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Sleep Quality Moderates the Association Between Physical Activity Frequency and Feelings of Energy and Fatigue in Adolescents

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Abstract

Physical activity (PA) can improve sleep quality, low energy, and fatigue. Though poor sleep quality may induce feelings of low energy and fatigue, the potential moderating effect of sleep quality on associations between PA and feelings of energy and fatigue among adolescents is unknown. Thus, this study examined the moderating effect of sleep quality on associations between PA frequency and feelings of energy and fatigue among adolescents in Ireland. Adolescents (N=481; 281 male, 200 female) aged 15.1±1.7y self-reported PA frequency, feelings of energy and fatigue, and sleep quality September to December 2015. Two-way ANCOVAs examined variation in feelings of energy and fatigue according to the interaction of PA and sleep quality. Standardized mean difference (*d*) quantified the magnitude of differences. Poor sleepers with low PA reported greater feelings of fatigue compared to normal sleepers with low PA (*d*=1.02; 95%CI: 0.60, 1.44), and poor sleepers with moderate PA reported greater feelings of fatigue compared to normal sleepers with moderate PA (*d*=0.50; 0.17, 0.82). Poor sleepers with low PA reported greater feelings of fatigue compared to both poor sleepers with moderate PA (*d*=0.44; 0.05, 0.83) and poor sleepers with high PA (*d*=0.87; 0.46, 1.28). Poor sleepers with moderate PA reported greater feelings of fatigue compared to poor sleepers with high PA (*d*=0.52; 0.14, 0.91). Poor sleep did not moderate the association between PA and feelings of energy. Sleep quality moderates the association between PA frequency and feelings of fatigue. Fatigue symptoms improve as PA frequency increases among adolescents with poor sleep quality.

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Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent: Informed consent was obtained from all individual participants included in the study.

Keywords

physical activity; sleep quality; energy; fatigue; moderation; adolescents

Introduction

Feelings of low energy and fatigue contribute to automobile accidents [1], reduced school attendance [2], and poor academic performance in adolescents [3]. Prevalence of severe fatigue has ranged from 11% to 60% across studies of European and United States adolescents [4–7], while prevalence of prolonged fatigue has ranged from ~1% – ~7.5% among community samples of adolescents [8–10]. The prevalence of fatigue appears to increase as adolescents age. The Avon Longitudinal Study of over 4000 adolescents found that disabling fatigue of greater than six months duration increased from 1.47% to 2.99% between the age of 13 to 18 years [11].

Sleep quality, a multidimensional construct integrating a variety of sleep-related parameters such as sleep duration, sleep satisfaction, and sleep fragmentation [12], is a key contributor to daytime feelings of energy and fatigue [13]. Poor sleep quality has been shown to negatively impact academic performance through low energy and fatigue [14]. Arising from potential causes including academic and social stressors, a preference for delayed sleep timing, excessive electronic media use, and high caffeine consumption, poor sleep quality is common during adolescence and can contribute to daytime fatigue [15]. Poor sleep can also predict changes in fatigue across adolescence; for example, baseline sleep disturbances predicted longitudinal fatigue among 171 adolescents [16].

Physical activity (PA) is related to both sleep quality and feelings of energy and fatigue. Epidemiologic research consistently supports a bidirectional relationship between physical activity and sleep [17], while experimental studies report reduced sleep onset latency, greater slow-wave sleep, and improved sleep quality following acute exercise or chronic exercise training [18]. Indeed, convergent evidence from human and rodent research suggests that physical activity is associated with increased electroencephalogram spectral power in slow frequencies (0.5–4 Hz), a marker of sleep homeostasis [19]. It is plausible that adolescence represents a sensitive maturational period during which the effects of sedentary behavior and feelings of energy and fatigue are amplified by poor sleep efficiency [20]. The available population-based evidence from adults supports that physical inactivity is associated with sleep complaints and feelings of low energy and fatigue, whereas PA is associated with better sleep quality and a reduced risk of reporting fatigue. Physically active individuals, on average, have 39% reduced odds of experiencing feelings of fatigue, and experimental evidence supports that acute and chronic exercise improve feelings of energy and fatigue [18,21–23]. It is plausible that similar neurobiological pathways underlie the benefits of physical activity and exercise for both sleep and feelings of energy and fatigue [22,24].

There is less evidence for these associations among adolescents. One longitudinal study has shown that adolescents who reported low PA during the first two months of transition between the end of adolescence and the start of college also reported lower levels of energy and higher levels of fatigue compared to those who maintained adequate PA levels [25].

Another study showed that fatigue severity and PA during adolescence predicted fatigue during young adulthood [26]. Although few experimental data exist on the impact of exercise on sleep in adolescents [27], a meta-analysis of 12 studies of 16,549 individuals found that greater levels of physical activity were associated with greater sleep efficiency and greater sleep quality [28]. However, these studies did not adequately consider fatigue outcomes [28]. Thus, there is a continued need to investigate both the association between PA and fatigue and factors which may influence that association (e.g., sleep) in adolescents.

The potential moderating effect of sleep or sleep quality on the association between PA and feelings of energy and fatigue among adolescents has not yet been documented. The aims of the study reported here were to test whether there were: 1) differences in feelings of energy and fatigue between those reporting different frequencies of PA; 2) differences in PA and feelings of energy and fatigue based on those who reported poor and good sleep quality; and 3) moderating effects of sleep quality on relations between PA and feelings of energy and fatigue.

Methods

Participants & Recruitment.

The research protocol was approved by the university's research ethics committee. Before data collection began, all participants' parents/guardians and participants provided written informed consent. Data were collected October to December 2015 from seven single-sex and eight mixed-sex secondary schools (i.e., middle/junior high/high school) in both urban (n=6) and rural (n=9) regions across the four provinces of Ireland.

First- to sixth-year students (aged 12–18 years) were identified within each school in an effort to achieve equal age and gender distributions. Potential participants within each year were then randomly selected using a random number generator. Nine hundred students were invited to participate; 481 (male=281; female=200) adolescents aged 15.1 ± 1.7 years completed a paper-and-pencil battery of questionnaires and provided data (53.4% response rate) [29]. Participants were otherwise healthy adolescents who did not report health problems that could influence sleep quality and/or feelings of energy and fatigue (e.g., migraine, cognitive disorders) [30–32]. Of the 481 respondents, 476 (99%), 463 (96.3%), 467 (97.1%), and 461 (95.8%) provided data for PA, feelings of fatigue, feelings of energy, and sleep quality, respectively.

Physical Activity.

A modified version of the PACE + (Patient-Centered Assessment and Counselling for Exercise Plus Nutrition) adolescent PA measure [33] was used to measure the number of days each participant had accumulated at least 60 minutes of moderate and vigorous PA during the prior seven days and for a typical week. As previously reported [29], the final score was an average of the two items. PA frequency was classified as low (0–2 d/wk), moderate (3–4 d/wk), or high (5+ d/wk).

Feelings of Energy & Fatigue.

The vigor and fatigue subscales of the Profile of Mood States – Brief Form [34] were used to measure the intensity of feelings of energy and feelings of fatigue, respectively. Substantial published evidence supports that the five-item sub-scales reliably and accurately measure subjective feelings of energy and fatigue [35,34]. Each participant was asked to respond according to “how you have felt during the past week including today.” Internal consistency was acceptable for both the fatigue ($\alpha=0.87$) and vigor ($\alpha=0.80$) subscales.

Sleep Quality.

Sleep quality was measured with the Pittsburgh Sleep Quality Index (PSQI) [12]. This 19-item self-report instrument integrates multiple sleep-related dimensions (e.g., sleep latency, sleep duration, perceived sleep quality, daytime function) to provide a global sleep quality score. The PSQI is a widely used measure of sleep quality among adolescents with substantial published reliability and validity evidence. Scores >5 are indicative of poor sleep quality [12].

Covariates.

Participants provided information on covariates which may influence PA, feelings of energy and fatigue, and/or sleep quality, including age, sex, participant residence (rural/urban) and school type (all boys, all girls, mixed-sex) [29].

Statistical Analyses.

All analyses were conducted with SPSS Version 22.0 (Armonk, NY: IBM Corp.). Independent samples t-tests examined differences in feelings of energy and fatigue and continuous sleep quality based on sex and participant residence. One-way ANOVA examined differences in feelings of energy and fatigue and continuous sleep quality based on age and school type. ANCOVA followed by Bonferroni-corrected *post-hoc* tests quantified differences in feelings of energy and fatigue according to PA (aim 1) and poor sleep status (aim 2), adjusted for covariates. Binary logistic regression adjusted for covariates quantified the association (crude and adjusted odds ratios) between PA and poor sleep quality. Two-way ANCOVAs followed by Bonferroni-corrected *post-hoc* tests examined variation in feelings of energy and fatigue according to the interaction of PA and sleep quality (aim 3). The magnitude of differences were quantified with standardized mean differences (d) [36].

Results

Participant Characteristics & Differences Between Genders & Covariate Levels.

Table 1 presents participant characteristics. Feelings of energy were significantly greater among males compared to females ($t_{465}=2.58$, $p=0.01$; $d=0.26$, 95%CI: 0.07, 0.44); feelings of fatigue ($t_{461}=0.96$, $p>0.33$; $d=-0.09$, 95%CI: -0.27, 0.10) and sleep quality ($t_{459}=-0.66$, $p>0.51$; $d=-0.06$, 95%CI: -0.25, 0.12) did not significantly differ based on gender. Of 461 participants who provided complete sleep data, 171 (37.1%) of participants were classified as poor sleepers. The frequency of poor sleepers did not significantly differ by gender ($\chi^2_{(1)}=0.60$, $p>0.43$).

Table 2 presents mean (SD) feelings of energy and fatigue and continuous sleep quality by age, participant residence, school type, sleep quality status, and PA level. Feelings of fatigue were significantly higher among: 18-year-olds compared to all ages (all $p < 0.04$) except 12-year-olds ($p > 0.20$) and 17-year-olds ($p = 1.00$); and, participants from all-female schools compared to both all-male ($p = 0.003$) and mixed-sex schools ($p < 0.001$). Mixed-sex schools reported significantly better sleep quality compared to participants from all-female schools ($p = 0.002$).

Differences in Feelings of Energy & Fatigue by Physical Activity Level (Aim 1).

Feelings of energy ($F_{(2,436)}=19.79$, $p < 0.001$, $\eta_p^2=0.083$) and fatigue ($F_{(2,433)}=7.39$, $p = 0.001$, $\eta_p^2=0.033$) were significantly different among PA levels (Figure 1). Significantly lower feelings of energy were reported for low PA (8.6 ± 4.3) compared to both high (12.1 ± 4.6 , $p < 0.001$; $d = 0.78$, 95% CI: 0.52, 1.04) and moderate (11.0 ± 3.5 , $p = 0.001$; $d = 0.63$, 95% CI: 0.39, 0.88) PA; and, feelings of energy were significantly lower for moderate PA compared to high PA ($p = 0.046$; $d = 0.27$, 95% CI: 0.06, 0.49). For feelings of energy, there were no significant covariates in the ANCOVA model (all $p > 0.11$).

Feelings of fatigue were significantly lower for high PA (5.6 ± 4.9) compared to both low (8.0 ± 4.8 , $p < 0.001$; $d = 0.49$, 95% CI: 0.24, 0.75) and moderate (6.9 ± 4.2 , $p = 0.02$; $d = 0.29$, 95% CI: 0.07, 0.50) PA; and, feelings of fatigue were significantly lower for moderate compared to low PA ($p = 0.05$; $d = 0.25$, 95% CI: 0.01, 0.49). For feelings of fatigue, age ($F_{(1,433)}=8.22$, $p = 0.004$), school type ($F_{(1,433)}=4.69$, $p < 0.031$), and participant residence ($F_{(1,433)}=4.20$, $p = 0.041$) were significant covariates. Table 2 highlights differences in fatigue across levels of these covariates.

Physical Activity & Poor Sleep Quality (Aim 2).

Compared to low PA, moderate (OR: 0.51, 95% CI: 0.31, 0.83) and high PA (OR: 0.55, 95% CI: 0.33, 0.91) were associated with 49% and 45% lower odds of poor sleep quality, respectively. After adjustment for the covariates, moderate (OR: 0.49, 95% CI: 0.29, 0.81) and high (OR: 0.53, 95% CI: 0.31, 0.92) PA were associated with 51% and 47% lower odds of poor sleep quality.

Feelings of Energy & Fatigue by Poor Sleep Status (Aim 2).

Feelings of fatigue ($F_{(1,418)}=14.69$, $p < 0.001$, $\eta_p^2=0.034$) significantly differed based on sleep quality status. Poor sleepers reported significantly greater feelings of fatigue (7.9 ± 5.3) compared to normal sleepers (5.9 ± 4.0 , $d = 0.44$, 95% CI: 0.24, 0.64). Age was the only significant covariate ($F_{(1,418)}=7.29$, $p = 0.007$). Feelings of energy, however, did not significantly differ based on sleep quality status ($F_{(1,422)}=2.98$, $p > 0.08$, $\eta_p^2=0.007$). Poor sleepers reported non-significantly lower feelings of energy (10.4 ± 4.9) compared to normal sleepers (11.1 ± 4.0 , $d = 0.16$, 95% CI: -0.04, 0.36). Sex was the only significant covariate ($F_{(1,418)}=7.30$, $p = 0.007$).

Moderating Effect of Poor Sleep Quality (Aim 3).

Figure 2 illustrates feelings of energy and fatigue by PA for poor sleepers and normal sleepers. A statistically significant two-way interaction between poor sleep status and PA

was found for feelings of fatigue ($F_{(2,413)}=5.91$, $p=0.003$, $\eta_p^2=0.028$). Age was the only significant covariate ($F_{(1,413)}=4.42$, $p=0.036$). Simple effects analysis showed that poor sleepers with low PA (10.1 ± 4.9) reported significantly greater feelings of fatigue compared to normal sleepers with low PA (5.8 ± 3.4 ; $p<0.001$; $d=1.02$, 95%CI: 0.60, 1.44), and poor sleepers with moderate PA (8.1 ± 4.3) reported significantly greater feelings of fatigue compared to normal sleepers with moderate PA (6.1 ± 3.9 ; $p=0.015$; $d=0.50$, 95%CI: 0.17, 0.82). Poor sleepers with low PA (10.1 ± 4.9) reported significantly greater feelings of fatigue compared to both poor sleepers with moderate PA (8.1 ± 4.3 ; $p=0.022$; $d=0.44$, 95%CI: 0.05, 0.83) and poor sleepers with high PA (5.5 ± 5.6 ; $p<0.001$; $d=0.87$, 95%CI: 0.46, 1.28). Poor sleepers with moderate PA reported significantly greater feelings of fatigue compared to poor sleepers with high PA ($p=0.007$; $d=0.52$, 95%CI: 0.14, 0.91).

The two-way interaction of poor sleep and PA was not significant for feelings of energy ($F_{(2,417)}=0.55$, $p>0.57$, $\eta_p^2=0.003$). No covariates were significant in the model.

Discussion

The primary novel finding was that sleep quality moderated the association between PA frequency and feelings of fatigue. Among adolescents with good sleep quality, fatigue scores were invariant across PA frequency categories, but a dose-response relationship was suggested among adolescents with poor sleep quality. Poor sleepers who reported a greater frequency of PA (>5 days per week) reported lower fatigue severity compared to their less active counterparts. To the authors' knowledge, these are the first data to concomitantly support a moderating effect of sleep quality on the relationship between PA and feelings of fatigue, and demonstrate a dose-response relationship between PA and feelings of fatigue among adolescents with poor sleep quality.

For the entire sample, dose-response relationships were found between PA frequency and both feelings of energy and feelings of fatigue (see Figure 1); higher PA frequency was associated with lower feelings of fatigue and greater feelings of energy as well as better sleep quality. These findings are generally consistent with other community-based studies in adults [37] and interventions among adolescents [38].

Feelings of energy and feelings of fatigue significantly differed between individuals reporting low and moderate PA levels. These data suggest that a greater threshold of PA may be necessary to experience reduced feelings of fatigue and improved feelings of energy. These findings are consistent with cross-sectional studies showing associations between PA and feelings of energy in the general population [21]. Studies in adults suggest that it is plausible that the chronic effects of PA may be related to or represent a summation of acute effects of single bouts of activity [21]. However, an assessment of German adolescents suggests that a daily increase in moderate-to-vigorous PA reduces mood disturbance the day after, but not the evening of, an increase in PA, potentially implicating sleep quality on active days as a mediating factor [39].

Age, sex, including sex distribution of included schools, and residence, known to be correlates of PA, also appeared to be factors that may influence associations between sleep

quality, PA, and feelings of energy and fatigue. Data are consistent that PA declines during adolescence, especially among girls, and girls engage less frequently in strenuous PA and sports [40]. Large studies have shown small, inconsistent associations between the location of residence and mental health problems such as depression [41]. In the current study, the relationship between PA frequency and fatigue was partially explained by age, school type, and participant residence, consistent with reports of PA and sedentary behavior from other European cohorts [42,43]. However, the authors are not aware of prior studies that have examined all of these variables in relation to sleep and fatigue in a single investigation, and these factors warrant future research.

The present findings should be considered in light of study limitations. These data are cross-sectional and cause-effect relationships should not be inferred. Indeed, published data suggest that variables not measured here may influence sleep quality. For example, one study of 1,295 children and adolescents reported that poor sleep quality was predicted by low blood zinc concentrations [44]. One brain imaging study of 299 young adults concluded that greater threat-related amygdala activity predicted more negative affect and perceived stress, factors often positively correlated with fatigue, in poor sleepers but not normal sleepers [45].

Although no information was provided here that would support a biological basis for the observed relationships, the benefits of physical activity may be partially explained by the reorganization of functional networks that give rise to improved cortico-cortical synchrony and sleep efficiency. A quantitative review of the physical activity and sleep literature showed that acute and chronic exercise improved sleep efficiency [18], and, in adults, subjective insomnia is associated with low sleep efficiency and fatigue [46]. Connectivity within the default mode network—comprised of brain regions which demonstrated correlated activity at rest and anti-correlated activity during tasks—is disrupted in patients reporting persistent fatigue and sensitive to the acute effects of sleep deprivation [47,48]. Physiological perturbation and sensorimotor load associated with physical activity may improve resting-state connectivity [49]. Future translational research in adolescents should seek to identify relationships between physical activity, resting-state network dynamics, and sleep electroencephalography. In addition, the present analyses were not designed to assess the potential relationship between the timing of physical activity and sleep, energy, and fatigue. Laboratory studies indicate that exercise has the potential to impact the timing of the circadian system depending upon the time at which exercise is performed [50], which could also impact the timing and magnitude of energy and fatigue [51].

Conclusions

The relationships reported from the current cross-sectional assessment of Irish adolescents should inform randomized controlled trials designed to test sleep quality as a potential mediator of the relationship between increases in PA and prospective changes in feelings of energy and fatigue. Despite evidence supporting the PACE+ and PSQI as sufficiently valid measures of self-reported PA and sleep quality, future research should include objective assessments of physical activity and sleep to further elucidate causal, dose-response relationships. Nonetheless, the preliminary findings reported here contribute to accumulating

evidence that supports the use of sleep quality measures in trials aimed to increase PA for the purpose of improving feelings of energy and fatigue.

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Figure 1.
Feelings of Energy and Fatigue by Physical Activity Frequency Category

Figure 2.
Feelings of Energy and Fatigue by Physical Activity Frequency and Sleep Quality

Table 1.

Participant Characteristics

	Male (n=281)	Female (n=200)	Total (n=481)
Age (mean (SD))	15.0 (1.6)	15.3 (1.7)	15.1 (1.7)
Residence (%)^a			
Town/city	37.2	28.1	33.4
Village/countryside	62.8	71.9	66.6
Participants by School Type (%)^c			
Male-only School	60.4	0.0	35.2
Female-only School	0.0	29.5	12.3
Mixed	39.6	70.5	52.5
POMS-B Fatigue (mean (SD))	6.5 (4.5)	6.9 (4.8)	6.6 (4.6)
POMS-B Energy (mean (SD))^b	11.3 (4.3)	10.2 (4.2)	10.8 (4.3)
PSQI Sleep Quality (mean(SD))	5.1 (2.9)	4.9 (2.9)	5.0 (2.9)
Poor Sleepers (PSQI>5) (n (%))	103 (37%)	68 (34%)	171 (36%)
Physical Activity Level^c			
Low (n (%))	48 (17.1)	59 (29.5)	107 (22.2)
Moderate (n (%))	95 (33.8)	107 (53.5)	202 (42.0)
High (n (%))	133 (47.3)	34 (17.0)	167 (34.7)

^a
 $p < 0.05$ ^b
 $p < 0.01$ ^c
 $p < 0.001$ for differences between males and females

Abbreviations: POMS-B; Profile of Mood States – Brief Form; PSQI: Pittsburgh Sleep Quality Index

Table 2.

Mean (SD) Feelings of Energy and Fatigue and Sleep Quality by Levels of Physical Activity, Sleep Quality Status, and Covariates

	Fatigue (POMS-B)	Energy (POMS-B)	Sleep Quality (PSQI)
Age			
12–13y	6.8 (4.6)	11.1 (3.4)	4.4 (2.9)
13–14y	6.4 (4.2) ^a	10.3 (4.6)	4.9 (3.1)
14–15y	5.8 (4.6) ^b	10.8 (4.3)	4.9 (2.8)
15–16y	6.6 (5.2) ^c	11.5 (4.2)	5.1 (3.0)
16–17y	6.2 (4.0) ^d	11.4 (3.8)	4.7 (2.8)
17–18y	8.0 (4.4)	10.5 (5.4)	5.7 (2.8)
18–19y	9.6 (4.7) ^{a,b,c,d}	9.4 (4.3)	6.0 (2.9)
Residence			
Town/city	6.9 (5.0)	10.6 (4.2)	5.3 (2.8)
Village/countryside	6.4 (4.3)	10.9 (4.4)	4.8 (2.9)
School Type			
Male-only School	6.5 (4.4) ^e	11.0 (4.7)	5.3 (3.0)
Female-only School	8.9 (5.8) ^{e,f}	9.8 (5.1)	6.1 (2.9) ^g
Mixed	6.1 (4.2) ^f	10.9 (3.9)	4.6 (2.8) ^g
Sleep Quality			
Poor Sleepers (PSQI>5)	7.9 (5.3)	10.4 (4.9)	8.1 (2.0) ^h
Normal Sleepers (PSQI ≤ 5)	5.9 (4.0)	11.1 (4.0)	3.2 (1.5) ^h
Physical Activity Level			
Low	8.0 (4.8)	8.6 (4.3)	5.6 (3.4)
Moderate	6.9 (4.2)	11.0 (3.5)	4.8 (2.5)
High	5.6 (4.9)	12.1 (4.6)	4.8 (3.0)

^{a,b,c,d} Each subscript letter denotes categories that significantly differed from each other at $p \leq 0.05$

Abbreviations: POMS-B, Profile of Mood States – Brief Form; PSQI, Pittsburgh Sleep Quality Index; y, years