Daily Satisfaction with Life Is Regulated by Both Physical Activity and Sedentary Behavior

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Abstract:

Recent research revealed that on days when college students engage in more physical activity than is typical for them, they also experience greater satisfaction with life (SWL). That work relied on self-reported physical activity and did not differentiate between low levels of physical activity and sedentary behavior. This study was designed to (1) determine if the association between self-reported physical activity and SWL would exist when physical activity was monitored objectively and (2) examine the between- and within-person associations among physical activity, sedentary behavior, and SWL. During a 14-day ecological momentary assessment study, college students (N = 128) wore an accelerometer to objectively measure physical activity and sedentary behavior, and they self-reported their physical activity, sedentary behavior, and SWL at the end of each day. Physical activity and sedentary behavior had additive, within-person associations with SWL across self-reported and objective-measures of behavior. Strategies to promote daily well-being should encourage college students to incorporate greater amounts of physical activity as well as limit their sedentary behavior.

Keywords: well-being | exercise | sitting | accelerometer | college students

Article:

Satisfaction with life (SWL) has a variety of important consequences, including decreased depressive symptoms and worry, increased workplace productivity, and greater longevity (Diener & Chan, 2011; Lyubomirsky, King, & Diener, 2005). Given the many outcomes associated with SWL, it would be valuable to better understand factors, such as physical activity and sedentary behavior, that influence SWL. This investigation is especially relevant for the college student population because people's global evaluations of their well-being appear to worsen more from ages 18 to 25 years than during any other time in the adult lifespan (Stone, Schwartz, Broderick, & Deaton, 2010). The level and intensity of physical activity also decline during this age range (Troiano et al., 2008) and those changes may help to explain the simultaneous decline in SWL.

Satisfaction With Life and Physical Activity

Subjective well-being is commonly conceptualized as "happiness" and incorporates both affective (i.e., pleas- ant and unpleasant emotions) and evaluative (i.e., SWL) components (Diener, 1984, 2000). Influences on SWL can be framed as either between- or within-person, with between-person influences reflecting dispositional (i.e., time-invariant, trait-level) correlates of SWL and within- person influences reflecting the effect of time-varying factors, including daily life events, behaviors, or states, on SWL (Diener, 1984). Although between- and within- person factors both represent viable influences on SWL, the majority of research concerning factors that influence SWL has emphasized between-person influences and within-person influences have received limited attention.

Physical activity is a behavior that may exert either a between- or within-person influence on SWL. Much of the evidence for an association between physical activity and SWL derives from research on adult samples drawn from the second half of the adult lifespan. For example, cross-sectional and prospective studies on middle-aged women and older adults indicated that participating in regular physical activity was associated with enhanced SWL (Elavsky & McAuley, 2005; Elavsky et al., 2005; McAuley et al., 2008). In these studies, physical activity improved SWL through its influence on affect, self- worth, self-efficacy, and mental health. These studies attributed the effect of physical activity on SWL to between-person differences (i.e., differences in SWL between more and less active people); however, none of these studies examined the potential within-person processes that may be responsible for the association between physical activity and SWL (i.e., changes in SWL on more or less active days).

Physical activity is likely linked to SWL through within-person processes because the accumulation of physical activity within a day has a revitalizing effect, which is likely to increase resource availability for goal pursuits (Gauvin, Jack, & Reboussin, 2000; Kanning & Schlicht, 2010; Thayer, 1996). Increased resources for goal pursuit help to facilitate goal attainment and achieving relevant goals is likely to result in increased SWL in college students. Recent findings by Maher et al. (2013) support the notion that physical activity is associated with SWL through a within-person process. In two separate samples of college students, controlling for a variety of established and plausible between- and within-person influences on SWL, Maher et al. (2013) found that there were no differences in SWL between more or less active people (i.e., no between-person association), but rather that SWL increased on days when people were more active than was typical for them (i.e., a within-person association). Although previous findings in samples of middle and older adults suggest that physical activity and SWL may be linked through between-person processes (i.e., Elavsky & McAuley, 2005; Elavsky et al., 2005; McAuley et al., 2008), findings from Maher et al. (2013) suggest that in college students, physical activity and SWL may be linked through within-person processes. However, research by Maher et al. (2013) had two significant limitations: (1) it relied solely on self- report measures of physical activity, and (2) it failed to differentiate the effect of insufficient physical activity from actual sedentary behavior.

Objective Measures of Physical Activity. Self-report measures of physical activity tend to emphasize moderate-to-vigorous intensity leisure time activities as opposed to light-intensity work-, household-, or transportation-related activities (Troiano et al., 2008). Consequently, light-intensity physical activity embedded in daily life demands is often unmeasured in self-report measures of physical activity. These light-intensity activities are, however, captured by objective measures of physical activity (Haskell, 2012). Previous research investigating associations between physical activity and SWL has relied on self-report measures that indicate the total volume of physical activity. Yet, light intensity activities represent a significant proportion of the total amount of physical activity each day (Owen, Sparling, Healy, Dunstan, & Matthews, 2010). Therefore, objective measures of physical activity provide a more accurate representation of the total volume of physical activity (Matthews, Moore, George, Sampson, & Bowles, 2012). Although there are a variety ways to quantify the complex behavior of physical activity (and many corresponding hypotheses), it is first important to establish an association between total physical activity volume measured objectively and SWL. It is not yet clear whether the association between physical activity and SWL is due to overall physical activity volume itself or the displacement of sedentary behavior (Powell, Paluch, & Blair, 2011). In addition to using objective measures for the first time, this study will strengthen conclusions about physical activity–SWL relations by measuring and controlling the influence of sedentary behavior, which has been omitted in previous studies and may confound relations because it can displace physical activity.

Satisfaction With Life and Sedentary Behavior

Sedentary behavior is defined as a unique class of behaviors that involve being in a seated or reclined position and expending low levels of energy (i.e., less than 1.5 METs); it is most commonly operationalized as time spent sitting (Sedentary Behavior Research Network, 2012). According to recent national panel data of objectively measured sedentary behavior, college students sit for nearly 8 hr/ day, which is equivalent to slightly more than half of their waking hours (Matthews et al., 2008). Compared with adolescents, college students spend almost 2 hr more each day sitting (Matthews et al., 2008). This increase in sedentary time may be a contributing factor to worsening SWL between the ages of 18 and 25 years; however, physical activity levels decline during this point in the lifespan as well (Troiano et al., 2008). It is unclear whether sedentary behavior, insufficient levels of physical activity, or both are associated with SWL.

Although there is limited research concerning the relation between sedentary behavior and SWL in adults, there appears to be a negative between-person association between overall sedentary behavior and SWL. People who, on average, engage in greater sedentary behavior (operationalized as TV viewing) also tend to experience lower SWL compared with people who are less sedentary (Depp, Schkade, Thompson, & Jeste, 2010; Frey, Benesch, & Stutzer, 2007).

The adverse health consequences of chronic sedentary behavior in adult populations can help explain the between-person influence of sedentary behavior on SWL (e.g., decreased mental health, increased risk for premature death, cardiovascular disease, metabolic syndromes; Atkin, Adams, Bull, & Biddle, 2012; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Proper, Singh, van Mechelen, & Chinapaw, 2011; Teychenne, Ball, & Salmon, 2010; Thorp, Owen, Neuhaus, & Dunstan, 2011). Acute sedentary behavior (i.e., engaging in more sedentary behavior than usual on a given day) also has adverse health consequences that may diminish SWL (e.g., increased perceptions of fatigue and muscle stiffness, decreased mental health, lipid metabolism, glucose uptake and insulin sensitivity, thwarted goal pursuits; Beach, Parkinson, Stothart, & Callaghan, 2005; Bey & Hamilton, 2003; Dunstan et al., 2012; Peper & Lin, 2012). Based on these acute effects of sedentary behavior, previously reported between-person associations between sedentary behavior and SWL may be an artifact of an unmeasured within-person process over time.

Physical activity and sedentary behavior may also interact to influence SWL. Physical activity and sedentary behavior are thought to be distinct and largely independent health behaviors (Marshall & Ramirez, 2011; Owen, Sparling, et al., 2010; Pate, O'Neill, & Lobelo, 2008). In fact, within recent years, the term *active couch potato* has been coined to describe individuals who meet or exceed physical activity guidelines for moderate or vigorous intensity physical activity but still sit for excessive periods of time throughout the day (Healy et al., 2008; Owen, Healy, Matthews, & Dunstan, 2010). Conversely, there are adults who do not engage in moderate or vigorous intensity physical activity, but engage in a large amount of light intensity activity and sit for a very small portion of the day (Owen, Healy, et al., 2010). It is unclear whether these types of people have different protection from physical activity or risk from sedentary behavior. Researchers investigating the physiological effects of physical activity and sedentary behavior have advocated for investigating the interactive effects of these two health behaviors (e.g., Owen, Healy, Matthews, & Dunstan, 2010). Understanding potential interactive effects would inform strategies to enhance SWL. If results revealed a significant interaction between physical activity and sedentary behavior, such that excessive sedentary behavior could reduce the SWL benefits conferred by physical activity, it might indicate that interventions to increase SWL should target both increases in physical activity and reductions in sedentary behavior. To the best of our knowledge, no study has examined this question, so we conducted exploratory analyses to evaluate whether the association between physical activity and SWL was moderated by daily or overall levels of sedentary behavior.

THE PRESENT STUDY

A 14-day ecological momentary assessment study with daily diary and ambulatory monitoring components was designed to evaluate relations between physical activity, sedentary behavior, and SWL using both self-report and objective measures of behavior. Our first objective was to determine if the association between self-reported physical activity and SWL would be robust when physical activity was measured with an accelerometer. We hypothesized that objectively measured physical activity would have a positive within-person association with SWL.

Our second objective was to examine between- and within-person relations among physical activity, sedentary behavior, and SWL. We hypothesized that the within-per- son association between physical activity and SWL would remain positive after controlling for sedentary behavior. We also hypothesized that sedentary behavior and SWL would have a within-person association. In addition, we conducted exploratory analyses to determine whether the association between physical activity and SWL varied as a function of daily or overall levels of sedentary behavior.

In testing each of these hypotheses, we controlled for plausible between- and within-person confounds. For example, both mental and physical health have been associated with these health behaviors and SWL (McAuley et al., 2006), so we controlled both daily mental and physical health status. All hypothesized associations between physical activity, sedentary behavior, and SWL were expected to be robust after controlling for these variables.

METHODS

Participants and Procedures

Participants were 130 college students who participated in an ecological momentary assessment study as part of a class project. All but one participant indicated that they were physically capable of performing regular physical activity. Another participant did not give permission to use his data for research purposes. Those two participants were excluded from analyses, resulting in a final sample of 75 women and 53 men for data analysis. The majority of the sample reported that they were White (87%). In addition, almost the entire sample reported that they were non-Hispanic (96%). Women made up more than half of the sample (58%). The mean age of the sample was 21.3 years (SD = 1.1). Participants were classified as mostly normal weight (60%) or overweight (32%) based on World Health Organization cutoffs for body mass index.

At an introductory laboratory session, participants provided informed consent, permission for their data to be used for research purposes, and demographic information. They were then trained how to access a secure website to complete a brief questionnaire about their daily behaviors and evaluations at the end of every day (7 pm to 4 am) over the course of the 14-day study. Participants were instructed to wear the accelerometer on their right hip (over the midline of their knee) during all waking hours for the duration of the study, except while engaging in water- related activities (e.g., showering). Participants were also given a log to record the times they put the monitor on each morning and took the monitor off each night. The local institutional review board approved all study protocols.

Measures

Satisfaction With Life. Daily SWL was assessed using a single item from the Satisfaction with Life Scale (i.e., "I was satisfied with my life today;" Diener, Emmons, Larsen, & Griffin, 1985). In a previous daily diary study, Maher et al. (2013) administered the complete 5-item Satisfaction with Life Scale and found that this single-item best captured the latent SWL factor. Using a single-item measure of SWL reduces the participant burden inherent in completing measures with multiple items when assessing the same construct over extended periods of time. Participants rated the item on a visual analog scale ranging from 0 (*strongly disagree*) to 100 (*strongly agree*).

Physical Activity. Daily self-report physical activity was assessed using a version of the International Physical Activity Questionnaire (IPAQ), a validated measure of adult physical activity

(Booth, 2000; Craig et al., 2003). The IPAQ was modified to focus on daily instead of weekly physical activity. This daily adaptation reduced the threat of retrospective bias and recall errors and has been used in previous research (Maher et al., 2013; Matthews et al., 2012). Standard scoring procedures for the IPAQ were used to convert duration of reported activities into metabolic equivalents. Activity times were weighted by standard MET estimates (vigorous physical activity = 8, moderate physical activity = 4, walking = 3.3) and summed to create a daily physical activity MET·min·day^{-1} score (Sjöström et al., 2002, 2005).

Daily physical activity was measured objectively using a triaxial accelerometer (Actigraph model GT3×, Pensacola, FL). Activity counts were aggregated into 1-min epochs and processed using the Actilife data analysis soft- ware from Actigraph (version 5.1.5). Data were screened to identify valid days. A valid day of recording consisted of ≥ 10 hr of valid wear time with every period of 90 consecutive minutes of zero being considered nonwear. Accelerometer logs were used to determine participant's nonwear time due to sleeping. Physical activity was estimated as the average activity counts per hour (adjusted for valid wear time). This adjustment eliminates the potential confound of high activity counts being the result of accruing more valid wear time hours rather than a result of accruing more activity (Matthews, 2005).

Sedentary Behavior. Daily sedentary behavior was assessed using the sitting time item from the IPAQ (Booth, 2000). Rosenberg et al. (2008) found that the IPAQ-based weekly measure of sedentary behavior was a reliable measure of sitting time. Prompted with examples of opportunities to be sedentary (i.e., "Think about the time you spent sitting today. This includes times spent at work, at home, while doing course work, and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting down to watch television."), participants reported the total amount of time they had spent engaged in sedentary behavior that day.

Daily sedentary behavior was also measured objectively using a triaxial accelerometer (Actigraph model GT3×, Pensacola, FL). Data processing and adjustment for valid days and wear time were the same as those described for objectively measured physical activity. Sedentary behavior was estimated as the percentage of valid wear time spent in sedentary behavior (i.e., < 100 counts·min^{-1}) each day (Freedson, Melanson, & Sirard, 1998).

Mental and Physical Health Status. Two items from the Health-Related Quality of Life Questionnaire were used to assess global mental and physical health status (Hennessy, Moriarty, Zack, Scherr, & Brackbill, 1994). These items were modified to reflect daily health status. Daily mental health status was assessed using the single item, "Today, my mental health was NOT GOOD." Daily physical health status was assessed using the single item, "Today, my physical health was NOT GOOD." Participants rated each item on a scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*). Higher scores indicated a poorer health status.

Time. Time was accounted for in two different ways. First, to control for the possibility that SWL changed as a result of, or was reactive to, participating in the study we created a within-person variable to represent time of exposure to study procedures. Second, six dummy variables representing the day of the week were created as within-person variables to account for possible day-of-week effects as a result of the social calendar. Thursday served as the reference category because the majority of participants began data collection on a Thursday.

Data Analysis

Multilevel models were used to examine between- and within-person associations between physical activity and SWL, while accommodating the nested data structure (days nested within people; Snijders & Bosker, 1999). Models were estimated using SAS 9.2 PROC MIXED with missing observations (self-report: < 1%, $n_{\text{observations}} = 10$; objectively measured: 7%, $n_{\text{observations}} = 101$) treated as missing completely at random (Littell, Milliken, Stroup, & Wolfinger, 1996). The final sample consisted of 1,643 daily self-reports and 1,384 daily objective measures of behavior from 128 persons. In accordance with standard multilevel modeling practice, pseudo-R^2, the additional proportion of variance explained by the predictors (e.g., daily physical activity, sedentary behavior) compared with a baseline model, was considered as an effect size estimate (Snijders & Bosker, 1999). In addition, intraclass correlation estimates were calculated to describe the proportion of variance in each variable attributable to between-person differences.

Data Preparation. To differentiate between- from within- person variance, within-person means and daily residual scores around those within-person means were calculated for daily ratings of physical activity, sedentary behavior, and mental and physical health status (Bolger, Davis, & Rafaeli, 2003; Schwartz & Stone, 1998). For example, person i's usual level of physical activity (Usual PA_i) was calculated as the within-person mean of her daily responses across the 14 days and each person's daily level of physical activity (Daily PA_{di}) was calculated as the deviation of day d's score from their Usual PA_i. Within-person mean scores across the 14 days (i.e., differentiating more or less active people) represented potential between-person influences on SWL and daily deviations (i.e., differentiating more or less active than usual days) represented potential within-person influences on SWL.

For variables with skewed distributions, power law transformations were conducted using the Box–Cox method to find the optimal normalizing transformation for each variable (Box & Cox, 1964; Osborne, 2010). The Box–Cox method examines a series of power law trans- formations that will optimally normalize many skewed distributions (Box & Cox, 1964), thus eliminating the need to randomly try different transformations to determine the best transformation option (Osborne, 2010). Transformed values were used to calculate correlations and estimate parameters in the multilevel models.

To control for the possibility that SWL, physical activity, or sedentary behavior changed as a result of, or were reactive to, participating in the study we created another within-person variable ($Time_{di}$) to represent the sequence of the day in the study. Six dummy variables representing the day of the week were created as within-person variables (e.g., $Monday_{di}$).

Model Specification. Separate models of SWL were estimated using the self-report (Model 1) and objective measures (Model 2) of physical activity and sedentary behavior. The final model is presented as follows.

Level 1:

$$SWL_{di} = \beta_{0i} + \beta_{1i}(\text{Daily PA}_{di}) + \beta_{2i}(\text{Daily SB}_{di}) + \beta_{3i}(\text{Daily PA}_{di} \times \text{Daily SB}_{di}) + \beta_{4i}(\text{Daily Mental Health Status}_{di}) + \beta_{5i}(\text{Daily Physical Health Status}_{di}) + \beta_{6i}(\text{Monday}_{di}) + \beta_{7i}(\text{Tuesday}_{di}) + \beta_{8i}(\text{Wednesday}_{di}) + \beta_{9i}(\text{Friday}_{di}) + \beta_{10i}(\text{Saturday}_{di}) + \beta_{11i}(\text{Sunday}_{di}) + \beta_{12i}(\text{Time}_{di}) + e_{di} \quad (1)$$

Level 2:

$$\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Overall PA}_i) + \gamma_{02}(\text{Overall SB}_i) + \gamma_{03}(\text{Overall Mental Health Status}_i) + \gamma_{04}(\text{Overall Physical Health Status}_i) + u_{0i} \quad (2)$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Overall SB}_i) + u_{1i} \quad (3)$$

$$\beta_{2i} = \gamma_{20} + u_{2i} \quad (4)$$

$$\beta_{3i} = \gamma_{30} \quad (5)$$

$$\beta_{(4\text{-}5)i} = \gamma_{(4\text{-}5)0} + u_{(4\text{-}5)i} \quad (6)$$

$$\beta_{(6\text{-}12)i} = \gamma_{(6\text{-}12)0} \quad (7)$$

where γ_{01} to γ_{04} represented the between-person influence of physical activity, sedentary behavior, mental health status, and physical health status (between-person effects) on daily SWL (SWL_{di}); γ_{10} to γ_{120} represented the average strength of the within-person influences of physical activity, sedentary behavior, the interaction between physical activity and sedentary behavior, mental health status, physical health status, day of the week, and time of exposure to study procedures on daily SWL; γ_{11} represented the average strength of the between-person influence of sedentary behavior on the association between within-person physical activity and daily SWL; and u_{0i} to u_{2i} and u_{4i} to u_{5i} are person-specific residual deviations that are uncorrelated with the day-level residuals e_{di}. The residual variance for sedentary behavior in models using objectively measured data, u_{2i}, and the within-person interaction term between physical activity and sedentary behavior, u_{3i}, were removed to accommodate the limited sample size, and the residual variance for the day of week and day in study sequence (i.e., $u_{6i} – u_{12i}$) were treated as unconditional fixed effects to reduce model complexity.

RESULTS

Participants provided self-report data for a total of 1,653 of the 1,792 possible person-days (93% response rate). The median number of days participants provided self- report data were 14 days (*M* = 12.9, *SD* = 1.4). Participants also provided valid objectively measured data for a total of 1,485 of the 1,792 possible person-days (83% response rate). The median number of days participants provided objectively measured data were 13 days (*M* = 11.7, *SD* = 2.9). On average, participants provided over 14 valid wear-time hours of data each day (*M* = 14.7, *SD* = 2.8).

Descriptive statistics are displayed in Table 1. Self- reports indicated that participants experienced moderate levels of SWL (75.6 on a 0 to 100 scale) and engaged in the equivalent of 1.5 hr of walking and moderate physical activity each day. Objectively measured physical activity indicated that participants accumulated an average of 28,488.3 activity counts per hour (*SD* = 13,892.2). Participants also reported sitting for almost six waking hours each day. Accelerometer data indicated that participants engaged in sedentary behavior for 66.9% of their waking hours each day (*SD* = 8.5%).

Significant skew was present in all predictor variables ($p < .05$). Using the Box–Cox method (Box & Cox, 1964; Osborne, 2010), the optimal power-law transformations were determined to normalize the distributions of self-reported physical activity ($\lambda = 0.30$), objectively measured physical activity ($\lambda = 0.30$), self-reported sedentary behavior ($\lambda = 0.60$), objectively measured sedentary behavior ($\lambda = 2.00$), mental health status ($\lambda = -0.10$), and physical health status ($\lambda = 0.10$). Transformed variables were used to estimate correlations and multilevel models.

Table 1 also presents two different types of bivariate correlations. The first type comprise the between-person correlations (i.e., correlations between each person's average rating of variables over the course of the study; above diagonal). These correlations are insensitive to within-person variation in ratings. The second type comprise the within-person correlations (i.e., correlations between each day's rating of variables; below diagonal). These correlations are insensitive to dependencies between observations due to the nesting of daily scores within people as a result of the intensive sampling design of this ecological momentary assessment study.

Table 1 Descriptive Statistics, Intraclass Correlations, and Correlations Between Satisfaction with Life, Physical Activity, Sedentary Behavior, and Mental and Physical Health Status

		M	*SD*	1	2	3	4	5	6	7
1	Satisfaction With Life	75.56	20.11	(.42)	.08	.03	−.05	.05	−.66	−.61
2	Self-Reported Physical Activity ($MET \cdot min \cdot day^{-1}$)	648.88	504.65	.15	(.47)	.27	−.27	−.37	.03	−.07
3	Objectively Measured Physical Activity ($counts \cdot hr^{-1}$)	28,488.29	13,892.24	.15	.42	(.30)	−.20	−.59	−.02	−.17
4	Self-Reported Sedentary Behavior ($min \cdot day^{-1}$)	365.46	154.45	−.13	−.31	−.26	(.48)	.25	.04	.17
5	Objectively Measured Sedentary Behavior (% waking hours)	66.92	8.45	−.11	−.38	−.57	.33	(.28)	−.09	.01
6	Mental Health Status	2.54	1.50	−.52	−.04	−.08	.07	.04	(.42)	.85
7	Physical Health Status	2.96	1.78	−.44	−.18	−.25	.18	.14	.69	(.40)

Note. Intraclass correlation coefficients representing the proportion of between-person variance appear in parentheses on the diagonal of the correlation matrix. Coefficients below the diagonal represent correlations across days and people (i.e., within-person correlations). Coefficients above the diagonal represent correlations of intraindividual means (i.e., between-person correlations). Descriptive statistics were calculated using raw data. Correlations were calculated using transformed scores. *M* = sample-level mean, *SD* = sample-level standard deviation.

Due to the limitations associated with each type of correlation, we interpret these correlations descriptively rather than inferentially. In both sets of correlations, physical activity and SWL had a weak positive association ($rs \geq .03$). Conversely, sedentary behavior and SWL tended to have a weak negative association (except for the within-person association between objectively measured sedentary behavior and SWL; $rs \leq -.05$). It should also be noted that self-report and objective measures of physical activity were correlated only moderately ($rs = .27$ and $.42$). Similarly, self-report and objective measures of sedentary behavior were correlated moderately ($rs = .33$ and $.25$).

Multilevel Models of Satisfaction With Life

Unstandardized parameter estimates from both multilevel models are presented in Table 2. Model 1 (left column of coefficients) regressed daily SWL on self-reported physical activity and sedentary behavior, and the remaining covariates. Model 2 (right column of coefficients) regressed daily SWL on objectively measured physical activity and sedentary behavior, and the remaining covariates. Consistent with our first hypothesis, the within-person association between physical activity and SWL was significant in both models even after controlling for those additional between- and within-person factors, indicating that on days when people engaged in more physical activity than usual, they also tended to experience greater SWL (Model 1: $\gamma_{10} = 0.35$, $p < .05$; Model 2: $\gamma_{10} = 0.14$, $p < .05$). Consistent with our second hypothesis, the within-person association between sedentary behavior and SWL was significant so, on days when people sat more than was typical for them, they reported lower SWL (Model 1: $\gamma_{20} = -0.12$, $p < .05$; Model 2: $\gamma_{20} = -0.003$, $p < .05$). Neither the between-person influence of overall physical activity (Model 1: $\gamma_{01} = 0.19$, $p = .43$; Model 2: $\gamma_{01} = -0.08$, $p = .65$) nor that of overall sedentary behavior (Model 1: $\gamma_{02} = 0.04$, $p = .63$; Model 2: $\gamma_{02} = -0.01$, $p = .69$) were significant predictors of SWL. Thus, there were no differences in SWL between more or less active people or more or less sedentary people. None of the potential interactions were significant (Model 1: $\gamma_{11} = -0.01$, $p = .88$, $\gamma_{30} = 0.01$, $p = .58$; Model 2: $\gamma_{11} = -0.01$, $p = .85$, $\gamma_{30} = -0.01$, $p = .42$).

Table 2 Multilevel Model Coefficients Predicting Daily Satisfaction with Life

	Parameter Estimate (Standard Error)	
	Model 1	**Model 2**
Fixed Effects		
Intercept, γ_{00}	76.61* (1.43)	77.80* (1.55)
Overall Physical Activity, γ_{01}	0.19 (0.24)	–0.08 (0.18)
Daily Physical Activity, γ_{10}	0.35* (0.12)	0.14* (0.07)
Overall Sedentary Behavior, γ_{02}	0.04 (0.09)	–0.01 (0.01)
Daily Sedentary Behavior, γ_{20}	–0.12* (0.04)	–0.003* (0.001)
Daily Physical Activity × Overall Sedentary Behavior, γ_{11}	–0.01 (0.01)	–0.01 (0.01)
Daily Physical Activity × Daily Sedentary Behavior, γ_{30}	0.01 (0.01)	–0.01 (0.01)
Overall Mental Health Status, γ_{04}	–17.24* (3.93)	–21.51* (4.12)
Daily Mental Health Status, γ_{40}	–12.46* (1.49)	–13.04* (1.56)
Overall Physical Health Status, γ_{05}	–5.25 (3.26)	–1.30 (3.38)
Daily Physical Health Status, γ_{50}	–3.16* (0.91)	–2.81* (0.95)
Monday, γ_{60}	–0.78 (1.23)	–0.52 (1.39)
Tuesday, γ_{70}	–1.86 (1.16)	–1.99 (1.23)
Wednesday, γ_{80}	0.31 (1.17)	0.08 (1.26)
Friday, γ_{90}	–1.61 (1.20)	–0.69 (1.33)
Saturday $\gamma_{10,0}$	0.13 (1.25)	–0.40 (1.36)
Sunday $\gamma_{11,0}$	–0.88 (1.27)	–0.76 (1.40)
Exposure, $\gamma_{12,0}$	–0.06 (0.09)	–0.21* (0.10)
Random Effects		
Variance Intercept, u_0	95.12* (13.73)	100.52* (15.38)
Variance Physical Activity, u_1	0.68* (0.25)	0.07* (0.03)
Variance Sedentary Behavior, u_2	0.04* (0.03)	—
Variance Mental Health Status, u_4	115.19* (33.09)	113.41* (36.89)
Variance Physical Health Status, u_5	16.46 (11.98)	15.15 (12.74)
Residual	153.98	152.78
–2 log likelihood	13,393.9	11,272.3
Akaike information criterion	13,425.9	11,294.3

Note. Unstandardized estimates and standard errors. Model 1 (left column of coefficients) regressed daily SWL on self-reported physical activity and sedentary behavior, and the remaining covariates. Model 2 (right column of coefficients) regressed daily SWL on objectively measured physical activity and sedentary behavior, and the remaining covariates. Multilevel models are based on 14 occasions nested within 128 participants for a total of 1643 (self-report) and 1384 (objectively measured) observations. Transformed scores were used to estimate parameters.

*$p < .05$.

Mental health status, both overall (Model 1: $\gamma_{04} = -17.24$, $p < .001$; Model 2: $\gamma_{04} = -21.51$, $p < .001$) and daily (Model 1: $\gamma_{40} = -12.46$, $p < .001$; Model 2: $\gamma_{40} = -13.04$, $p < .001$), were negatively associated with SWL. Daily physical health status had a negative within-person association with SWL (Model 1: $\gamma_{50} = -3.16, p < .05$; Model 2: $\gamma_{50} = -2.76, p < .05$), but overall physical health was not associated with SWL at the between-person level. People reported greater SWL on days when their physical or mental health were better than usual, and people with better mental health overall reported greater SWL than people with poorer mental health overall.

The within-person effect of physical activity (Model 1: $\sigma^2_{u1} = 0.68, p < .05$; Model 2: $\sigma^2_{u1} = 0.07, p < .05$), Sedentary behavior (Model 1: $\sigma^2_{u2} = 0.04, p < .05$), and mental health status (Model 1: $\sigma^2_{u4} = 115.19, p < .001$; Model 2: $\sigma^2_{u4} = 113.41, p < .05$) on SWL all varied significantly between people.

As indicated by the pseudo-R^2, the final model using self-reported measures of behavior to predict SWL accounted for approximately 35% of the variance in SWL, with daily physical activity and sedentary behavior combining to account for 46% of the explained variance. Similarly, the final model using objectively measured behavior to predict SWL accounted for approximately 37% of the variance in SWL, with daily physical activity and sedentary behavior combining to account for 47% of the explained variance.

Additional Analyses

This study examined the influence of accumulated physical activity and sedentary behavior each day on subsequent evaluative judgments at the end of each day; however, due to the nonexperimental research design of this study, strong conclusions regarding causality could not be drawn. To rule out alternative temporal sequences that threaten the assumption that behavior (i.e., physical activity, sedentary behavior) influences subsequent evaluations (i.e., SWL), we regressed daily physical activity and sedentary behavior on previous-day SWL. Neither the between- nor within-person association between previous-day SWL and subsequent physical activity were significant using self-report physical activity ($\gamma_{01} = 0.03, p = .28$; $\gamma_{10} = 0.01, p = .71$) or objectively measured physical activity ($\gamma_{01} = 0.02, p = .63$; $\gamma_{10} = 0.01, p = .77$). The between-person association between previous-day SWL and subsequent sedentary behavior also were not significant (self-reported sedentary behavior: $\gamma_{02} = -0.04, p = .60$; objectively measured sedentary behavior: $\gamma_{02} = 0.02, p = .56$). Previous-day SWL was negatively associated with subsequent self-reported sedentary behavior ($\gamma_{20} = -0.04, p = .02$) but not with the objective measure of sedentary behavior ($\gamma_{20} = -0.01, p = .40$).

DISCUSSION

This study extended our understanding of the links between physical activity, sedentary behavior, and SWL in college students by incorporating objective measures of physical activity and sedentary behavior. The within- person association between physical activity and SWL was significant across both self-report and objective measures of physical activity, even after accounting for daily variation in sedentary behavior, possible interactions between physical activity and sedentary behavior, and plausible third variable influences.

Behavioral data from this study regarding objectively measured physical activity and sedentary behavior roughly corresponded to results from the National Health and Nutrition Examination

Survey 2003–2004 data (Matthews et al., 2008; Troiano et al., 2008). Accelerometer- derived activity counts as well as distributions of time spent in light, lifestyle, moderate, vigorous, and very vigorous activities in this study were comparable to activity counts in young adults (age 20–29) reported by Troiano et al. (2008). In addition, results from this sample indicated that emerging adults sat for approximately 69% of their waking hours whereas Matthews et al. (2008) reported that young adults (age 20–29) engaged in sedentary behavior for approximately 55% of their waking hours. It should be noted that the validity of these comparisons is limited somewhat by the lack of standardized procedures to adjust accelerometer data for valid wear time.

Intraclass correlation estimates from this study sup- ported previous claims that there is substantial within- person variability in ratings of SWL (Fujita & Diener, 2005; Gerstorf et al., 2010; Heller, Watson, & Ilies, 2006; Maher et al., 2013). Notably, the within-person variability in ratings of SWL was similar to that of variability in ratings of core affect (Hyde, Conroy, Pincus, & Ram, 2011; Röcke, Li, & Smith, 2009). Despite the evaluative and hedonic differences between SWL and affect, both serve as indicators of global well-being and are often related (Diener, 1984); therefore, it may be difficult to disentangle these constructs. Variability in ratings of SWL has been documented on a variety of time scales including hourly (Heller et al., 2006), daily (Maher et al., 2013), and yearly (Fujita & Diener, 2005; Gerstorf et al., 2010), indicating that SWL changes on both fast and slow timescales.

This study added to the accumulating body of evidence that physical activity is positively associated with SWL and that this association reflects a within-person process (Maher et al., 2013). Unlike previous studies which only examined the link between physical activity and SWL at the between-person level (Elavsky & McAuley, 2005; Elavsky et al., 2005; McAuley et al., 2008), this study simultaneously examined associations between physical activity and SWL at both the between- and within-person level and revealed a significant within- person, but not between-person, association. In addition, the current study extended previous findings by Maher et al. (2013) linking self-reported physical activity and SWL at the within-person level by linking physical activity and SWL at the within-person level using an objective measure of physical activity. These findings strengthened confidence that increased daily physical activity is associated with greater SWL.

Given that the within-person association between physical activity and SWL remained after controlling for physical and mental health status, a likely mechanism that accounts for this association involves the revitalizing effect of physical activity. When people feel exhausted, they are less likely to pursue relevant goals. Physical activity has a revitalizing effect, which is likely to increase resource availability for goal pursuits (Gauvin et al., 2000; Kanning & Schlicht, 2010; Thayer, 1996). Increased resources for goal pursuit should facilitate striving for and achieving relevant goals and, therefore, are likely to result in increased SWL. In addition, changes in affect may play a role in the mechanism underlying the within-person association between physical activity and SWL (Diener, 1984; Elavsky et al., 2005).

These within-person mechanisms likely differ from the between-person mechanisms highlighted in studies by Elavsky and colleagues (Elavsky & McAuley, 2005; Elavsky et al., 2005; McAuley et al., 2008). Elavsky and colleagues studied between-person associations between physical activity and SWL in middle-aged women and older adults. As individuals age, health decrements accrue and functional ability declines. Regular physical activity is one way to delay the onset and slow the progression of some functional declines, through fitness and health adaptions, that occur during later life (Keysor, 2003; Miller, Rejeski, Reboussin, Ten Have, & Ettinger, 2000; Paterson & Warburton, 2010; Unger, Johnson, & Marks, 1997). Conversely, for college students, SWL may not depend on the health benefits of regular physical activity because they typically have yet to experience age-related declines in health. These fitness and health adaptations from regular physical activity are one potential mechanism of the between-person association previously found in middle and older adults. Investigating the between- and within-person mechanisms of relations between physical activity and SWL across the lifespan is an important direction for future research.

This study also differentiated insufficient physical activity from actual sedentary behavior. Results indicated that physical activity and sedentary behavior had additive within-person influences on SWL in this study. The independent effects of sedentary behavior on physiological outcomes, regardless of physical activity have been documented (e.g., Healy et al., 2011; Proper et al., 2011; Thorp et al., 2011); however, this is one of the few studies to document the negative association between sedentary behavior and a global indicator of well-being irrespective of physical activity (Depp et al., 2010; Frey et al., 2007). Yet, unlike previous studies that only examined the link between sedentary behavior and SWL at the between- person level (Depp et al., 2010; Frey et al., 2007), this study simultaneously examined associations between physical activity and SWL at both the between-and within-person level, revealing a significant within-person, but not between-person, association. Given the deleterious acute physiological effects of sedentary behavior (Bey & Hamilton, 2003; Dunstan et al., 2012), and the growing evidence of the association between acute sedentary behavior and psychological consequences (Atkin et al., 2012; Gilson, Burton, van Uffelen, & Brown, 2011; Peper & Lin, 2012; Teychenne et al., 2010; Thorp et al., 2011), it is not surprising that sedentary behavior detracts from SWL at the within-person level. In addition to strategies aimed at promoting physical activity in people's lives, finding ways to reduce sedentary behavior (e.g., standing while talking on the telephone, standing during TV commercials) may represent manageable daily changes people can make to enhance their SWL. The null findings regarding the interaction between physical activity and sedentary behavior suggest that the influence of each health behavior on SWL was not conditioned on the other. Taken as a whole, these findings suggest that physical activity and sedentary behavior are both important targets for behavior change. Furthermore, the most efficient way to enhance SWL in college students may be to displace sedentary behavior with physical activity.

Strategies aimed at improving well-being, through reductions in sedentary behavior, may benefit from investigating whether the association between sedentary behavior and SWL varies as a function of the type of sedentary behavior in which an individual engages (e.g., sitting to watch TV, go on the computer, study, socialize with friend, attend classes or meetings) and an individual's preference for that particular type of sedentary behavior. It is likely that sedentary behavior that is consistent with goals (e.g., wanting to socialize with friends and sitting to do so) has a differential impact on SWL than sedentary behavior that conflicts with goals (e.g., wanting to exercise but having to sit and study for an exam). Investigating these nuanced effects of different sedentary activities within their motivational context may provide more effective strategies to enhance well-being.

Although conclusions from this study were limited by the nonexperimental research design, alternative causal pathways were evaluated to strengthen conclusions about the direction of the behavior-SWL association. Previous-day SWL did not predict subsequent day physical activity at the between- or within-person level. This finding was consistent with work by Maher et al. (2013), who found previous day's SWL was not associated with subsequent day's self-reported physical activity in 8- and 14-day diary studies. These findings support our assumption that physical activity plays a role in regulating SWL; however, experimental research is needed to draw strong conclusions about causality.

To the best of our knowledge, this study was the first to examine the alternative temporal pathway between sedentary behavior and SWL. Results from self-reported sedentary behavior revealed that previous-day SWL negatively influenced subsequent sedentary behavior at the within-person level; however, this association was not found when examining the objective measure of sedentary behavior. It is possible that SWL may influence a person's awareness of sedentary behavior, but not influence that actual amount of time spent in sedentary behavior.

Although findings were inconclusive in this study regarding the directional pathway between sedentary behavior and SWL, it seems likely that sedentary behavior would be associated with reduced SWL because sedentary behavior adversely effects physiological and psychological factors that may ultimately detract from SWL. This study statistically controlled for physical and mental health status so many of the originally proposed mechanisms, such as increased risk for metabolic syndromes, increased perceptions of muscle stiffness, and decreased mental health and glucose tolerance, may not account for the findings. One potential mechanism of the association between daily sedentary behavior and SWL that was not investigated in this study involves the adverse impact of thwarted goal pursuits. Individuals who spend excessive amounts of time sitting due to obligations such as school, work, extracurricular meetings may feel that the time they spend sitting actually interferes with other goal pursuits. Spending excessive amounts of time engaging in sedentary behavior due to obligations may also decrease feelings of perceived control. Finally, sedentary behavior may increase negative affect or decrease positive affect leading to lower SWL (Balboa-Castillo, León-Muñoz, Graciani, Rodríguez-Artalejo, & Guallar-Castillón, 2011; Teychenne et al., 2010).

Conversely, SWL may influence sedentary behavior. Low SWL may lead to greater depressive symptoms, which are associated with feelings of lethargy and more sedentary time (Elliot, Kennedy, Morgan, Anderson, & Morris, 2012). Previous research on older adults and adolescents has also indicated bidirectional pathways between depressive symptoms and sedentary behavior (operationalized as a combination of frequency of sedentary behavior and low levels of physical activity; Lindwall, Larsman, & Hagger, 2011; Teychenne & York, 2013). Experimental research is needed to draw more precise conclusions related to the causal sequence linking sedentary behavior and SWL.

It was not surprising that poor mental and physical health status were negatively related to SWL. Findings from this study replicated the established between-person negative association between mental health status and SWL (McAuley et al., 2006) and added to accumulating evidence that daily variation in mental health status is negatively associated with SWL (Maher et al., 2013). The mechanism underlying any effect of mental health status likely results from thwarted goal pursuits which would otherwise contribute to SWL; however, this speculation requires evaluation. This study was the first to indicate that physical health status was associated with SWL by way of a within-person, and not a between-person, process. Poor physical health status often hinders a person's ability to function normally and independently when completing activities of daily living. The consequences associated with being unable to function normally can have implications for goal pursuit and ultimately SWL. In fact, the effect of physical health status may be even more relevant in populations where deficits in physical health accrue as a result of age-related decline. So although results from this study suggest that physical health status does not represent a viable mechanism linking physical activity and sedentary behavior with SWL in college students, it may be that physical health status serves as a mechanism linking physical activity and sedentary behavior to SWL in older adulthood.

Results from this study suggested that the observed associations between physical activity, sedentary behavior, and SWL were not due to reactivity to the study procedures or the social calendar. Future work should examine other plausible temporal processes that may influence associations between physical activity, sedentary behavior, and SWL such as developmental differences or seasonal effects. The negative effect of exposure to study procedures suggests that as time went on in the study, participants' SWL decreased. It may be that the burden associated with participating in the study decreased SWL as time went on. Alternatively, this change may represent a shrinking reaction to the research methods.

LIMITATIONS AND FUTURE DIRECTIONS

The present sample was fairly homogenous with respect to age, race, education, and physical abilities. Examining associations between physical activity, sedentary behavior, and SWL with more heterogeneous samples are necessary before these results can be generalized to broader populations. For example, the association between behavior and SWL may also differ at other points in the adult lifespan as motives and goals change (Heckhausen, Wrosch, & Schulz, 2010).

Second, this study focused on SWL and did not attempt to distinguish it from affect. We suspect that momentary or daily ratings of SWL and positive affect may be strongly associated but take no stand on the temporal precedence of either response because third variables, such as physical activity and sedentary behavior, are likely to influence both. The contribution of this study is in showing the benefits of physical activity and the risks of sedentary behavior on an evaluative measure of subjective well-being. Future work will need to evaluate whether these evaluative and affective processes can be differentiated as well as whether they have differential impacts on outcomes such as motivation and adherence.

Due to the intensive sampling design of this ecological momentary assessment study, we used a single-item measure of SWL to reduce participant burden. This score includes measurement error and may represent a narrow band of the SWL content universe. Associations between variables in these models may be attenuated as a result; however, the general conclusion based on the direction of the significant model coefficients is unlikely to be impacted. Nevertheless, future research should examine within-person associations between physical activity, sedentary behavior, and SWL using other measures of SWL, which represent the broader content universe and permit measurement error to be estimated and statistically controlled.

It is also worth noting that our measures of physical and mental health status were negatively worded. Negatively worded items have previously been found to contain systematic method variance, which can confound conclusions about the construct in question (DiStefano & Motl, 2006). Future research should consider using positively worded measures to assess physical and mental health status.

Finally, sedentary behavior was operationalized using the 100 counts per minute criterion (Freedson et al., 1998). There is some debate as to what the best cutoff point is for measuring sedentary behavior; however, findings indicate that this criterion for sedentary behavior is comparable to dual accelerometers/inclinometers (Kozey-Keadle, Libertine, Staudenmayer, & Freedson, 2012). In addition, accelerometers cannot distinguish time spent sitting from other stationary activities.

SUMMARY

We concluded that physical activity and sedentary behavior were linked to SWL in college students through a within-person process. Importantly, this association was robust across self-report and objective measures of behavior. Understanding the role that physical activity and sedentary behavior play in influencing daily SWL is especially relevant for college students because SWL decreases more during those years than any other period in the lifespan and the transition into this phase is accompanied by distinct changes in people's physical activity and sedentary behavior. These findings not only illustrate the importance of increasing daily physical activity, but also introduce the novel idea of reducing daily sedentary behavior as a way to enhance SWL during this develop- mental stage.

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