Active and Sedentary Behaviors Influence Feelings of Energy and Fatigue in Women

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ABSTRACT

ELLINGSON, L. D., A. E. KUFFEL, N. J. VACK, and D. B. COOK. Active and Sedentary Behaviors Influence Feelings of Energy and Fatigue in Women. *Med. Sci. Sports Exerc.*, Vol. 46, No. 1, pp. 192–200, 2014. **Purpose**: The purpose of this study was to determine whether physical activity and sedentary behaviors interact to influence feelings of energy and fatigue in women. **Methods**: Feelings of energy and fatigue and physical activity and sedentary behaviors were assessed in 73 women (mean ± SD age = 37 ± 10) who were dichotomized based on physical activity status (meets physical activity recommendations [n = 40] vs insufficiently active [n = 33]) and the amount of uninterrupted sedentary time they accumulated (high [n = 38] vs low [n = 35]). Three 2 × 2 ANOVA were conducted to determine the relationships between physical activity and sedentary behaviors and between energy (vigor and vitality) and fatigue. **Results**: Results demonstrated a significant main effect for meeting physical activity recommendations for both vigor (P = 0.004) and vitality (P < 0.001). For fatigue, there was a significant interaction between physical activity and sedentary behaviors (P = 0.005). Analyses of simple main effects demonstrated that in women who were not meeting physical activity recommendations, those who were less sedentary had significantly lower levels of fatigue than their more sedentary peers (P = 0.003). **Conclusions**: Our results suggest that meeting physical activity recommendations has benefits for energy and fatigue even when combined with an otherwise sedentary lifestyle. Moreover, in women who are insufficiently active, being less sedentary is associated with lower levels of fatigue that are comparable with women who are meeting recommendations. **Key Words:** MOOD, PHYSICAL ACTIVITY RECOMMENDATIONS, INACTIVITY, ACCELEROMETER

Feelings of low energy and fatigue are prevalent, costly, and have a significant negative impact on mental health and quality of life. Population estimates of fatigue prevalence range from 20% to 40%, and women experience significantly higher rates of fatigue than men (23). Fatigue is among the most common reasons for doctor visits and is a prominent symptom of several mental health conditions, including depression, anxiety, and insomnia (3,11,33). The cause of fatigue is often difficult to determine, and consequently finding an effective treatment is challenging. Fortunately, emerging data suggest that being physically active is related to both feelings of energy and fatigue.

The mental health benefits of exercise are well documented (31,40), and there is promising evidence demonstrating that exercise has the potential to be a viable treatment for fatigue (41). Results from population-based studies are uniformly supportive of a positive dose–response relationship between self-reported participation in exercise and feelings of energy (6,27). Studies involving both acute and chronic exercise interventions have also shown significant benefits for both energy and fatigue in individuals with persistent fatigue (12,39–41). Exercise interventions in nonfatigued adults have been less conclusive with results, either demonstrating positive effects of exercise or no change (2,5). However, it is likely that the nonsignificant results were at least partially explained by high baseline levels of energy and low baseline levels of fatigue, which left little room for improvement (35,43). Taken together, these studies suggest that increases in exercise behaviors are beneficial for improving energy and decreasing fatigue.

Despite the established benefits of an active lifestyle, rates of adoption and adherence to exercise at a level sufficient to meet current physical activity recommendations remain low (19). Accordingly, physical activity research has broadened its focus to highlight the risks of a sedentary lifestyle (28). There is increasing evidence that sedentary behavior is a distinct risk factor for many chronic health conditions (e.g., diabetes and cardiovascular disease) (4,21,25,37). These risks are independent of participation in moderate- and vigorous-intensity exercise and occur even for individuals who are meeting physical activity recommendations. There is also emerging evidence demonstrating that sedentary behavior is associated with negative mental health

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consequences, including increased depressive symptoms, lower levels of emotional well-being (16), and higher rates of incidence for depression and anxiety disorders (44). At present, it is unknown how physical activity and sedentary behaviors might interact to influence aspects of mental health including feelings of energy and fatigue.

The purpose of the present investigation was to determine whether objectively measured physical activity and sedentary behaviors interact to influence feelings of energy and fatigue in women. Women were the focus of this study due to their higher reported levels of fatigue and higher prevalence of fatigue-related illnesses such as chronic fatigue syndrome and fibromyalgia (23). To assess the associations of physical activity and sedentary behaviors on feelings of energy and fatigue, physical activity and sedentary time were measured, and participants were dichotomized based on whether or not they met current physical activity recommendations (meets recommendations vs insufficiently active) and also based on how much uninterrupted sedentary time they accumulated (high vs low). On the basis of the body of research demonstrating the positive effects of exercise on feelings of energy and fatigue, it was hypothesized that participants who were meeting current physical activity recommendations would report lower fatigue and higher vigor and vitality than their insufficiently active peers, regardless of their sedentary behavior. On the basis of emerging evidence regarding the beneficial health effects of higher amounts of light activity in place of sedentary activities (37), it was also hypothesized that participants who were not meeting guidelines but were also not highly sedentary would report lower fatigue and higher vigor and vitality than those who were not meeting guidelines and who were also highly sedentary.

METHODS

Participants. To test our hypotheses, we stratified our recruitment efforts to target women who were regularly physically active as well as women who were inactive (e.g., representative of the general population). To recruit active women, we placed flyers in local gyms and health clubs. The remainder of our participants were recruited from the local community using flyers and by contacting individuals who had previously volunteered for research studies in our lab. Eligibility criteria included 1) being female, 2) between the ages of 20 and 55 yr, 3) absence of a current diagnosis of depression or anxiety and 4) not currently taking medications that would affect mood (e.g., opioids and antidepressants). Participants were paid $15 as compensation for their time.

Procedures. The institutional review board approved all procedures, and all participants signed informed consent documents. Participants reported to the Exercise Psychology Laboratory at the University of Wisconsin for two visits separated by a 7-d physical activity-monitoring period. Participants were instructed to schedule their visits during a time that was representative of their normal routine (e.g., not a vacation or holiday). During the first visit, participants completed several questionnaires to assess feelings of energy and fatigue in conjunction with general mood, health, and well-being. Questionnaires included a brief 24-h health history, the POMS, the State-Trait Anxiety Inventory, and the SF-36v2 Health Survey (30,46,50).

Feelings of fatigue and energy were assessed using the POMS and the SF-36v2. These questionnaires are the most widely used measures for assessing the mood states of energy and fatigue (36). The POMS is designed to assess the intensity of several mood states by asking participants to rate the degree to which a list of adjectives best describes how they have been feeling during the past week, including today (30). This questionnaire includes two conceptually orthogonal, unipolar subscales, vigor and fatigue, that allow for these mood states to be assessed independently from one another. Vigor, an eight-item subscale, is intended to represent a mood of vigorousness, ebullience, and high energy. Sample items include lively, active, and full of pep. Fatigue, a seven-item subscale, is intended to represent a mood of weariness, inertia, and low energy level. Sample items include worn out, exhausted, and weary. Higher scores are indicative of higher levels of these mood states. The POMS has demonstrated acceptable levels of reliability and validity for use with the general adult population (30,34). Internal consistency reliability coefficients for vigor and fatigue range from $\alpha = 0.87$ to 0.94 with test–retest reliability estimates of 0.65 to 0.66 (30). Construct validity has been demonstrated by significant positive correlations between the POMS-vigor and Visual Analog Mood Scale ($r = 0.62$) for energy and the POMS-fatigue and Visual Analog Mood Scale for tired ($r = 0.67$) (34).

The SF-36v2 is designed to assess the frequency of feelings of health and well-being during the last 4 wk and includes a single bipolar vitality subscale to examine the feelings of energy at one end and fatigue at the other, along a single dimension (50). Vitality is a four-item measure where high scores are indicative of feeling full of energy all or most of time and low scores are indicative of feelings of tiredness and being worn out. Items include the following: Did you feel full of life? Did you have a lot of energy? Did you feel worn out? Did you feel tired? Internal consistency reliability coefficients range from 0.80 to 0.90 for vitality with test–retest reliability ranging from 0.68 to 0.80 (50). Validation studies for the SF-36 have demonstrated content, concurrent, criterion, construct, and predictive validity (50). For example, comparisons between the SF-36 vitality subscale and items of the Medical Outcomes Survey demonstrate significant positive correlations between vitality and positive affect ($r = 0.61$), psychological well-being ($r = 0.57$), positive perception of current health ($r = 0.65$), and significant negative correlations with depression ($r = -0.55$), anxiety ($r = -0.51$), and health distress ($r = -0.59$).

Although these questionnaires measure similar constructs, we chose to include both because they conceptualize feelings

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of fatigue and energy somewhat differently (e.g., single continuum vs independent dimensions). There is evidence that physical activity differentially influences feelings of energy and fatigue (24), providing support for considering these variables separately as in the POMS. However, the POMS assesses the intensity of these feelings for a relatively short period, as described earlier. The SF-36 conceptualizes energy and fatigue differently as a single construct. However, it assesses the frequency of these feelings for a longer and perhaps more stable period. Therefore, we included both measures as they may reveal different relationships for physical activity and sedentary time.

After completion of the questionnaires, participants were issued an ActiGraph™ GT1M accelerometer (Pensacola, FL) to objectively measure physical activity. The ActiGraph™ is an electromechanical device designed to measure acceleration forces generated by the movement of the wearer. Research has shown that this accelerometer is sufficiently reliable for use in physical activity research with a mean intrainstrument coefficient of variability of 4.1% and a mean interinstrument coefficient of variability of 4.9% (14). The ActiGraph has also been shown to be a valid measure of physical activity, with an error rate of ≤3% when compared with the direct observation of walking and running at several different speeds (1). This device is also validated for the purposes of measuring sedentary behavior with an error rate of less than 5% when compared with direct observation (26).

The ActiGraph is attached to an elastic belt and worn on the hip. Participants were asked to wear the accelerometer during waking hours, with the exception of water-based activities, for the 7 d in between their first and second testing sessions. Standardized instructions were provided. Briefly, participants were told that the monitor should be worn at waist level between their hip and naval in the upright position. They were instructed that they could wear it either on the left or the right side, but positioning should be consistent throughout the week. Proper placement was demonstrated, and the participant put the monitor on in front of one of the study personnel to ensure the understanding of verbal instructions. Physical activity data were recorded continuously in 1-min epochs for the 7-d period. Participants were also asked to complete a daily log including wake-up time, the time(s) the monitor was put on and taken off during the day, any time spent participating in water-based physical activity such as swimming, and bedtime. The second visit occurred 1 wk after the first and included the return of the accelerometer and log sheet as well as a verbal check to confirm that the information on the log sheet was complete and accurate.

Data processing. Standard criteria for the inclusion of accelerometer data were applied, including at least 10 h of valid wear time for a minimum of three weekdays and one weekend day (48). In-house software was used to process this information to calculate wear time as well as the average number of minutes per day spent doing sedentary, light, moderate, and vigorous physical activity. Cut points for accelerometer counts per minutes were as follows: sedentary <100, light = 101–760, moderate = 761–5724, and vigorous >5725 (15,28,29). Time spent in moderate- and vigorous-intensity activity, in bouts of at least 10 min, was calculated to determine whether participants were meeting current physical activity recommendations of 150 min of moderate activity or 75 min of vigorous activity during the course of the week (49). Both average sedentary time and minutes spent during prolonged periods of uninterrupted sedentary behavior were calculated and used to assess sedentary time. Prolonged sedentary time was operationally defined as 100 or less counts per minute sustained for at least 60 consecutive minutes. For example, for the purposes of this study, 59 consecutive minutes of sedentary time would not qualify as prolonged sedentary behavior and would thus not be included in this variable. Questionnaire data for mood and health-related quality of life were analyzed using standard scoring equations (30,50). Subscales for vigor, fatigue, and vitality were calculated from the POMS and SF-36v2 to be used as dependent variables in the primary analyses. The remaining questionnaire data were used to characterize the participants.

Statistical analyses. All statistical analyses were conducted using the Statistical Package for the Social Sciences (version 19.0; IBM Corp., Armonk, NY). To examine potential relationships between physical activity and sedentary behaviors and feelings of energy and fatigue, participants were classified into four physical activity patterns. Participants were first divided into two groups based on whether they met current physical activity recommendations or were insufficiently active. The entire sample of participants was then dichotomized into high or low sedentary groups based on the amount of prolonged sedentary behavior they accumulated per day during the week of monitoring. High sedentary was operationally defined as those participants who averaged more than 60 min of prolonged sedentary time (bouts ≥60 min) per day during the course of the week. Thus, patterns were as follows: P1, meets recommendations, low sedentary; P2, meets recommendations, high sedentary; P3, insufficiently active, low sedentary; and P4, insufficiently active, high sedentary.

Univariate ANOVA were conducted to assess differences in age, BMI, mood, health-related quality of life, and physical activity measures among the physical activity patterns. *Post hoc* analyses were performed after a significant univariate result using the Tukey HSD to control for multiple comparisons. To address relationships between physical activity and sedentary behaviors and feelings of energy and fatigue, three 2×2 univariate ANOVA were conducted. Independent variables were physical activity status (meets recommendations/insufficiently activity) and amount of uninterrupted sedentary time (high/low), and dependent variables were vigor, vitality, and fatigue. Analyses of simple main effects were conducted *post hoc* after a significant univariate interaction.

TABLE 1. Demographics.

	P1, *n* = 18, Mean ± SD	P2, *n* = 22, Mean ± SD	P3, *n* = 17, Mean ± SD	P4, *n* = 16, Mean ± SD
Age	38.00 ± 9.92	32.23 ± 10.10	39.62 ± 10.09	37.75 ± 8.34
BMI[a]	24.82 ± 4.15	21.43 ± 2.07	25.46 ± 4.34	25.10 ± 4.35
Education (% college graduate)	100	95	94	100
Race/ethnicity (% white)	100	77	77	81
Employment (% employed)	100	82	100	94

P1, meets recommendations, low sedentary; P2, meets recommendations, high sedentary; P3, insufficiently active, low sedentary; P4, insufficiently active, high sedentary.
[a]Patterns significantly different, $P < 0.05$.

To further examine the effects of physical activity and sedentary behaviors on feelings of energy and fatigue, two split-half comparisons were conducted. For physical activity, the entire data set was split in half comparing those who met guidelines with those who did not, thus allowing sedentary time to vary. Correlation coefficients were then calculated between minutes of prolonged sedentary time per week and vigor, vitality, and fatigue separately for each group. Similarly, to assess the effects of sedentary time, the whole data set was split in half again into high and low sedentary groups, allowing physical activity to vary. Correlation coefficients were then calculated between minutes of moderate- and vigorous-intensity activity that counted toward meeting recommendations and vigor, vitality, and fatigue. Because of the nonnormality of the physical activity variables, a nonparametric correlation test was used (Spearman ρ). Significance was set at $\alpha = 0.05$ for all analyses. Observed power for the primary analyses ranged from 0.80 to 0.99 (*post hoc* using G*Power 3.1 based on calculated effect sizes (f) ranging from 0.33 to 0.65).

RESULTS

Seventy-three women (mean age = 37 ± 10) completed testing procedures. A subset of these data ($n = 19$) were drawn from a sample of healthy female controls who completed all the same procedures, with the exception of the SF-36v2, during participation in another study in our laboratory examining brain responses to heat and cognitive tasks. Consequently, analyses including the SF-36v2 have 54 participants. To ensure that this subset of the data did not unduly influence the results, all analyses were conducted with and without these individuals. For the 54 participants who were recruited for this study, all individuals who expressed interest and met eligibility criteria signed the consent form and completed the study. For the 19 women who were drawn from the separate study, this included all control participants from that study who had complete accelerometer data. Participants all reported being in good health. Forty participants met current physical activity recommendations and 33 did not. On the basis of our operational definition of prolonged sedentary behavior, 38 participants were categorized as high sedentary and 35 were categorized as low sedentary.

Demographic information for each physical activity pattern, including age, BMI, education level, and race/ethnicity, is presented in Table 1. Analyses of demographics showed no significant age differences among patterns ($P > 0.05$). However, there was a significant difference in BMI across groups, and *post hoc* analyses showed that participants in P2 (meets recommendations, high sedentary) had a significantly lower BMI than participants in the other patterns ($P < 0.05$).

Minutes spent in different intensity categories of physical activity and sedentary behaviors are presented in Table 2. Accelerometer wear time was not significantly different among the patterns ($P > 0.05$). Results from the univariate ANOVA demonstrated significant differences among the patterns for average sedentary ($F_{3,69} = 9.71$, $P < 0.001$), light ($F_{3,69} = 5.51$, $P = 0.002$), moderate ($F_{3,69} = 10.35$, $P < 0.001$), and vigorous ($F_{3,69} = 9.96$, $P < 0.001$) intensities of activity. Results from *post hoc* pairwise comparisons among patterns are detailed in Table 2. Analyses were not conducted to assess pattern differences in time that counted toward meeting physical activity recommendations or prolonged sedentary time as these variables were used to define the patterns themselves.

Measures of mood and health-related quality of life, including the primary dependent variables, are presented in Table 3. In support of our hypotheses, participants who met physical activity recommendations had significantly higher levels of vigor ($F_{1,69} = 8.73$, $P = 0.004$) and vitality ($F_{1,50} = 22.109$, $P < 0.001$) than those who were insufficiently active. For fatigue, there was a significant interaction between

TABLE 2. Physical activity measures.

		P1, Mean ± SD	P2, Mean ± SD	P3, Mean ± SD	P4, Mean ± SD
Sedentary behaviors	Sedentary (average minutes per day)[a]	548.67 ± 65.12	632.60 ± 51.17	548.89 ± 59.76	639.84 ± 97.56
	Prolonged sedentary (average minutes per day)	25.33 ± 16.26	109.60 ± 53.74	22.91 ± 13.28	100.16 ± 89.99
Physical activity behaviors	Light (average minutes per day)[b]	206.35 ± 45.91	170.38 ± 38.10	227.11 ± 56.02	183.05 ± 45.81
	Moderate (average minutes per day)[c]	127.42 ± 29.66	113.99 ± 27.84	98.71 ± 28.04	79.24 ± 18.51
	Vigorous (average minutes per day)[d]	8.57 ± 9.64	13.56 ± 11.32	1.50 ± 2.19	1.80 ± 2.87
	PA Recommendation (average minutes per week)	281.89 ± 84.49	355.01 ± 142.52	60.41 ± 44.83	69.44 ± 45.10

P1, meets recommendations, low sedentary; P2, meets recommendations, high sedentary; P3, insufficiently active, low sedentary; P4, insufficiently active, high sedentary.
[a]P2 and P4 significantly greater than P1 and P3, $P < 0.05$.
[b]P3 significantly greater than P2 and P4, $P < 0.05$.
[c]P1 significantly greater than P3 and P4; P2 significantly greater than P4, $P < 0.05$.
[d]P2 significantly greater than P3 and P4, $P < 0.05$.

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TABLE 3. Mood measures.

		P1, Mean ± SD	P2, Mean ± SD	P3, Mean ± SD	P4, Mean ± SD
State-Trait Anxiety Inventory	State	29.28 ± 5.37	28.64 ± 8.94	25.76 ± 4.79	28.94 ± 7.11
	Trait	33.11 ± 5.46	32.95 ± 8.28	29.71 ± 6.34	31.63 ± 5.57
POMS subscales	Tension	6.28 ± 3.39	6.00 ± 5.06	3.82 ± 2.65	6.75 ± 4.33
	Depression	4.67 ± 5.24	4.05 ± 4.49	1.82 ± 2.51	4.69 ± 4.44
	Anger	4.67 ± 4.58	3.55 ± 3.58	1.65 ± 2.03	5.44 ± 4.66
	Vigor[a]	19.39 ± 4.75	19.91 ± 3.84	18.00 ± 4.19	15.38 ± 4.26
	Fatigue[b]	5.33 ± 3.41	3.82 ± 2.28	4.35 ± 3.14	7.50 ± 4.69
	Confusion	4.89 ± 2.99	5.00 ± 3.57	3.06 ± 2.11	5.38 ± 3.74
SF-36—Mental Health Components	Physical function	97.35 ± 5.89	93.25 ± 16.96	95.63 ± 5.63	93.88 ± 7.41
	Role physical	93.01 ± 13.95	95.63 ± 7.61	92.97 ± 13.12	90.97 ± 16.27
	Bodily pain	82.85 ± 10.66	86.03 ± 14.83	85.13 ± 20.73	77.78 ± 13.87
	General health	80.27 ± 12.32	83.01 ± 15.81	81.50 ± 14.81	79.89 ± 13.87
	Vitality[a]	69.49 ± 10.57	73.75 ± 9.42	58.59 ± 11.54	53.47 ± 15.66
	Social function	97.06 ± 7.03	90.00 ± 15.49	95.31 ± 13.26	93.06 ± 9.08
	Role emotional	94.12 ± 10.53	89.17 ± 14.07	95.83 ± 6.30	96.29 ± 6.05
	Mental health	82.79 ± 9.01	79.50 ± 6.47	80.63 ± 8.21	79.44 ± 9.50

P1, meets recommendations, low sedentary; P2, meets recommendations, high sedentary; P3, insufficiently active, low sedentary; P4, insufficiently active, high sedentary.
[a]Meets recommendations (P1 and P2) significantly greater than insufficiently active (P3 and P4), $P < 0.05$.
[b]Significant interaction between physical activity and sedentary behaviors (P4 significantly greater than P3), $P < 0.05$.

physical activity and sedentary behaviors ($F_{1,69} = 8.41$, $P = 0.005$). *Post hoc* analyses demonstrated that for the group of women who were insufficiently active, those with lower levels of uninterrupted sedentary time had significantly lower levels of fatigue ($F_{1,31} = 5.19$, $P = 0.003$). These results were consistent when excluding the 19 individuals whose data were collected as part of a separate protocol.

Results from the correlational analyses showed that there were no significant relationships between minutes of prolonged sedentary time per week and vigor, vitality, or fatigue ($P > 0.05$) for those who met physical activity recommendations. However, for participants who were insufficiently active, there were significant correlations between sedentary time and vigor ($\rho = -0.461$, $P = 0.009$)

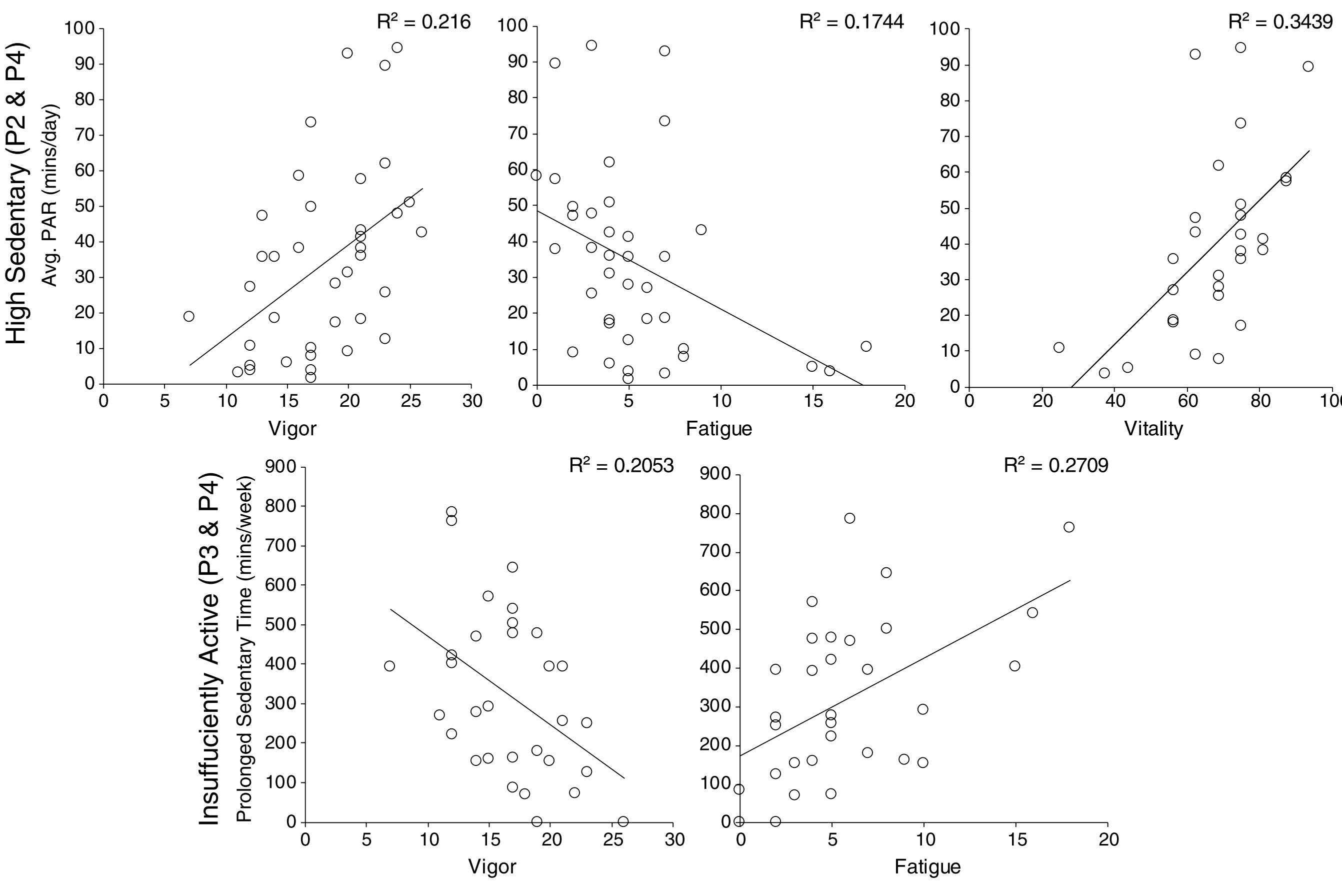

FIGURE 1—Scatterplots and associated correlations (Spearman *ρ*) for significant relationships between minutes that count toward meeting physical activity recommendations (PAR) and feelings of vigor, vitality, and fatigue for those who are highly sedentary (top row). Scatterplots and associated correlations (Spearman *ρ*) for significant relationships between minutes of prolonged sedentary time per week and feelings of vigor and fatigue for those who are not meeting physical activity recommendations (bottom row). *Statistically significantly correlations, *P* < 0.05.

and fatigue (ρ = 0.530, P = 0.002). There were also no significant relationships between minutes that counted toward meeting recommendations and vigor, vitality, or fatigue for those who were categorized as low sedentary. However, in those who were categorized as high sedentary, minutes that counted toward meeting recommendations were significantly and positively related to vigor (ρ = 0.501, P = 0.001) and vitality (ρ = 0.609, $P < 0.001$) and significantly and negatively related to fatigue ($\rho = -0.476$, P = 0.003). Scatterplots for significant correlations are presented in Figure 1.

DISCUSSION

Our study demonstrates that meeting current physical activity recommendations is associated with higher levels of energy and lower levels of fatigue in women. Moreover, these positive effects of being physically active were present regardless of prolonged sedentary behaviors, suggesting that physical activity may have a protective effect against the mental health-related risks of an otherwise sedentary lifestyle. Second, and perhaps more importantly, we found that women who were not active enough to meet recommendations but who have relatively lower amounts of prolonged sedentary time had lower levels of fatigue than their insufficiently active but also highly sedentary peers. Thus, the influence of both physical activity and sedentary behavior patterns are important to consider when examining determinants of and treatments for health conditions that include symptoms of low energy and fatigue.

Underscoring this are our results from the vitality scale of the SF-36, the most widely used measure of health-related quality of life (18). A minimally important difference on the SF-36v2 is defined as a difference of three points for scores higher than 40, and a three-point lower score on vitality has been associated with an approximately 38% decreased ability to work (50). Our results demonstrated that participants who were meeting physical activity recommendations had a vitality score that was, on average, 10 to 20 points higher than their insufficiently active peers. Importantly, in those not meeting recommendations, having a lower amount of prolonged sedentary time was also associated with a 5-point greater vitality score. Thus, our results suggest that both physical activity and sedentary behaviors have a meaningful impact on vitality.

The positive effects of exercise on mood are well established (38). Both epidemiological and experimental evidence have shown that increases in exercise behaviors result in increases in feelings of energy and decreases in fatigue (35). Although these outcomes are promising, there are several notable limitations in the extant literature. Physical activity has typically been either self-reported (e.g., time spent in recreational activities and television viewing time) or manipulated through chronic exercise training. Moreover, to our knowledge, the unique and/or interactive contributions of both physical activity and sedentary behaviors have not been examined with respect to mental health outcomes. Objective measures including accelerometry provide a more accurate and complete picture of an individual's physical activity behaviors and are currently the best way to accurately measure prolonged sedentary time (7). Further, although the manipulation of exercise behaviors is certainly necessary for determining the causal direction of the relationships between physical activity and mood, to our knowledge, these studies have neglected to measure physical activity outside the exercise intervention. We add to the existing literature in this area by examining the differential influences of both physical activity and sedentary behaviors and measuring physical activity objectively.

Our results suggesting that reductions in sedentary time could have mental health-related benefits in individuals who are insufficiently active are consistent with previous research showing the positive effects of lower-intensity physical activity on mood (42,43). For example, Puetz et al. (40) found that feelings of energy were increased by approximately 20% after 6 wk of low-intensity aerobic exercise training in sedentary adults. Typically, sedentary time is significantly and inversely related to low-intensity activity and weakly related to moderate and vigorous activity (22). This was true in our data set as well, with a moderate correlation of $\rho = -0.53$ ($P < 0.05$) between minutes of sedentary behavior and light-intensity activity, whereas correlations between sedentary time and moderate and vigorous activity were small at $\rho = -0.16$ and $\rho = 0.23$ ($P > 0.05$), respectively. Thus, our data would support existing literature in promoting decreases in sedentary time for improving mental health, as this would likely result in increases in low-intensity physical activity behaviors.

There are a host of potential psychobiological mechanisms that underlie the relationships between physical activity and sedentary behaviors and feelings of energy and fatigue. Functional neuroimaging research has demonstrated the involvement of the central nervous system in feelings of fatigue in both fatigued and nonfatigued individuals (9,10), and pharmacological therapies for influencing fatigue and energy have established the involvement of several neurotransmitters in these moods (e.g., serotonin, dopamine) (47). However, to date, few studies have addressed potential mechanisms of the relationships between energy and fatigue and physical activity behaviors, and to our knowledge, no studies have examined mechanisms of the relationship between sedentary behavior and these mood states. Recently, Dishman et al. (12) examined whether changes in feelings of energy and fatigue following acute exercise after 6 wk of aerobic training were related to changes in brain activity as measured by electroencephalography. Results demonstrated that theta activity in the posterior portion of the brain accounted for approximately 50% of the improvement in mood immediately postexercise and that these improvements were unrelated to changes in aerobic fitness during the course of the training trial (40). These results support central nervous system contributions to changes in feelings of energy and fatigue associated with participation physical activity and further underscore that changes in fitness (i.e., high-intensity exercise) are not necessary for mental health benefits. Future research using functional neuroimaging tools (e.g., electroencephalography, positron emission tomography, and functional magnetic resonance imaging) in the context of physical activity and/or sedentary behavior interventions will be instrumental to improve our understanding of central nervous system mechanisms that underlie relationships between physical activity and sedentary behaviors and mood.

There are several limitations to this study. Our design was cross sectional in nature and therefore it is not possible to determine the directions of the relationships between physical activity behaviors and mental health outcomes with the present data set. Previous research including a manipulation of exercise behaviors has demonstrated that increasing physical activity improves mood and decreasing physical activity results in mood disturbance (32,41). However, to date, there are no intervention studies that manipulate sedentary time to influence mental health outcomes. Thus, the direction of the relationship between sedentary behavior and mental health outcomes has yet to be established. Although it is possible that decreases in prolonged sedentary time result in increases in energy and decreases in fatigue, it is also possible that individuals who are more energetic and less fatigued choose to do more physical activity and sit less. Future research in which physical activity and sedentary behaviors are manipulated and objectively measured under naturalistic conditions and feelings of energy and fatigue are assessed pre- and postintervention are needed to determine the causal direction of these relationships.

Our sample consisted of women between the ages of 20 and 55 yr who were almost all college educated. Thus, it is not known if our results can be generalized to younger or older individual males or those without a college degree. Further, as a group our participants had relatively high levels of energy and low levels of fatigue and a positive mood profile overall. Effect size calculations (Cohen *d*) (8) comparing our participants with age- and sex-matched normative data (34,50) demonstrated that those who met physical activity recommendations had comparable levels of vigor (d = 0.13), had markedly lower levels of fatigue (d = 0.92), and had markedly higher levels of vitality (d = 0.81), whereas those who did were insufficiently active, had moderately lower levels of both vigor (d = 0.41) and fatigue (d = 0.55), and had comparable levels of vitality (d = 0.20). However, participants who were insufficiently active and also highly sedentary, who are most representative of the physical activity and sedentary behavior patterns of the general population, had moderately lower levels of vigor (d = 0.65), had comparable levels of fatigue (d = 0.22), and had lower levels of vitality (d = 0.34) than normative data. It has been suggested that the impact of physical activity on these outcomes will be decreased in individuals with higher baseline levels of energy and lower baseline levels of fatigue due to ceiling/floor effects (35,43). However, the comparisons with normative data serve to underscore our results showing the potentially positive impact of increasing physical activity and decreasing sedentary time on feelings of energy and fatigue. Nonetheless, additional research is needed to determine whether physical activity behaviors and sedentary time interact differently with respect to feelings of energy and fatigue in other populations, especially in those with persistently fatiguing conditions and/or a less positive mood profile.

Lastly, we operationally defined prolonged sedentary time as sedentary behavior lasting for more than an hour without a break. To date, no definitive recommendations exist regarding how long people can sit without consequence or how often breaks in sitting time should be taken (20). We recently demonstrated that time spent in prolonged sedentary behavior of greater than an hour was negatively associated with brain responses, indicative of the ability to modulate pain in women with fibromyalgia, another group that experiences significant levels of fatigue (13). Moreover, in our previous study, these associations were not significant when replacing our prolonged sedentary measure with average minutes of sedentary behavior per day or prolonged sedentary behaviors that were shorter in duration (e.g., 30 min). We chose this same duration based on the results of our previous study and found it to be a useful starting point for differentiating individuals who were highly sedentary and those who were not. Further, on the basis of the limitations of our monitoring device, sedentary time was defined by acceleration below a particular cut point (100 counts per minute) as opposed to a particular body position (e.g., sitting or lying). Sedentary behavior has recently been defined in the literature as any waking behavior characterized by a sitting or reclining posture and an energy expenditure of $\leq$1.5 METs (45). Thus, the gold standard for measuring sedentary time requires a device that monitors both body position and movement. The accelerometer used in this study is a validated device for assessing sedentary behaviors but does not monitor body position. More research that includes a manipulation of prolonged sedentary behaviors, assesses the effects of several durations of prolonged sedentary time (e.g., 30, 45, and 60 min), and uses a device that measures body position in addition to movement is warranted to determine both the causal direction and the specificity of the effects.

In conclusion, consistent with our hypotheses, we found that meeting physical activity recommendations is associated with higher levels of energy and lower levels of fatigue, regardless of prolonged sedentary behavior. More importantly, we also determined that in individuals who are not currently meeting physical activity recommendations, benefits for fatigue could be realized through reductions in prolonged sedentary behavior. Our results are supportive of a recent Position Stand released by the American College of Sports Medicine, which states that "in addition to exercising regularly, there are health benefits in concurrently reducing total time spend in sedentary pursuits and also by interspersing frequent short bouts of standing and physical activity between periods of sedentary active, even in physically active adults" (17). There is good evidence that exercise is one of the few consistently effective treatments for fatigue (35). However, exercise adoption and adherence are especially challenging for fatigued individuals. Consistent with the American College of Sports Medicine position stand, our data suggest that perhaps fatigue-related benefits similar to those resulting from exercise could be realized by reducing the number and length of periods of prolonged sedentary time.

Understanding the relationships between patterns of physical activity behaviors including sedentary time and feelings of energy and fatigue has the potential to contribute to improvements in quality of life and productivity, in addition to improving treatments for both physical and mental health conditions and lowering healthcare costs. Additional research, including interventions designed to reduce prolonged periods of sedentary time in both men and women, is needed to determine whether individuals who are not active enough to meet physical activity recommendations can improve their feelings of energy and fatigue through decreases in sedentary behavior. Only then can we create guidelines to provide specific advice to patients and the general population regarding the mental health-related benefits of increasing physical activity and reducing prolonged sedentary behaviors.

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