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BRIEF REPORT

Daily physical activity and sleep in veterans: the role of insomnia severity

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Abstract Physical activity (PA) is suggested as an easily accessible adjunctive lifestyle intervention for insomnia. It is not clear if PA is equally beneficial across different levels of insomnia severity. The current study examined the relationship between daily PA (steps) and sleep (duration, efficiency, and quality) across the spectrum of insomnia severity. Multilevel models estimated day-to-night relationships between PA and sleep, and if insomnia severity moderated these relationships. Days with greater PA were associated with nights with longer sleep duration. This was moderated by insomnia severity; PA was associated with longer sleep that night in participants with mild insomnia and associated with less sleep in those with severe insomnia. PA was not associated with sleep efficiency or quality. PA is potentially an easily accessible and impactful intervention to promote sleep duration in participants who are experiencing less severe sleep disturbance. More complex, resource-intensive interventions may be needed as insomnia severity increases.

Keywords Insomnia · Exercise · Stepped care · Sleep disturbance · Walking

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Introduction

Insomnia, or difficulty falling or staying asleep, affects approximately 6 – 10% of adults (Qaseem et al., 2016), and 24 – 54% of post-9/11 veterans (e.g., those returning from Operations Iraqi Freedom, Enduring Freedom or New Dawn) report some form of sleep disturbance (Hoge et al., 2008). Sleep disturbances can be the consequence of various physiological (e.g., high BMI), psychological (e.g., PTSD), and/or behavioral factors (e.g., poor sleep hygiene), which are often more common in veterans than civilians (Balba et al., 2018; Pigeon et al., 2013).

Interest in physical activity (PA) for insomnia treatment stems from the need for more easily accessible behavioral interventions for sleep improvement. While cognitive behavioral therapy for insomnia (CBTI) is the first-line treatment for chronic insomnia (Qaseem et al., 2016), it can be time- and resource-intensive (Espie, 2009). To augment therapist-delivered CBTI, patient-facing mobile applications, such as the VA's CBT-i Coach, have been developed to guide users through the process of learning about sleep, developing positive sleep routines, and improving their sleep environments, and providing a structured program that teaches evidence-based strategies to improve sleep and help alleviate symptoms of insomnia. CBT-i Coach is not intended to replace traditional CBTI for those who need it, but rather to provide options for self-reported sleep assessments (e.g., daily sleep dairies, use of the Insomnia Severity Index), sleep hygiene education, and opportunities for making behavioral changes that may enhance sleep even outside co-use of the app during insomnia treatment by a sleep clinician.

Given the need for more accessible interventions for insomnia, researchers have assessed whether adjunctive lifestyle-based treatments, such as increasing PA, can help improve sleep outcomes (Markwald et al., 2018). Due to

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the positive association between PA and improvements in sleep, PA has been proposed as an easily accessible, non-pharmacological treatment alternative for sleep disturbance (Buman & King, 2010; Hartescu et al., 2015).

Though research has pointed to PA in the form of walking as a potentially accessible addition to insomnia treatment, there is not yet consensus on its efficacy across insomnia severity levels. To better characterize the appropriateness and efficacy of PA interventions on insomnia, recent sleep studies have begun to examine within-person associations. Within-person variability in sleep often accompanies insomnia (Kay et al., 2013). Similarly, variation in daily behaviors can impact nightly variations in sleep (Bisson et al., 2019). One study documented improvements in sleep after days with more acute moderate-intensity activity in participants with chronic insomnia (Passos et al., 2010). Much of this within-person work has been primarily in healthy adults and there exists far less research examining these daily relationships in participants with insomnia. Understanding the daily relationships between PA and sleep in individuals with insomnia can inform clinical recommendations for adjunctive lifestyle interventions.

The goal of the current study was to examine the association between daily PA (i.e., walking) and sleep outcomes across varying levels of insomnia severity. This secondary analysis used data from a pilot randomized controlled trial (RCT) that examined whether use of the CBT-i Coach app with a PA intervention would improve sleep outcomes more so than the app alone. We hypothesized that daily PA would be more beneficial for sleep in those with less severe insomnia. We used daily data to capture and illuminate within-person relationships between PA and sleep that may otherwise not be captured by traditional between-person approaches.

Method

Participant recruitment

Participants were from a pilot RCT (Clinicaltrials.gov NCT03305354) that aimed to determine if guided increases in PA combined with use of the CBT-i Coach app for insomnia self-management could further enhance sleep outcomes, over and above self-management use of the CBT-i Coach alone (Reilly et al., in press). Participants were recruited via flyers, outreach to local community organizations, referrals from VA health providers, and recruitment letters. Interested participants were screened for study eligibility by phone. Inclusion criteria included serving in post-9/11 conflicts and reporting current insomnia defined by an Insomnia Severity Index (ISI) score greater than 10 (Morin et al., 2011) with impaired daytime functioning for at least 1 month. Participants were excluded if they demonstrated moderate to severe cognitive impairment on the Telephone Mini Mental Status Exam (Norton et al., 1999), or if they self-reported sleep apnea, periodic leg movements, or circadian rhythm disorder. Additional details regarding recruitment and retention are found in the paper documenting the primary and secondary outcomes of the RCT (Reilly et al., in press).

Design

Participants were randomized to either self-management-based use of the CBT-i Coach app (CBT-i Coach alone) or self-management-based use of the CBT-i Coach plus a PA intervention (CBT-i Coach + PA arm) that included monitoring daily steps via an accelerometer (Fitbit Charge 2, hereafter Fitbit), and individualized goal setting to encourage increased daily steps. The CBT-i Coach app, released in 2013 by the Department of Veterans Affairs National Center for PTSD and the Department of Defense National Center for Telehealth, is a publicly-available mobile app designed to facilitate the delivery of major CBTI treatment components, including sleep education, reminders for completion of daily sleep diaries, stimulus control guidelines, and sleep restriction guidance. The app also provides anxiety management and cognitive therapy tools, including relaxation elements (e.g., guided meditations), and reminders for bedtime and waking times, when to stop using caffeine, when to wind down, and setting aside time for worry (Koffel et al., 2016; Kuhn et al., 2016).

Measures

Daily PA was operationalized as daily steps measured with the Fitbit. Insomnia severity was measured with the ISI (Bastien et al., 2001; Morin et al., 2011), a validated 7-item self-report measure frequently utilized as the primary outcome in sleep intervention research. Possible scores ranged from 0 to 28, with higher scores indicating more severe insomnia. ISI was included in the model as a continuous variable, however for ease of interpretation we also categorized the scores to reflect the ISI's common cut-points for clinical purposes: mild (below the clinical threshold) insomnia (10–14), moderate clinical insomnia (15–21), and severe clinical insomnia (22–28) (Morin et al., 2011). Scores below 10 reflect no insomnia; these participants were not eligible to enroll in the study.

Using the CBT-i Coach app, participants were asked to fill out a sleep diary every morning recording what time they went to bed, fell asleep, woke up, how many times they woke up during the night, total time awake, and quality of their sleep. Using the diary information, the app calculated sleep duration and sleep efficiency. Sleep duration (i.e., time asleep in minutes) accounted for when they want to bed and woke up, excluding time spent awake and the time it took to fall asleep.

Sleep efficiency measured the percent of time in bed spent asleep, accounting for when the participant reported going to bed, how long it took to fall asleep, sleep duration, and number of times awakened. Participants rated their sleep quality on a scale from 1 (very poor) to 5 (very good) every morning.

Analysis

Data were analyzed using SAS 9.4 (Cary, NC) with multilevel models to examine the within-person relationships between daily step counts and the three daily sleep outcomes (duration, efficiency, and quality). Our model (MIXED procedure) has the ability to adjust for unequal variances. Furthermore, our model used the Satterthwaite approximation to account for differences in sample variance. Intraclass correlation coefficients (ICC) were calculated to examine the proportion of within-person variability for each daily variable. Each person's daily steps were mean-centered to reflect the person's daily variation from their own average. A lagged variable for daily steps was created to capture the prior day's step counts; this allowed us to model the relationship between daily steps and that night's sleep (e.g., daily steps on Monday and sleep from Monday night through Tuesday morning). This model included an interaction between insomnia severity and daily steps. Age, sex, and RCT condition (CBT-i Coach alone or CBT-i Coach + PA) were included as covariates in all analyses.

$$\text{Level 1}: \text{Daily Sleep}_{ij} = \beta_{0j} + \beta_{1j}\left(\text{Daily Steps}_{ij}\right) + e_{ij}$$

$$\begin{aligned}\text{Level 2}: \beta_{0j} = {} & \gamma_{00} + \gamma_{01}\left(Age_j\right) + \gamma_{02}\left(Sex_j\right) \\ & + \gamma_{03}(Race) + \gamma_{04}\left(Condition_j\right) \\ & + \gamma_{05}(Insomnia\ Severity_j) \\ & + \gamma_{06}\left(Insomnia\ Severity_j * Daily\ Steps_{ij}\right) \\ & + u_{0j}\end{aligned}$$

Results

Table 1 includes descriptive statistics for all between-person variables for our sample (N = 33), shown by insomnia severity category (mild n = 7, moderate n = 18, severe n = 8). The ICC for daily steps was 0.43 (i.e., 43% of the variance in steps was between-persons and 57% of the variance in steps was within-persons). Similarly, the ICC for the sleep outcomes was 0.30 (sleep duration), 0.51 (sleep efficiency), and 0.40 (sleep quality), indicating that 70%, 49%, and 60% of the variance in sleep duration, efficiency, and quality was within-persons, respectively.

Table 2 shows parameter estimates for all multilevel models. Days with more steps were associated with nights with longer sleep duration ($\gamma = 0.01$, $p = 0.004$). Daily steps were not significantly associated with better sleep efficiency or quality that night. Baseline insomnia severity was negatively associated with mean daily sleep quality ($\gamma = -0.07$, $p = 0.026$). Insomnia severity was not significantly associated with sleep duration or efficiency.

Baseline insomnia severity moderated the relationship between daily steps and sleep duration ($\gamma = -0.001$, $p = 0.005$). Analysis of simple slopes estimated the relationship between daily steps and sleep duration for each of the three insomnia clinical cut-point-based groups: 1) mild (ISI 8–14, Mean = 13.43); 2) moderate (ISI 15–21, Mean = 17.00); and 3) severe (ISI 22–28, Mean = 23.88). There was a significant positive association between daily steps and sleep duration for those with mild insomnia ($\gamma = 0.003$, $p = 0.022$), and a significant negative association between daily steps and daily sleep duration for those who had severe insomnia ($\gamma = -0.004$, $p = 0.033$). There was no significant association between daily steps and daily sleep duration for those who had moderate insomnia. We also examined three reversed models, where daily sleep duration,

Table 1 Sample characteristics

Characteristic	All	Insomnia Severity Index (ISI) Mild	Clinical-Moderate	Clinical-Severe	*p*-value
N	33	7	18	8	–
Age	37.61 (9.34)	39.14 (7.73)	37.00 (9.79)	37.63 (10.57)	0.883[1]
Baseline Steps	9925.40 (5140.32)	16,172.4 (7530.73)	7868.40 (3149.68)	8729.42 (2950.26)	0.003[1]
Baseline ISI	17.91 (4.03)	13.43 (0.79)	17.00 (1.75)	23.88 (1.81)	<.001[1]
% Male	75.76%	100%	72.22%	62.50%	0.035[2]
% White	75.76%	57.14%	83.33%	75.00%	0.058[2]

ISI = Insomnia Severity Index. *P*-value obtained from

[1]one-way analysis of variance (ANOVA) or

[2]Fisher's Exact Test

Table 2 Multilevel model parameter estimates

Effect	Estimate	SE	*p*
Outcome = Sleep Duration			
Intercept	463.45	101.07	< 0.001
Age	0.57	1.57	0.721
Condition	3.04	28.16	0.915
Gender	−20.29	39.57	0.613
Race	−62.38	41.30	0.150
Daily Steps	0.01	0.00	0.004
Baseline ISI	−3.48	3.22	0.295
Daily Steps x Baseline ISI	−0.00	0.00	0.005
Outcome = Sleep Efficiency			
Intercept	108.22	13.67	< 0.001
Age	−0.09	0.21	0.675
Condition	−1.69	3.83	0.665
Gender	−6.38	5.26	0.238
Race	−3.75	5.68	0.518
Daily Steps	0.00	0.00	0.757
Baseline ISI	−0.81	0.44	0.084
Daily Steps x ISI	−0.00	0.00	0.834
Outcome = Sleep Quality			
Intercept	3.85	0.91	< 0.001
Age	0.02	0.01	0.157
Conditions	−0.09	0.26	0.729
Gender	−0.58	0.35	0.116
Race	0.18	0.38	0.637
Daily Steps	−0.00	0.00	0.692
Baseline ISI	−0.07	0.03	0.026
Daily Steps x Baseline ISI	0.00	0.00	0.733

ISI = Insomnia Severity Index

efficiency, and quality predicted the next day's steps. There was no significant relationship between daily sleep outcomes and the following day's steps, further supporting the hypothesized directionality of the effect of PA on sleep.

Discussion

The results of the current study indicate that days with more PA are associated with longer sleep that night. This effect was moderated by insomnia severity. Walking more was associated with more time asleep in participants who were experiencing mild insomnia, and walking more was associated with less time asleep in participants who were experiencing severe insomnia. Consequently, PA as an adjunctive intervention to a self-guided app based on elements of CBTI, may be most beneficial when insomnia symptoms are less severe.

There was a substantial amount of within-person variation in our daily variables, supporting the importance of examining the relationship between PA and sleep outcomes from a within-person perspective. We found a positive relationship between daily PA and daily sleep duration in those with mild insomnia. This positive relationship has been previously documented in those without sleep disturbance, as well. In a sample of healthy middle-aged adults, daily steps were positively associated with both longer sleep duration and better sleep quality that night (Bisson et al., 2019). In contrast, a recent meta-analysis which included studies from samples both with and without sleep disturbance found both positive and negative associations between daily PA and sleep duration (Atoui et al., 2021). This meta-analysis noted variation across different samples (i.e., good sleepers, adults with insomnia symptoms, or adults with medical comorbidities) as a possible explanation for these inconsistent results. For example, it is possible that individuals with more severe insomnia who are practicing sleep restriction may have a temporary decrease in PA, whereas a decrease in insomnia symptoms in individuals with more mild insomnia may result in more daily time spent in physical activities (Atoui et al., 2021). The CBT-i Coach app does include sleep restriction guidance, although we were unable to ascertain if participants in our study used this feature, or how rigorously it may have been used. Future research would benefit from examining in more granular detail if sleep restriction strategies can negatively affect daily PA.

In the current study we did not find an association between daily PA and either daily sleep quality or sleep efficiency, contrasting Bisson et al.'s findings linking higher PA to greater sleep quality. Sleep quality and sleep efficiency are important outcomes in insomnia treatment, as they capture the crux of the problem for those suffering from insomnia – spending too much time in bed trying to fall and stay sleep. Improvement in these outcomes has thus become a primary objective for insomnia treatment (Reed & Sacco, 2016). Greater variability in total sleep time is also associated with decreased sleep quality (Baron et al., 2017); therefore, encouraging consistent daily PA to reduce variability in total sleep time is a possible means to supporting better sleep quality in those with mild insomnia.

Differences in the sample characteristics may partially explain inconsistencies between the current study and prior work. Our sample was purposively recruited on the basis of having functional sleep problems and thus have worse sleep quality compared to healthy adults (as sampled in Bisson et al., 2019). Gender imbalance in our sample is another possible explanation for this inconsistency as 76% of our sample was male. Gender has been suggested as possible moderator between PA and sleep outcomes (Bisson et al., 2019; Kredlow et al., 2015).

CBTI is recommended as the first-line behavioral treatment for all veterans with insomnia (Wells et al., 2019). However, access and implementation of CBTI can be poor due to multiple factors, including a limited number of VA clinicians who are formally trained in the evidence based psychotherapy and perceived lack of local clinical CBTI champions(Koffel & Hagedorn, 2020). Additionally, adherence to CBTI can be poor due to competing life demands of working-age participants (e.g., difficulties in attending CBTI sessions). Therefore, many researchers and clinicians have proposed use of a stepped-care model for insomnia treatment (Espie, 2009), where the base treatment level uses low-intensity interventions that can be easily delivered to most participants(Wells et al., 2019), such as self-administered CBTI. By applying this model, individuals with more severe insomnia can be referred to, and hopefully benefit from, more intensive treatments such as therapist-administered CBTI, given their more severe symptoms and greater health care needs (Espie, 2009). A potential problem when applying a stepped care approach is that individuals who would have benefitted from more intensive care (i.e., manualized clinician-delivered CBTI) may feel discouraged by a poor outcome with low-intensity treatments, such as self-administered CBTI. This may result in patients assuming that more intensive, validated behavioral interventions for sleep will not help them, such that patients will not pursue the next level of insomnia care. Stepped-care approaches using similar sleep self-management technologies should thus incorporate iterative evaluation and monitoring of patient symptoms, progress, and reactions to the intervention. This will help ensure both that decisions about where to begin in the stepped care model and the patient's retention and progression through care steps is appropriate (Espie, 2009).

Our results demonstrate that increasing PA is a readily accessible, low-cost treatment for less severe insomnia. This is particularly true for walking which can be done at many places and times. The current study supports that PA, in combination with a self-guided app based on components of CBTI, should be considered as a possible treatment for sleep disturbance for those experiencing mild insomnia. PA combined with a CBTI-informed sleep self-management app could serve as an adjunctive lifestyle intervention for insomnia, although it may not be sufficient to improve sleep in those with moderate-to-severe insomnia.

Limitations

The current study cannot establish directionality. Notably, in the current study at baseline, those with mild insomnia walked on average more than those with moderate and severe insomnia, suggesting a possible bidirectional effect. However, we did not see statistical evidence for a bidirectional relationship. A final limitation of this study is that most of our sample was white, male, and all veterans who served post 9/11 and the results of this study may be limited in generalizability.

Conclusion

The current study demonstrated a significant association between days with more walking and nights with longer sleep duration. This association was positive among participants with less severe insomnia, and negative among participants with severe insomnia. Engaging in PA while simultaneously using a self-guided app based on CBTI components is an easily accessible, low-cost treatment that has the potential to improve sleep, although it may be most beneficial in those with less severe insomnia. PA should be considered as an adjunctive intervention in a stepped care approach utilizing mobile CBTI treatments for those on the lower end of the insomnia severity spectrum.

Author Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Stephanie A. Robinson, Erin D. Reilly, Beth Ann Petrakis, and Karen S. Quigley. The first draft of the manuscript was written by Stephanie A. Robinson and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Conflict of interest S. R. Robinson, E. D. Reilly, B. A. Petrakis, R.S. Wiener, C. Castaneda-Sceppa, K. S. Quigley, does not have any conflict of inteerst.

Human and animal rights All procedures performed in the study, which involved human participants, were in accordance with the ethical standards of the institutional review board and with the 1964 Helsinki declaration.

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

Consent for publication Consent was obtained to publish deidentified, summary data from all participants.

Availability of data Deidentified data and study materials are available upon request.

Code availability Data was coded using SAS 9.4. Coding syntax is available upon request.

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