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# Physical activity and sleep: Day-to-day associations among individuals with and without Bipolar Disorder

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## Abstract

**Objective—**To evaluate the relative role of psychopathology in the relationship between physical activity and sleep, the present study investigated the day-to-day relationship between physical activity and sleep in individuals without a psychiatric disorder and individuals with bipolar disorder using a longitudinal, naturalistic design.

**Method—**Participants in two groups—a healthy group with no psychiatric illness (N=36) and an inter-episode bipolar disorder group (N=32)— were studied over a two-month period. Physical health was assessed by the SF-36. Daily subjective and objective measures of physical activity and sleep were collected. A total of 6,670 physical activity measurements and 6,548 sleep measurements were logged.

**Results—**The bipolar disorder group exhibited poorer physical health on the SF-36 and more sleep disturbance relative to the healthy group. No group differences were found in physical activity, nor in models examining the relationship between physical activity and sleep. Hierarchical linear models indicated that for every standard deviation increase in sleep disturbance (i.e., increased total wake time), there was a three percent decrease in subsequent day physical activity, in both the healthy and bipolar groups. Increased physical activity was associated with improved sleep for participants who reported greater average sleep disturbance.

**Conclusions—**The results for all participants in the study suggest that reduced physical activity and sleep difficulties may be mutually maintaining processes, particularly for individuals who suffer from poor sleep. Findings also raise the potential importance of targeting physical activity and sleep concurrently in interventions aimed at improving physical and mental health.



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**Keywords**

Physical Health; Sleep; Physical Activity; Bipolar Disorder; Actigraphy

Evidence is accruing for the importance of both physical activity and adequate sleep for physical and mental health. Low levels of physical activity have been linked to a wide range of medical problems (Ekelund et al., 2012; Anzuini et al., 2011). Similarly, poor sleep is a risk factor for medical illness and mortality (Mallon et al., 2002). There is some evidence for a bidirectional relationship between low levels of physical activity and poor sleep. For example, correlational studies indicate that individuals who sleep less than eight hours per day are more sedentary (Garaulet et al., 2011). In addition, exercise confers benefits for sleep among healthy individuals (Driver & Taylor, 2000) and can be used as an effective treatment for chronic insomnia (Reid et al., 2010). Prescribed structured exercise improves reported sleep quality, increases total sleep time, reduces pre-sleep anxiety and improves reported quality of life and general mood (Passos et al., 2011). However, there is a dearth of studies on the effects of exercise in a naturalistic setting as opposed to the effects of prescribed or supervised exercise. Moreover, very little research has examined day-to-day associations of these health behaviors even though accumulating evidence suggests that physical activity and sleep are highly variable behaviors within people (e.g., Maher, Doerksen, Elavsky, Hyde, et al., 2013; Knutson, Rathouz, Yan, Liu, Lauderdale, 2007). Additionally, most of the research on physical activity and sleep has examined cross-sectional or between-person associations. This leaves the question of whether there are unmeasured within-person associations that may be helpful in informing strategies to promote health or quality of life in the general population as well as populations who are particularly vulnerable to low physical activity and poor sleep. Hence, the goal of the current study was to prospectively investigate the proposed day-to-day bidirectional relationship between physical activity and sleep in both healthy individuals and individuals for whom both physical activity and sleep are characteristically disturbed; namely, individuals with bipolar disorder.

## Physical Health in Bipolar Disorder

Like other psychiatric disorders such as major depression and schizophrenia (Harris & Barraclough, 1998), bipolar disorder is a severe and chronic psychiatric illness that is associated with high rates of medical morbidity and premature mortality (Kupfer, 2005; Thompson et al., 2006). Medical costs are 2.5 times higher among individuals with bipolar disorder relative to the general population. One influential model by Wolkowitz and colleagues (2010) proposes that the biological stress associated with having a psychiatric illness may result in “accelerated aging” at a cellular level. This cellular damage renders the individual more vulnerable to diseases associated with aging, such as cardiovascular and cerebrovascular diseases. The model suggests that understanding the mechanisms involved in cell damage may one day lead to a reconceptualization of psychiatric illness as a “whole body disease rather than just a mental illness” (p. 327, Wolkowitz et al., 2010). Both physical activity (Cherkas et al., 2008) and sleep (Prather et al., 2011) have been implicated in cellular aging among individuals without a psychiatric disorder. Thus, understanding the conditions that constitute high risk for poor physical health in individuals with bipolar disorder could contribute to an increased understanding of mechanisms associated with accelerated aging.

## Physical Activity, Sleep and Bipolar Disorder

Recent surveys indicate that individuals with bipolar disorder lead predominantly sedentary lives (Chuang et al., 2008), similar to many other severe mental illnesses (Davidson, Judd, Jolley, Hocking, Thompson & Hyland, 2001). Additionally, relative to healthy individuals, individuals with bipolar disorder exhibit lower physical activity levels during the day as measured by actigraphy (Harvey et al., 2005; Salvatore et al., 2008). Individuals with bipolar disorder have poorer exercise habits relative to healthy individuals, such as infrequent walking and infrequent strength exercises (Kilbourne et al., 2007). However, there have been some notable exceptions to this line of evidence with one study finding no differences in self-reported physical activity levels between individuals with bipolar disorder and the general population (Cairney, Veldhuizen, Faulkner, Schaffer, & Rodriguez, 2009).

Bipolar disorder is also associated with pervasive sleep difficulties, particularly insomnia and hypersomnia, even during periods of clinical remission (for reviews see Harvey, 2008; Kaplan & Harvey, 2009). Furthermore, there is evidence that rates of obesity and hypertension are greater in individuals with bipolar disorder and insomnia compared to good sleeping individuals with bipolar disorder (Soehner & Harvey, 2012). This study also found that as the severity of insomnia symptoms increases, so does the risk of obesity, hypertension and diabetes. This is an important area of investigation given that changes in physical activity and sleep are important diagnostic features in bipolar disorder (American Psychiatric Association, 2000) and are also associated with poor health outcomes (Roshanaei-Moghaddam & Katon, 2009). Hence, bipolar disorder is an ideal population for studying the potential bidirectional relationship between physical activity and sleep. To our knowledge, no research to date has focused on a naturalistic observation of the day-to-day relationship between physical activity and sleep in either healthy individuals or individuals with bipolar disorder. The evidence to date suggests that bipolar disorder is associated with poorer health outcomes relative to healthy individuals, leading us to hypothesize that the relationship between physical activity and sleep will also be different. However, there is minimal research investigating whether the relationship between physical activity and sleep are different in bipolar disorder.

## The Current Study

As the evidence above outlines, there is likely a connection between physical activity and sleep that exists in all people. To understand the full continuum of this relationship, we examine both healthy adults and adults diagnosed with bipolar disorder, for whom this connection may be particularly strong. We also examine each individual's daily physical activity and sleep in order to better understand within-person associations. Using a longitudinal, naturalistic design, healthy participants (no psychiatric illness) and an inter-episode bipolar disorder group, were studied daily over a two-month period using subjective and objective measures of physical activity and sleep. The study had three aims. First, we

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sought to investigate overall physical health functioning and physical activity levels in a group diagnosed with bipolar disorder relative to the healthy group. The hypothesis tested was that the bipolar group would exhibit poorer physical health and engage in less physical activity, measured both subjectively and objectively, relative to the healthy group (Kilbourne et al., 2007; Salvatore et al., 2008). Second, we examined the relationship between physical activity and sleep in all participants. For this aim, we hypothesized that sleep disturbance would be associated with less engagement in subsequent day physical activity, as measured by both self-report and actigraphy (Garaulet et al., 2011). We also examined the flip side of this relationship; namely, that increased physical activity during the day would be associated with less subsequent sleep disturbance (Driver & Taylor, 2000). The third aim was to determine if the relationship between physical activity and sleep disturbance is differentially impacted in the bipolar disorder group relative to the healthy group. For this aim, we tested the hypothesis that the bipolar group would experience a more pronounced relationship between physical activity and sleep relative to the healthy group (Soehner & Harvey, 2012).

# Method

## Participants

As part of a larger study, we recruited 32 adults (ages 18–64) diagnosed with bipolar I disorder who were currently inter-episode and 36 healthy adults with no history of psychiatric or sleep disorders. The two groups were recruited to match by age and gender. Two publications report findings from this study (Gershon et al., 2012; Eidelman et al., 2012). This paper focuses uniquely on physical activity and its relation to sleep.

Participants were recruited through internet advertisements and flyers distributed in the community. A telephone interview was completed to screen for eligibility. Individuals who were considered likely to be eligible were invited for a baseline visit.

Individuals in the bipolar group were eligible to participate if they (a) met DSM-IV criteria for a diagnosis of bipolar I disorder (American Psychiatric Association, 2000) based on the SCID; (b) did not meet criteria for a diagnosis of substance or alcohol abuse or dependence in the past six months based on the SCID; and (c) did not meet criteria for narcolepsy, sleep apnea, restless leg syndrome or periodic limb movement disorder based on the Duke Structured Interview for Sleep Disorders (DSISD; Edinger et al., 2004). In addition, participants in the bipolar group were included only if they met criteria for inter-episode symptom cutoffs, as established in prior research (Chengappa et al., 2003): a score of less than 12 on the Young Mania Rating Scale (YMRS; Young et al., 1978) and a score of less than 24 on the Inventory of Depressive Symptomatology, Clinician Rating (IDS-C; Rush et al., 1996). All participants in the bipolar group were required to be in the care of a psychiatrist. For the duration of the study, 30 out of the 32 participants in the bipolar group were being treated with psychiatric medications, including antidepressants ($n$ = 15), lamotrigine ($n$ = 13), lithium ($n$ = 5), antipsychotics ($n$ = 20), and valproic acid ($n$ = 3). Six participants were also taking hypnotics and 19 participants in the bipolar group were taking two or more psychiatric medications. Although anti-depressant, antipsychotic, and mood-stabilizing medications are likely to influence sleep, temporary discontinuation would have

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been unethical (given health-related risks of patients with bipolar disorder being unmedicated), impractical (given long washout/titration periods), and unrepresentative (Philips et al., 2008). The Somatotherapy Index (Bauer et al., 1997) was used to assess medication treatment level on a 5-point scale (0–4), with higher scores indicating a more intense medication regimen. The Somatotherapy Index is reliable and has been used in bipolar samples (e.g., Sajatovic et al., 2006).

Participants in the healthy group were eligible if they (a) did not meet DSM-IV criteria for any past or current Axis I disorder; (b) did not meet criteria for any past or current sleep disorder based on the DSISD; and (c) had scores of less than 12 on the YMRS and less than 24 on the IDS-C. No healthy group participants were being treated with psychotropic medications.

## Materials

**Physical Health and Function—**Three subscales of the Medical Outcome Study 36-item Short-Form Health Survey (SF-36; physical health, physical functioning and physical role functioning; Ware et al., 2000) were obtained, with higher scores indicating better health functioning. The SF-36 assesses general health status, is psychometrically sound, and has been used with individuals with bipolar disorder (Arnold et al., 2000).

**Sleep Diary—**The sleep diary followed standard recommendations for sleep research, with question wording that mirrored current consensus recommendations (Carney et al., 2012). The present study focused on total wake time, defined as sleep onset latency (i.e., time to fall asleep) + wake after sleep onset (i.e., total amount of time awake overnight) + terminal wakefulness (i.e., amount of time awake between final awakening and when a participant got out of bed to start the day). Henceforth, the sleep diary data will be referred to as “reported total wake time.”

**Actigraphy—**To gather an objective estimate of sleep and daily physical activity levels, participants wore an actiwatch (Mini Mitter AW64 Actiwatch Inc.). Actiwatches provide an estimate of the sleep/wake cycle and activity levels by measuring movement (sampled in 60 second epochs). Data are stored in the watch’s embedded miniaturized accelerometer, downloaded, and used to estimate sleep parameters and activity levels using Respironics Actiware Version 5.5 (Copyright 2004-09, Respironics, Inc.). The frequency of motions is summarized into the 60 second epochs and then similar to the sleep diary, total wake time is calculated as sleep onset latency + wake after sleep onset + terminal wakefulness. The start and end points of the night are approximated from the time a participant presses an event marker on the actiwatch, indicating that he/she is going to sleep and waking for the day. In cases of unclear or lack of event marker, the sleep and wake times from the sleep diary were used to approximate the actiwatch night. The correlation between actigraphy-defined sleep estimates has been validated against polysomnography in individuals with bipolar disorder (Kaplan et al., 2012).

Actigraphy also provides indices of activity intensity and has been successfully used to measure activity levels in individuals with bipolar disorder (e.g., Jones et al., 2005). Minute-byminute raw activity values were analyzed for each participant’s maximum daily activity levels. Actigraphy is ideal for naturalistic assessment of sleep and activity, as it is non-invasive and capable of storing large amounts of continuously collected data. Henceforth, the nighttime actigraphy data will be referred to as “actigraphy total wake time” and the daytime actigraphy data will be referred to as “actigraphy activity.”

**Daily Exercise—**To assess exercise, participants were asked the following question about physical exercise: “Please list the activity; if more than one then list most strenuous.” Information on duration of exercise was not available for the majority of participants. This reported physical activity was coded by the research team and assigned a MET (MET = metabolic equivalent of task, expressing the energy cost of physical activity) based on the standards defined by Ainsworth (Ainsworth et al., 1993, Ainsworth et al., 2000). The use of MET’s has been well-validated (Ainsworth et al., 2000) and used to measure exercise in psychiatric populations (e.g., Mata et al., 2011). Henceforth, this measure will be referred to as “reported exercise.”

### Design and Procedure

All procedures were approved by the University of California, Berkeley Committee for the Protection of Human Subjects. During a baseline visit participants signed informed consent and were interviewed by a postdoctoral fellow or trained psychology doctoral student using the SCID, the DSISD, the YMRS, and the IDS-C. Once eligibility was determined by these measures, participants completed the SF-36 to assess physical health and function. Upon completion of the baseline visit, eligible participants were sent home to complete the sleep diary each morning, the exercise question each evening, and to wear the actiwatch continuously for one month. Participants were required to call in each time they completed the morning and evening items in order to time stamp their responses daily. At the end of one month, participants returned for a second study visit. The YMRS and IDS-C were re-administered to ensure continued inter-episode status. Participants who were found to be more than mildly hypomanic (defined as a YMRS score more than 12) or mildly depressed (defined as an IDS-C score more than 24) over the previous month were assessed for safety, paid and sent home with no further procedures. Upon completion of this visit, all participants who remained eligible for the study were asked to continue to complete the daily sleep diary, report their daily exercise, and wear the actiwatch for an additional month. At the end of the second month of data collection, participants returned for a final study visit where the YMRS and IDS-C were administered. Only participants who remained inter-episode throughout the two-month study period were included in the analyses.

### Data Analytic Strategy

Henceforth, the term “physical activity” encompasses both “reported exercise” and “actigraphy activity.” The term “sleep disturbance” encompasses both “reported total wake time” and “actigraphy total wake time.” Group differences in reported exercise and actigraphy activity were tested using independent samples t-tests. To examine the relationships between physical activity and sleep disturbance we used multilevel modeling (STATA version 12). Hierarchical linear modeling (HLM) was chosen given the nested structure of our data, in which physical activity and sleep disturbance measures (Level 1) are nested within measurement methods (Level 2), which are nested within individuals (Level

3). This statistical strategy allows us to simultaneously evaluate between-person associations and within-person associations (Bolger, Davis, & Rafaeli, 2003; Schwartz & Stone, 1998), which is a novel contribution of this research given the daily longitudinal data. All HLM analyses were first conducted on the most complex variance-covariance structure assuming random intercepts and slopes at each level and allowing them to be correlated, followed by a step-by-step process of assuming they were not correlated and finally by a random intercept only analysis. The final model analyses were based on the simplest variance-covariance structure not significantly different from the most complex as determined by the comparison of models through the restricted log-likelihood. Actigraphy and self-report measurements were mean centered at 0 with standard deviations equal to 1.

### Missing Data

A high response rate was achieved. Participants provided approximately 103 valid physical activity responses (counting both the reported exercise and actigraphy activity measurements each day) and 101 valid sleep responses (counting both the reported total wake time and actigraphy total wake time each day). The final data set consisted of 6,670 physical activity measurements (95% of the possible total of 7,020) and 6,548 sleep measurements (93% of the possible total of 7,006). There were no differences between groups in the mean number of days of recording (sleep: bipolar $M$ = 47.47 nights; healthy $M$ = 52.25 nights; physical activity: bipolar $M$ = 50.31 days; healthy $M$ = 54.89 days).

## Results

### Participant Characteristics and Physical Health and Functioning

Participants were recruited for a larger study and have previously been described in Gershon et al. (2012) – demographic characteristics and baseline clinical data of the sample are repeated here along with physical functioning data of participants (see Table 1). The bipolar and healthy groups did not differ significantly in age, gender, race/ethnicity, annual household income, or employment status, although there was a trend for differences in race/ethnicity. The groups differed with respect to marital status (a greater proportion of the healthy group were married or cohabiting with a partner). Participants in the bipolar group exhibited significantly more symptoms than the healthy group participants. Bipolar participant symptom scores were well below established clinical cutoffs (Rush et al.,1996; Young et al., 1978). The average medication treatment level (as assessed by Somatotherapy Index) was low. Participants with bipolar disorder obtained significantly lower scores than the healthy participants on the three SF-36 physical functioning subscales, indicating that participants with inter-episode bipolar disorder experienced more physical functioning difficulties over the past year (SF-36 physical health subscale, $t(50) = 3.05$, $p < 0.01$, Cohen's $d = 0.9$; SF-36 physical functioning subscale, $t(50) = 2.41$, $p < 0.05$, Cohen's $d = 0.7$; SF-36 physical role functioning subscale $t(50) = 2.58$, $p < 0.05$, Cohen's $d = 0.8$).

### Daily measures of physical activity and sleep disturbance

Table 2 presents the means and standard deviations of the physical activity and sleep disturbance variables for each method (self-report and actigraphy) and each group (bipolar and healthy). In order to check how much the continuous variables differ between and within participants, three different standard deviations are reported: The overall, between-subjects, and within-subjects standard deviations. Independent sample t-tests revealed no significant differences between groups on physical activity in either reported exercise ($t(68) = 0.18$, $p = 0.86$, Cohen's $d = 0.1$) or actigraphy activity ($t(68) = 0.69$, $p = 0.49$, Cohen's $d = 0.1$). Group differences in reported total wake time were significant ($t(68) = 2.84$, $p < 0.01$, Cohen's $d = 0.4$), but not actigraphy total wake time ($t(68) = 1.59$, $p = 0.12$, Cohen's $d = 0.3$) as previously reported in Gershon et al. (2012). For all variables, there was more within-subject variability than between-subject variability. This result supports the use of multilevel modeling for examining the physical activity—sleep disturbance relationship between the bipolar group and healthy group. Values in Table 2 are reported in their original measurement scales for ease of interpretation, however mean centered values are used in the models below, such that the regression coefficients can be explained as percent variations away from the mean.

We examined correlations between physical activity and sleep variables and medication treatment level in the bipolar group (e.g., average somatotherapy score, level of antidepressant treatment, presence/absence of mood stabilizer treatment, presence/absence of antipsychotic treatment, and number of alternative treatments). No significant correlations were found. There was a trend difference in actigraphy activity between participants taking ($n = 20$) and those not taking ($n = 12$) an antipsychotic medication. Participants taking an antipsychotic medication were less active ($t(30) = 2.14$, $p = 0.05$).

## Physical Activity—Sleep Relationships

Sleep Disturbance—Subsequent Day Physical Activity Relationship. The following 3- level model was the best fit to the data based on log-likelihood:

$$Physical\ Activity_{ijk}=\beta_1+\beta_2 Sleep_{ijk}+\beta_3 Bipolar_k+\beta_4 Sleep_{ijk} Bipolar_k+\zeta_{jk}^{(2)}+\zeta_k^{(3)}+\varepsilon_{ijk}$$

Participants' physical activity at a particular occasion ($i$), using a particular method ($j$), for a particular individual ($k$) is modeled as a function of a participant specific intercept ($\alpha_1$), and participant specific sleep disturbance (with coefficient $\alpha_2$ on occasion ($i$)). The dummy coded variable for bipolar disorder group status (with coefficient $\alpha_2$) and an interaction term (with coefficient $\alpha_4$) are the final fixed part of the model. In additional HLM models we tested the effects of gender, race/ethnicity, marital status, employment status and income; none of these predictors were significant nor did they significantly change the results. $\zeta_{jk}^{(2)}$ represents the random intercept for method $j$ and subject $k$.$\zeta_k^{(3)}$ is the random intercept for subject $k$.$\varepsilon_{ijk}$ represents the with-in person residual error term.

There was a significant main effect of sleep disturbance on physical activity, such that for every standard deviation increase in total wake time, there was a three percent decrease in subsequent day physical activity across groups, estimate = −0.03, $SE = 0.01$, $t(68) = -2.04$, $p < 0.05$. Bipolar group status resulted in a 5% lower mean physical activity relative to the healthy group, however this was not a statistically significant difference, estimate = −0.05, $SE = 0.10$, $t(6670) = 0.46$, *ns*. The interaction between sleep disturbance and bipolar group status was not significant, estimate = 0.03, *SE* = 0.03, $t(6670) = 1.07$, *ns*. Hence, sleep disturbance was a significant predictor of subsequent day physical activity, but bipolar group status was not.

For the random effects, the average level of physical activity varied by participant with a standard deviation of 0.28. At the level of method, physical activity values varied with a standard deviation of 0.43.

Physical Activity—Subsequent Night Sleep Disturbance Relationship. The following 3-level HLM model assuming correlated random intercept and random slope at the method level and random intercept only at the participant level best fit the data based on log-likelihood:

$$\begin{aligned} Sleep_{ijk} = & \beta_1 + \beta_2 Physical\ Activity_{ijk} \\ & + \beta_3 Bipolar_k + \beta_4 Physical\ Activity_{ijk} Bipolar_k \\ & + \zeta_{1jk}^{(2)} + \zeta_{2jk} Physical\ Activity_{ijk}^{(2)} \\ & + \zeta_k^{(3)} + \varepsilon_{ijk} \end{aligned}$$

Participants' sleep disturbance at a particular occasion (*i*), using a particular method (*j*), for a particular individual (*k*) is modeled as a function of a participant specific intercept ($\alpha_1$), and participant specific physical activity (with coefficient $\alpha_2$ on occasion ($i$–$1$)). The dummy coded variable for bipolar group status (with coefficient $\alpha_3$) and an interaction term (with coefficient $\alpha_4$) are the final fixed part of the model. In additional HLM models we tested the effects of gender, race/ethnicity, marital status, employment status, income and prior night sleep; none of these predictors were significant, with the exception of prior night sleep ($p <$ 0.001). However, none of the predictors significantly changed the results. $\zeta_{1jk}^{(2)}$ represents the random intercept for method *j* and subject *k*. $\zeta_{2jk}^{(2)}$ represents the random slope for physical activity using method *j* for subject *k*. $\zeta_k^{(3)}$ is the random intercept for subject $k$.$\varepsilon_{ijk}$ represents the with-in person residual error term.

The main effect of physical activity on sleep disturbance was not significant, estimate = −0.01, *SE* = 0.01, $t(68) = 0.69$, *ns*. There was a significant main effect for bipolar group status, estimate = 0.34, *SE* = 0.11, $t(6548) = 3.14$, $p = 0.002$, such that bipolar group status resulted in 34% higher average sleep disturbance relative to the healthy group. The interaction between bipolar group status and physical activity was not significant, estimate = −0.01, *SE* = 0.03, $t(6548) = 0.26$, *ns*. Hence, physical activity was not a significant predictor of subsequent night sleep disturbance, but bipolar group status was.

For the random effects, the average level of sleep disturbance varied by participant with a standard deviation of 0.26. At the level of method, sleep disturbance values varied with a standard deviation of 0.50, while the rate of change for every increase in physical activity had a standard deviation of 0.08. The correlation between the intercept and slope was −0.40 ($p < 0.01$), suggesting that higher average reported total wake time resulted in larger decreases in reported total wake time for every standard deviation increase in reported exercise. Hence, participants who reported higher average reported total wake time gained the most benefit to their sleep (i.e., decreased reported total wake time) from reported exercise.

## Discussion

This study investigated the day-to-day relationship between physical activity and sleep in individuals without a psychiatric illness and individuals diagnosed with inter-episode bipolar disorder. Our first aim was to examine group differences in physical health and physical activity. We predicted that the bipolar group would report poorer physical health and exhibit less physical activity relative to the healthy group. In partial support of this hypothesis, the bipolar group exhibited poorer physical health, physical functioning and physical role functioning as measured by the SF-36, relative to the healthy group. Groups did not differ, however, in either reported exercise or actigraphy activity. This is consistent with previous findings that self-reported physical activity levels do not differ between individuals with bipolar disorder and the general population (Cairney, Veldhuizen, Faulkner, Schaffer, & Rodriguez, 2009). There are at least two possible interpretations of the latter results. First, even healthy individuals struggle to stay physically active on a day-to-day basis (e.g., Nelson et al., 2007). For almost two decades, the benefits of physical activity have been promoted, and recommendations to be physically active have been made to the broad population (e.g., Pate et al., 1995). Unfortunately, these efforts have been met with minimal success (Hallal et al., 2012). Second, high levels of within-subject variability may have precluded significant findings in between-group comparisons. High levels of within-subject variability likely reflect inconsistent exercise habits, which are prevalent in the general population (e.g., Armstrong & Welsman, 2006; Caspersen, Christenson & Pollard, 1986). This study was not designed to specifically address the question of whether the relationship between physical activity and sleep affect later physical health. We believe this is an important next step and present the current study as preliminary, naturalistic data that we hope will inform future longitudinal studies on the long-term effects of physical activity and sleep on later physical health.

The question of whether there is more within-person variability in physical activity and sleep versus between-person variability was a primary question in this research. Hence, the second aim was to examine the proposed day-by-day, bidirectional relationship between physical activity and sleep. The first prediction was that more sleep disturbance (increased total wake time) would be associated with decreased subsequent day physical activity. Consistent with this hypothesis, every standard deviation increase in sleep disturbance corresponded to a three percent decrease in subsequent day physical activity. The use of a longitudinal, within-person design, demonstrates that this association occurred at the level of each individual, and is not simply a comparison between participants with more sleep disturbance versus those with little or no sleep disturbance. Hence, every participant in this sample was vulnerable to a decrease in physical activity after having a night of more sleep disturbance. There are various mechanisms that may account for this finding. First, reduced total sleep time may limit the amount of restorative sleep obtained which may, in turn, contribute to increased exhaustion and energy expenditure resulting in diminished physical activity (Hursel et al., 2011). Second, sleep loss increases vulnerability to negative mood (McGlinchey et al., 2011; Franzen et al., 2008). In turn, negative mood may reduce motivation to perform physical activity (Scott et al., 2006). Third, after a night of sleep restriction, healthy participants substantially increase their calorie consumption relative to their normal consumption, without also increasing physical activity (Calvin et al., 2012). The current findings are consistent with previous evidence that sleep plays an important role in regulating energy balance.

We also predicted that increased physical activity during the day would be associated with less sleep disturbance. We found that for participants with relatively higher average reported total wake time (i.e., *more* disturbed sleep), exercise was associated with decreased reported total wake time on the subsequent night. Exercise did not impact the sleep of participants whose average reported total wake time was relatively lower (i.e., *less* disturbed sleep). Taken together, these results are consistent with previous reports that exercise may be an effective treatment for reducing symptoms of insomnia (Driver & Taylor, 2000). To better understand the connection between physical activity and sleep, future studies should consider a broader range of sleep outcome measures, such as percentage of slow wave sleep or reported sleep quality, given previous findings that these outcomes are sensitive to changes in exercise regimen in healthy sleeping samples (Dworak et al., 2008; Hague et al., 2003).

The third aim was to examine the effect of bipolar disorder group status on the physical activity-sleep disturbance relationship. Our prediction was that the bipolar group would experience a more pronounced relationship between physical activity and sleep disturbance relative to the healthy group. The bipolar group experienced more sleep disturbance relative to the healthy group, consistent with previous research (e.g., Harvey et al., 2005). However, the evidence for mutual maintenance of physical activity and sleep disturbance was apparent in *both* groups. Perhaps the minimal differences between the groups reflect that low physical activity and sleep disturbance are so prevalent in the general population (Crespo et al., 1999; Ohayon, 2002). We emphasize that findings such as these may be increasingly important given the rising importance of Research Domain Criteria (Insel et al., 2010), dimensional approaches (Watson, 2005) and transdiagnostic processes (Harvey et al., 2004), all of which emphasize that understanding basic dimensions of functioning is a critical pathway toward progressing knowledge in cures for severe mental illnesses like bipolar disorder. The emphasis of this approach is location on a continuum of functioning and relative risk, rather than statistical significance per se (Keyes, 2005). Another explanation for lack of differences between the groups, and possible limitation of this study, is that this may have been a relatively high functioning bipolar group, rendering it unrepresentative of individuals with bipolar disorder. Our goal was to study individuals with bipolar disorder who were currently not experiencing a depressed or manic episode, however, our symptom cut-off scores may have been overly stringent in assessing for depression or mania. Further evidence that this may have been the case is the fact that level of psychopharmalogical treatment was relatively low, indicating that despite being potentially under medicated, the bipolar participants remained relatively asymptomatic. Future research in this area should allow for more fluctuations in symptoms, as this is likely more representative of patients with bipolar disorder in clinical practice. Nonetheless, these results also extend our understanding of the within-person relationship between physical activity and sleep in daily naturalistic settings, regardless of diagnostic overlay.

Several limitations are important to consider. First, the relatively small sample size may have limited statistical power. Second, although physical activity and sleep were measured by both self-report and objective estimate, physical health was measured only via self-report. Future work in this area should include an objective measure of physical health, such as blood pressure or body mass index, in order to adequately address whether the relationship between physical activity and sleep has an effect on later physical health. Third, information on the duration of physical exercise was not available for most participants. Future work should aim to use a validated self-report measure of daily physical exercise. Finally, psychotropic medications have effects on both sleep and activity levels. However, it would be neither ethical nor representative to conduct research on a medication free sample (Harvey et al., 2008; Philips et al., 2008). We found minimal differences between medication subgroups on outcome variables, with the exception of a trend for differences in actigraphy activity between bipolar individuals taking and not taking an antipsychotic medication. While we acknowledge that the potential confounding effect of medication use remains, we also note that a within-subject design was used in the current study so that inter-subject variability in medication use could be minimized (Harvey et al., 2008). We also note that, although the observational nature of the data was a strength of the current analysis, it also means that causal conclusions about the relationship between physical activity and sleep can not be made. It is our hope that this observational study may guide future experimental work on the relationship between physical activity and sleep.

In conclusion, the results support the hypothesis that reduced physical activity and sleep difficulties may be mutually maintaining processes, particularly for those individuals who suffer from poor sleep. Moreover, the association between physical activity and sleep was found at the level of each individual, suggesting that every participant in this sample was vulnerable to the vicious cycle of low physical activity and more sleep disturbance. This relationship was true for both healthy individuals and individuals with bipolar disorder. If *both* poor sleep and reduced activity could be addressed in a single intervention, the potential improvements to overall health could double. Moreover, given the high within-subject variability in both physical activity and sleep, future intervention research may want to examine whether interventions should focus on changing physical activity and sleep at specific daily levels versus the overall level, and whether benefits or decrements can be measured by the end of a particular day. Intervention recommendations made at an individual, daily level may increase motivation to improve these important health behaviors. This may be particularly important to consider in developing interventions for individuals with a serious mental illness such as bipolar disorder. Improved physical activity and sleep may be crucial ingredients for helping to reduce the physical and medical burdens associated with bipolar disorder.

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## Highlights

- We examine sleep and physical activity among individuals with bipolar disorder.
- We find physical activity and sleep difficulty are mutually maintaining processes.
- We find this was true for both healthy control and bipolar individuals.
- Both poor sleep and reduced activity should be addressed in interventions.

**Table 1**

Demographic Characteristics and Baseline Clinical and Physical Health and Functioning Data

| | **Bipolar Group (*n* = 32)** | **Healthy Group (*n* = 36)** | **Statistical difference values** |
|---|---|---|---|
| Mean age in years (SD) | 34.7 (10.5) | 33.3 (12.6) | $t$ = .492, $p$ =.624 |
| Gender | | | $\chi^2(1) = 1.63$, $p$ = .442 |
| Male | 12 | 17 | |
| Female | 20 | 19 | |
| Race/Ethnicity (N) | | | $\chi^2(5) = 10.44$, $p$ = .064 |
| African American | 3 | 1 | |
| Asian | 3 | 12 | |
| Hispanic | 3 | 6 | |
| Native American | 1 | 0 | |
| Caucasian | 20 | 17 | |
| Biracial/Other | 2 | 0 | |
| Marital Status (N) | | | $\chi^2(2) = 14.30$, $p$ =.001 |
| Single | 22 | 19 | |
| Married/Live-in partner | 1 | 14 | |
| Divorced/separated/widowed | 9 | 3 | |
| Annual Household Income[a] (N) | | | $\chi^2(4) = 3.71$, $p$ =.447 |
| Less than $25,000 | 8 | 12 | |
| $25,000–50,000 | 14 | 12 | |
| $50,000–75,000 | 2 | 5 | |
| $75,000–100,000 | 5 | 2 | |
| Over $100,000 | 3 | 2 | |
| Employment Status (N) | | | $\chi^2(3) = 1.40$, $p$ =.705 |
| Full-time | 10 | 15 | |
| Part-time | 10 | 8 | |
| Unemployed/Retired | 7 | 6 | |
| Student | 5 | 7 | |
| Mean Symptom Values (SD) | | | |
| Depressive Symptoms (IDS-C)[b] | 8.6 (4.7) | 2.2 (1.9) | $t$ = 4.0, $p$ <.001 |
| Manic Symptoms (YMRS)[b] | 3.2 (3.0) | .7 (1.3) | $t$ = 4.1, $p$ <.001 |
| Mean Somatotherapy Index Score (SD) | 1.8 (1.4) | -- | |
| Means of physical functioning values (SD)[c] | | | |
| SF-36 physical health | 58.2 (11.2) | 65.9 (4.8) | $t$ = 3.05, $p$ =.004 |
| SF-36 physical functioning | 92 (14) | 99 (3) | $t$ = 2.41, $p$ =.020 |
| SF-36 physical role functioning | 33.6 (8.3) | 38.5 (4.2) | $t$ = 2.58, $p$ =.013 |

*Note*.

[a]Three healthy group cases missing annual household income.

[b]One healthy group case missing depressive and manic symptom scores.

[c]Bipolar Group N = 28, Healthy Group N = 23.

IDS-C = Inventory of Depressive Symptomatology – Clinician Rating; YMRS = Young Mania Rating Scale

## Table 2

Means and standard deviations of within and between level by method and group

| Variable | | All Participants (N = 68) | | Bipolar Group (N = 32) | | Healthy Group (N = 36) | | Statistical difference values | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | ***t*** | ***p*** | ***d*** |
| Total Wake Time | | | | | | | | | | |
| Self-report[a] | Overall | 49.19 | 53.32 | 60.61 | 63.25 | 39.96 | 41.47 | 2.84 | .006 | .4 |
| | Between | | 32.76 | | 36.76 | | 25.17 | | | |
| | Within | | 42.79 | | 52.27 | | 33.24 | | | |
| Actigraphy[a] | Overall | 117.36 | 75.06 | 127.60 | 86.77 | 109.05 | 62.83 | 1.59 | .116 | .3 |
| | Between | | 44.28 | | 56.53 | | 28.02 | | | |
| | Within | | 59.92 | | 64.18 | | 56.25 | | | |
| Physical Activity | | | | | | | | | | |
| Self-report[b] | Overall | 2.67 | 3.32 | 2.58 | 3.34 | 2.74 | 3.31 | .18 | .862 | .1 |
| | Between | | 1.81 | | 1.82 | | 1.82 | | | |
| | Within | | 2.78 | | 2.79 | | 2.78 | | | |
| Actigraphy[c] | Overall | 2531.60 | 1058.20 | 2488.87 | 1034.39 | 2565.16 | 1077.38 | .69 | .494 | .1 |
| | Between | | 537.32 | | 582.87 | | 500.75 | | | |
| | Within | | 916.05 | | 855.96 | | 960.86 | | | |

[a] Unit of measurement = Minutes

[b] Unit of measurement = METs (Metabolic Equivalent of Task)

[c] Unit of measurement = Activity level measured in g-force