social support, reinforcement, time management, and relapse prevention) and executive functioning. Physical activity and sedentary behaviors were measured using accelerometers during waking hours for seven consecutive days at each time point. Isotemporal substitution analyses were conducted to examine the effect on self-regulation and executive functioning should an individual substitute sedentary time with light activity, MVPA, or sleep.

Results—The substitution of sedentary time with both sleep and MVPA influenced both self-regulatory strategy use and executive functioning. Sleep was associated with greater self-monitoring ($B = .23$, $p = .02$), goal-setting ($B = .32$, $p < .01$), and social support ($B = .18$, $p = .01$) behaviors. Substitution of sedentary time with MVPA was associated with higher accuracy on 2-item ($B = .03$, $p = .01$) and 3-item ($B = .02$, $p = .04$) spatial working memory tasks, and with faster reaction times on single ($B = -23.12$, $p = .03$) and mixed-repeated task-switching blocks ($B = -27.06$, $p = .04$). Substitution of sedentary time with sleep was associated with marginally faster reaction time on mixed-repeated task-switching blocks ($B = -12.20$, $p = .07$) and faster reaction time on mixed-switch blocks ($B = 17.21$, $p = .05$), as well as reduced global reaction time switch cost ($B = -16.86$, $p = .01$). Substitution for light intensity physical activity did not produce significant effects.

Conclusions—By replacing sedentary time with sleep and MVPA, individuals may bolster several important domains of self-regulatory behavior and executive functioning. This has important implications for the design of long-lasting health behavior interventions.

Keywords

Sedentary Behavior; Sleep; Physical Activity; Self-regulation; Executive Function

Introduction

Adults in the United States are facing a crisis of chronic disease: seven of the top 10 causes of death in 2010 were chronic diseases (e.g., cancer, heart disease, Alzheimer’s Disease), and approximately one in two individuals lives with such a condition (Centers for Disease Control and Prevention 2015a; Ward et al. 2014). Importantly, these high prevalence rates are often perpetuated by the daily behaviors in which a person spends their time. A considerable body of evidence has been built around the importance of engaging in moderate-to-vigorous physical activity (i.e., MVPA: activities requiring an energy expenditure of at least 3.0 metabolic equivalents (METS); World Health Organization (WHO) 2015) for improving health and quality of life, and for reducing the prevalence and impact of these diseases. Regular participation in MVPA is vital for physical and cognitive function at any stage in the lifespan, and insufficient activity affects as many as 25 separate physical and psychological diseases (Warburton and Bredin 2016). In recent years, health behavior researchers have begun to focus on sedentary behaviors, which are waking activities defined by both their posture (i.e., seated or laying in position) and low metabolic cost (i.e., 1.5 METS; Owen 2010). Although this area of research is fairly nascent, a consistent literature has emerged highlighting the negative effects that long and unbroken bouts of sedentary behaviors have on a number of health outcomes. The strongest evidence supports a positive relationship between breaks in sedentary time and metabolic health, and many of these effects are independent of time spent in MVPA, such that a regular exerciser with a large amount of occupational or recreational sitting may still be exposed to substantial health risk (Healy et al. 2008, 2011; Owen 2010).

The amount of time an individual is able to spend engaging in physical activity, sedentary behavior, or sleep is finite; and this unsurprising fact is nonetheless an important one for health researchers. Consider a sedentary individual who sleeps eight hours per night: The remaining 16 hours may be spent sitting in the car, walking to and from the office, sitting at a desk, and sitting in front of the television in the evening. Should this individual aim to add 30 minutes of exercise to their day, he or she may choose to wake up early or go to sleep later, thereby replacing sleep. Alternatively, he or she may choose to reduce sedentary time by engaging in light activity (e.g., slow walking) or MVPA instead of watching TV at night. It is also quite likely the type, quality, and quantity of these behaviors operate synergistically (Buman et al. 2015). For instance, engaging in physical activity has demonstrable and positive effects on one's sleep habits (Benloucif et al. 2004; Dzierzewski et al. 2014), while improved sleep has been shown to increase an individual's ability to engage in physical activity the following day (Dzierzewski et al. 2014; Lambiase et al. 2013; Talbot et al. 2014). Therefore, while reducing sedentary time is likely to have important implications for a number of psychosocial and health outcomes, it is certainly feasible that the activity with which sedentary behavior is substituted (i.e., sleep, light activity, MVPA) is likely to influence the type and magnitude of these effects.

Of particular interest to health behavior researchers is the potential effect of these substitutions on self-regulatory behaviors and the cognitive processes thought to underlie them. A person's behavior is driven in large part by the interaction between their own behaviors, personality factors, and environmental influences (Bandura 2004; Buckley et al. 2014). Moreover, a person's cognitive processes play an important role in mediating the influence of external or environmental pressures on behavior (Bandura 2001). Chief among these cognitive processes are executive functions (i.e., working memory, inhibition, task-switching; Diamond 2013), which are effortful top-down mental processes that regulate, control, and modulate information from several brain regions (Buckley et al. 2014; Diamond 2013), and allow an individual to conceptualize, manipulate, and plan for the future (Buckley et al. 2014). Importantly, these functions subserve a person's self-regulatory behavior: successful self-regulation requires an individual to hold specific values and standards for their behavior, to possess sufficient motivation to achieve those standards, and to have access to sufficient regulatory capacity to achieve their goals despite obstacles (Baumeister and Heatherton 1996; Carver and Scheier 1981; Hofmann et al. 2012). Strong working memory capacity is required when managing personal health goals and strategies for achieving them (Kruglanski et al. 2002; Miller and Cohen 2001), for shielding important goals from interference (Shah et al. 2002), and for down-regulating desires and cravings (Hofmann et al. 2012; Wranik et al. 2007). Both working memory and inhibition are necessary for resisting tempting and distracting goals and stimuli (Dreisbach and Haider 2009; Hofmann et al. 2009), and task-switching helps one to identify and move to better strategies for achieving one's goals (Marien et al. 2012). Together, these functions allow an individual to cope with and adapt to changing demands and circumstances, and to plan for and carry out behavioral goals across time (Bandura 1997; Buckley et al. 2014).

Fostering a strong self-regulatory capacity is important for those seeking to develop and maintain health behaviors (e.g., reduced sitting, increased exercise) for a number of reasons. For example, exercise is an effortful behavior that requires an individual to suppress the desire to engage in more comfortable and enjoyable activities (e.g., watching television) in favor of activities that often require physical exertion and discomfort. It is unsurprising, then, that research has consistently demonstrated a positive association between executive functioning and self-regulation of physical activity behavior. McAuley and colleagues (2011) demonstrated that better performance on several measures of executive functioning, alongside greater use of self-regulatory strategies, was associated with higher levels of exercise self-efficacy, which in turn was predictive of better adherence to a physical activity regimen over a one year period. Further evidence suggests this relationship is likely reciprocal, such that increased participation in MVPA is associated with improvements in select aspects of executive functioning, which may support self-regulation (e.g., Daly et al. 2014; Voss et al. 2011). Importantly, a strong and growing body of evidence suggests that these executive functioning enhancements may be linked to exercise and improvements in physical fitness, which beget improvements in brain structure and function in key areas associated with executive functions (Colcombe et al. 2006; Erickson et al. 2011).

In addition to time spent in MVPA, independent studies have demonstrated a person's sitting and sleep habits have important implications for their cognitive abilities. Poor sleepers have been shown to have impaired executive functioning (Anderson et al. 2009; Goel et al. 2009) and poorer self-regulatory capacity (Hagger 2009). Sleep deprivation has also been shown to impair reaction time and speed on task-switching tasks in young adults (Couyoumdjian et al. 2010). Excessive sleep is associated with impairment in a number of cognitive functions in older adults (Yaffe et al. 2014), and daily variations in sleep duration, quality, and tiredness appear to contribute to impaired working memory capacity among children (Könen et al. 2015). Gohar and colleagues (2009) demonstrated that decreased sleep duration among medical residents corresponded with impaired working memory capacity and a greater number of errors on an arithmetic test. Unsurprisingly, there are a number of hypotheses relative to the acute and chronic impact of poor sleep on cognition, ranging from decreased activation in important brain regions that are supportive of executive functioning (Chee and Choo 2004), to amyloid-β accumulation (Ju et al. 2014) and chronic neuroinflammation (Zhu et al. 2012). Nonetheless, this body of work suggests that sleep has an important impact on an individual's cognitive functioning and daily self-regulatory capacity, and this is closely tied to their ability to engage in physical activity.

Finally, as with the study of sedentary behaviors as a whole, the study of relationships between sedentary behavior and cognition is relatively novel. Although high-quality experimental or observational studies employing direct assessments of sedentary behavior are lacking, several longitudinal studies indicate that lower levels of sedentary behavior (i.e., more overall physical activity) may be associated with reduced cognitive impairment in later years (Buchman et al. 2012; Middleton et al. 2011). The lack of research related to sedentary behavior, cognition, and self-regulation highlights an important area for additional research, as self-regulatory capacity is vitally important for inhibiting the urge to sit in favor of standing or physical activity (Buckley et al. 2014). Unlike with physical activity, an individual must continually inhibit this urge across the day. This requires a strong ability to hold the goal in memory and to act upon it, and an ability to flexibly switch between mental sets in order to avoid the habitual behavior (Buckley et al. 2014). Accordingly, there is a need for researchers to utilize objective assessments of sedentary behavior to study its impact on important executive functions.

For interventionists interested in reducing sedentary behavior, understanding the complex and cyclical relationship between the distribution of an individual's daily behaviors, their cognitive functioning, and their self-regulatory abilities may be of importance for designing effective, long-lasting interventions. Rather than simply targeting one activity to replace sedentary behaviors (e.g., light intensity physical activity), it may instead be beneficial to identify and target multiple behaviors that foster important executive functions and self-regulatory abilities. Thus, the purpose of this exploratory study was to utilize isotemporal substitution analysis to examine the estimated effect of substituting sedentary time with sleep, light activity, or MVPA on self-regulatory behaviors and executive functions. This analytical technique, which allows for the examination of the "substitution association" of replacing one type of activity for another, offers valuable insight into the ways in which these important and related behaviors impact health and wellbeing.

Methods

Participants and Procedures

The data presented herein represent baseline (i.e., pre-intervention) data collected from low-active healthy older adults ($N = 247$) recruited to participate in a six month randomized controlled exercise trial examining the effects of various modes of exercise on brain health and function (see ClinicalTrials.gov protocol number NCT00438347 for more information). Eligible individuals were (1) aged 60–79 years; (2) able to speak English; (3) scored ≥75% right-handedness as assessed on the Edinburgh Handedness Inventory (Caplan and Mendoza 2011); (4) scored 23 on the Mini-Mental State Exam (MMSE; Folstein et al. 1975); (5) scored > 21 on the Telephone Interview of Cognitive Status (de Jager et al. 2003); (6) engaging in 20 or more minutes of MVPA on two or fewer days per week as assessed via self-report; (7) and not involved in another physical activity intervention. All participants wore an Actigraph accelerometer during waking hours for one week, submitted a series of psychosocial questionnaires, and completed a battery of computerized cognitive performance measures prior to the start of the intervention period. All computerized cognitive assessments were completed in a quiet, distraction-free room. Although task instructions were provided within each computerized task, trained staff members were present to clarify any questions related to the task instructions.

Measures

Physical Activity and Sedentary Behavior—All individuals enrolled in this study received an Actigraph accelerometer (Model GT1M or GT3X; Actigraph, Pensacola, FL).

Each participant was instructed to wear the accelerometer on the non-dominant hip during waking hours for seven consecutive days, and record the time that they wore the device each day on a log. When scored with an interruption period of 60 minutes, those with at least 10 hours of wear time on at least three days were retained in analyses (Evenson et al. 2012; Troiano et al. 2008). These data were downloaded as activity counts, which represent raw accelerations that have been summed over a specific epoch length (e.g., 60 seconds), and these counts vary based on frequency and intensity of the recorded acceleration (Actigraph 2011). Next, these data were processed using cut points designed specifically for older adults (Copeland and Esliger 2009) such that 50 or fewer counts per minute corresponded with sedentary behavior, 51–1040 counts per minute corresponded to light activity, and 1041 counts or greater represented MVPA.

Sleep—Participants provided self-reported assessments of average nightly sleep using an item from the Pittsburgh Sleep Quality Index (Buysse et al. 1989). Participants report average nightly sleep duration over the previous month, and this was utilized to calculate average minutes of sleep per night.

Self-Regulatory Strategy Use—To assess the use of self-regulatory strategies related to physical activity behavior, all participants completed the 12-item Physical Activity Self-Regulation Scale (Umstattd et al. 2009). Participants responded to a series of questions related to six types of self-regulation strategies (i.e., self-monitoring, goal-setting, social support, reinforcement, time management, and relapse prevention) by indicating how often they participated in each strategy. Responses were provided on a 5-point Likert scale with options ranging from 1 (never) to 5 (very often). Each of the six subscales is comprised of two questions, with scores ranging from 2–10 and higher scores indicating greater use of a respective strategy. The total scale score is calculated by summing all items, with possible scores ranging from 12–60, again with higher scores representing greater strategy use. Internal consistency was excellent ($\alpha = 0.96$).

Spatial Working Memory Paradigm—To assess the visuospatial domain of working memory, participants completed a computer-based spatial working memory task (Erickson et al. 2009, 2011). This required participants to focus on a cross in the middle of a white screen. Two, three, or four black dots appeared briefly (i.e., for 500 ms) on the screen before disappearing for one second. A red dot then appeared for two seconds, and participants were asked to indicate whether the red dot was in the same location (match) or a different location (non-match) than one of the black dots, and this was accomplished by pressing a designated key on a keyboard. Participants received 12 practice trials (6 match, 6 non-match) prior to task administration to familiarize them with the task. Accuracy rates and reaction times were recorded for the two, three, and four dot conditions, and were averaged separately to create mean accuracy and latency (i.e., reaction time) scores, respectively (Erickson et al. 2009, 2011).

Task-Switching Paradigm—To assess each individual’s task-switching ability, participants were asked to switch back and forth between two different tasks that used the same numeric stimuli, which appeared in the center of the computer screen. In one condition, participants determined whether the digit presented was greater or less than five; and in the other condition, participants determined whether the digit presented was odd or even. During each trial, the digit was present in front of a blue or pink background, which instructed participants as to which decision to make (i.e., greater or less than five, odd or even). Participants received three blocks of stimuli. The first two blocks were the homogenous conditions, in which only one task was performed, and were counterbalanced across participants (hereafter referred to as "single" tasks). The third block consisted of the task-heterogeneous condition in which participants were required to switch between equiprobable task sets on some trials (i.e., "mixed-switch" trials) and repeatedly perform the same task over trials in other cases (i.e., "mixed-repeat" trials). That is, in the heterogeneous block the two tasks alternated randomly, with seven consecutive trials as the maximum number that were performed repeatedly for each task. Numeric stimuli were presented very briefly (200 ms) on a black background, with a two-second inter-stimulus interval from stimulus offset to onset. Participants first completed 10 practice trials in each of the homogenous conditions and in the heterogeneous condition. Next, they were provided 50 trials in each of the homogenous conditions and 256 trials in the heterogeneous condition. Global switch cost analyses examined differences in reaction time between homogenous and heterogeneous conditions, whereas local switch cost analyses examined differences in reaction time between switch and non-switch trials during the heterogeneous block condition (adapted from Hillman et al. 2006). Both cognitive assessments were completed in a quiet, dedicated testing room using E-Prime version 1 (Psychology Software Tools, Inc).

Data Analysis

Isotemporal Substitution Models—Isotemporal models estimate the effect of replacing one type of behavior for another of the same amount of time (see Mekary et al. 2009, for a detailed description). These techniques were employed in the present study to examine the "substitution association" of replacing time spent sedentary for time spent in light activity, MVPA, or sleep. First, all variables were scaled to 30 minute increments to aid in interpretability, and then a "total time" score was calculated to represent the average daily time spent in sleep, sedentary behavior, light activity, and MVPA (i.e., total time = sleep + sedentary + light + MVPA). Next, total time, all behaviors, and covariates (i.e., age, gender, race) were entered into a regression model simultaneously with the exception of the behavior of interest (i.e., sedentary time). An example model can be expressed as follows:

$$Self-Regulatory\ Strategy\ Use = (\mathrm{B}_1)light\ activity + (\mathrm{B}_2)MVPA + (\mathrm{B}_3)sleep + (\mathrm{B}_4)total\ time + (\mathrm{B}_5)covariates$$

such that B_1–B_5 are coefficients of respective activities or covariates. Because sedentary time was omitted from the model, the remaining coefficients represent the consequence of engaging in 30 minutes of the respective activity instead of engaging in 30 minutes of sedentary behavior while holding the other activities constant (e.g., B_1 represents the change in self-regulatory strategy use if 30 minutes of sedentary time are substituted with 30 minutes of light activity while holding other activities and covariates constant; Mekary et al. 2013). Importantly, because the data are cross-sectional, these substitutions cannot be inferred as temporal substitutions within individuals. Statistical significance was established at $p \leq .05$ in all models.

Results

Of the 1119 individuals screened for eligibility, 247 met inclusion criteria and agreed to enroll in the study. Of these individuals, 240 (97%) provided valid data relative to their self-regulation strategy use, 206 (83%) provided valid spatial working memory data, and 200 (81%) provided valid task-switching data. The mean age was 65.4± 4.6 years, and the sample was primarily female (n = 169; 68.4%), married (n = 146; 59.1%), retired (n = 118; 47.8%), white (n = 207; 83.3%), college-educated (n = 145; 58.7%), and earning > $40,000 per year (n = 139; 56.3%). Participant characteristics are displayed in Table 1.

Spatial Working Memory

Substituting sedentary time with MVPA was associated with better accuracy on the 2-item and 3-item tasks ($B = .03$, $SE = .01$, $p = .01$ and $B = .02$, $SE = .01$, $p = .04$ respectively). There were no significant effects on 4-item accuracy, nor were there significant associations between the substitution of sedentary time with MVPA or sleep and reaction time for any task. Similarly, there were no significant associations between spatial working memory measures and light physical activity.

Task-Switching

The substitution of sedentary time with MVPA corresponded with faster reaction time on the single and mixed-repeated tasking-switching tasks ($B = -23.12$, $SE = 10.63$, $p = .03$ and $B = -27.06$, $SE = 13.24$, $p = .04$ respectively), and a substitution of sedentary time with sleep approached significance on the mixed-repeated task ($B = -12.20$, $SE = 6.61$, $p = .07$). Only the substitution of sedentary time with sleep was significantly associated with faster reaction time on the mixed-switch task ($B = - 17.21$, $SE = 8.704$, $p = .05$). Finally, only a substitution sedentary time with sleep was related to reduced global switch cost for reaction time ($B = -16.86$, $SE = 6.77$, $p = .01$). There were no significant relationships between the substitution of sedentary time with light activity on any task-switching outcome.

Self-Regulatory Strategy Use

The substitution of 30 minutes of sedentary time with 30 minutes of sleep or MVPA was associated with more favorable total scores on the self-regulation scale ($B = 1.29$, $SE = .39$, $p < .01$ and $B = 1.81$, $SE = .80$, $p = .02$, respectively). A substation for sleep was significantly associated with greater scores on the self-monitoring subscale ($B = .23$, $SE = .09$, $p = .02$), the goal-setting subscale ($B = .32$, $SE = .09$, $p < .01$), and the social-support subscale ($B = .18$, $SE = .07$, $p = .01$). Substituting sedentary time with light activity was not associated with changes in any subscale. Results from all isotemporal substitution models can be found in Table 2.

Discussion

The purpose of the present study was to explore the effect of substituting time in sedentary behaviors with time spent engaging in light activity, MVPA, or sleep on self-regulatory behaviors and two domains of executive functioning thought to underlie self-regulatory behaviors. Results indicate substituting MVPA for sedentary time corresponded with higher accuracy on a spatial working memory task and faster reaction time on “easier” (i.e., single and mixed-repeated) task-switching tasks. Shifting time from sitting to sleep had beneficial effects on global reaction time switch cost, and reaction time for more “challenging” (i.e., mixed-repeated and mixed-switch) task-switching tasks. Importantly, substituting sedentary time with either of these behaviors had implications for the physical activity-related self-regulatory behaviors a person engaged in (i.e., self-monitoring, goal-setting, seeking social support), with sleep influencing the greatest number of behaviors.

These findings build on previous work demonstrating the positive effects of physical activity and sleep on working memory and task-switching (Couyoumdjian et al. 2010; Hawkes 2014; Kramer et al. 2005) by providing evidence for the ways in which sleep, physical activities, and sedentary behaviors work in unison to impact these cognitive functions. Perhaps more importantly, the findings of this study indicate that a multifaceted approach to addressing time spent sedentary may best suit an individual attempting to initiate and maintain a chronic health behavior such as physical activity. At the present time, messaging aimed at reducing sedentary behaviors typically targets an increase in time spent in light intensity physical activity, as these activities account for the greatest proportion of daily energy expenditure. Although researchers have demonstrated that increases in light intensity activity may improve a number of cardiometabolic outcomes (Buman et al. 2014), the results of the present study indicate such a singular focus on light intensity activity may not build the self-regulatory capacity needed for long-term behavior change. Instead, targeting MVPA may help to support working memory, while addressing both sleep and MVPA may help to improve task-switching ability. These executive functions are vital for maintaining personal goals, avoiding distraction, down-regulating competing desires, and identifying and utilizing alternative strategies for achieving goals (Baumeister and Heatherton 1996; Carver and Scheier 1981; Dreisbach and Haider 2009; Hofmann et al. 2009, 2012; Kruglanski et al. 2002; Marien et al. 2012; Miller and Cohen 2001; Shah et al. 2002; Wranik et al. 2007). With this in mind, health researchers targeting sedentary behaviors may consider the application of intervention techniques aimed at replacing sedentary behaviors with activities of various intensities, and by emphasizing the importance of high quality sleep.

It is worth noting that many of the same technologies that have contributed to reductions in light activity and increases in sedentary time (e.g., computers, smartphones) yield negative effects on other health behaviors, including sleep. For instance, accumulating evidence links exposure to light-emitting diode (LED) screens (common in computers, smartphones, and tablet devices) to insomnia, altered circadian physiology, and ultimately wake-sleep regulation(Cajochen et al. 2011; Fossum et al. 2014; Khalsa et al. 2003; van der Lely et al. 2015). Additionally, the specific ways in which the individual engages with these technologies also appears to impact sleep habits. For instance, in very recent years, a number of publications have drawn associations between greater social networking website usage, as well as higher levels of digital media usage before bedtime, with poorer sleep outcomes in young adults (Levenson et al. 2016; Orzech et al. 2016).

Interestingly, accumulating evidence indicates we may be able to leverage these technologies to develop effective multiple health behavior interventions that support an individual across the day (Manini et al. 2014). Driven largely by a very rapid increase in availability and ownership of smartphone devices, the fields of eHealth and mHealth have grown tremendously in recent years. Because smartphones are often carried with the individual at all times, researchers have sought to utilize the devices to better measure, understand, and impact a number of human behaviors, including sleep, sedentary behavior, and physical activity.

Fortunately, a number of successful eHealth and mHealth interventions have been developed to target each of these disparate outcomes. For instance, Ritterband and colleagues adapted core concepts from cognitive behavioral therapy for insomnia for delivery via the internet (Ritterband et al. 2009). Those who received the 9-week intervention demonstrated improvements in insomnia severity, wake after sleep onset, and sleep efficiency. With regard to physical activity, a number of systematic reviews and meta-analyses have demonstrated that a growing number of internet and mobile-delivered interventions have been effective for promoting physical activity behavior (Fanning, Mullen, & McAuley, 2012; Vandelanotte et al., 2016). Still, very few researchers have integrated these intervention components. Recently, Buman and colleagues (2015) described the design of a forthcoming mHealth intervention utilizing a mobile phone app to target sleep and sedentary and active behaviors across the day. Experts in each behavior worked together to design and implement individual intervention components, which could be tested individually or delivered in combination with one another. This approach has been emphasized in a number of newer intervention design frameworks (e.g., the multiphase optimization strategy; Collins et al. 2007), as they allow researchers to examine the individual and combined efficacy of the intervention components. In light of the findings of this study, this promising approach holds potential for affecting meaningful change across multiple behaviors.

Finally, this multicomponent approach also builds upon recommendations from a number of researchers in recent years that interventions adopt a multilevel approach to reducing sedentary behavior (Fanning et al. 2016; Manini et al. 2014; Owen 2010), emphasizing the need to consider influences at the intrapersonal, perceived environmental, settings, and policy levels. It is argued that addressing these interacting levels of influences is necessary to support long term maintenance of the behavior. Still, these models are typically designed to be specific to the behavior of interest (Sallis et al. 2008). The results of the present study suggest that researchers begin to consider the development of interventions which act across these levels of influence to support individuals as they strive to shift sitting time to light activity, MVPA, and sleep. Doing so may prove an important step in developing long-lasting health behavior interventions.

Strengths and Limitations

We believe there are several notable strengths to this exploratory study. First, it examines the effect of sedentary behavior on outcomes related to executive functioning and self-regulation of behavior, and these important factors that have previously received limited attention. Additionally, the use of isotemporal analytic techniques is particularly interesting in this regard, as it acknowledges that our physical activities, sleep, and sedentary behaviors occupy the same finite pool of time, and results demonstrated that these are behaviors do, indeed, work together to impact self-regulation and cognition. Accordingly, the findings of this study add to our growing understanding of the impact of sedentary behaviors on human health and well-being. Moreover, this information provides an interesting first step toward the design of interventions which may better support the long term maintenance of a health behavior regimen.

There are also a number of limitations to the present study. First, although performance measures of working memory and task-switching were collected in the present study, assessments of inhibition were not. Because individuals must consistently inhibit the desire to engage in habitual behaviors (e.g., sitting; Buckley et al. 2014), future work will benefit from the inclusion of measures of inhibition. Similarly, participants in the present study only wore activity monitors during waking hours. Accordingly, a single-item measure of self-reported sleep duration was used present study; a measure which has not yet been validated and may be prone to overestimation and bias (Lauderdale 2008). Additional research leveraging more objective measures of sleep duration may be warranted. Next, the sample was recruited to participate in a physical activity study. As such, the findings relate to older adults recruited in a relatively small geographic area, who were largely female, and who were low-active. Although the population of older adults are largely low-active such that 84% do not meet federal recommendations for physical activity (Centers for Disease Control and Prevention 2015b), it is nonetheless necessary for future work to examine these relations in a larger, more representative sample of older adults. Finally, as isotemporal techniques are cross-sectional by nature, these findings do not represent individual change, but more closely resemble population-level shifts in behavior (Buman et al. 2014).

Conclusion

Despite these limitations, we believe the present study adds new and important information to our understanding of the role of sedentary behavior in human health, and challenges health professionals to consider building upon approaches focused on shifting sedentary behaviors to light intensity activities alone. Indeed, our daily health behaviors are interrelated and intertwined, and considering this relationship may lead to the development of more effective and long-lasting health behavior interventions.

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Table 1

Participant characteristics.

Measure	***N*=247**	
Female	169	(68.4)
Marital Status		
Married	146	(59.1)
Significant other	6	(2.4)
Single	30	(12.1)
Divorced or separated	36	(14.6)
Widowed	29	(11.7)
Employment Status		
Full Time	51	(20.6)
Part Time	34	(13.8)
Retired, working part time	35	(14.2)
Retired, not working at all	118	(47.8)
Laid off or unemployed	5	(2.0)
Other (e.g., volunteer)	4	(1.6)
Race		
White	207	(83.8)
Black	32	(13.0)
Asian	8	(3.2)
Hispanic	3	(1.2)
Education		
College Graduate	145	(58.7)
Income		
<$40,000 per year*	67	(32.5)
Chose not to answer	41	(16.6)
Age, *M* ± SD	65.4±4.6	
Sleep (min/day), *M*±SD	418.40±65.34	
Sedentary Time (min/day), *M*±SD	533.81±83.91	
LPA (min/day), *M*±SD	276.75±68.03	
MVPA (min/day), *M*±SD	46.45±30.49	

Note: Percentages expressed in relation to the total number of participants who chose to answer. M = mean; SD = standard deviation; LPA = light physical activity; MVPA = moderate to vigorous physical activity.

Table 2

Isotemporal Substitution Models, adjusted for age, race, and gender. Sedentary time is dropped; $B_1 – B_3$ represent unstandardized mean change in the respective variable if substituted with sedentary time.

	Sedentary ***B_0* (*SE*)**	**LPA** ***B_1* (*SE*)**	**MVPA** ***B_2* (*SE*)**	**Sleep** ***B_3* (*SE*)**	**Total Minutes** ***B_4* (*SE*)**
Self-Regulation					
Total Score	*Dropped*	.60 (.38)	1.81 (.80)*	1.29 (.39)**	−.52 (.30)
Self-Monitoring	*Dropped*	.15 (.09)	.27 (.19)	.23 (.09)**	−.11 (.07)
Goal Setting	*Dropped*	.11 (.08)	.27 (.18)	.32 (.09)**	−.12 (.07)$^{\sim}$
Social Support	*Dropped*	.09 (.06)	.08 (.13)	.18 (.07)**	−.08 (.03)
Spatial Working Memory					
2-item: RT	*Dropped*	−.16 (6.20)	−4.46 (13.09)	1.13 (6.50)	1.94 (4.90)
3-item: RT	*Dropped*	−.19 (6.18)	−5.60 (13.06)	−1.11 (6.49)	1.22 (4.89)
4-item: RT	*Dropped*	−5.87 (6.57)	−4.61 (13.88)	−.21 (6.89)	−.93 (5.19)
2-item: ACC	*Dropped*	−.01 (.00)	.03 (.01)**	−.00 (.01)	−.00 (.00)
3-item: ACC	*Dropped*	−.01 (.01)	.02 (.01)*	−.00 (.01)	.00 (.00)
4-item: ACC	*Dropped*	−.00 (.01)	.01 (.01)	−.00 (.01)	.00 (.00)
Task-Switching					
Single RT	*Dropped*	7.45 (5.01)	−23.12 (10.63)*	4.12 (5.31)	−4.23 (4.00)
Mixed-Repeat RT	*Dropped*	5.00 (6.24)	−27.06 (13.24)*	−12.2 (6.61)$^{\sim}$	−.07 (4.98)
Mixed-Switch RT	*Dropped*	1.04 (8.23)	−28.24 (17.45)	−17.21 (8.71)*	−.32 (6.56)
Local Switch Cost RT	*Dropped*	−3.93 (5.98)	−.40 (12.67)	−5.19 (6.33)	−.32 (4.76)
Global Switch Cost RT	*Dropped*	−2.84 (6.39)	−1.54 (13.55)	−16.86 (6.77)**	4.65 (5.09)
Single ACC	*Dropped*	−.00 (.00)	.01 (.01)	−.01 (.00)	.00 (.00)
Mixed-Repeat ACC	*Dropped*	−.01 (.01)	.01 (.01)	−.01 (.01)	.00 (.00)
Mixed-Switch ACC	*Dropped*	−.01 (.01)	.01 (.01)	−.01 (.01)	.00 (.01)
Local Switch Cost ACC	*Dropped*	.00 (.00)	.00 (.01)	−.00 (.00)	.00 (.00)
Global Switch Cost ACC	*Dropped*	.00 (.01)	−.00 (.01)	.01 (.01)	−.00 (.00)

Note: SE = Standard Error; ACC = Accuracy; RT = Reaction Time;

$^{\sim}p \leq .07$,

[*] $p \le .05$,

[**] $p \le .01$