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Using actigraphy feedback to improve sleep in soldiers: an exploratory trial☆

Amy B. Adler, PhD [a,*], Brian C. Gunia, PhD [a,b], Paul D. Bliese, PhD [a,c], Paul Y. Kim, MA [a], Matthew L. LoPresti, PhD [a,1]

[a] Walter Reed Army Institute of Research, 503 Robert Grant Ave, Silver Spring, MD 20910, USA
[b] Johns Hopkins University, Carey Business School, 100 International Dr, Baltimore, MD 21202, USA
[c] University of South Carolina, Darla Moore School of Business, 1014 Greene St, Columbia, SC 29208, USA

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ABSTRACT

Objectives: The objective of this study was to assess the impact of wearing an actigraph and receiving personalized feedback on the sleep of a high-risk occupational group: United States soldiers recently returned from a combat deployment.
Design: Following a baseline survey with a full sample, a subsample of soldiers wore an actigraph, received feedback, and completed a brief survey. Two months later, the full sample completed a follow-up survey. The actigraph intervention involved wearing an actigraph for 3 weeks and then receiving a personalized report about sleep patterns and an algorithm-based estimate of cognitive functioning derived from individual sleep patterns.
Results: Propensity score matching with a genetic search algorithm revealed that subjects in the actigraph condition (n = 43) reported fewer sleep problems (t value = −2.55, $P < .01$) and getting more sleep hours (t value =1.97, $P < .05$) at follow-up than those in a matched comparison condition (n = 43, weighted). There were no significant differences in functioning, somatic symptoms, and mental health outcomes (posttraumatic stress disorder symptoms and depression). A significant interaction indicated that the actigraph had a more beneficial effect on those with more somatic symptoms at baseline but not those with more sleep problems. Most participants rated the personalized report as helpful.
Conclusion: Actigraphs combined with personalized reports may offer a useful, simple intervention to improve the sleep patterns of large, high-risk occupational groups.

Introduction

Sleep problems such as short sleep duration and insomnia are risk factors for mental health problems[1] and impaired cognitive functioning.[2] Furthermore, the negative effects of sleep problems may be exacerbated in high-risk occupations with elevated incidence of mental health problems.[3]

One possible way to improve sleep is through increased self-awareness, and one way to improve self-awareness is through actigraphy. Wrist-worn actigraphs measure movement acceleration from which sleep/wake timing and duration are estimated. These devices have been validated against polysomnography in both normal sleepers[4,5] and adults with insomnia.[6] Not only do actigraphs track sleep patterns, but the data can be converted into an estimate of cognitive functioning based on an algorithm developed by the Walter Reed Army Institute of Research.[7,8] This algorithm was developed using psychomotor vigilance test data from laboratory studies of sleep restriction and sleep deprivation,[9] with color codes (green, amber, and red) reflecting the comparable level of impairment that results from various blood alcohol concentration levels. There is also a graph of "cognitive effectiveness" that can be generated as part of a personalized report. This graph is color coded to indicate the likelihood of good, moderate, and poor cognitive performance.[10]

Research has shown that increasing personal awareness of health-related behaviors is associated with improved health habits, such as eating, smoking and exercise,[11] and providing normative feedback alone can result in changed behavior, such as reduced

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* Corresponding author. Tel.: +1 301 319 9444; fax: +1 301 319 9484.
E-mail address: amy.b.adler.civ@mail.mil (A.B. Adler).
[1] Present address: The United States Army Medical Research Directorate-West, 9933 West Hayes St, Joint Base Lewis McChord, WA 98431, USA.

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alcohol consumption.[12] Presumably, providing individuals with feedback about their sleep patterns and cognitive functioning status can produce similar change. Simple sleep-related interventions can build on the concept of health-related "nudges." Nudges increase the likelihood of certain behaviors by altering subtle features of the surrounding environment[13]; for instance, presenting calorie information using heuristic accentuation (eg, traffic lights, letter grades) tends to encourage healthy eating.[14]

Although the literature on nudges has not, to our knowledge, investigated sleep-related nudges, informing individuals about the link between their unique sleep patterns and cognitive functioning may motivate change by clarifying the cognitive benefits or consequences of sleep patterns over which individuals have some control. We hypothesized, therefore, that an actigraph feedback intervention would be associated with better sleep.

In a series of secondary research questions, we also examined distal outcomes associated with sleep problems: functioning,[15,16] somatic symptoms,[15,17] and mental health problems (such as posttraumatic stress disorder [PTSD] and depression).[18] In addition, we examined whether the intervention was particularly beneficial for individuals already experiencing sleep, functioning, somatic, and mental health problems at baseline because they have the most to gain from an intervention. Finally, we examined user acceptability of wrist actigraphy and a personalized report.

To investigate the impact of actigraph feedback, we sampled from a population known to be at risk for significant sleep problems: soldiers recently returned from combat.[19] Previous studies have documented substantial sleep problems in this group, especially among those who experienced combat-related events,[20,21] and have demonstrated links to functional impairment,[22] somatic symptoms, PTSD, and depression[3,21] in service members returning from combat. Adequate sleep and cognitive functioning are particularly important in occupational groups such as the military where accidents brought on by lapses in judgment can have serious consequences.[23,24]

Participants and methods

Participants

Study participants were active-duty US soldiers from one brigade that completed a 6-month combat deployment to Afghanistan. Soldiers were surveyed 1 month after returning from the deployment (time 1; T1) in February-April 2014 and again 3 to 4 months later (time 2; T2) in June and July 2014. Prior to enrollment, participants provided informed consent under a protocol approved by the Institutional Review Board at Walter Reed Army Institute of Research; 2914 of the 3469 soldiers who attended the recruitment briefing consented to participate (84%).

Of the 2914 in the T1 sample pool, 115 were offered an opportunity to participate in the actigraph condition. The only inclusion criterion for this phase was that the individual expected to be available for the follow-up survey. Two declined because they did not like wearing watches; 113 agreed (98%). Subsequently, 1 watch failed, 2 were not returned, and 2 were not worn, resulting in 108 who completed the actigraph portion of the study. Given that surveys were anonymous and linked over time using a personalized code, some surveys were not able to be matched over time because codes were mismatched or blank, consistent with other efforts to use this approach.[25] Moreover, individuals were not necessarily available for follow-up because of competing work-related requirements, consistent with other studies conducted with military units.[26] Consequently, of the 108 participants in the actigraph condition, we were able to link 95 to their T1 survey, and of those, 66 were linked to the postactigraph survey, and 43 were then linked to their T2 survey. Our analyses use these 43 participants because they provided outcome values and T2 and had completed all phases of the study (n sizes used for calculations vary slightly due to missing variables).

The original 113 actigraph participants were selected from a range of companies across 1 battalion. Because information from this study was being used to inform a separate project examining sleep and junior leaders, we oversampled junior officers (eg, lieutenants) in the actigraph portion of the study. According to battalion leadership, individuals were selected arbitrarily; however, we cannot exclude the possibility that the 113 participants represent a convenience sample. In the nonactigraph condition, 1102 participants from T1 were surveyed again at T2. See Table 1 for a comparison between the full nonactigraph sample and the full actigraph sample at T1, as well as T1 data from the actigraph sample linked across all 3 time periods (T1, postactigraph, and T2).

Procedure

As part of a large-scale data collection on postdeployment adjustment, subjects were assembled in a gymnasium or large conference room on a US military post in Germany. After being briefed, individuals provided their informed consent; to reduce the possibility of undue influence, leaders were separately briefed and consented. The baseline survey was then administered in this large-group setting. As noted, both the baseline survey and the follow-up survey were part of a broader longitudinal study; here, we only report items relevant to the current analyses. Within a day of the baseline survey, individuals from this baseline sample were selected and assigned to the actigraph condition. There were no other specific selection criteria. Individuals were then briefed, consented, and fitted with a wrist-worn actigraph. The specific device was the Fatigue Science Readiband 3 (Sleep Performance Inc), which continuously monitored wearer movement. Participants were instructed to wear the actigraph at all times and that the device would not transmit their data to any external sources, ensuring privacy. At the end of the 3-week wear period, the actigraphs were collected by study staff, and the data were downloaded to a computer for analysis using software specifically designed for this device. This software scored the movement data into sleep/wake periods using standardized algorithms for actigraphy-based sleep analysis.[27] Prior to generating individual reports, the data were edited to ensure that only periods where the actigraph was actually worn were included in the report, following standardized procedures for excluding invalid data whereby extended periods with zero activity (eg, device was removed) were "cropped" out of the data set to avoid those periods being inaccurately coded as sleep. Two days later, participants returned to receive their personalized reports and briefly reviewed the content of the report with a study staff member. A sample report is included in a Supplemental file.

The personalized report included several sections: (1) sleep data from the previous 3 weeks highlighting daily activity and sleep/wake scoring; (2) summary sleep data comparisons with data from the general US population, including average total sleep time per 24 hours, time of nightly sleep onset, sleep onset time variability, and sleep efficiency (scores differing from the norm were indicated with an asterisk); (3) cognitive functioning estimates mapped onto green, amber, and red bands based on the individual's sleep data and algorithms from previous studies[9]; and (4) recommended actions for improving sleep. Each report section was identified. For the sleep section, it was explained that the lines going up indicated activity and the lines that were low and flat indicated periods of sleep. It was then explained that scores outside of the norm were identified with an asterisk. Next, participants were told that their cognitive functioning pattern was graphed for the period of time that they wore the actigraph, and that any scores in the green band indicated optimal cognitive functioning and scores in the red band

Table 1
Demographics and sleep, functioning, somatic, and mental health ratings of actigraph, full nonactigraph, and follow-up actigraph samples at T1

	Full sample		
	Actigraph sample[a] (n = 95)	Nonactigraph sample (n = 2819)	Follow-up actigraph sample[b] (n = 43)
Male, n (%)	94 (98.9)	2598 (92.8)	42 (97.9)
Age, n (%)			
18-24	52 (54.7)	1390 (49.5)	23 (53.5)
25-29	29 (30.5)	771 (27.4)	13 (30.2)
30-39	11 (11.6)	529 (18.8)	5 (11.6)
40 or older	3 (3.2)	119 (4.2)	2 (4.7)
Rank, n (%)			
E1-E4	47 (49.5)	1642 (58.5)	15 (34.9)
E5-E9	39 (41.1)	934 (33.3)	21 (48.8)
Officer/Warrant Officer	9 (9.5)	231 (8.2)	7 (16.3)
No. of combat experiences, mean ± SD	7.37 ± 6.31	6.1 ± 6.32	7.62 ± 6.77
Sleep problems, n (%)	27 (28.4)	617 (22.1)	10 (23.3)
Sleep quantity (time ± SD)	5.51 ± 1.27	5.71 ± 1.31	5.51 ± 1.37
Functional impairment (mean ± SD)	18.45 ± 7.19	19.74 ± 8.26	17.82 ± 7.21
Somatic symptoms (mean ± SD)	5.24 ± 4.69	4.23 ± 4.16	5.16 ± 3.99
PTSD symptoms (mean ± SD)	24.74 ± 9.26	24.71 ± 11.45	24.19 ± 8.98
Depression symptoms (mean ± SD)	3.57 ± 4.11	3.29 ± 4.41	3.30 ± 3.28

Sleep problems are operationalized by the 4-item Insomnia Severity Index, sleep quantity is a 1-item measure of sleep hours, functional impairment is from the WRFIS, somatic complaints are from the adapted version of the PHQ-15, PTSD is based on the PCL, and depression is measured by the PHQ-9.
[a] The actigraph sample consists of all the individuals who wore the actigraph and could be linked to their T1 survey.
[b] The follow-up actigraph sample consists of all the individuals who wore the actigraph and could be linked to their T1, postactigraph, and T2 surveys.

indicated less effective cognitive functioning. Finally, recommendations for improving sleep were pointed out at the bottom of the report. Participants then completed a 10-minute postactigraph survey. Two months later, the full sample was surveyed again in a large-group setting.

Measures

Covariates

Following prior research in a military setting, covariates included sex, military rank (categorized in terms of junior enlisted, noncommissioned officer, or officer/warrant officer), and degree of combat exposure (measured by 22 items adapted from previous surveys with soldiers).[26]

Primary sleep outcomes

Sleep was assessed in 2 ways: sleep problems using a cutoff score and sleep quantity. Sleep problems were measured with 4 items from the Insomnia Severity Index,[28] and this shortened form has been used in other studies with soldiers.[21,26] The items included difficulty falling asleep and staying asleep (1 = none to 5 = very severe), sleep satisfaction (1 = very satisfied to 5 = very dissatisfied), and the degree to which sleep interfered with functioning (1 = not at all to 5 = very much). Items were summed for a continuous score; cutoff values were based on a validation study conducted with soldiers[29] and used in previous research.[26] Individuals were considered to be at risk for having a sleep problem if they endorsed at least 3 items in the “at risk” range: items 1 and 2 were coded at risk if answered “moderate” or higher, item 3 was coded at risk if answered “dissatisfied” or “very dissatisfied,” and item 4 was coded at risk with responses of “somewhat” or higher. Sleep quantity was assessed by asking about individuals' average sleep in a 24-hour period (3 or fewer to 8 or more). Overall, at T1, participants reported getting 5.74 hours (SD = 1.28) of sleep per 24 hours, and 20.1% of respondents exceeded the cutoff for sleep problems based on the criteria established for the shortened 4-item Insomnia Severity Index.

Functioning and health outcomes

Functional impairment was assessed using the 14-item Walter Reed Functional Impairment Scale (WRFIS),[30] with 5 response options (1 = no difficulty at all to 5 = extreme difficulty). Somatic symptoms were measured using an adapted version of the Patient Health Questionnaire-15 (PHQ-15).[31] Given the predominantly male sample, items assessing problems with menstruation and painful sexual intercourse were omitted. Individuals indicated how much they were bothered by each of the symptoms (0 = not bothered to 2 = bothered a lot), corresponding to scoring procedures from previous military studies.[32]

In terms of mental health problems, PTSD symptoms were measured using the 17-item PTSD Checklist (PCL)[33] which has been used in previous studies with soldiers.[26] Symptoms were scored with 5 response options (1 = not at all to 5 = extremely). Depression symptoms were measured using the 9-item Patient Health Questionnaire for Depression (PHQ-9),[34] scored with 4 response options (1 = not at all to 4 = nearly every day).

Attitudes toward the actigraph and sleep report

Seven items developed for this study assessed the degree to which wearing the actigraph (2 items) and receiving the actigraph report (5 items) were helpful for increasing individuals' awareness of sleep. All items were rated on a 5-point scale (1 = strongly disagree to 5 = strongly agree).

Analytic approach

Although threats to validity resulting from the lack of random assignment cannot be eliminated, inferences can be strengthened by selecting a sample from the nonactigraph condition equated on key demographics and preexisting, theoretically grounded confounders. One well-established statistical technique for equating samples across key variables is propensity scoring.[35–37] Propensity scoring uses logistic regression or other discriminate functions to estimate a probability that any single observation comes from either the intervention (ie, actigraph) or control (ie, nonactigraph) group. Taking confounders into account, algorithms match the propensity score for each observation in the intervention group to identical (or nearly identical) propensity scores from the larger control group, creating equivalent groups.

Confounders were selected based on literature on sleep in postcombat populations.[26] Specifically, each model controlled for sex, military rank, combat exposure, and a continuous measure of sleep problems as measured by the 4-item Insomnia Severity Index

Table 2
Matched sample results for sleep, functioning, somatic, and mental health outcomes

	Actigraph sample	n	Nonactigraph sample (matched)	Unweighted n	Estimate	AI SE	*T* statistic	*P* value
T2 sleep problems (dichotomous)	19.51%	41	38.47%	100	−0.19	0.07	−2.55	.01
T2 sleep quantity (time)[a]	5:28	41	5:03	60	0.41	0.21	1.97	.05
T2 functional impairment (mean)	19.59	39	19.80	69	−0.21	2.14	−0.10	.92
T2 somatic symptoms (mean)	0.35	41	0.30	78	0.05	0.05	0.89	.37
T2 PTSD symptoms PCL (sum)	23.17	41	24.63	120	−1.46	1.69	−0.87	.39
T2 depression symptoms (mean)	3.88	41	3.69	91	0.19	0.57	0.33	.74

Each line represents an independent model controlling for the relevant T1 variables. AI SE refers to the Abadie and Imben's standard error. Sleep problems are operationalized by the 4-item Insomnia Severity Index, sleep quantity is a 1-item measure of sleep hours, functional impairment is from the WRFIS, somatic complaints are from the adapted version of the PHQ-15, PTSD is based on the PCL, and depression is measured by the PHQ-9. Covariates include T1 outcomes (linear and quadratic), sex, rank, sleep quality T1 (linear and quadratic), and combat exposure (linear and quadratic).

[a] To convert to minutes, multiply by 60.

at T1. In addition, the T1 versions of the T2 outcome variables were included in their respective models to control for the possibility of baseline differences in the outcomes of interest.

As is common in propensity score matching, higher-order variants (squared terms) associated with the continuous variables were used in the matching along with the raw variables.[37] In almost all cases, the default propensity score algorithms failed to create equivalent groups. Therefore, we used a more computationally intensive algorithm referred to as a *genetic matching algorithm*. Genetic matching can be used as an alternative when default propensity score matching fails to create equivalent groups.[37] We provide propensity score results based on the genetic matching algorithm using the default of 1-to-1 matching; however, when multiple controls were matched to the actigraph group, we kept all the matched controls and weighted results. After matching, the smallest *P* value for differences in confounders between the 2 groups was .55 (in the sample drawn for depression). All other *P* values were greater than .55. These values suggest successful matching. All analyses were conducted using using the R library "Matching."[37] The matching algorithm returns mean values for each group, a standard error estimate (Abadie and Imben's standard error), and an independent *T* statistic.

Finally, in a series of multiple regressions, we tested for interaction effects between at-risk status (baseline sleep, functioning, somatic, and mental health scores) and intervention condition, controlling for rank, sex, and combat exposure.

Results

Primary sleep outcomes

Table 2 summarizes results contrasting matched samples. The referent is the actigraph group, so negative values indicate that the actigraph group was lower on the outcome than controls (nonactigraph group). Participants who received actigraphs were significantly less likely than controls to meet the threshold criteria for sleep problems at T2 (19.5% vs 38.5%, respectively; estimate $= -0.19$, SE $= 0.07$, $P = .01$). Those who received actigraphs also reported sleeping more at T2 than controls (sleep quantity); on average, those in the actigraph condition reported sleeping 25 minutes more per 24-hour period than those in the control condition (5:28 vs 5:03 minutes; estimate $= 0.41$, SE $= 0.21$, $P = .05$).

Secondary outcomes and at-risk status

Table 2 shows that none of the secondary outcomes significantly differed between groups.[i] With respect to soldiers potentially at elevated risk, the actigraph intervention had a significant salutary impact on T2 somatic symptoms for those with higher levels of somatic symptoms at T1 ($\beta = -.17$, SE $= .05$, $P = .002$) when the sleep items were removed from the somatic symptoms scale (not when they were included). Specifically, among individuals with high somatic symptoms at T1, those who wore an actigraph had lower T2 levels than those in the control group. The interactions between condition and T1 variables were not significant for the remaining outcomes (with or without the additional sleep items).

[i] When using somatic, PTSD, and depression symptoms in the models, we replicated the analyses using the scales with any sleep-related items omitted (2 from the somatic measure, 1 from the PTSD measure, and 1 from the PHQ-9). In each case, the results for the main effects did not substantively change; the same pattern was observed.

Postactigraph survey: subjective reactions to the actigraph and report

Table 3 presents the subjective reactions to wearing the actigraph and to the report for the 78 participants linked to a postactigraph survey. Most individuals in the actigraph condition agreed that the actigraph report was helpful, made them more aware of their sleep schedule, motivated them to improve their sleep habits, identified sleep issues that they could improve, and increased their awareness of the link between sleep and accidents or serious errors. Fewer individuals reported that wearing the actigraph itself had made them more aware of their own sleep schedule, suggesting that the report may have been particularly important (Table 3).

Discussion

This study assessed the effects of a relatively simple intervention—wearing a wrist actigraph and receiving automated but personalized feedback—on sleep and related outcomes in a high-risk occupational group. Although the multimodal intervention was associated with improved self-reported sleep, it did not directly impact secondary study outcomes (functioning, somatic symptoms, and mental health). Nevertheless, the results suggest that a wrist actigraphy intervention could be a useful and practical tool to help improve sleep, especially among high-risk populations like service members.

The intervention may be particularly useful for soldiers reporting elevated somatic symptoms. In one of the analyses, soldiers who reported higher levels of T1 somatic symptoms reported greater T2 benefit from the actigraph intervention than those reporting low levels of T1 somatic symptoms. This pattern suggests that prioritizing individuals who are at risk for somatic symptoms may be a good way to screen for individuals who would benefit most from the actigraph intervention. However, we are cautious in interpreting this result given that when we examined the somatic symptoms measure including sleep items, the interaction was not significant.

The present study had some limitations. First, it relied on self-reports of sleep and health as outcome measures, introducing possible self-reporting biases. Second, the study compared the actigraph intervention group against a group that only completed surveys. Thus, we recognize the possibility of a placebo effect for those in the actigraph condition, although the null effects on some variables and interaction analyses argue against this interpretation. Third, wearing an actigraph

Table 3
Soldier attitudes toward actigraph and postactigraph sleep report

	Disagree/strongly disagree	Neither agree nor disagree	Agree/strongly agree
Wearing the actigraph watch made me more aware of my own sleep schedule, n (%)	24 (31)	29 (37)	25 (32)
Wearing the actigraph watch made me more aware of how much sleep soldiers in my unit were getting, n (%)	18 (23)	34 (44)	26 (33)
The sleep report was helpful, n (%)	4 (5)	11 (14)	62 (81)
The sleep report has made me more aware of my sleep schedule, n (%)	3 (4)	10 (13)	65 (83)
The sleep report has motivated me to improve my sleep habits, n (%)	5 (6)	27 (35)	46 (59)
The sleep report identified sleep issues that I can target for improvement, n (%)	6 (8)	24 (31)	48 (62)
The sleep report made me aware of how being sleep deprived impacts my risk of accidents or making serious errors, n (%)	3 (4)	22 (28)	53 (68)

The number of participants that completed a sleep report is n = 78. Item responses may not sum to 78 because of missing data.

and receiving a report were necessarily confounded, as we viewed both elements as essential to the intervention. Accordingly, it is not clear whether both elements are needed for positive effects to emerge. Fourth, although we controlled for potential confounders through propensity score matching, it is possible that some other, unmeasured confounding variable influenced the pattern of results.

Implications and conclusions

Given the promising results of the present study, future research could replicate this study using methods that address some of the limitations. For example, future research could use fully random assignment and disentangle the effects of the different components of the intervention (eg, an actigraph vs an actigraph with a report vs an actigraph with a report and in-person feedback). Such work would shed light on whether commercially available devices can effectively nudge individual behavior or whether devices need to be augmented (with a report, with the cognitive effectiveness data, and/or with personalized feedback). Furthermore, future research could examine whether receiving a more in-depth personalized report can boost the efficacy of the intervention. For example, future research could provide sleep reports that include data normed specifically for the population studied. In the present study, the sleep data were presented relative to norms collected from the larger US population, not from a military sample. Personalizing these results even more through a more closely matched comparison group might improve their perceived relevance. Finally, it would be useful to test this intervention with a group that has diagnosed sleep problems.

This study also expands the understanding of behavior change using nudges. Although there is a growing body of evidence on the effectiveness of nudges for improving a range of health-related behaviors,[11] the present study suggests that sleep-related problems may be included in this list of behavioral targets. The multimodal feedback provided here started with the importance of personal awareness and included the “so what” factor in terms of cognitive effectiveness. There may be ways to enhance the impact of that awareness. For example, the fact that the feedback was compiled automatically may have heightened its perceived objectivity and validity. Similarly, the personalized nature of the report and particularly its implications for something that likely mattered to participants—cognitive functioning—may have led them to pay particular attention. Estimates of cognitive functioning based on an algorithm were provided in an easy-to-read colored graph that could highlight when someone was likely to perform at their best. Given that personal readiness is highly valued in this specific work culture, linking sleep habits to cognitive functioning may have been particularly effective for alerting individuals to the relevance of one specific health-related behavior (ie, sleep). In addition, the personalized report provided norms for the purpose of comparison. Although derived from the general population, these norms may have nevertheless provided a sense of what is appropriate and may have motivated individuals to change their own behavior.[38] One way to extend the impact of this normative information would be to provide actigraph feedback over a longer period of time or for an organizational leader to reinforce and endorse it.[39]

The results are encouraging in that they suggest concrete yet simple ways to improve the sleep of large groups of people subject to high levels of risk and stress. The model of personalized feedback tested here may build from people's documented preference for self-management,[40] subtly demonstrating the costs of suboptimal behavior while clearly providing recommendations for change.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.sleh.2017.01.001.

Disclosure

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