

REALLOCATING SEDENTARY TIME TO SLEEP OR PHYSICALLY ACTIVE
BEHAVIORS: ASSOCIATIONS WITH BODY MASS INDEX
IN COLLEGE STUDENTS

by

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ABSTRACT

More than 160 million US adults aged 20 years and older are overweight or obese. The greatest increase in the prevalence of overweight and obesity has occurred among young adults aged 18 to 29 years. College students represent a subpopulation at a higher risk for excess weight gain, which is often perpetuated by daily health behaviors, particularly, how time is spent in sleep, sedentary time (SED), and physically active behaviors. This study applied a novel isotemporal substitution model approach to investigate how reallocating time spent in SED activities to sleep and physically active behaviors influenced body mass index (BMI). College-age (20.1 ± 1.5 years) students ($n=1,533$) of normal weight ($BMI=24.4 \pm 4.7 \text{ kg/m}^2$) provided self-reported BMI (height and weight), sleep, SED, and physical activity data anonymously through an online survey. Sleep and physical activity (SED and physically active behaviors) were assessed via the Pittsburgh Sleep Quality Index and International Physical Activity questionnaires. Sleep ($r=-.070$) and moderate-to-vigorous intensity physical activity (MVPA) ($r=-.068$) behaviors were weakly but significantly associated with BMI (all $P < .05$). SED ($r=.043$) and light-intensity-physical activity (LPA) ($r=-.014$) behaviors were not associated with BMI (all $P > .05$). In both the single and partition models, sleep ($B=-.223$ and $B=-.238$) and MVPA ($B=-.333$ and $B=-.348$) were inversely associated with BMI (all $P < .05$). Among the total sample ($BMI: 24.4 \pm 4.7 \text{ kg/m}^2$), reallocating 60-min of SED behavior with sleep ($B=-.277$, 95% CI s: $-.461, -.093$) or MVPA ($B=-.386$, 95% CI s: $-.635, -.147$) resulted in small but significant

reductions in BMI. When limited to individuals with overweight and obesity ($n=543$, BMI: $29.2 \pm 4.3 \text{ kg/m}^2$), reallocating 60-min of SED behavior with sleep ($B=-.384$, 95% CIs: $-.667$, $-.108$) or MVPA ($B = -.796$, 95% CIs: -1.15 , $-.436$) resulted in small to large reductions in BMI, with the greatest effect coming from MVPA in overweight/obese individuals, was inversely associated with a lower BMI. Reallocating 60-min of sedentary time with sleep or MVPA produced favorable effects on BMI among college students. Reductions in BMI were greater among overweight and obese individuals, especially when SED was replaced with 60-min of MVPA.

LIST OF ABBREVIATIONS AND SYMBOLS

B	unstandardized beta coefficient
BMI	body mass index
CI	confidence interval
IPAQ	International physical activity questionnaire
ISM	isotemporal substitution model
LPA	light-intensity physical activity
MVPA	moderate-to-vigorous intensity physical activity
PA	physical activity
PSQI	Pittsburgh sleep quality index
SED	sedentary time
SD	standard deviation
US	United States

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INTRODUCTION

Approximately 160 million adults (70.7%) in the United States (US), aged 20 years and older, are classified as overweight or obese [1]. The economic burden of obesity exceeds 150 billion dollars in healthcare expenditures annually [2]. If obesity rates continue in their current trajectory, it is estimated that 65 million more US adults, will be classified as obese by 2030, accounting for roughly 44% of the population [3]. Although the rates of obesity have more than doubled in the general population since the 1980s, the greatest increase in the prevalence of overweight and obesity has occurred among young adults aged 18 to 29 years [4].

The available data indicates that the prevalence of obesity in young adults has steadily increased since the 1980s, however those obtaining a college education demonstrated an even greater increase in rates of overweight and obesity (from 10.6% to 17.8%) [4]. Therefore, college students may represent a specific subgroup of this population that is at a particularly high risk of excess weight gain [5]. Approximately 20 million students were expected to attend US universities in 2015, and of these, roughly 12.1 million (60%) were between the ages of 18 to 24 [6]. In 2017, the American College Health Association reported that more than one-third (37.2%) of college students (ages 18 to 25) are currently overweight or obese [7]. Weight gain in college students is a concern given the numerous health problems directly associated with obesity, and because rapid weight gain can occur within a short time period (i.e., a 9-month academic year) [1]. The rate of weight gain among college students during an academic year is roughly 5-times larger than among young adults outside of a university setting [8,9]. Body mass index (BMI) is

the most commonly used anthropometric measure used to classify the weight-status of individuals using well-established thresholds for overweight (25-29.9 kg/m²) and obese (> 30 kg/m²) [11-14]. Like other traditional cardiovascular disease risk factors (dyslipidemia, impaired, fasting glucose, hypertension, etc.), BMI during adolescence and young adulthood is a strong predictor of BMI later in life [10,11]. Moreover, men and women who are overweight by the age of 25 are more likely to develop obesity by the age of 35 (35% and 25%, respectively) [10].

Since the 1980s, there have been numerous researchers studying and documenting the phenomenon of weight gain in college students [9,15]. Historically, this research has focused specifically on weight gain that occurs in the freshman year. More recent investigations have shifted the research focus on weight gain and changes in body composition beyond the freshman year, concluding that unfavorable changes in weight and adiposity occur throughout the typical 4-year undergraduate period [15,16]. The transition to the university environment is a crucial time for young adults in terms of establishing weight management behaviors [15]. Successful weight maintenance can be attributed to several health behaviors; however, physical activity (PA) has been identified as one of the most important determinants in preventing overweight and obesity [15,17,18]. In addition to the considerable evidence supporting PA in obesity prevention, there is a growing body of literature to suggest that sleep duration and prolonged periods of sedentary time (SED) are also critical for weight management [1,19,46]. Establishing a balance across movement and non-movement patterns appears to be most challenging for young adults once outside the structure of the family home [19,26].

Concurrent with the trends of increased overweight and obesity among the US adult population, are changes in sleep duration [20]. A scientific statement from the American Heart

Association found that 50 to 70 million US adults suffer from a sleep disorder or report habitually insufficient sleep [21]. According to outcome-based recommendations issued recently by the National Sleep Foundation, the recommended sleep durations for adults is between 7 to 9 hours per night [22]. Sleep duration, mostly short sleep (short sleep, defined as less than 7 hours per night, unless otherwise noted), and sleep disorders have emerged as being related to adverse cardiometabolic risk, including obesity, hypertension, type 2 diabetes mellitus, and cardiovascular disease [21]. Adults that experience habitual short sleep durations are at an increased risk of overweight and obesity than those who accumulate longer sleep durations [21,23]. During the college years, time is focused on the competing demands of coursework and a newfound sense of independence, lack of sleep can lead to unwanted health consequences. Most college students are sleep deprived, as 70.6% of students report obtaining less than 8 hours of sleep [24,25]. Specific to college students, previous studies have showed a consistent and significant inverse association between hours of sleep and BMI [23]. Furthermore, sleep duration is inversely associated with BMI such that every one-hour increase in sleep duration, BMI was reduced by roughly 0.4 kg/m² for adults who obtained less than 5 hours of sleep [23]. Given that college students are a population at an increased risk for weight gain and obesity attributable, in part, to decreased PA and increased sedentary behaviors, better identifying how sleep duration and the influences of these relationships, may serve as an additional behavioral target to address obesity prevention [12-27,28,46].

Sedentary behavior is defined as any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalents (METs), while in a seated, reclining or lying posture [29]. The most common sedentary activities exhibited among college students include reading, studying, and computer use; these activities often take precedent over physical activities when

students are making choices about how to spend their discretionary time [30]. Despite an overall trend of increased SED and decreased time-spent in moderate-to-vigorous intensity PA (MVPA) over the last three decades, the magnitude of these changes differed across age groups. College aged students demonstrated the greatest change in both health behaviors when compared to adults in other age cohorts [19,27]. For example, as college aged young adults transition to a university setting, PA levels tend to decrease and are unlikely to improve later in adulthood [31-35]. Unfortunately, work sites, schools, homes, and public spaces have been, and continue to be, re-engineered in ways that minimize human movement and muscular activity [35]. These changes exert dual effects on human behavior, that is, people move less and sit more [35].

PA is defined as any bodily movement produced by skeletal muscles that requires energy expenditure [36]. The health benefits of PA are vast and plentiful, providing ample and compelling evidence to adopt and maintain an active lifestyle [1,37]. Yet, more than half (51.4%) of college students in the US do not meet the current PA guidelines for healthy adults (i.e., \geq 150 min/wk. (2 hours and 30 minutes) a week of moderate-intensity, or 75 min/wk. (1 hour and 15 minutes) of vigorous-intensity aerobic PA, or an equivalent combination of moderate- and vigorous-intensity aerobic activity) [7,38,39]. The association between physical inactivity and increased risk for developing overweight and obesity has been well-documented, however the independent role of sedentary behaviors and their contribution to this public health problem have only recently garnered attention [20,27,40,41].

Sleep, SED, and physically active behaviors are interdependent as increasing the time spent engaged in one of these behaviors will ultimately decrease the time available to engage in other health behaviors due to the finite number of hours in a day [42]. Greater amounts of SED have consistently been associated with unfavorable health outcomes, even after accounting for

PA. Yet, previous research has failed to account for the potential impact of sleep behaviors on this relationship [43]. For example, increasing the time spent in light-intensity PA (LPA) by 60-min will have different effects on BMI depending on how this increase in LPA displaces the time spent in other activities (i.e., sleep, SED, MVPA) [44]. Therefore, understanding how the reallocation of SED to alternative activities such as sleep, LPA, and MVPA impacts BMI among college students is highly relevant for obesity prevention in this population [45]. The primary aim of the current study was to examine the independent associations between the independent variables of time spent in sleep, SED, LPA, and MVPA on the dependent variable of BMI using the single activity and partition models. We hypothesize that higher levels of sleep and PA (both LPA and MVPA) will be associated with a lower BMI, whereas higher levels of SED will be associated with a higher BMI among college-aged students. Our secondary aim of the proposed study was to examine the potential effect of reallocating time spent in SED with either sleep, LPA, or MVPA on BMI using isotemporal substitution analysis. We hypothesize that time spent in sleep and higher levels spent in PA (both LPA and MVPA) will be associated with a lower BMI, whereas time spent in SED will be associated with a higher BMI among college-aged students.

METHODS

Experimental Design

Participants were recruited for this study from the University of Alabama (UA). Data were collected anonymously online through the UA Qualtrics system from January 20, 2018 to February 2, 2018. Potential participants were contacted via email through their UA student email account. Individuals who were interested in participating in this survey-based research were instructed to visit the study Qualtrics webpage through a hyperlink provided in the email.

Participants

Inclusion Criteria

- Student enrolled at the UA during the Spring 2018 semester
- 18-24 years of age
- Fluent in English

Exclusion criteria

- Individuals with zero self-reported walking minutes were excluded from the analysis

Recruitment

A total number of 28,877 potential participants were initially contacted through their UA email account at the beginning of the Spring 2018 semester through an email list provided by the

Office of the Registrar. The registrar helped ensure anonymity and protected the identities of the study participants for this internet-based research study. Upon receiving the email, potential participants were also provided with information regarding the nature and scope of the research, the study requirements, inclusion criteria, outcomes measures that would be collected, and participant remuneration. Interested participants were directed to the consent webpage and online survey through a hyperlink in the original recruitment email. No personally identifiable information (i.e., name, student identification number, email, IP address, etc.) was collected as part of this study. Approximately 2,126 potential participants clicked on the link, with roughly 74% (n =1,570) consenting and completing the survey. Table 1 details those participants who consented to take the survey, stratified by participants with complete data and participants that consented to participate but did not complete the survey responses.

Table 1. Baseline sample and descriptive characteristics of consented study participants stratified by those who completed the online survey versus those that did not.

Characteristics	Completers		Non-Completers		<i>P</i> ^b
	N ^a	M ± SD	N ^a	M ± SD	
Age (years)	1,541	20.1 ± 1.5	174	20.1 ± 1.5	.923
BMI (kg/m ²)	1,533	24.4 ± 4.7	214	24.4 ± 5.4	.983
<i>Time spent in:</i>					
Sleep (hr/day)	1,541	7.2 ± 1.3	70	1.6 ± 0.2	.902
SED (hr/day)	1,541	7.3 ± 3.5	217	7.1 ± 4.4	.390
LPA (hr/day)	1,541	1.5 ± 0.9	191	1.5 ± 0.9	.999
MVPA (hr/day)	1,541	1.0 ± 1.0	206	1.0 ± 1.2	.749

^a Total number of participants who completed / did not complete the survey.

^b Between-group difference (two-tailed significance).

BMI, body mass index; hr, hours; LPA, light-intensity physical activity; M, mean; MVPA, moderate-intensity physical activity; SD, standard deviation; SED, sedentary time.

Study Outcomes

Demographic and health behavior/ status covariates

Participant characteristics were assessed for descriptive purposes and to identify potential covariates in the proposed analyses. Participant demographics were obtained via self-report and included: Age (in years), gender (categorized as male, female, or “I choose not to answer”), race (categorized as Asian, Black or African American, Native Hawaiian or Other Pacific Islander, American Indian or Alaskan Native, White or Caucasian), ethnicity (categorized as Hispanic or Latino and Non-Hispanic or Latino), height (feet and inches), and weight (in pounds).

Self-reported Body Mass Index

Self-reported BMI was calculated from height and weight (reported to the nearest inch and pound). Inches were converted to meters (m) and pounds were converted to kilograms (kg) and BMI was determined using the following equation: $BMI (kg/m^2) = \frac{Weight (kg)}{Height (m^2)}$ [47,61]. Self-reported BMI is easy and cost-effective to obtain, and large epidemiological studies have shown it to be reliable and valid when compared to objectively measured BMI within the age range of our study participants [31].

Self-reported Physical Activity and Sedentary Behavior

Subjective measurements of PA and SED were obtained through the short-version of the International Physical Activity Questionnaire (IPAQ-S) [47]. The IPAQ has become the most widely used PA questionnaire, with two versions available for use: The 31-item long form (last month recall) and the 9-item short form [47-50]. The IPAQ-S provides information on time spent walking, in MVPA, and in SED [48]. The short form is recommended due to its “last 7-day recall” over the long form, in part because the burden on participants to report their activity is small. The IPAQ-S is comparable to other self-reported PA measures. Although the IPAQ-S is

positively correlated with the objectively measured PA assessed via accelerometer ($r = 0.19 - 0.23$, $p < 0.05$), the relationship is weak. The intraclass correlation coefficients ranged from 0.71 - 0.89, indicating moderate to high reliability of the questionnaire items. [61]. IPAQ-S has acceptable stability reliability and criterion validity indices similar to other self-report PA questionnaires [51]. The IPAQ-S was scored using guidelines for data processing and analysis for the IPAQ-S [52,53].

Self-Reported Sleep Duration and Sleep Quality

Average sleep duration in the last month was assessed using a single-item question from the Pittsburgh Sleep Quality Index (PSQI) [54]. The PSQI is a self-report questionnaire that is widely used by clinicians and researchers to broadly assess several dimensions of sleep [55]. The PSQI has been validated in numerous populations including college students [55]. The PSQI demonstrates moderate convergent validity and good divergent validity with measures of daytime sleepiness, circadian phase preference, and drug use [55].

Data Analysis

Self-reported BMI data were inspected using the same review criteria used for the 1999–2016 National Health and Nutrition Examination Survey (NHANES) body measurement data. Accordingly, values that were above the 99th or below the 1st percentiles were flagged for review. Once flagged, the entire body measurement record was reviewed for accuracy, taking into consideration participant characteristics (i.e., height, weight, age, race, and gender). After visually examining the accuracy of the data, the participant case in question was excluded from the current analysis if the responses were indeed deemed inaccurate or unrealistic by consensus from the researchers (R.M.S. and M.V.F.), [59]. PA data was cleaned and processed according to the scoring procedures provided by the IPAQ group and assessed for skewness and kurtosis to

ensure normality [53]. A total of 37 participants were excluded from the analyses (2.4% of the final sample with complete data).

To address our study aims, we used unadjusted bivariate correlations (Pearson's r) to examine the independent associations between time spent in sleep, SED, LPA, and MVPA with BMI. In addition, the partition model was performed separately for: male versus female participants and for each race group with adequate sample size. We used a series of linear regression models, single activity, full partition and ISM, to evaluate the influence of time spent in sleep, SED, LPA, and MVPA on BMI under varying conditions (e.g., increasing/decreasing time spent in a particular activity, after accounting for the presence of other activities in the model, etc.). These models are explained in greater details below. The ISM, another linear regression model, was used to determine the differences in these associations and BMI after reallocating SED with other activities (i.e. sleep, LPA, and MVPA).

Single Activity Model

The single activity model assesses each activity component separately (e.g., slow walking), without taking into account the other types of activities and is expressed as follows [44]:

$$\text{BMI} = (b_1) \text{MVPA} + (b_6) \text{covariates}$$

Partition Model

The partition model partitions “total activity” among its components and is expressed as follows [38]:

$$\begin{aligned} \text{BMI} = & (b_1) \text{MVPA} \\ & + (b_2) \text{LPA} \\ & + (b_3) \text{sleep} \end{aligned}$$

+ (b₄) SED

+ (b₅) covariates

In this model, the coefficient for one type of activity represents the effect of increasing this type of activity while holding the other activity types constant [44]. Therefore, this model represents the effect of “adding” rather than substituting an activity type. Note, the total time for PA is not held constant, and thus, it is not considered isotemporal.

Isotemporal Substitution Model

ISM, by definition, estimates the effect of replacing one PA type with another PA type, while keeping the amount of time or duration constant (e.g., replacing 60-min of sedentary time with 60-min of MVPA). Substitution model A is expressed as follows [44]:

BMI = (b₁) MVPA

+ (b₂) LPA

+ (b₃) sleep

+ (b₄) SED

+ (b₅) total activity

+ (b₆) covariates,

Where b₁-b₆ are unstandardized coefficients of respective activities or covariates. By eliminating one activity component from the model (e.g., SED), the coefficient (b₅) for total activity represents the omitted activity component (SED). The remaining coefficients represent the consequence of substituting 60-min of that activity instead of sedentary time while holding other activity types constant [44].

Statistical Computing

All analyses were performed in SPSS version 24 [56,57]. Descriptive statistics (mean [M] and standard deviation [SD], median [MED] and interquartile range [IQR], and the minimum, maximum values) were generated for each variable of interest. “Dummy” coded variables were generated for race (0 = non-White/Caucasian or “other”; 1 = White/Caucasian) and gender (0 = male ; 1 = female) and examined as potential covariates. Due to the non-directional hypotheses in our study, a two-tailed alpha level of .05 was used to determine significance [60].

RESULTS

Our final sample consisted of 1,533 college-age students (20.1 ± 1.5 years) who were predominantly White/Caucasian (88.9%, $n = 1,378$), female (68.0%, $n = 1,042$) and of normal weight ($BMI=24.4 \pm 4.7 \text{ kg/m}^2$). The majority of our sample (67.7%, $n = 1,038$) reported meeting the current PA guidelines for adults [36]. Baseline sample and activity characteristics are summarized in Tables 2 and 3.

Table 2. Baseline sample stratified by gender and activity characteristics of the total sample.

Characteristics	Total Sample (N = 1,533)		Stratified by Gender (Mean \pm SD)		P ^a
	M \pm SD	Median (IQR)	Male (n = 491)	Female (n = 1,042)	
Age (years)	20.1 ± 1.5	20.0 (19.0 - 21.0)	20.4 ± 1.6	20.0 ± 1.5	.000
BMI (kg/m^2)	24.4 ± 4.7	23.5 (21.2 - 26.1)	24.9 ± 4.3	24.1 ± 4.8	.001
<i>Time spent (hr/day) in:</i>					
Sleep	7.2 ± 1.3	7.0 (6.5 - 8.0)	7.3 ± 1.3	7.2 ± 1.3	.866
SED	7.3 ± 3.4	6.0 (5.0 - 9.0)	7.3 ± 3.3	7.3 ± 3.5	.826
LPA	1.5 ± 0.9	1.3 (0.8 - 2.0)	1.3 ± 0.9	1.5 ± 0.9	.000
MVPA	1.0 ± 1.0	0.7 (0.3 - 1.4)	1.1 ± 1.0	1.0 ± 1.0	.018

^a Between-gender difference (two-tailed significance).

BMI, body mass index; IQR, Interquartile range; LPA, light-intensity physical activity; M, mean; MVPA, moderate-to-vigorous intensity physical activity; SD, standard deviation; SED, sedentary time.

Table 3. Baseline sample stratified by race and activity characteristics.

Characteristics	Caucasian or White (n = 1,378)	Other (n = 155)^a	P^b
Age (years)	20.1 ± 1.5	20.4 ± 1.6	.07
BMI (kg/m ²)	24.3 ± 4.6	25.3 ± 5.1	.01
<i>Time spent (hr/day) in:</i>			
Sleep	7.3 ± 1.3	6.9 ± 1.3	.00
SED	7.3 ± 3.4	7.6 ± 3.7	.33
LPA	1.5 ± 0.9	1.4 ± 0.9	.61
MVPA	1.0 ± 1.0	1.0 ± 1.0	.69

Data are summarized as M ± SD.
^a Other self-report races included: Black or African American (n = 83), Undisclosed (n= 28), Asian (n = 35), American Indian or Alaskan Native (n = 7), Native Hawaiian or Other Pacific Islander (n = 2)
^b Between-race difference (two-tailed significance).
 BMI, body mass index; LPA, light-intensity physical activity; M, mean; MVPA, moderate-to-vigorous physical activity; SD, standard deviation; SED, sedentary time.

Unadjusted bivariate correlational analysis of BMI and time spent (hr/day) in various activity types over the course of 24-hours are presented in Table 4. A weak but positive association between SED and BMI ($r = .046$, $p < .05$), indicating that greater time spent in SED was associated with a higher BMI. Conversely, sleep duration ($r = -.068$, $p < .05$) and MVPA ($r = -.069$, $p < .05$) were inversely associated with BMI, indicating that greater time spent dedicated to either behavior was associated with lower BMI, although these correlations were weak. LPA was not associated with BMI in the current sample ($r = -.024$, $p > .05$). After statistically controlling for potential gender-related differences, the inverse relationship between MVPA ($r = -.068$, $p < .05$) and sleep duration ($r = -.070$, $p < .05$) and BMI remained statistically significant.

Table 4. Correlation analysis of body mass index and time spent in sleep, sedentary time, light and moderate to-vigorous physical activity. ^a

Variables	1	2	3	4
1. Body mass index	—			
2. Sleep	-.068 *	—		
3. SED	-.046 *	-.045 *	—	
4. LPA	-.024	-.078 **	-.104 **	—
5. MVPA	-.069 *	.077 *	-.136 **	-.298 *

Two-tailed significance at: ** $P \leq 0.01$; * $P \leq 0.05$. ^a
 Unadjusted bivariate correlations.
 LPA, light-intensity physical activity; MVPA, moderate-to-vigorous physical activity;
 SED, sedentary time.

The results of our single activity, full partition and ISM regression models are summarized in Tables 5 and 6, adjusted for gender and race. In the single activity model, sleep ($B = -.223, p = .013$) and MVPA ($B = -.333, p = .004$) were inversely associated with BMI, indicating that college students who spent more time in these behaviors had lower BMIs. In contrast, SED and LPA were not associated with BMI among college students (Table 5). The full partition model, which included all types of activities (i.e., sleep, SED, LPA, and MVPA), indicated that sleep ($B = -.238, p = .008$) and MVPA ($B = -.348, p = .004$) explained unique variance in the BMI values observed in our sample, controlling for the influence of SED and LPA behaviors (Table 5). Consistent with the single activity model, the partition model revealed that greater time spent in sleep and MVPA was associated with lower BMI values.

Table 5. Multivariate regression analysis: The associations of sleep, sedentary time, light and moderate to-vigorous physical activity with body mass index in college students using single activity and full partition models.

Analysis Method ^a	Type of Activity							
	Sleep		SED		LPA		MVPA	
	B	95% CI	B	95% CI	B	95% CI	B	95% CI
Single Activity Model	-.223	-.397, -.049	.056	-.033, .101	-.077	-.340, .186	-.333	-.056, -.108
Full Partition Model	.238	-.414, -.062	.038	-.036, .107	-.033	-.234, .309	-.348	-.585, -.110

Data are summarized as unstandardized regression coefficients (B) and corresponding 95% confidence interval (CI).

^a All analyses are adjusted for gender and race.

LPA, light-intensity physical activity; MVPA, moderate-to-vigorous intensity physical activity; SED, sedentary time.

Table 6. Isotemporal substitution model: The effect of reallocating 60-min of time spent engaged in sleep, sedentary time, light and moderate to-vigorous intensity physical activity on body mass index.^a

Isotemporal Substitution Model ^b	Type of Activity							
	Sleep		SED		LPA		MVPA	
	B	95% CI	B	95% CI	B	95% CI	B	95% CI
Model A: Substitution of Sleep	Dropped		.277	.093, .046 *	.272	.045, .590	-.110	-.396, .176
Model B: Substitution of SED	-.277	-.461, -.093 *	Dropped		-.005	-.285, .275	-.386	-.635, -.147 *
Model C: Substitution of LPA	.272	-.046, .590	.005	-.275, .285	Dropped		-.386	-.635, -.147 *
Model D: Substitution of MVPA	.110	-.176, .396	.386	.147, .625 *	.381	-.032, .795	Dropped	

Data are summarized as unstandardized regression coefficients (B) and corresponding 95% confidence interval (CI). Negative values indicate a reduction in body mass index as a result of the activity substitution.

^a All analyses are adjusted for gender and race.

^b Analyses show the effect of substituting 60-min of sleep (Model A), SED (Model B), LPA (Model C) or MVPA (Model D) behaviors with 60-min of the respective activity type (listed in table, from left to right) on body mass index.

* Indicates re-allocation of time spent had a significant effect on body mass index ($P < 0.05$).

LPA, light-intensity physical activity; MVPA, moderate-to-vigorous intensity physical activity; SED, sedentary time.

As summarized in Table 6, reallocating 60-min of SED to either sleep ($B = -.277$, $p = .003$) or MVPA ($B = -.386$, $p = .002$) using the ISM was associated with a lower BMI. However, reallocating 60-min of SED to LPA did not elicit significant changes in BMI (Table 6). We further stratified our sample by weight status and re-examined how reallocating 60-min of SED with either sleep, LPA, or MVPA influenced BMI among normal weight compared to overweight and obese college students (Table 7). We found that reallocating 60-min of SED with 60-min of sleep among overweight and obese college students was associated with a significantly lower BMI ($B = -.384$, $p = .008$) compared to normal weight ($B = -.062$, $p > .05$). Moreover, reallocating 60-min of SED with 60-min of MVPA among overweight and obese college students reduced BMI by nearly $\approx 1 \text{ kg/m}^2$ ($B = -.797$, $p = .000$), nearly six-times the reduction observed among normal weight students ($B = .126$, $p > .05$). These findings suggest that reallocating time spent in SED with either sleep or MVPA had a greater impact on students classified as overweight and obese than normal weight.

Table 7. Isotemporal substitution model: The effect of reallocating 60-min of sedentary behavior with time spent engaged in sleep, sedentary time, light and moderate to-vigorous intensity physical activity on body mass index by weight status. ^a

Activity Type	Weight Status ^b			
	Normal Weight (n = 990)		Overweight and Obese (n = 543)	
	B	95% CI	B	95% CI
Sleep	-.062	-.156, .032	-.384	-.667, -.108
LPA	-.048	-.191, .095	.145	-.282, .572
MVPA	.126	.002, .249	-.796	-1.15, -.436

Data are summarized as unstandardized regression coefficients (B) and corresponding 95% confidence interval (CI).

^a All analyses are adjusted for gender and race.

^b Determined using self-reported body mass index values: Normal weight = $21.7 \pm 1.9 \text{ kg/m}^2$ (minimum, maximum = 14.0, 24.9); Overweight and obese = $29.2 \pm 4.3 \text{ kg/m}^2$ (minimum, maximum = 25.0, 46.2).

LPA, light-intensity physical activity; MVPA, moderate-to-vigorous intensity physical activity.

DISCUSSION

The primary results of the current analysis indicated that substituting SED with either sleep or MVPA was associated with a lower BMI among college aged students, an effect that was greater among students classified as overweight or obese than normal weight. Importantly, college students who are overweight or obese appear to benefit the most from reallocating 60-min of SED to MVPA.

The results of this study have clinical relevance as overweight and obesity are major risk factors for cardiovascular disease, including coronary heart disease, stroke, and coronary heart failure [1]. It is well known that PA is inversely related with most overweight and obesity-related risk factors and with obesity itself. Previous research has suggested that adults should accumulate 45 to 60-min of moderate-intensity PA each day for successful weight management [61]. This is consistent with the findings in our sample, in which we found marked improvements in BMI in overweight and obese college students after adding 60-min to MVPA. However, for many adults accumulating 60-min of MVPA each day (i.e., recommended amount of 250 min/wk of MVPA) can prove challenging, and for some, may not be feasible.

Previous studies have shown sleep duration to be negatively associated with BMI, such that for every one-hour increase in sleep duration, BMI is reduced $\approx 0.4 \text{ kg/m}^2$ for adults who obtained less than 5 hours of sleep [23]. This is consistent with research findings conducted in the general population (i.e., short sleep duration, defined as fewer than 7 hours, is associated with higher BMI) [21,23] and our study involving college students. Indeed, we found that reallocating

time spent in SED with sleep had beneficial effects on BMI, and these effects were greatest among those who were overweight or obese. These findings confirm previous research outcomes indicating an association between SED and MVPA. Although replacing SED with MVPA is associated with a lower BMI, replacements with equal amounts of SED with MVPA and sleep may have a greater impact on BMI [52]. As such, a tailored intervention program aimed at increasing sleep duration and MVPA concurrently, using more manageable increments (i.e., 30 min/day toward each behavior), could prove to provide equal health benefits with a less intimidating approach.

ISM is a relatively new technique, in fact, only 4 studies have used ISM to examine associations between BMI, sleep, SED, LPA, and MVPA. Despite a relatively small literature and widely varying study populations, the investigations conducted to date, including ours, have consistently found MVPA to be inversely associated with BMI [42, 62-64]. Of note, only one of these studies involved participants of a similar age as ours [62]. Colley et al. conducted one of the largest studies to date, 10,621 adults ages 18 to 79 years, concluding that reallocating 30-min from sleep, SED, LPA to MVPA resulted in a lower BMI, particularly for older, overweight and obese individuals [62]. Cruz et al. found that replacing at least 30 min/day of SED with MVPA among adults aged 20 to 24 resulted in an estimated decrease of 1 kg/m² in BMI, which is consistent with our findings. While the results of Cruz et al. and Colley et al. are in agreement with our findings, other studies have concluded that replacing SED with LPA or MVPA was associated with lower BMI [62,66]. Although LPA was not associated with SED in our study, it is premature to disregard the benefit of LPA on BMI among college students and should be examined in future research.

Isotemporal Substitution Model – Detailed considerations

Historically rooted in nutritional epidemiology, the ISM explores the consequences of alternating allocations of time in one behavior with another while holding total time constant. The number of hours in a 24-hour day is finite and can be distributed among working, eating, sleeping, and discretionary time [65]. However, not only can activities in which one engages during discretionary time be highly heterogeneous between individuals (depending on socioeconomic status, occupation, and other social circumstances), but the relative expense and sacrifice of the activities displaced when one partakes in a period of activity may also vary widely [67]. Researchers must understand not only the health impact of a given health behavior, but also the health impact of the behavior it displaces [68]. This is important because, although the benefits of exercise are well recognized, the optimal pattern of PA and SED during waking hours has yet to be determined. Therefore, an advantage of the ISM, is that it allows comparisons involving the substitution of a fixed time of one activity type for another activity performed for the same duration of time. This approach helps to answer the current public health question, of how best to spend our discretionary time for optimal health [68].

Limitations and Strengths

This study is not without limitations. First, the current study was a part of a larger study examining health related behaviors beyond the scope of this analysis. Undergraduate or graduate student status was not assessed in the current study, and it is possible that sleep and PA behaviors differ between these two groups. In addition, campus residency was not assessed, and it is possible that sleep and physically active behaviors differ between students living on- and off-campus. Participants were not excluded due to their inability to ambulate. To account for this, participants were excluded if they reported zero minutes of walking activity. However, future

studies using the IPAQ in college students should potentially address this issue as priority. In addition, fluency in English was not confirmed beyond the participant's self-reported fluency. Diet was also not accounted for in this study.

The cross-sectional study design does not allow inferences of causality, and as a result, these results should be examined in prospective and experimental research. Participants were not required to answer all the survey questions using the online survey platform which provided the freedom to withdraw from the study at any time and allowed participants to not answer any questions they did not feel comfortable with. As a result, a substantial number of participants were excluded from the analyses due to incomplete survey questions. It is unclear whether these incomplete responses may have changed the results of our analyses. Additionally, common among large-scale population-based studies, self-reported behaviors are subject to known biases. Self-reported methods are often wrought with issues of recall inaccuracies and response bias (e.g. inaccurate memory, social desirability) [69]. When reporting health outcomes, over-reporting of PA by the IPAQ-S is not uncommon, and it remains a key limitation of most self-reported measures of PA [47]. The PSQI suffers from similar problems as other self-report inventories in that scores can be easily exaggerated or minimized by the person completing them [70]. Social desirability describes the tendency of respondents to distort self-reports in a favorable direction (i.e. give answers that make the respondent look good when completing self-report measurements). The influence of social desirability is not uncommon amongst college students when reporting health related outcomes [71]. Finally, there was an expectation that our unadjusted bivariate correlations may be weak due to the use of self-reported data, specifically the use of the IPAQ-S [50,51]. Although the questionnaire had a weak correlation to objective measures of PA, our large study sample size allowed us to identify a relationship between BMI,

sleep, SED, and MVPA [51]. More current research has examined these relationships using objective measurements of sleep and PA and future studies using ISM should continue to use more objective assessments.

The strength of this study is bolstered by the use of isothermal substitution analyses. Individuals cannot feasibly participate in PA during all waking hours [72]. Understanding the potential benefits of replacing SED with other behaviors (i.e. sleep or LPA), above and beyond time spent in PA, is an important task which warrants future research [72]. Currently, the model has been applied to different populations such as cancer survivors, US non-institutionalized, civilian low-active elderly adults, and US female nurses. The ISM has yet to be applied in US college students. Therefore, the ISM is a novel approach. Another strength of the current study is the inclusion of a large sample size that is representative of the typical student body in a university setting, strengthening the external validity for this study. Furthermore, the PSQI and IPAQ-S are well known instruments used in many epidemiological studies which allow these results to be compared to other populations.

To the best of our knowledge, this was the first study to examine the isothermal substitution analysis of sleep, SED, LPA, and MVPA and their impact on BMI in college students. Most likely due to self-reported measures, the relationships found in this study may actually be larger than observed. Although SED and LPA were not associated with BMI despite previous research indicating the contrary, we believe that LPA and SED are associated with BMI. We also believe that if these associations were examined with objective measurements, the relationships observed between sleep and MVPA would be stronger than were observed in the current study. Future research should examine the complex independent and interactive associations of sleep, SED, and PA with BMI in college students with objective measures.

With the current overweight and obesity rates, it is evident there are difficulties with promoting past and current PA guidelines. For interventional purposes, the isothermal approach may contribute to programs seeking to reduce SED. We think this approach may be promising in not just college students but other populations and clinical groups where the PA guidelines are difficult to achieve on a daily basis.

Conclusion

In summary, we found that substituting SED with either sleep or MVPA was associated with a lower BMI among college aged students, which is consistent with previous published studies. We found that reallocating 60-min of SED with sleep or MVPA produced larger reductions in BMI among students classified as overweight or obese than normal weight. Importantly, overweight or obese students reduced BMI to the greatest extent when SED was replaced with 60-min of MVPA. These results highlight the importance of incorporating sleep and PA during discretionary time among college students, especially for weight management purposes. It may not seem feasible for many individuals to accumulate the amount of PA recommended for successful weight management. However, increasing time spent in sleep and MVPA concurrently may prove to be an equally effective intervention strategy for young adults seeking to prevent weight gain in a university setting. The use of ISM facilitated a novel approach investigate the impact of time spent engaged in sleep and physically active behaviors on BMI. Future research should continue to investigate these relationships and their impact on weight in this specific subpopulation.

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APPENDIX



January 10, 2018

Michael Fedewa, Ph.D.
Assistant Professor
Department of Kinesiology
College of Education
The University of Alabama
Box 870312

Re: IRB # 17-OR-254-ME-A "Behavioral Determinants of Physical Activity: A Study of College Students"

Dear Dr. Fedewa:

The University of Alabama Institutional Review Board has reviewed the revision to your previously approved expedited protocol. The board has approved the change in your protocol.

Please remember that your protocol will expire on August 6, 2018.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants.

Good luck with your research.

Sincerely,

Stuart Usdan, Ph.D.
Chair, Non-Medical Institutional Review Board
The University of Alabama

Inform/Consent

You are invited to participate in a research study conducted by Rachel Sanders and Melissa Sharpe, from The University of Alabama Department of Kinesiology. The study titled 'Behavioral Determinant of Physical Activity: A Study of College Students.'

The purpose of this study is: The purpose of this study is to assess the overall health status of college students aged 18-24 through physical activity, diet, sleep, and other health behaviors. This study is part of a project that will be presented at the Undergraduate Research and Creative Activity Conference, and partially satisfy the requirements for a Master's Thesis at the University of Alabama during the Spring semester of 2018. Miss Sanders and Miss Sharpe are being supervised by Dr. Michael V. Fedewa, Assistant Professor in the Department of Kinesiology.

You were selected as a possible participant in this study because you are a student enrolled at The University of Alabama during the spring semester of 2018. If you decide to participate, you are being asked to complete a web survey that will take approximately 20 minutes. The survey contains questions about your sleep behaviors and physical activity level. You will also be asked questions about potentially sensitive issues like alcohol and substance use. No personally identifiable information will be collected from you, and there will be no way for the researchers, or anyone else, to link your responses back to you in any way. The researchers would like you to answer the questions honestly, and remind you that there are no 'correct' answers. This study will help the research team develop a clearer picture of the health behaviors of students here at the University of Alabama.

The student researchers and primary investigator will protect your confidentiality by using Qualtrics, an anonymous online survey software. Only the investigators will have access to the data. The data collected will be password protected. Only summarized data will be presented at meetings or in publications.

There will be no direct benefits to you. There are no known risks or discomforts associated with your participation in this study. However, there is a possibility that some of the questions may make you

uncomfortable. This is an anonymous survey and all answers are completely voluntary. You may also stop the survey at any time by closing your browser.

If you have any questions about this study, please contact the UA faculty advisor for this project, Dr. Michael V. Fedewa, at 205.348.9779. If you have any questions, concerns, or complaints about your rights as a research participant you may contact Ms. Tanta Myles, The University of Alabama Research Compliance Officer, at 205.348.8461, or toll free 877.820.3066. If you have complaints or concerns about this study, you may file them through the UA IRB outreach website at http://osp.ua.edu/site/PRCO_Welcome.html. After you participate, you are encouraged to complete the short survey for research participants that is found online at this website. This helps UA improve its protection of human research participants.

Again, your participation is completely voluntary. Your decision whether or not to participate will not affect your relationship with The University of Alabama. You are free to stop participation any time before your answers are submitted.

If you are at least 18 years of age, understand the statements above, and freely consent to participate in this study, please begin the survey.

I am at least 18 years of age, understand the statements above, and freely consent to participate in this study.

I understand the statements above, and do not wish to participate in this study.

Demographic

UNIVERSITY OF ALABAMA IRB
CONSENT FORM APPROVED: 1-10-18
EXPIRATION DATE: 8-6-18

What is your age? (whole number responses : 1, 2, 3, etc.)

What is your sex?

Male

Female

I choose not to answer

What is your race? Please specify all categories that apply.