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Evaluating the impact of a sleep health education and a personalised smartphone application on sleep, productivity and healthcare utilisation among employees: results of a randomised clinical trial

Rebecca Robbins ,[1,2] Matthew D Weaver ,[1,2] Stuart F Quan ,[1,2] Jason P Sullivan ,[1] Salim Qadri ,[1] Laura Glasner,[3,4] Mairav Cohen-Zion ,[4] Charles A Czeisler ,[1,2] Laura K Barger [1,2]

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For numbered affiliations see end of article.

Correspondence to
Dr Rebecca Robbins;
rrobbins4@bwh.harvard.edu

ABSTRACT

Objectives We evaluated an online Sleep Health and Wellness (SHAW) programme paired with dayzz, a personalised sleep training programme deployed via smartphone application (dayzz app) that promotes healthy sleep and treatment for sleep disorders, among employees at a large healthcare organisation.

Design Open-label, randomised, parallel-group controlled trial.

Setting A healthcare employer in the USA.

Participants 1355 daytime workers.

Intervention Participants were randomised to intervention (n=794) or control (n=561) on consent. Intervention participants received the SHAW educational programme at baseline plus access to the personalised dayzz app for up to 9 months. The control condition received the intervention at month 10.

Primary and secondary outcome measures Our primary outcome measures were sleep-related behavioural changes (eg, consistent sleep schedule); sleep behaviour tracked on an electronic sleep diary and sleep quality. Our secondary outcome measures included employee absenteeism, performance and productivity; stress, mood, alertness and energy; and adverse health and safety outcomes (eg, accidents).

Results At follow-up, employees in the intervention condition were more likely to report increased sleep duration on work (7.20 vs 6.99, p=0.01) and on free (8.26 vs 8.04, p=0.03) nights. At follow-up, the prevalence of poor sleep quality was lower in the intervention (n=160 of 321, 50%) compared with control (n=184 of 327, 56%) (p=0.04). The mean total dollars lost per person per month due to reduced workplace performance (presenteeism) was less in the intervention condition (US$1090 vs US$1321, p=0.001). Employees in the intervention reported fewer mental health visits (RR 0.72, 95% CI 0.56 to 0.94, p=0.01) and lower healthcare utilisation over the study interval (RR 0.81, 95% CI 0.67 to 0.98, p=0.03). We did not observe differences in stress (4.7 (95% CI 4.6 to 4.8) vs 4.7 (95% CI 4.6 to 4.8)), mood (4.5 (95% CI 4.4 to 4.6) vs 4.6 (95% CI 4.5 to 4.7)), alertness (4.9 (95% CI 4.8 to 5.0) vs 5.0 (95% CI 4.9 to 5.1)) or adverse health and safety outcomes (motor vehicle crashes: OR 0.82 (95% CI 0.34 to 1.9); near-miss crashes: OR=0.89 (95% CI 0.5 to 1.5) and injuries: 0.9 (95% CI 0.6 to 1.3)); energy was higher at follow-up in the intervention group (4.3 vs 4.5; p=0.03).

Conclusions Results from this trial demonstrate that a SHAW programme followed by access to the digital dayzz app can be beneficial to both the employee and employer.

Trial registration number NCT04224285

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ We conducted a unique randomised controlled trial to evaluate a sleep health-focused educational wellness programme coupled with access to the dayzz digital health app to support ongoing behavioural change among daytime employees at a large employer in the healthcare industry in the US Northeast.

⇒ The trial evaluated outcomes of the intervention (sleep health education plus access to the dayzz digital health app) on employee health as well as measures of workplace performance and productivity (eg, presenteeism and absenteeism).

⇒ The dayzz app delivers personalised 'just-in-time' messages to support ongoing sleep health behavioural changes after receiving the educational programme.

⇒ Limitations of this trial include that the participants were recruited from a single employer; several outcomes are self-reported; eligible participants reported owning smartphone and regularly using smartphone apps; and dropouts were higher in the intervention condition than in the control condition.

INTRODUCTION

Seventy per cent of adults in the USA admit routinely obtaining insufficient sleep (less than the recommended 7 hours minimum).[1 2]

Additionally, sleep disorders are very common. Approximately 50–70 million adults in the USA are at risk for a sleep disorder,[3] with 30%–40% of employees screening positive for at least one common sleep disorder.[4–7] Moreover, approximately 85% of those at risk for a sleep disorder are undiagnosed and untreated.[4 8]

Sleep deficiency and/or untreated sleep disorders are associated with significant consequences for employee health. Specifically, insufficient sleep is associated with an increased risk for hypertension,[9 10] obesity,[9 11] type II diabetes[12] and cancer.[13] Also, insufficient sleep among employees carries a significant burden in terms of workplace outcomes, including lower productivity[14] and greater absenteeism.[15] The worldwide social and economic burden of undiagnosed and untreated sleep disorders on employees, employers and the healthcare system is staggering. According to the WHO, insomnia is responsible for 3.6 million disability-adjusted life-years lost per year worldwide, representing the 11th highest global burden among all mental, neurological and substance use disorders.[16] In Germany, the direct and indirect costs for insomnia are as high as €40–€50 billion annually[17] whereas in France, the total costs of workplace loss per employee are estimated at €1139.[18] In the USA, the direct and indirect costs attributed to insomnia are approximately US$150 billion per year due to lost work productivity, absenteeism and healthcare utilisation,[19] while the absolute cost of insufficient sleep is estimated to be almost three times as much, US$$411 billion per year (2.23% in GDP (Gross Domestic Product) terms) and growing annually.[20] People with obstructive sleep apnoea (OSA), another common sleep disorder with serious health implications, are 10 times more likely to suffer from reduced productivity and increased illness and healthcare costs.[21] They are also at a much higher risk for work and motor crashes, which increase the potential for workplace disability and liability.[5 22–24] Researchers found that treating employees with sleep apnoea is associated with significant cost savings totaling on average US$6000 over 2 years in terms of reduced healthcare and disability-related costs.[25]

Workplace-based health programmes hold promise for improving employee health and workplace outcomes, yet research on the effectiveness of such programmes has found mixed results.[26–28] Recent randomised controlled trials that did not prioritise sleep found that behavioural change resulting from the wellness programmes was not followed by improved downstream health, healthcare utilisation or workplace productivity.[27 28] However, previous research has shown that when sleep is prioritised, workplace health programmes can be effective for improving employee sleep, overall health and workplace outcomes. In a randomised controlled trial of an in-person sleep education and sleep disorders screening intervention, researchers found that there was a significant reduction in injuries and disability day usage.[8] Further, among employees at a national trucking company, diagnosing and treating the sleep disorder sleep apnoea through an employer-sponsored programme was associated with significant savings in terms of reduced healthcare costs.[29]

Despite the importance of sufficient sleep and overall sleep health for workplace productivity as well as employee health and safety, nationally representative data collected among US employers shows that fewer than 10% of employers report that they provide sleep-focused programmes for their employees, yet nearly one-third report nutrition or exercise programming for employees.[30] There is a need for more research on sleep-focused workplace wellness programmes and technologies (eg, smartphone applications, apps) have the potential to increase the reach and impact of such programmes due to their capabilities, such as the ability to sense a user's location and deliver personalised messages.[31 32] We conducted a randomised controlled trial evaluating the impact of a Sleep Health and Wellness (SHAW) programme combined with access to a smartphone app ('dayzz') on employee sleep (eg, sleep duration, sleep health behavioural changes); workplace outcomes (eg, employee presenteeism, absenteeism and performance) and healthcare utilisation (eg, mental health, ambulatory visits and emergency room visits).

METHODS

Study design

As described in detail elsewhere,[33] we conducted an open-label, randomised, parallel-group remote clinical trial using a waitlist control design among daytime employees at a large healthcare organisation in the Northeast USA. The study recruitment was originally intended to be conducted in-person. However, due to the onset of the COVID-19 pandemic at the start of study implementation, recruitment, enrolment, randomisation, baseline and follow-up procedures were redesigned and completed entirely online. Researchers were blinded to study group allocation and there was no interaction with study participants other than to facilitate payment for study incentives for both groups. The statistical analysis was conducted without knowledge of group allocation.

Eligible participants were daytime workers and were recruited remotely via system-wide emails to the >40 000 member organisation. An advertisement for the study was also posted on a website hosted by the organisation devoted to recruitment for research studies, with a wide circulation (>10 000 visitors monthly) and targeted social media advertisements were commissioned to individuals who reported the organisation as their primary employer on Facebook and LinkedIn.

Potential participants were directed to an online landing page with more information about the study. An online screener was administered which automatically scored responses to determine eligibility according to the study inclusion/exclusion criteria. Eligible participants received a message inviting them to provide consent and complete the baseline

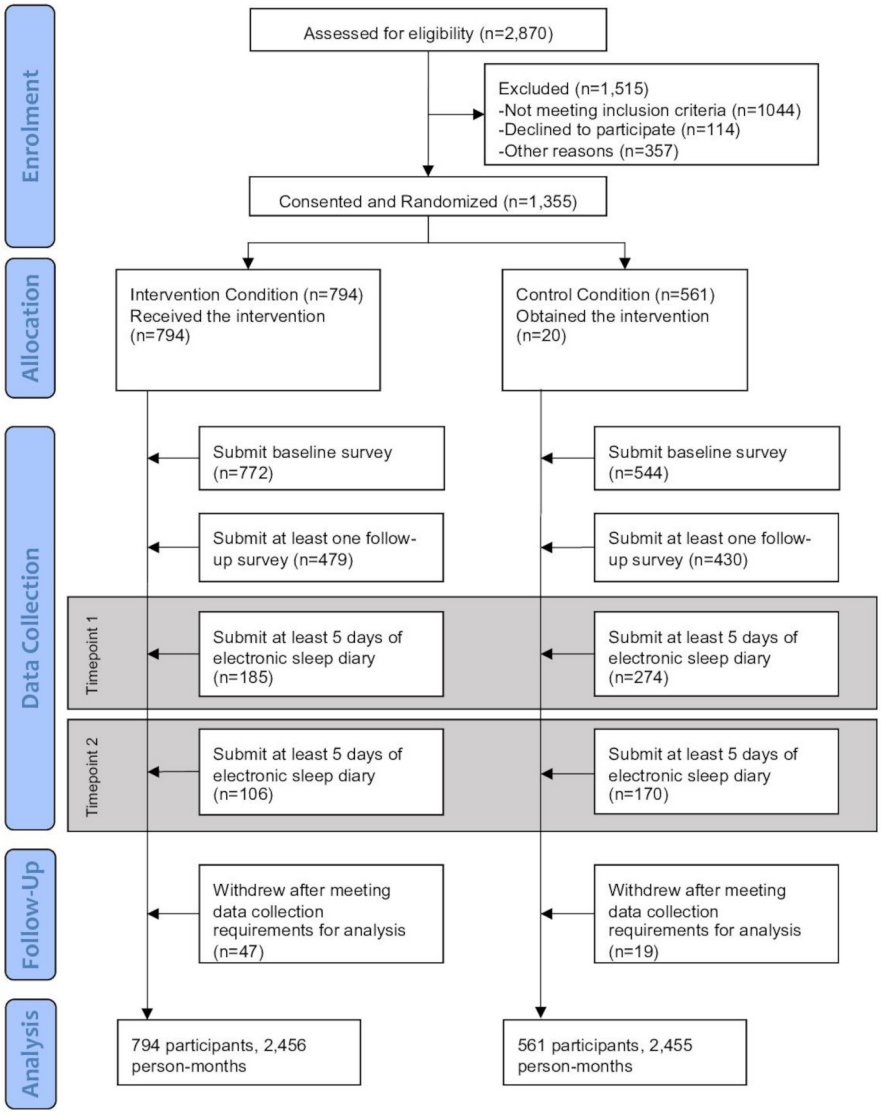

Figure 1 Flow chart of study procedures.

procedure. Ineligible participants received a message indicating they were not eligible.

Consent was collected via electronic signature. After providing electronic consent via the online landing page, a random number generator built into the study webpage randomised participants to either the control or intervention. Because additional steps (eg, downloading the app, viewing a sleep health educational video) were required in the intervention condition, we employed an adaptive randomisation strategy whereby the likelihood of being assigned to the intervention condition was approximately 1.3–1 to ensure that sufficient participants were recruited in each condition (figure 1). Reporting followed Consolidated Standards of Reporting Trials guidelines.[34]

Intervention: a SHAW programme plus access to a personalised digital health app (dayzz)

After randomisation, participants assigned to the intervention condition received the online SHAW programme, which included a 20 min sleep educational programme. The SHAW programme covered topics including (A) the problem of insufficient sleep in our society; (B) research on sleep and its relationship to a variety of domains of health, performance and safety; and (C) tips and strategies on how to improve sleep. Then, as part of the SHAW programme, participants received a screener for common sleep disorders. Those that screened positive for OSA, restless leg syndrome or shiftwork disorder received a referral to an accredited sleep clinic to facilitate further evaluation and treatment, as appropriate.

After completing the online SHAW programme, participants in the intervention condition received information on how to access the personalised digital health app on their mobile device. To prevent contamination, the personalised digital health app was password protected. The password was only provided to intervention participants on the download page. The control condition participants were offered the intervention (SHAW plus dayzz) at the end of the study.

The dayzz personalized app begins with a brief onboarding and registration process. Users may elect

to connect a personal (not provided by the study) wearable device (eg, Fitbit) or a digital health data platform (eg, Apple Health), that is then streamed directly into the app, or manually entered by the user using the app's sleep tracker. Based on the user's sleep assessment outcome and available sleep and behavioural data, the dayzz app offered each user a personalised sleep training programme through a combination of tailored modules to deliver evidence-based therapies for the specific sleep issue(s) users reported. In the case of users at risk for sleep disorders, participants received modules that provided messages to help navigate the user toward recommended care. All users received modules covering basic sleep hygiene principles and tools, such as bedroom environment optimisation (integrating smartphone noise and light sensors), white noise audios and written or auditory content to promote sleep health. Modules were dynamic and modified based on user's engagement level, sleep and behaviour patterns, and programme progress. The dayzz app used just-in-time adaptive intervention mechanisms to deliver treatment content at targeted times. Screenshots of the digital health app can be found in online supplemental file, and details of the dayzz app functionality can be found elsewhere.[35]

Outcomes

All participants were asked to complete baseline, monthly and end-of-study questionnaires; as well as a detailed daily sleep diary for consecutive weeks at two separate time points near the beginning and again near the end of the study interval. We evaluated changes in sleep behaviours on the monthly and end-of-study questionnaire using a checklist that asked participants to select the healthy sleep changes they have made since starting the study. Specifically, participants were asked 'During this study, have you changed any sleep-related behaviours to improve your sleep since participating in the study (check all that apply)?' Participants had the option to select changes they may have made, such as 'Go to bed earlier,' 'Keep a more consistent sleeping schedule' and 'Set an alarm to remind you of your bedtime'.

Participants were also asked to self-report their sleep duration and timing on the sleep diary. The Sleep Regularity Index (SRI), percentage probability of an individual being in the same state (asleep vs awake) at any two time points 24 hours apart, was calculated and averaged across each sleep diary interval.[36] An individual who sleeps and wakes at exactly the same times each day scores 100 (better outcome), whereas an individual who sleeps and wakes at random scores 0 (worse outcome).

Participants also reported their sleep quality using the Pittsburgh Sleep Quality Index (PSQI) on the baseline, monthly and end-of-study questionnaires.[37] The PSQI differentiates 'poor' from 'good' sleep by measuring seven domains: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction over the last month. The participant self-rated each of these seven areas of sleep.

Absenteeism, performance and productivity were evaluated using the WHO Health and Work Performance Questionnaire Short Form (HPQ).[14] Participants were asked the number of hours worked in a typical week. The HPQ asks participants to report their absence from work (absenteeism) in terms of days and their relative performance at work (presenteeism) on a 0–100 scale each month, where 100 is the level of a top worker and 0 is no work at all. Participant salary information is then used to convert absenteeism and presenteeism into cost estimates based on work time lost.[38]

Mood, alertness and energy were assessed on the sleep diary by asking participants to report, using 100 mm Visual Analogue Scales, their: (1) mood from 'sad' (0) to 'happy' (100); their (2) alertness from 'sleepy' (0) to 'alert' (100) and (3) energy from 'sluggish' (0) to 'energetic' (100). Higher scores indicated a better outcome. On the monthly questionnaires, we also assessed mood on a 7-point scale from 'very poor' (0) to 'very good' (7), alertness from 'very poor' (0) to 'very good' (7) and energy from 'very low' to 'very high' (7).

Healthcare utilisation was assessed monthly using a modified version of a validated scale.[39] The scale was updated to include specific visits more likely to occur in our study, such as home or laboratory sleep studies. Participants reported interactions with the healthcare system, such as visits to the emergency room or urgent care, or to their primary care or mental health providers. The total number of each type of visit was calculated over the study interval.

Motor vehicle crashes and near-crashes were captured via self-report on the monthly questionnaire, consistent with previous studies.[5 40] Participants were asked, 'In the last month, did you have any motor vehicle accidents or crashes (actual collisions) in which you were driving,' and 'In the last month, did you have any near miss motor vehicle accidents or crashes (narrowly avoided property damage or bodily harm) in which you were driving.' Participants who responded yes were be asked to provide the number of times that each outcome occurred during the month. We also assessed injuries by asking participants 'In the last month, how many injuries did you have' and attentional failures by asking participants the number of times they 'Nodded off or fell asleep during meetings at work,' '…on the telephone,' '…while driving,' and '…while stopped in traffic.'

Finally, feasibility and acceptability were assessed on the end-of-study questionnaire. Participants in the intervention condition only were asked 'Did the study app provide helpful information?' 'Would you recommend the study app to others?' and 'Did you find the study app easy to use?' on scales from 1 'not at all' to 7 'very much so' Adverse events were captured across the study duration, from baseline through 10 months follow-up.

Sample size calculation

The power analysis was performed prior to study recruitment. We estimated that a cohort of 1000 active participants would provide sufficient data for comparison (500 in each arm of the protocol). Power was estimated for each of the aims using GPower V.3.1.9.4. A sample size of 500 in each group enabled us to detect an effect size of 0.16 between the groups, roughly translating to a relative risk of 1.20. In anticipation of potential attrition, we noted this sample size would still be able to detect a small difference in effect size if we enrolled at least 600 participants.

Statistical analysis

Analyses were conducted using an intention-to-treat approach (ITT). Outcome measures were compared by assignment to the intervention and waitlist control conditions. The ITT analysis included all participants randomised in the study. Due to variability in study start date and study duration depending on the date of enrollment, baseline to follow-up comparisons were conducted using the first available datapoint (96% reported in month 1 or month 2) and the mean responses from months 7–9. The distribution of the data was examined. No transformations were necessary for the comparisons reported in this paper.

The odds of changing sleep behaviours each month relative to the start of the study were tested using mixed effects logistic regression models. Sleep quality was assessed using the PSQI. We examined sleep duration, PSQI score, mood, alertness and energy, respectively, at baseline (first submitted survey) and follow-up (the mean of submitted values in months 7–9) in both conditions using two-sample t-tests. We compared the mean total costs of absenteeism and presenteeism over the study interval using two-sample t-tests.

We compared monthly utilisation of the healthcare system and the incidence of crashes, near-crashes and injuries between conditions using mixed models that accounted for the dependence between repeated measures. The relative risk of each type of visit were compared using mixed models. An incidence rate ratio for all visits was constructed between conditions using a Poisson distribution in a mixed model that accounted for repeated measures. We computed mean responses to the feasibility questions among intervention participants on the end-of-study questionnaire. An overall mean above the scale midpoint (4) on the feasibility questions was used to determine that the app is feasible and accessible.[41] Finally, to consider the impact of missingness on the results we conducted sensitivity analyses that restricted the study population to those that completed at least three surveys for primary outcomes that relied on monthly reports. Alpha was set at 0.05 for all comparisons. Stata V.15.1 was used to conduct the statistical analysis.

Patient and public involvement

None.

RESULTS

The final cohort was composed of 794 participants assigned to the intervention condition and 561 assigned to the control condition. A total of 1355 individuals completed 4911 surveys over the study interval. The number of control condition participant surveys (n=2455) and intervention condition surveys (2,456) was similar. With respect to the SRI analyses, there were 459 participants who provided sufficient responses to the daily diaries at timepoint 1 (185 in the intervention and 274 in the control). There were 276 participants who provided sufficient responses to the daily diaries at timepoint 2 (106 in the intervention and 170 in the control). Demographic characteristics of the study sample are reported in table 1.

Changes in self-reported sleep behaviours

Overall, 39% (1424 of 3637) of participant-months reported less fatigue or sleepiness, 62% (2207 of 3540) of participant-months reported increased sleep consistency, 42% (1497 of 3540) reported increased sleep duration and 39% (1386 of 3540) reported sleeping in later. The intervention condition was 30% more likely to feel less fatigued or sleepy (OR 1.30; 95% CI 1.08 to 1.57). They were approximately 40% more likely to report increased sleep consistency (OR 1.40; 95% CI 1.12 to 1.75) and sleep duration (OR 1.44; 95% CI 1.17 to 1.78). There was no difference between conditions in the odds of sleeping in later (p=0.58, figure 2).

Changes in self-reported sleep duration

Overall, the mean hours of sleep for the study population at baseline was 6.59 hours (SD=1.22) on workdays and 7.73 hours (SD=1.75) free days. The mean hours of sleep at baseline did not differ between the intervention and control conditions on workdays (intervention: 6.59 (95% CI 6.49 to 6.69); control: 6.60 (95% CI 6.49 to 6.71), p=0.91) or free days (intervention: 7.70 (95% CI 7.55 to 7.85); control: 7.76 (95% CI 7.61 to 7.91), p=0.57). At follow-up assessment, the intervention condition reported significantly more sleep than the control condition, both on work nights (intervention: 7.20 (95% CI 7.08 to 7.33); control: 6.99 (95% CI 6.89 to 7.09), p=0.01) and on free nights (intervention: 8.26 (95% CI 8.11 to 8.42); control: 8.04 (95% CI 7.91 to 8.16), p=0.03, figure 3A,B).

Changes in sleep quality

The mean PSQI score at baseline in the intervention condition was 6.83 (95% C: 6.53 to 7.12), while the mean PSQI in the control condition was 6.97 (95% CI 6.65 to 7.28). The conditions did not significantly differ at baseline (p=0.52). At follow-up, the mean PSQI score in the intervention condition was 5.12 (95% CI 4.88 to 5.36), while the mean PSQI in the control condition was 5.52 (95% CI 5.29 to 5.76). Although the mean PSQI improved in both conditions, the mean PSQI was significantly lower at follow-up assessment in the intervention condition compared with the control condition (p=0.02).

Table 1 Demographic characteristics of the study sample (n=1355)

Baseline characteristics	Intervention condition n=794	Control condition n=561
Age mean (SD)	36 (11)	35 (11)
Female gender n (%)	635 (80)	453 (81)
Missing	36 (5)	25 (4)
Race n (%)		
White	525 (66)	378 (67)
Asian	69 (9)	46 (8)
Black or African American	121 (15)	66 (12)
Native Hawaiian or other Pacific Islander	4 (1)	4 (1)
American Indian or Alaskan Native	6 (1)	6 (1)
Other or Multiple Races	43 (5)	37 (7)
Missing	26 (2)	24 (4)
Ethnicity n (%)		
Hispanic or Latino	89 (11)	59 (11)
Not Hispanic or Latino	676 (85)	481 (86)
Missing	29 (4)	21 (4)
Education n (%)		
High school	89 (11)	42 (7)
College	406 (51)	297 (53)
Graduate school	273 (34)	204 (36)
Missing	26 (3)	18 (3)
Income		
Less than US$35 000	157 (20)	108 (19)
US$35 000–US$54 999	232 (29)	163 (29)
US$55 000–US$74 999	130 (16)	104 (19)
US$75 000–US$99 999	114 (14)	69 (12)
US$100 000–US$149 999	92 (12)	56 (10)
US$150 000–US$199 999	24 (3)	22 (4)
US$200 000 or more	18 (2)	20 (4)
Missing	27 (3)	19 (3)
Job type condensed		
Research	153 (19)	105 (19)
Healthcare	281 (35)	205 (37)
Other	336 (42)	234 (42)
Missing	24 (3)	17 (3)
Current diagnosis of:		
Insomnia	42 (7)	37 (7)
Obstructive sleep apnoea	24 (4)	20 (4)
Diabetes	15 (2)	15 (3)
Hypertension	35 (6)	25 (5)
Depression	76 (12)	78 (15)
Anxiety disorder	80 (13)	101 (19)
Missing	177 (22)	28 (5)
Self-reported health n (%)		
Excellent	123 (15)	107 (19)
Very good	234 (29)	230 (41)

Continued

Table 1 Continued

Baseline characteristics	Intervention condition n=794	Control condition n=561
Good	210 (26)	160 (29)
Fair	52 (7)	40 (7)
Poor	3 (0)	1 (0)
Missing	172 (22)	23 (4)
Epworth Sleepiness Scale	6.3 (4.5)	6.2 (4.2)
PSQI score	6.8 (3.6)	7.0 (3.6)
Screening results (n=2870)		
Insomnia	267 (38)	N/A
Obstructive sleep apnoea	158 (22)	N/A
Restless legs syndrome	63 (9)	N/A

Responses were optional. Missing data are listed in a row for each variable.
The Epworth Sleepiness Scale is a validated assessment of sleepiness.[47]
N/A, not available; PSQI, Pittsburgh Sleep Quality Index.

The prevalence of poor sleep quality at baseline (PSQI ≥5) was 59% (n=349 of 587) in the intervention condition compared with 62% (n=307 of 497) in the control condition (p=0.42). At follow-up, the prevalence of poor sleep quality was significantly lower in the intervention condition (50%) (n=160 of 321) compared with the control condition (56%) (n=184 of 327) (p=0.04). The odds of poor sleep quality at follow-up were significantly reduced by 21% in the intervention condition (OR 0.79, 95% CI 0.63 to 0.98, figure 3C).

Changes in sleep diary-derived sleep regularity

Using the sleep diary data, the SRI was similar at baseline (mean: 75, 95% CI 74 to 77 in the intervention compared with a mean of 75 (95% CI 73 to 77 in the control condition; p=0.99 between groups). On follow-up, the mean SRI increased to 78 (95% CI 76 to 81) in the intervention condition and stayed at 75 (95% CI 73 to 77) in the control condition (p=0.06 between groups at follow-up, figure 4).

Changes in presenteeism and absenteeism

The mean total dollars lost per participant per month from absenteeism and presenteeism were calculated for each participant over the study interval. The mean total dollars lost per person per month due to absenteeism was similar in the intervention compared with the control condition (US$478, 95% CI: US$396 to US$561 vs US$475, 95% CI US$370 to US$579) (p=0.96). The mean total dollars lost per person per month due to reduced workplace performance (presenteeism) was less in the intervention condition (US$1090, 95% CI: US$1007 to US$1172) compared with the control condition (US$1321, 95% CI: US$1215 to US$1428) (p=0.001, see figure 5). The cumulative total

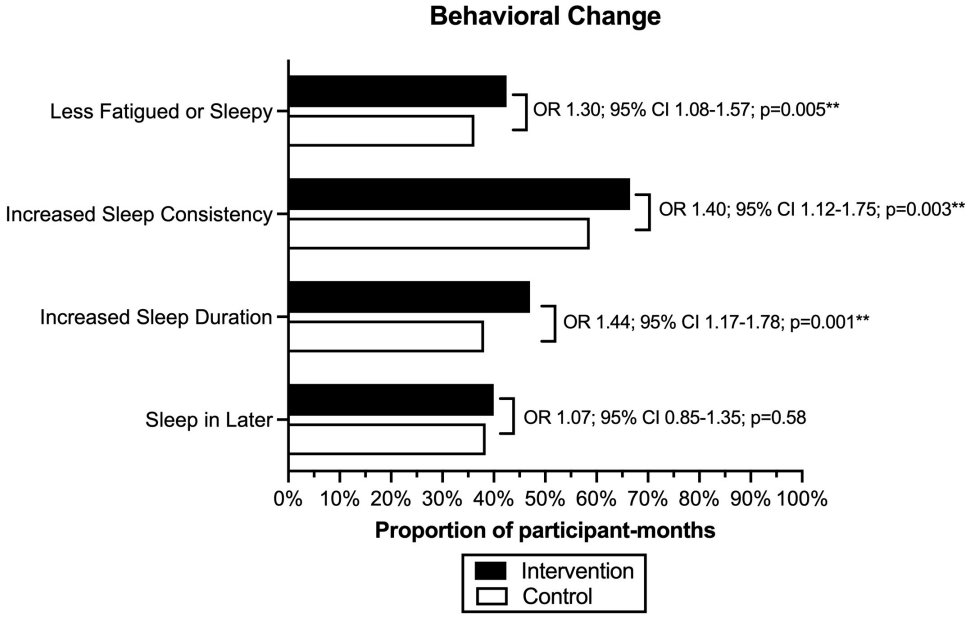

Figure 2 Self-reported sleep behavioural changes during the study between intervention and control conditions.

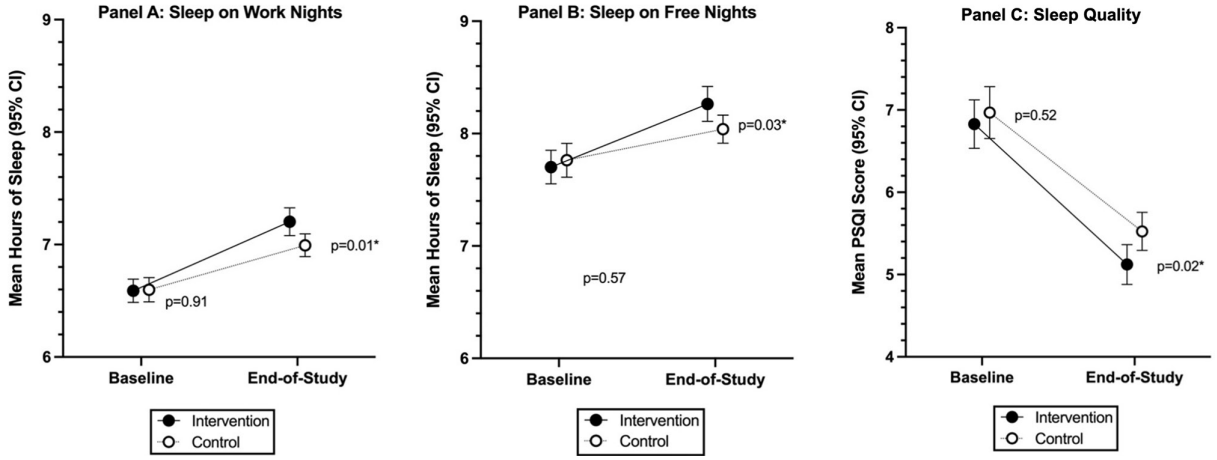

Figure 3 Changes to self-reported sleep duration during the study between intervention and control conditions. A higher PSQI score indicates worse sleep quality. PSQI, Pittsburgh Sleep Quality Index. Note: *p<0.05.

lost due to presenteeism in the control condition was 3.24 (95% CI US$2.98 to US$3.51) million US dollars, compared with 2.68 (95% CI: USD$2.47 to USD$2.88) million dollars in the intervention condition, for a savings of approximately US$567 000 in presenteeism across the study interval.

Changes in healthcare utilisation

Healthcare utilisation in the intervention condition was similar to the control condition for most common complaints (figure 6). However, we observed a significant reduction in the relative risk of at least one mental health visit (RR 0.72, 95% CI 0.56 to 0.94, p=0.01) and a reduction in the rate of overall healthcare utilisation (RR 0.81, 95% CI 0.67 to 0.98, p=0.03) among those assigned to the intervention condition compared with those assigned to the control condition.

Stress, mood, alertness and energy

Stress, mood, alertness and energy were not statistically different between the groups at baseline. At follow-up, the groups remained similar in assessments of stress (control 4.7, 95% CI 4.6 to 4.8 vs intervention 4.7, 95% CI 4.6 to 4.8), mood (control 4.5, 95% CI 4.4 to 4.6 vs intervention 4.6, 95% CI 4.5 to 4.7) and alertness (control 4.9, 95% CI 4.8 to 5.0 vs intervention 5.0, 95% CI 4.9 to 5.1). The intervention group reported a higher mean value for

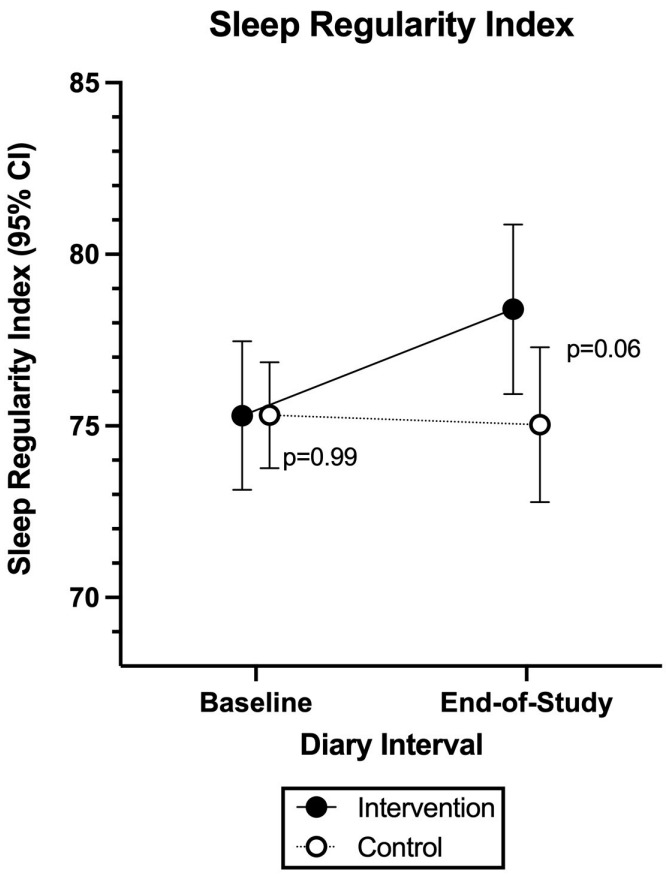

Figure 4 Changes in the Sleep Regularity Index during the study between intervention and control conditions.

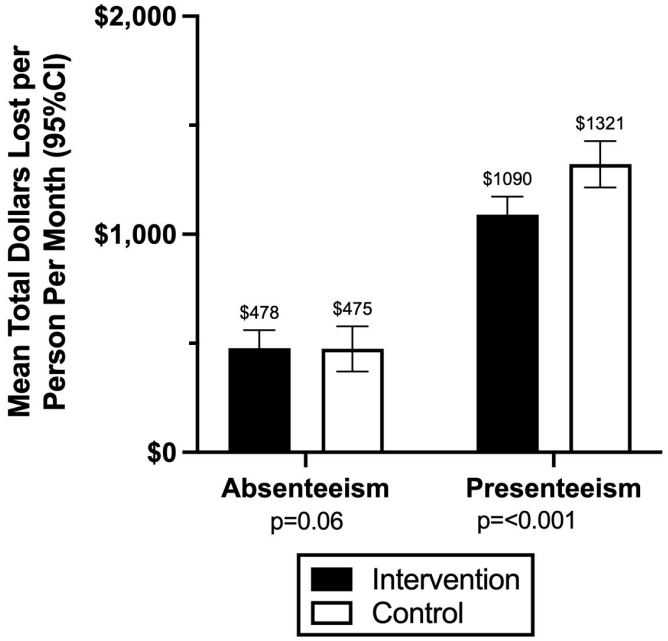

Figure 5 Changes in absenteeism and presenteeism during the study between intervention and control conditions.

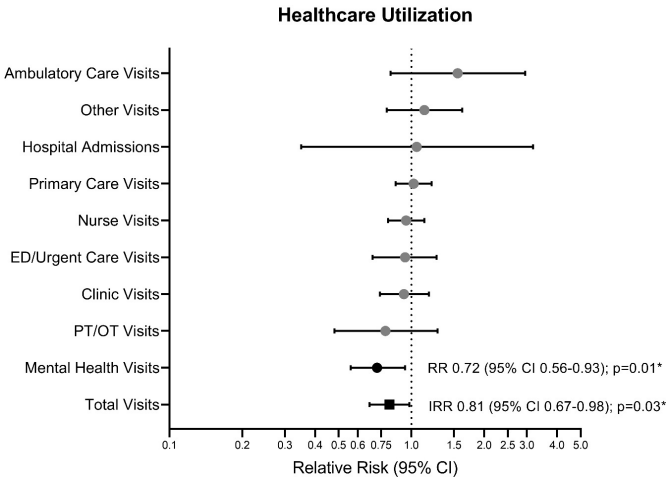

Figure 6 Changes in healthcare utilisation during the study between intervention and control conditions. Left indicates either fewer healthcare visits or total utilisation. PT/OT, Physical Therapy/Occupational Therapy. Notes: *p<0.05.

energy at follow-up ((control 4.3, 95% CI 4.2 to 4.4 vs intervention 4.5, 95% CI 4.3 to 4.6); p=0.03).

Adverse health and safety outcomes

No difference was observed in the rate of adverse safety outcomes. The rate of motor vehicle crashes was 5.6 per 1000 person-months in the control group and 4.6 per 1000 person-months in the intervention group (p=0.99). The rate of near-miss crashes was 49.7 per 1000 person-months in the control group and 36.2 per 1000 person-months in the intervention group (p=0.19). The rate of injuries was 41.4 per 1000 person-months in the control group and 37.8 per 1000 person-months in the intervention group (p=0.57).

Feasibility and acceptability

Responses to questions assessing feasibility were all above the scale midpoint (4). Specifically, the average response to usefulness of the app was 4.5-point on a 7-point scale (SD=1.8), responses to likelihood of recommending the app to another person was 4.6 on a 7-point scale (SD=2.0), and response to the app's ease of use was a 4.9 on a 7-point scale (SD=1.9).

Adverse events

No adverse events were reported by participants in this study.

Sensitivity analyses

We conducted sensitivity analyses for outcomes relying on monthly reports that restricted the study population to those that completed at least 3 monthly surveys. In this subset of participants, our findings related to fatigue/sleepiness, sleep consistency, sleep duration and sleeping later were the same as found for the entire study population.

DISCUSSION

This randomised clinical trial implemented at a large healthcare organisation found that a sleep health education programme, followed by ongoing access to a personalised digital health tool demonstrated several favourable outcomes on employee sleep and health, workplace productivity and employee healthcare utilisation. Specifically, those randomly assigned to the intervention condition self-reported an increase in healthy sleep behavioural changes (ie, more sleep consistency, and increased sleep duration). Also, according to the daily sleep diary, participants in the intervention condition demonstrated improved sleep quality and longer sleep duration at the end of the study. Regarding workplace outcomes, those in the intervention condition also reported significantly lower presenteeism compared with the control condition. We observed lower healthcare utilisation (fewer mental health visits, specifically and fewer total healthcare visits, broadly) in the intervention condition. Finally, we did not detect significant differences in mood or adverse health and safety outcomes between the intervention and control conditions.

The finding observed in our trial of behavioural change as well as improvements in measures of workplace productivity and reduced healthcare costs contrast with a cluster randomised trial evaluating a workplace health programme targeting a variety of health behaviours delivered to randomly selected worksites across a large retailer (>32 000 employees) that found no effect of the intervention on economic outcomes.[27] Our findings also contrast with a randomised controlled trial evaluating a 'comprehensive' employee health programme that addressed a variety of health behaviours (eg, physical activity, nutrition) and was delivered to more than 4000 employees at a large university that did not find improvements in measured health outcomes or healthcare costs.[28] A review of more than 100 studies also found little evidence for the efficacy of such programmes, which authors attributed to heterogeneity in study designs and intervention duration.[26] These findings, taken together, could beg the question: are workplace-based health programmes worthwhile? However, 90% of workplace programmes to date have lacked attention to employee sleep.[30] Therefore, a possible explanation for the mixed evidence for workplace wellness programmes to date is the lack of focus on employee sleep, yet sleep health is critical for a variety of favourable employee health and workplace outcomes.[9–11 14 42]

Although sleep-focused workplace wellness programmes are far less prevalent compared with programmes addressing physical activity or nutrition,[30] there has been growing attention to these programmes and their results suggest positive effects on employee sleep. One workplace-based sleep health for police officers in Italy demonstrated an improvement in sleep quality and sleep duration among officers.[43] Another sleep-focused workplace-based programme for employees in Japan showed that exposure to the programme was associated with an increase in sleep duration.[44] Finally, a study that

combined a live sleep education session with follow-up emails demonstrated improvements in employee sleep duration and a reduction in sleep difficulties.[45] Our results contribute to the literature by evaluating a new and novel approach to sustaining behavioural change, an educational programme combined with an app that provides ongoing personalised health advice. It is possible that our approach, which featured the online SHAW programme coupled with ongoing access to personalised sleep health curricula based on the specific user and their needs that employed just-in-time and machine learning technologies to navigate users toward better sleep health, resulted in sustained change over the study interval. Many workplace health programmes feature education alone without additional features to increase adherence to recommended health behaviours and a sleep disorder care regimen.[46] Therefore, a significant strength of this study is the use of a digital app for delivering ongoing support for sleep health and sleep disorders care. Access to the personalised digital app following exposure to the SHAW programme may have allowed for the sustained improvement on self-reported behaviours, actual behaviours, and economic outcomes that were observed in our study. Finally, responses to questions assessing feasibility and acceptability of the digital health app were all above the midpoint, suggesting likability and usability of this component of the intervention.

With respect to clinical significance, the approach outlined in this trial of a sleep health education session followed by ongoing access to a digital health coach, demonstrated improvement in sleep-related outcomes, but also on other compelling outcomes such as presenteeism and healthcare utilisation, thereby suggesting that the intervention is a viable approach for improving sleep, but also possibly productivity and general health and well-being among workers.

The cost of sleep insufficient and untreated sleep disorders in the workplace is staggering.[17 19 20] Despite a growing number of studies evaluating the financial impact of sleep and sleep disorders, there's a paucity of evidence regarding the utility of a workplace wellness programme focused on sleep improvement for addressing these social and economic costs. Our study offers a validated assessment of the cost-effective benefits resulting from a SHAW programme coupled with access to a tailored, digitally enabled and highly personalised smartphone app (dayzz).

LIMITATIONS

This study has several limitations. First, the participants recruited in our trial were affiliated with a single employer. Though the occupational roles in our sample were diverse, our results may not generalise to other employee or employer populations. Moreover, access to a smartphone and regular use of smartphone apps was a requirement for study participation. It is possible that this study did not include low wage workers in the employee population without access to these resources, which limits the generalisation of our findings. Another limitation of our findings is that we only included day workers in this study. Shift workers have well-documented barriers to healthy sleep and increased burden of untreated sleep disorders. Future research is needed to determine the feasibility of this intervention for those employee groups. Further, the pandemic offered greater flexibility of work schedules for many workers. It is worth noting that both groups increased sleep duration during the study interval, which spanned the COVID-19 pandemic, yet employees in the intervention condition increased their sleep to a greater extent than employees in the control condition. The outcomes in this study are subject to several forms of bias, including selection bias and healthy worker bias at study entry, as well as recall or self-reporting bias and social desirability bias throughout data collection. The groups were balanced on known confounders at baseline. The randomised design limits the likelihood of differential misclassification of outcomes throughout the study. Finally, attrition was greater in the intervention group, compared with the control, perhaps due to more initial study requirements, which may have biased the results. Differential attrition was considered in the statistical plan, and the total number of surveys completed between the groups was nearly identical.

CONCLUSION

In summary, this randomised, remote, employee-centred clinical trial demonstrates that a brief, online sleep health education paired with a digital personalised sleep training programme is effective at increasing sleep quality and sleep duration, lowering presenteeism and reducing the rate of healthcare utilisation, presenting a clinical and economic benefit to the employee and employer. Future research may apply the approach taken in this trial to employees on other work schedules, such as shift workers.

Author affiliations
[1]Division of Sleep and Circadian Disorders, Departments of Medicine and Neurology, Brigham and Women's Hospital, Boston, Massachusetts, USA
[2]Division of Sleep Medicine, Harvard Medical School, Boston, Massachusetts, USA
[3]Psychiatric Division, Sheba Medical Center, Tel Hashomer, Israel
[4]dayzz Live Well Ltd, Herzliya, Israel

Twitter Division of Sleep Medicine, Harvard Medical School @HarvardSleepMed

Contributors RR, MDW, SFQ, LKB and CAC, with JPS and SQ, conceptualised the study. MDW conducted the statistical analysis. RR wrote the first draft of the manuscript. MZC and LG provided the manuscript sections detailing the dayzz application. All authors approved the submitted manuscript. LKB is responsible for the finished work, has access to the data, and controlled the decision to publish.

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Competing interests MC-Z and LG are employees at dayzz Live Well. MDW reports consulting fees from the National Sleep Foundation and the University of Pittsburgh. LKB reports consulting fees from the University of Helsinki, the AAA Foundation, Puget Sound Pilots, and Boston Children's Hospital. RR reports consulting fees from SleepCycle AB; Rituals Cosmetics BV; Denihan Hospitality Group; AdventHealth; and With Deep. SFQ has served as a consultant for Best Doctors, the Bryte Foundation, Jazz Pharmaceuticals, and Whispersom. CAC reports grants and contracts to BWH from Dayzz Live Well, Delta Airlines, Jazz Pharma, Puget Sound Pilots, Regeneron Pharmaceuticals/Sanofi; is/was paid consultant/speaker for Inselspital Bern, Institute of Digital Media and Child Development,

Klarman Family Foundation, M.D and Co, National Council for Mental Wellbeing, National Sleep Foundation, Physician's Seal, SRS Foundation, State of Washington Board of Pilotage Commissioners, Tencent, Teva Pharma Australia, With Deep, and Vanda Pharmaceuticals, in which CAC holds an equity interest; received travel support from Aspen Brain Institute, Bloomage International Investment Group, Dr. SH Medical Development Foundation, German National Academy of Sciences, Ludwig-Maximilians-Universität München, National Highway Transportation Safety Administration, National Safety Council, National Sleep Foundation, Salk Institute for Biological Studies/Foundation Ipsen, Society for Research on Biological Rhythms, Stanford Medical School Alumni Association, Tencent Holdings, and Vanda Pharmaceuticals; receives research/education gifts through BWH from Arbor Pharmaceuticals, Avadel Pharmaceuticals, Bryte, Alexandra Drane, Cephalon, DR Capital Ltd, Eisai, Harmony Biosciences, Jazz Pharmaceuticals, Johnson & Johnson, Mary Ann & Stanley Snider via Combined Jewish Philanthropies, NeuroCare, Optum, Philips Respironics, Regeneron, Regional Home Care, ResMed, Resnick Foundation (The Wonderful Company), San Francisco Bar Pilots, Sanofi SA, Schneider, Simmons, Sleep Cycle AB. Sleep Number, Sysco, Teva Pharmaceuticals, Vanda Pharmaceuticals; is/was an expert witness in legal cases, including those involving Advanced Power Technologies, Aegis Chemical Solutions, Amtrak; Casper Sleep Inc, C&J Energy Services, Catapult Energy Services Group, Covenant Testing Technologies, Dallas Police Association, Enterprise Rent-A-Car, Espinal Trucking/Eagle Transport Group/Steel Warehouse Inc, FedEx, Greyhound, Pomerado Hospital/Palomar Health District, PAR Electrical Contractors, Product and Logistics Services/Schlumberger Technology, Puckett EMS, Puget Sound Pilots, Union Pacific Railroad, UPS and Vanda Pharmaceuticals; serves as the incumbent of an endowed professorship given to Harvard by Cephalon; and receives royalties from McGraw Hill and Philips Respironics for the Actiwatch-2 and Actiwatch Spectrum devices. CAC's interests were reviewed and are managed by the Brigham and Women's Hospital and Mass General Brigham in accordance with their conflict-of-interest policies.

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Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. Anonymised study data will be made available on request, consistent with our institution's IRB policies and procedures. Data and supporting documentation will become available 2 years following the primary publication and remain available for 5 years. Interested individuals will be asked to provide a research plan. Requests will be reviewed and granted as appropriate.

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ORCID iDs

Rebecca Robbins http://orcid.org/0000-0003-0288-2505
Matthew D Weaver http://orcid.org/0000-0003-3578-336X
Stuart F Quan http://orcid.org/0000-0002-9474-7679
Jason P Sullivan http://orcid.org/0000-0002-4256-5304
Salim Qadri http://orcid.org/0000-0003-2972-1197
Mairav Cohen-Zion http://orcid.org/0000-0001-8603-6466
Charles A Czeisler http://orcid.org/0000-0002-7408-1849
Laura K Barger http://orcid.org/0000-0001-8547-7331

REFERENCES

1 Watson NF, Badr MS, Consensus Conference Panel, *et al*. Recommended amount of sleep for a healthy adult: a joint consensus statement of the American Academy of sleep medicine and sleep research Society. *J Clin Sleep Med* 2015;11:591–2.
2 Hirshkowitz M, Whiton K, Albert SM, *et al*. National sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health* 2015;1:40–3.
3 Institute of Medicine (US) Committee on Sleep Medicine and Research.Colten HR, Altevogt BM, eds. *Sleep disorders and sleep deprivation: an unmet public health problem*. US: National Academies Press, 2006. http://www.ncbi.nlm.nih.gov/books/NBK19960/
4 Rajaratnam SMW, Barger LK, Lockley SW, *et al*. Sleep disorders, health, and safety in police officers. *JAMA* 2011;306:2567–78.
5 Barger LK, Rajaratnam SMW, Wang W, *et al*. Common sleep disorders increase risk of motor vehicle crashes and adverse health outcomes in firefighters. *J Clin Sleep Med* 2015;11:233–40.
6 Weaver MD, Robbins R, Quan SF, *et al*. Association of sleep disorders with physician burnout. *JAMA Netw Open* 2020;3:e2023256.
7 Weaver MD, Vetter C, Rajaratnam SMW, *et al*. Sleep disorders, depression and anxiety are associated with adverse safety outcomes in healthcare workers: a prospective cohort study. *J Sleep Res* 2018;27:e12722.
8 Sullivan JP, O'Brien CS, Barger LK, *et al*. Randomized, prospective study of the impact of a sleep health program on Firefighter injury and disability. *Sleep* 2017;40. doi:10.1093/sleep/zsw001. [Epub ahead of print: 01 Jan 2017].
9 Buxton OM, Marcelli E. Short and long sleep are positively associated with obesity, diabetes, hypertension, and cardiovascular disease among adults in the United States. *Soc Sci Med* 2010;71:1027–36.
10 Gangwisch JE, Heymsfield SB, Boden-Albala B, *et al*. Short sleep duration as a risk factor for hypertension. *Hypertension* 2006;47:833–9.
11 Gangwisch JE, Malaspina D, Boden-Albala B. Inadequate sleep as a risk factor for obesity: analyses of the NHANES I. *Sleep* 2005;28:1289–96.
12 Cappuccio FP, D'Elia L, Strazzullo P, *et al*. Quantity and quality of sleep and incidence of type 2 diabetes: a systematic review and meta-analysis. *Diabetes Care* 2010;33:414–20.
13 Kakizaki M, Inoue K, Kuriyama S, *et al*. Sleep duration and the risk of prostate cancer: the Ohsaki cohort study. *Br J Cancer* 2008;99:176–8.
14 Kessler RC, Ames M, Hymel PA, *et al*. Using the world Health organization health and work performance questionnaire (HPQ) to evaluate the indirect workplace costs of illness. *J Occup Environ Med* 2004;46:S23–37.
15 Hui S-KA, Grandner MA. Associations between poor sleep quality and stages of change of multiple health behaviors among participants of employee wellness program. *Prev Med Rep* 2015;2:292–9.
16 Collins PY, Patel V, Joestl SS, *et al*. Grand challenges in global mental health. *Nature* 2011;475:27–30.
17 Ebert DD, Zarski A-C, Christensen H, *et al*. Internet and computer-based cognitive behavioral therapy for anxiety and depression in youth: a meta-analysis of randomized controlled outcome trials. *PLoS One* 2015;10:e0119895.
18 Léger D, Guilleminault C, Bader G, *et al*. Medical and socio-professional impact of insomnia. *Sleep* 2002;25:621–5.
19 Reynolds SA, Ebben MR. The cost of insomnia and the benefit of increased access to evidence-based treatment: cognitive behavioral therapy for insomnia. *Sleep Med Clin* 2017;12:39–46.
20 Hafner M, Stepanek M, Taylor J. Why sleep matters — the economic costs of insufficient sleep, 2016. Available: https://www.rand.org/pubs/research_reports/RR1791.html [Accessed 17 Aug 2017].
21 Knauert M, Naik S, Gillespie MB, *et al*. Clinical consequences and economic costs of untreated obstructive sleep apnea syndrome. *World J Otorhinolaryngol Head Neck Surg* 2015;1:17–27.
22 Burks SV, Anderson JE, Bombyk M, *et al*. Nonadherence with Employer-Mandated sleep apnea treatment and increased risk of serious truck crashes. *Sleep* 2016;39:967–75.
23 George CF, Nickerson PW, Hanly PJ, *et al*. Sleep apnoea patients have more automobile accidents. *Lancet* 1987;2:447.
24 Young T, Blustein J, Finn L, *et al*. Sleep-Disordered breathing and motor vehicle accidents in a population-based sample of employed adults. *Sleep* 1997;20:608–13.
25 Hoffman B, Wingenbach DD, Kagey AN, *et al*. The long-term health plan and disability cost benefit of obstructive sleep apnea treatment

in a commercial motor vehicle driver population. *J Occup Environ Med* 2010;52:473–7.
26 Peñalvo JL, Sagastume D, Mertens E, *et al*. Effectiveness of workplace wellness programmes for dietary habits, overweight, and cardiometabolic health: a systematic review and meta-analysis. *Lancet Public Health* 2021;6:e648–60.
27 Song Z, Baicker K. Effect of a workplace wellness program on employee health and economic outcomes: a randomized clinical trial. *JAMA* 2019;321:1491–501.
28 Reif J, Chan D, Jones D, *et al*. Effects of a workplace wellness program on employee health, health beliefs, and medical use: a randomized clinical trial. *JAMA Intern Med* 2020;180:952–60.
29 Burks SV, Anderson JE, Panda B, *et al*. Employer-mandated obstructive sleep apnea treatment and healthcare cost savings among truckers. *Sleep* 2020;43:zsz262.
30 Robbins R, Weaver MD, Quan SF, *et al*. Employee sleep enhancement and fatigue reduction programs: analysis of the 2017 CDC workplace health in America POLL. *Am J Health Promot* 2021;35:503–13.
31 Lupton D. Quantifying the body: monitoring and measuring health in the age of mHealth technologies. *Crit Public Health* 2013;23:393–403.
32 Davis TL, DiClemente R, Prietula M. Taking mHealth forward: examining the core characteristics. *JMIR Mhealth Uhealth* 2016;4:e97.
33 Robbins R, Weaver MD, Quan SF, *et al*. A clinical trial to evaluate the dayzz smartphone APP on employee sleep, health, and productivity at a large US employer. *PLoS One* 2022;17:e0260828.
34 Moher D, Hopewell S, Schulz KF, *et al*. Consort 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. *BMJ* 2010;340:c869.
35 Robbins R, Weaver MD, Quan SF. A clinical trial to evaluate the dayzz smartphone APP on employee sleep, health, and productivity at a large US employer. *medRxiv* 2021.
36 Phillips AJK, Clerx WM, O'Brien CS, *et al*. Irregular sleep/wake patterns are associated with poorer academic performance and delayed circadian and sleep/wake timing. *Sci Rep* 2017;7:1–13.
37 Buysse DJ, Reynolds CF, Monk TH, *et al*. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. *Psychiatry Res* 1989;28:193–213.
38 Bertera RL. The effects of workplace health promotion on absenteeism and employment costs in a large industrial population. *Am J Public Health* 1990;80:1101–5.
39 Lairson DR, Basu R, Begley CE, *et al*. Concordance of survey and billing data in a study of outpatient healthcare cost and utilization among epilepsy patients. *Epilepsy Res* 2009;87:59–69.
40 Barger LK, Cade BE, Ayas NT, *et al*. Extended work shifts and the risk of motor vehicle crashes among interns. *N Engl J Med* 2005;352:125–34.
41 Bangor A, Kortum PT, Miller JT. An empirical evaluation of the system usability scale. *Int J Hum Comput Interact* 2008;24:574–94.
42 Baicker K, Cutler D, Song Z. Workplace wellness programs can generate savings. *Health Aff* 2010;29:304–11.
43 Garbarino S, De Carli F, Nobili L, *et al*. Sleepiness and sleep disorders in shift workers: a study on a group of Italian police officers. *Sleep* 2002;25:648–53.
44 Nakada Y, Sugimoto A, Kadotani H, *et al*. Verification of effect of sleep health education program in workplace: a quasi-randomized controlled trial. *Ind Health* 2018;56:20–9.
45 Montagni I, Dehman A, Yu Z. Effectiveness of a blended web-based intervention to raise sleep awareness at workplace: the WarmUapp™ pilot study. *J Occup Environ Med* 2019;61:e253.
46 Chapman LS. Meta-evaluation of worksite health promotion economic return studies: 2012 update. *Am J Health Promot* 2012;26:1–12.
47 Johns MW, sleepiness D. Snoring, and obstructive sleep apnea: the Epworth Sleepiness scale. *Chest* 1993;103:30–6.