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Effect of Digital Cognitive Behavioral Therapy for Insomnia on Health, Psychological Well-being, and Sleep-Related Quality of Life: A Randomized Clinical Trial

Colin A. Espie, PhD; Richard Emsley, PhD; Simon D. Kyle, PhD; Christopher Gordon, PhD; Christopher L. Drake, PhD; A. Niroshan Siriwardena, PhD; John Cape, PhD; Jason C. Ong, PhD; Bryony Sheaves, DClinPsy; Russell Foster, PhD; Daniel Freeman, PhD; Joan Costa-Font, PhD; Antonia Marsden, PhD; Annemarie I. Luik, PhD

IMPORTANCE Digital cognitive behavioral therapy (dCBT) is a scalable and effective intervention for treating insomnia. Most people with insomnia, however, seek help because of the daytime consequences of poor sleep, which adversely affects quality of life.

OBJECTIVES To investigate the effect of dCBT for insomnia on functional health, psychological well-being, and sleep-related quality of life and to determine whether a reduction in insomnia symptoms was a mediating factor.

DESIGN, SETTING, AND PARTICIPANTS This online, 2-arm, parallel-group randomized trial comparing dCBT for insomnia with sleep hygiene education (SHE) evaluated 1711 participants with self-reported symptoms of insomnia. Participants were recruited between December 1, 2015, and December 1, 2016, and dCBT was delivered using web and/or mobile channels plus treatment as usual; SHE comprised a website and a downloadable booklet plus treatment as usual. Online assessments took place at 0 (baseline), 4 (midtreatment), 8 (posttreatment), and 24 (follow-up) weeks. Programs were completed within 12 weeks after inclusion.

MAIN OUTCOMES AND MEASURES Primary outcomes were scores on self-reported measures of functional health (Patient-Reported Outcomes Measurement Information System: Global Health Scale; range, 10-50; higher scores indicate better health); psychological well-being (Warwick-Edinburgh Mental Well-being Scale; range, 14-70; higher scores indicate greater well-being); and sleep-related quality of life (Glasgow Sleep Impact Index; range, 1-100; higher scores indicate greater impairment). Secondary outcomes comprised mood, fatigue, sleepiness, cognitive failures, work productivity, and relationship satisfaction. Insomnia was assessed with the Sleep Condition Indicator (range: 0-32; higher scores indicate better sleep).

RESULTS Of the 1711 participants included in the intention-to-treat analysis, 1329 (77.7%) were female, mean (SD) age was 48.0 (13.8) years, and 1558 (91.1%) were white. Use of dCBT was associated with a small improvement in functional health compared with SHE (adjusted difference [95% CI] at week 4, 0.90 [0.40-1.40]; week 8, 1.76 [1.24-2.28]; week 24, 1.76 [1.22-2.30]) and psychological well-being (adjusted difference [95% CI] at week 4, 1.04 [0.28-1.80]; week 8, 2.68 [1.89-3.47]; week 24, 2.95 [2.13-3.76]), and with a large improvement in sleep-related quality of life (at week 4, −8.76 [−11.83 to −5.69]; week 8, −17.60 [−20.81 to −14.39]; week 24, −18.72 [−22.04 to −15.41]) (all $P < .01$). A large improvement in insomnia mediated these outcomes (range mediated, 45.5%-84.0%).

CONCLUSIONS AND RELEVANCE Use of dCBT is effective in improving functional health, psychological well-being, and sleep-related quality of life in people reporting insomnia symptoms. A reduction in insomnia symptoms mediates these improvements. These results confirm that dCBT improves both daytime and nighttime aspects of insomnia, strengthening existing recommendations of CBT as the treatment of choice for insomnia.

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Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Author: Colin A. Espie, PhD, Sleep & Circadian Neuroscience Institute, Nuffield Department of Clinical Neurosciences, University of Oxford, Sir William Dunn School of Pathology, South Parks Road, Oxford OX1 3RE, United Kingdom (colin.espie@ndcn.ox.ac.uk).

Insomnia disorder, comprising reports of poor sleep with associated daytime effects occurring 3 or more nights per week for 3 or more months,[1] presents in 10% to 12% of adults.[2-4] In addition, insomnia is associated with mental health disorders,[5] cardiovascular disease,[6] and type 2 diabetes.[7,8] Increased fatigue, impaired work productivity, reduced quality of life, and relationship dissatisfaction are also common in those with insomnia.[9-11] Such impaired functioning is an important driver for help-seeking behavior.[12]

The recommended intervention for insomnia is cognitive behavioral therapy (CBT),[13-16] a psychological treatment designed to break patterns of maladaptive thinking and behavior. Cognitive behavioral therapy comprises a behavioral component (stimulus control, sleep restriction, and relaxation) combined with a cognitive (managing sleep-related worries, racing mind, and intrusive thoughts) and an educational (sleep hygiene) component. Meta-analyses indicate that CBT has moderate to large and durable effects on sleep quality, sleep efficiency, sleep-onset latency, and wake time after sleep onset.[17-19] Moreover, recent meta-analyses indicate that digital CBT (dCBT), delivered using automated web platforms or a mobile app,[20] is also efficacious.[21,22] The effects of CBT and dCBT on the nighttime symptoms of insomnia, therefore, appear robust. However, daytime symptoms are a core part of insomnia disorder, integral to its clinical presentation. Improving constructs such as functional health, psychological well-being, and quality of life may therefore be crucial to treating insomnia satisfactorily.

We investigated the attributable effect of a reduction in insomnia symptoms after receiving dCBT for insomnia on 3 key areas of quality of life: functional health status, psychological well-being, and patient-generated, sleep-related quality of life. Although there is evidence that CBT may yield generalized benefits in both the general population and patient groups[23-29] and some primary data that CBT for insomnia may reduce depressive or anxiety symptoms,[30-34] evidence is mixed,[35,36] and an adequately powered, definitive trial investigating functional health status, psychological well-being, and a patient-generated assessment of quality of life has not yet been conducted. Moreover, we wanted to conduct a formal test of the mediating effect of improved insomnia symptoms on these outcomes.

Our primary hypotheses were that dCBT for insomnia would improve functional health status and psychological well-being and would reduce sleep-related quality-of-life impairment at weeks 4, 8, and 24 (research question [RQ] 1) and that the effect of dCBT on these outcomes at weeks 8 and 24 would be mediated by a reduction in insomnia symptoms measured at weeks 4 and 8, respectively (RQ 2). Our secondary hypotheses were that dCBT would also improve domains of personal functioning (negative mood, fatigue, and relationship dysfunction) and daytime performance (sleepiness, concentration, and productivity) at weeks 4 and 8 (RQ 3), improvements would be maintained at the week 24 follow-up, and the effect of dCBT at weeks 8 and 24 would be mediated by a reduction in insomnia complaints at weeks 4 and 8, respectively (RQ 4).

Key Points

Questions Can digital cognitive behavioral therapy for insomnia improve functional health, psychological well-being, and sleep-related quality of life, and does a reduction in insomnia symptoms mediate these potential improvements?

Findings In a 2-arm, parallel-group randomized clinical trial that included 1711 persons, digital cognitive behavioral therapy significantly improved insomnia symptoms, functional health, psychological well-being, and sleep-related quality of life at 4, 8, and 24 weeks after initiation of treatment. Improvements at 8 and 24 weeks were mediated by improvements in insomnia at week 4 and 8, respectively.

Meaning Treating insomnia with digital cognitive behavioral therapy could be a therapeutic pathway for addressing self-reported health, well-being, and quality of life.

Methods

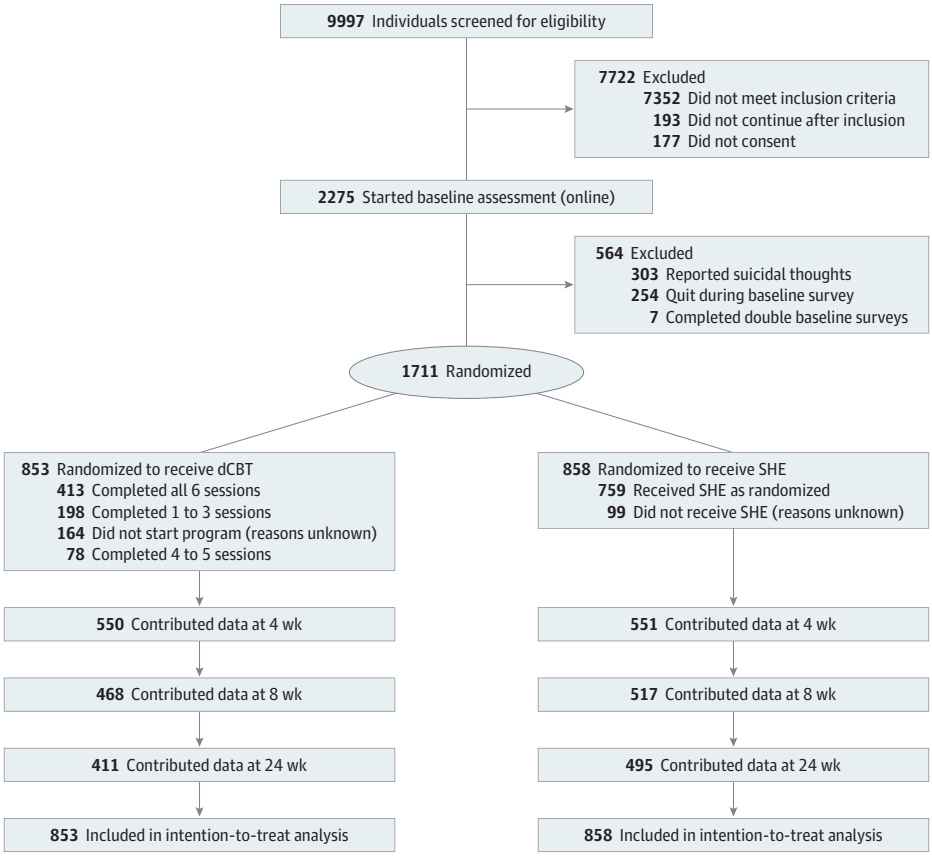
Research Design

The study was an online, 2-arm, single-blind, parallel-group, superiority randomized clinical trial of dCBT (Digital Insomnia Therapy to Assist Your Life as Well as Your Sleep [DIALS]) in addition to any treatment the participant was previously receiving (treatment as usual [TAU]) vs sleep hygiene education (SHE) in addition to TAU. We used simple randomization with an allocation ratio of 1:1 as recommended for large clinical trials.[37] Randomization was carried out by an outside automated online system (surveygizmo.eu), ensuring that allocation could not be influenced by the research team. The trial design and progress of participants through the trial are summarized in the **Figure**. Screening, informed consent, assessments, allocation to condition, and delivery of the interventions were carried out entirely online. Participants were recruited between December 1, 2015, and December 1, 2016; programs were completed within 12 weeks after inclusion. The study received ethical approval from the University of Oxford Medical Sciences Inter-Divisional Ethics Committee (ref MS-IDREC-C2-2015-024), and participants provided online informed consent. The DIALS trial has been registered at http://www.isrctn.com (ISRCTN 60530898); the protocol has been published and is available in Supplement 1.[38]

Participants

According to the original protocol, a sample size of 433 participants per treatment group was required to detect a standardized effect size of 0.25 with 90% power, assuming a significance level of $P < .01667$ (corrected for 3 primary outcomes), and to detect a large mediation effect with more than 80% power. To account for 13% attrition, we increased the sample size to 500 per treatment arm. During the trial, we further extended recruitment because the attrition rate was larger than expected. A total of 1718 participants enrolled, and the final sample comprised 1711 participants because 7 participants entered the trial twice. For each of these 7 participants, a single entry contributed to the analyses. When both entries were randomized to the same condition, the response with the most

Figure. Trial Design for the Digital Insomnia Therapy to Assist Your Life as Well as Your Sleep (DIALS) Study



dCBT indicates digital cognitive behavioral therapy; SHE, sleep hygiene education.

completed data was selected; when entries were randomized to different groups, the first response was selected unless the participant accessed treatment; if treatment was accessed, the response corresponding with the treatment allocation was used. Inclusion and exclusion criteria have been reported earlier and are available in Supplement 1.[38] Briefly, inclusion criteria comprised the following: a positive screening results based on the *DSM-5* criteria for insomnia disorder; a score of 16 or less on the 8-item Sleep Condition Indicator (SCI; scale, 0-4; range: 0-32, with higher scores indicating better sleep)[39]; aged 18 years or older; reliable internet access; and ability to read and understand English. We screened for comorbid conditions and medication use at baseline but excluded only those people whose health was expected to necessitate hospital admission or who had a life expectancy of less than 6 months, who currently received psychological treatment for insomnia or were expecting treatment within 6 months, and who reported suicidal thoughts. We did not exclude participants taking medication for sleep problems or for any other physical or mental health problem. Several methods were used to direct people to the online recruitment page. Persons who had completed previous sleep surveys (ie, Great British Sleep Survey[40]; World Sleep Survey[41]) were contacted by email, a recruitment button was placed on an insomnia intervention website,[42] advertisements were placed on Facebook and announcements on Twitter, and information about the study was presented via broadcast media.

Intervention

Digital cognitive behavioral therapy was delivered using the Sleepio program (Big Health Ltd)[43] and an associated iOS app (Big Health Ltd). The program is fully automated, and its underlying algorithms feed the delivery of information, support, and advice in a personally tailored manner. Delivery is structured into 6 sessions typically lasting 20 minutes each, and participants had access to the intervention for up to 12 weeks. Treatment content is based on CBT manuals[44-46] and includes behavioral, cognitive, and educational components. A more extensive description can be found in the study protocol (Supplement 1).[38] The program has been evaluated in multiple randomized clinical trials.[31,33,43,47-50]

SHE was selected for the control arm because this is the behavioral comparator that people with insomnia are most typically offered in routine care. SHE therefore was based on recognized sleep hygiene advice, for example, recommendations about bed routines and use of alcohol and caffeine.[46,51] To ensure consistency of approach and content, SHE was delivered on a dedicated study webpage where materials could be viewed and downloaded in a single session.

Measurements

Assessment Points

Assessments took place at weeks 0 (baseline), 4 (midtreatment), 8 (posttreatment), and 24 (follow-up). At week 25, all participants in the control group (SHE) were offered dCBT, which finished the controlled element of the trial. Uncontrolled follow-up data were collected at week 36 and week 48; these data are not presented herein.

Primary Outcomes

The 3 primary measures used to index physical health, psychological well-being, and sleep-related quality of life were the Patient-Reported Outcomes Measurement Information System: Global Health scale[52] for physical health (PROMIS-10; 10 items scored 1 to 5; range: 10-50, with higher scores indicating better health), the Warwick-Edinburgh Mental Well-being Scale[53] for psychological well-being (WEMWBS, 14 items scored 1 to 5; range: 14-70, with higher scores indicating better well-being), and the Glasgow Sleep Impact Index[54] (GSII), a patient-generated outcome rating in which participants rate self-defined sleep-related impairments (range: 0-100, with higher scores indicating greater impairment).

Secondary Outcomes

Secondary outcomes related to specific measurement of 6 areas of daytime consequences typically associated with the clinical diagnosis of insomnia disorder.[1,10] These outcomes were mood (9-item Patient Health Questionnaire[55] [PHQ-9]; scale, 0-3; range: 0-27, and the 7-item Generalized Anxiety Disorder[56] [GAD-7]; scale, 0-3; range: 0-21), energy (7-item Flinders Fatigue Scale[57] [FFS]; scale, 0-4; range: 0-28), relationship satisfaction (7-item Relationship Assessment Scale[58] [RAS]; scale, 1-5; range: 7-35), cognitive functioning (25-item Cognitive Failures Questionnaire[59] [CFQ]; scale, 0-4; range: 0-100), work performance and satisfaction (Work Productivity and Activity Impairment questionnaire: Specific Health Problem[60] [WPAI: SHP] and 1 item on job satisfaction[61]), and sleepiness (8-item Epworth Sleepiness Scale[62] [ESS]; scale, 0-3; range: 0-24]). As an exploratory measure, participants also completed 1 item about their general life satisfaction.[63] To appraise the mediating effects of improvement of insomnia symptoms per se, we used the SCI.[34,55] At week 8, potential adverse effects were assessed by asking participants to rate a number of potential adverse effects for frequency and severity.[64]

Statistical Analysis

All analyses were performed as intention to treat and blinded using Stata version 14 (StataCorp). In accordance with the Consolidated Standards of Reporting Trials guidelines, all participant flow is reported, including descriptive statistics of recruitment, dropout, and completeness of interventions.

The main efficacy analysis was based on randomized allocation including all participants with an outcome recorded at the relevant time point. No interim analyses for efficacy or futility were conducted.

Each primary outcome was analyzed using a linear mixed-effects model to account for the repeated measures at 4, 8, and 24 weeks.[65] This method implicitly accounts for missing-at-random outcome data. The baseline outcome measure, treatment assignment, and categorical time point were included as fixed effects, with a random participant-level effect. Adjusted, absolute between-group changes in outcome at each time point were obtained by including an interaction term between time point and treatment assignment in each model. Results are presented with 95% CIs and 2-sided *P* values. Cohen *d* standardized effect sizes were estimated by dividing the adjusted between-group difference by the baseline pooled SD of the corresponding outcome. Assumptions of normality were assessed graphically using histograms. The robustness of the assumptions regarding missing outcome data were examined in a series of sensitivity analyses (pattern mixture models, inclusion of baseline characteristics associated with having a missing outcome, and last observation carried forward). Secondary outcomes were analyzed using similar mixed-effects models as the primary outcomes.

A series of linear mixed-effects models were fitted to assess the extent to which the effect of the intervention on each outcome at 8 weeks was mediated by changes in insomnia at 4 weeks. The total effect of the intervention on outcome at 8 weeks was estimated from a model adjusting for baseline SCI but not the baseline outcome. The direct effect of the intervention at 8 weeks was estimated from a model adjusting for baseline SCI and SCI at 4 weeks. The effect of SCI at 4 weeks was also extracted from this model and multiplied by the estimated effect of the intervention on SCI at 4 weeks to obtain the indirect effect. This approach is similar to that described by Baron and Kenny[66] but uses linear mixed-effects models.[67] The percentage mediated, estimated as the indirect effect divided by the total effect, was obtained. The extent of mediation of the outcome effects at 24 weeks by insomnia at 8 weeks was evaluated in the same way.

Results

The final sample comprised 1711 adults, of whom 1329 (77.7%) were female and the mean (SD) age was 48.0 (13.8) years; 1558 (91.1%) were white, 45 (0.3%) were Asian, 19 (0.1%) were black, 36 (0.2%) were of mixed race/ethnicity, 35 (0.2%) were of another race/ethnicity, and 17 (0.1%) did not wish to state race/ethnicity. Participants were recruited between December 1, 2015, and December 1, 2016, and allocated to either dCBT plus TAU (n = 853) or SHE plus TAU (n = 858). An overview of sample descriptive statistics and baseline scores for the primary and secondary outcomes can be found in **Table 1**. Full details of sample characteristics and missing data can be found in eTable 1 in Supplement 2. Dropout from study assessments was greater in the treatment group than in the control group (Figure).

In the dCBT group, 689 of the 853 participants (80.8%) logged on for at least 1 session, 491 participants (57.6%) completed at least 4 sessions, and 413 participants (48.4%) completed all 6 sessions (Figure). Sleep hygiene education was accessed at least once by 759 of 858 participants (88.5%).

Treatment Effects on Primary Outcomes

At weeks 4, 8, and 24, dCBT was associated with significant improvement in global health (Cohen *d* for week 4, 0.16;

Table 1. Descriptive Characteristics

Characteristic	SHE + TAU (n = 858)	dCBT + TAU (n = 853)
Demographic		
Age, mean (SD), y	47.7 (13.6)	48.4 (13.9)
Sex, No. (%)		
Women	675 (78.7)	654 (76.7)
Men	183 (21.3)	199 (23.3)
Ethnic origin, No. (%)		
Asian	24 (2.8)	21 (2.5)
Black	12 (1.4)	7 (0.8)
Mixed	16 (1.9)	20 (2.3)
Other	23 (2.7)	12 (1.4)
White	773 (90.1)	785 (92.0)
Do not wish to state	9 (1.0)	8 (0.9)
Continuous full education, mean (SD), y	16.6 (3.5)	16.5 (3.9)
Employment, No. (%)		
Full-time employed	411 (47.9)	393 (46.2)
Part-time employed	187 (21.8)	161 (18.9)
Unemployed	34 (4.0)	40 (4.7)
Retired	149 (16.2)	152 (17.7)
Full-time student	32 (3.7)	46 (5.4)
Full-time homemaker or carer	52 (6.0)	56 (6.6)
Partner, No. (%)		
No	240 (28.0)	213 (25.0)
Yes, living apart	64 (7.4)	76 (8.9)
Yes, living together	553 (64.5)	560 (65.7)
Lifestyle		
Caffeine consumption, No. (%)		
Never	106 (12.1)	81 (9.5)
Less than once per day	114 (13.3)	111 (13.0)
Once per day	197 (23.0)	204 (23.9)
2-3 Times per day	305 (35.6)	330 (38.7)
≥4 Times per day	134 (15.6)	124 (14.5)
Alcohol consumption, No. (%)		
Never	200 (23.3)	205 (24.0)
Less than once per week	183 (21.3)	154 (18.1)
Once per week	116 (13.5)	127 (14.9)
2-3 Times per week	223 (26.0)	221 (25.9)
≥4 Times per week	135 (15.7)	145 (17.0)
Smoking, No. (%)		
Never	483 (54.9)	481 (56.6)
Previously	309 (36.0)	297 (34.8)
Rarely	29 (3.4)	31 (3.6)
1-10 per day	19 (2.2)	28 (3.3)
11-20 per day	19 (2.2)	13 (1.5)
≥21 per day	8 (0.9)	0
Exercising, No. (%)		
Never	85 (9.9)	77 (9.0)
Less than once per week	111 (12.9)	85 (10.0)
Once per week	134 (15.6)	136 (15.9)
2-3 Times per week	279 (32.5)	317 (37.2)
≥4 Times per week	247 (28.8)	237 (27.8)

(continued)

Table 1. Descriptive Characteristics (continued)

Characteristic	SHE + TAU (n = 858)	dCBT + TAU (n = 853)
Health		
BMI, mean (SD)	25.3 (6.0)	25.1 (5.1)
Medical diagnosis, No. (%)		
Heart disease or high blood pressure	106 (12.4)	106 (12.4)
Diabetes	18 (2.1)	18 (2.1)
Stroke or other neurological problems	8 (0.9)	16 (1.9)
Cancer	41 (4.8)	39 (4.6)
Arthritis/other joint problems	90 (10.5)	87 (10.2)
Digestive disorders	121 (13.9)	123 (14.4)
Depression or anxiety	333 (38.8)	317 (37.2)
Hormonal problems	57 (6.6)	70 (8.2)
Other comorbidity	115 (13.4)	127 (14.9)
Any diagnosis	570 (66.4)	561 (65.8)
Prescribed sleep medication, mean (SD), No. of nights per 14 d	1.6 (3.4)	1.6 (3.7)
Nonprescribed sleeping medication, mean (SD), No. of nights per 14 d	2.3 (3.9)	2.2 (3.9)
Outcomes at baseline, mean (SD)[a]		
Functional health (PROMIS-10)		
Total	31.8 (5.6)	31.8 (5.8)
Physical	14.3 (2.2)	14.4 (2.3)
Mental	11.4 (3.0)	11.2 (3.0)
Mental well-being (WEMWBS)	43.2 (7.9)	43.1 (7.7)
Sleep-related quality of life (GSII)		
Most important concern	87.3 (12.7)	87.8 (12.8)
Second most important concern	75.4 (16.4)	76.3 (17.3)
Third most important concern	60.2 (21.3)	60.9 (21.4)
Combined score	222.9 (44.5)	224.9 (45.9)
Insomnia (SCI)	6.6 (3.3)	6.5 (3.2)
Depressive symptoms (PHQ-9)	9.7 (4.2)	9.8 (4.1)
Anxiety symptoms (GAD-7)	7.4 (4.7)	7.4 (4.7)
Sleepiness (ESS)	6.2 (4.5)	6.1 (4.4)
Fatigue (FFS)	19.1 (5.4)	19.0 (5.5)
Relationship satisfaction (RAS)	27.6 (5.8)	27.8 (5.8)
Cognitive functioning (CFQ)	42.5 (16.8)	43.1 (15.4)
Work productivity and impairment, mean (SD), WPAI		
Presenteeism	41.0 (23.2)	42.2 (24.0)
Absenteeism	8.03 (16.9)	7.38 (16.3)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CFQ, Cognitive Failures Questionnaire; dCBT, digital cognitive behavioral therapy; ESS, Epworth Sleepiness Scale; FFS, Flinders Fatigue Scale; GAD-7, 7-item Generalized Anxiety Disorder; GSII, Glasgow Sleep Impact Index; PHQ-9, 9-item Patient Health Questionnaire; PROMIS-10, 10-item Patient-Reported Outcomes Measurement Information System; RAS, Relationship Assessment Scale; SCI, 8-item Sleep Condition Indicator; SHE, sleep hygiene education; TAU, treatment as usual; WEMWBS, Warwick-Edinburgh Mental Well-being Scale; WPAI, Work Productivity and Activity Impairment questionnaire.

[a] Outcome assessment scales are explained in the Measurements subsection of the Methods section.

week 8, 0.31; and week 24, 0.31) and mental well-being (Cohen *d* for week 4, 0.13; week 8, 0.35; and week 24, 0.38), and a significant reduction in sleep-related impairment to quality

Table 2. Effects of Digital Cognitive Behavioral Therapy vs Sleep Hygiene Education on Primary Outcomes: Physical Health, Psychological Well-being, Sleep-Related Quality of Life, and Insomnia

Assessment[a]	Unadjusted, Mean (SD)		Adjusted Difference (95% CI)	Cohen *d*	*P* Value
	SHE + TAU	dCBT + TAU			
PROMIS-10					
Week 4	32.52 (6.05)	33.84 (6.49)	0.90 (0.40 to 1.40)	0.16	<.001
Week 8	32.92 (6.18)	35.08 (6.65)	1.76 (1.24 to 2.28)	0.31	<.001
Week 24	33.10 (6.10)	35.24 (6.88)	1.76 (1.22 to 2.30)	0.31	<.001
WEMWBS					
Week 4	44.72 (8.21)	46.03 (8.55)	1.04 (0.28 to 1.80)	0.13	.007
Week 8	45.16 (8.77)	48.12 (8.82)	2.68 (1.89 to 3.47)	0.35	<.001
Week 24	45.31 (8.89)	48.62 (9.02)	2.95 (2.13 to 3.76)	0.38	<.001
GSII[b]					
Week 4	69.80 (23.64)	60.69 (26.20)	−8.76 (−11.83 to −5.69)	−0.69	<.001
Week 8	65.68 (25.86)	46.78 (29.90)	−17.60 (−20.81 to −14.39)	−1.38	<.001
Week 24	63.33 (27.26)	43.78 (31.25)	−18.72 (−22.04 to −15.41)	−1.46	<.001

Abbreviations: dCBT, digital cognitive behavioral therapy; GSII, Glasgow Sleep Impact Index; PROMIS-10, 10-item Patient-Reported Outcomes Measure; SHE, sleep hygiene education; TAU, treatment as usual; WEMWBS, Warwick-Edinburgh Mental Well-being Scale.

[a] Outcome assessment scales are explained in the Measurements subsection of the Methods section.

[b] Highest-ranked impairment.

Table 3. Mediation Effects of Insomnia Improvement on Primary Outcomes: Physical Health, Mental Well-being, Sleep-Related Impact, and Insomnia

Asssessment[a]	Mediation Tested	Total Effect		Direct Effect		Indirect Effect		Mediation, %
		Effect Size (SE)	*P* Value	Effect Size (SE)	*P* Value	Effect Size (SE)	*P* Value	
PROMIS-10								
Week 8	SCI week 4	1.76 (0.26)	<.001	0.65 (0.27)	.02	0.89 (0.12)	<.001	50.5
Week 24	SCI week 8	1.75 (0.27)	<.001	0.13 (0.29)	.66	1.47 (0.14)	<.001	83.8
WEMWBS								
Week 8	SCI week 4	2.67 (0.40)	<.001	1.21 (0.42)	.004	1.26 (0.17)	<.001	47.0
Week 24	SCI week 8	2.93 (0.41)	<.001	0.76 (0.45)	.09	2.17 (0.20)	<.001	74.9
GSII[b]								
Week 8	SCI week 4	−17.54 (1.63)	<.001	−8.69 (1.60)	<.001	−7.98 (0.93)	<.001	45.5
Week 24	SCI week 8	−18.63 (1.68)	<.001	−7.84 (1.68)	<.001	−12.27 (0.84)	<.001	65.9

Abbreviations: GSII, Glasgow Sleep Impact Index; PROMIS-10, 10-item Patient-Reported Outcomes Measure; SCI, Sleep Condition Indicator; WEMWBS, Warwick-Edinburgh Mental Well-being Scale.

[a] Outcome assessment scales are explained in the Measurements subsection of the Methods section.

[b] Highest-ranked impairment.

of life (Cohen *d* for week 4, -0.69; week 8, -1.38; and week 24, -1.46; RQ 1 [**Table 2**]). Effects were robust across sensitivity analyses investigating assumptions regarding missingness of the outcome.

Mediation Analysis

The results of the mediation analyses can be found in **Table 3** (indirect effects, RQ 2). The mediator (SCI) demonstrated an improvement compared with SHE (Cohen *d* for week 4, 0.89; week 8, 1.51; and week 24, 1.51; all $P < .01$ **Table 4**). When we considered functional health on PROMIS-10 as the outcome, the proportion of the effect of dCBT on PROMIS-10 score at 8 weeks that was mediated by changes in insomnia symptoms at 4 weeks was 50.5%, and the proportion of the effect of the intervention on PROMIS-10 scores at 24 weeks that was mediated by changes in insomnia symptoms at 8 weeks was 83.8%. For psychological well-being, these values were 47.0% at 8 weeks and 74.9% at 24 weeks. When we considered sleep-related quality of life, with GSII (rank 1: the most important impairment) as the outcome, the proportion of the effect of the intervention on GSII at 8 weeks that was mediated by changes in insomnia symptoms was 45.5% and increased to 65.9% at 24 weeks. eTable 2 in Supplement 2 provides mediation analyses on PROMIS subscales and the GSII total score and second- and third-ranked reported impairments.

Treatment Effects on Secondary Outcomes

Symptoms of depression (PHQ-9), anxiety (GAD-7), sleepiness (ESS), and cognitive failures (CFQ) all demonstrated significant differences in favor of dCBT at weeks 4, 8, and 24, reflecting small effect sizes (Table 4, RQ 3). There were moderate to large effects observed at weeks 4, 8, and 24 for fatigue (FFS). On the WPAI, productivity at work (presenteeism) that was attributed to sleep problems showed a small to moderate improvement after dCBT relative to control. A significant but small effect in terms of reduced absenteeism attributed to poor sleep and increased job satisfaction was observed at week 24. There were no significant effects at any time point on relationship functioning (RAS). Mediation analyses indicated that changes in insomnia symptoms also accounted for significant and sizeable proportions of effects on these secondary outcomes at both week 8 and week 24 (eTable 3 in Supplement 2, RQ 4).

Table 4. Effects of dCBT vs SHE on Mediator and Secondary Outcomes of Mood, Fatigue, Relationship, Cognition, Work Performance, and Sleepiness

Assessment[a]	Unadjusted, Mean (SE)		Adjusted Difference (95% CI)	Cohen *d*	*P* Value
	SHE + TAU	dCBT + TAU			
SCI[b]					
Week 4	9.96 (4.70)	13.00 (5.01)	2.88 (2.28 to 3.48)	0.89	<.001
Week 8	11.05 (5.32)	16.29 (6.17)	4.90 (4.28 to 5.53)	1.51	<.001
Week 24	11.66 (5.84)	16.89 (6.91)	4.91 (4.27 to 5.56)	1.51	<.001
PHQ-9					
Week 4	8.36 (4.38)	7.47 (4.26)	−0.72 (−1.15 to −0.29)	−0.17	.001
Week 8	8.16 (4.90)	6.22 (4.40)	−1.59 (−2.04 to −1.14)	−0.38	<.001
Week 24	7.94 (4.58)	6.13 (4.59)	−1.58 (−2.05 to −1.12)	−0.38	<.001
GAD-7					
Week 4	6.23 (4.52)	5.51 (4.18)	−0.49 (−0.91 to −0.06)	−0.10	.03
Week 8	6.10 (4.69)	4.68 (4.21)	−1.19 (−1.63 to −0.74)	−0.25	<.001
Week 24	6.05 (4.50)	4.70 (4.21)	−1.10 (−1.56 to −0.64)	−0.24	<.001
ESS					
Week 4	6.41 (4.64)	5.55 (4.34)	−0.52 (−0.88 to −0.17)	−0.12	.003
Week 8	6.14 (4.62)	4.81 (3.94)	−1.01 (−1.38 to −0.64)	−0.23	<.001
Week 24	6.24 (4.61)	4.67 (3.97)	−1.41 (−1.79 to −1.03)	−0.32	<.001
FFS					
Week 4	16.93 (5.87)	14.82 (5.96)	−2.01 (−2.63 to −1.39)	−0.37	<.001
Week 8	15.91 (6.08)	11.84 (6.54)	−3.83 (−4.48 to −3.19)	−0.71	<.001
Week 24	15.67 (6.46)	11.41 (6.64)	−4.06 (−4.72 to −3.39)	−0.75	<.001
RAS					
Week 4	24.45 (7.44)	24.98 (7.78)	0.12 (−0.38 to 0.62)	0.02	.64
Week 8	24.36 (7.50)	25.23 (7.64)	0.07 (−0.44 to 0.59)	0.01	.79
Week 24	24.72 (7.42)	25.45 (7.83)	0.01 (−0.53 to 0.54)	0.00	.98
CFQ					
Week 4	41.79 (16.79)	39.53 (15.54)	−2.08 (−3.23 to −0.92)	−0.13	<.001
Week 8	41.19 (16.97)	36.93 (16.44)	−4.18 (−5.38 to −2.99)	−0.26	<.001
Week 24	41.25 (16.49)	37.47 (15.47)	−3.38 (−4.60 to −2.16)	−0.21	<.001
WPAI presenteeism					
Week 4	33.61 (23.82)	31.26 (23.52)	−2.27 (−5.47 to 0.92)	−0.10	.16
Week 8	32.71 (23.32)	23.56 (21.21)	−9.55 (−12.89 to −6.21)	−0.41	<.001
Week 24	32.08 (23.37)	20.56 (20.69)	−9.94 (−13.42 to −6.46)	−0.42	<.001
WPAI absenteeism					
Week 4	2.56 (8.94)	3.22 (9.87)	0.39 (−1.31 to 2.10)	0.02	.65
Week 8	3.54 (11.59)	2.34 (8.26)	−1.23 (−3.02 to −0.56)	−0.07	.18
Week 24	4.61 (14.01)	3.41 (12.16)	−2.09 (−3.95 to −0.23)	−0.13	.03
Job satisfaction					
Week 4	3.48 (2.14)	3.30 (2.10)	−0.05 (−0.22 to 0.12)	−0.02	.58
Week 8	3.45 (2.07)	3.43 (2.14)	0.08 (−0.09 to 0.26)	0.08	.36
Week 24	3.49 (2.05)	3.58 (2.16)	0.27 (0.09 to 0.45)	0.27	.004
Life satisfaction					
Week 4	2.84 (0.72)	2.90 (0.72)	0.07 (−0.02 to 0.13)	0.10	.06
Week 8	2.86 (0.70)	2.96 (0.73)	0.12 (0.05 to 0.19)	0.18	<.001
Week 24	2.86 (0.70)	3.01 (0.74)	0.16 (0.09 to 0.24)	0.24	<.001

Abbreviations: CFQ, Cognitive Failures Questionnaire; dCBT, digital cognitive behavioral therapy; ESS, Epworth Sleepiness Scale; FFS, Flinders Fatigue Scale; GAD-7, 7-item Generalized Anxiety Disorder; PHQ-9, 9-item Patient Health Questionnaire; RAS, Relationship Assessment Scale, SCI, Sleep Condition Indicator; SHE, sleep hygiene education; TAU, treatment as usual; WPAI, Work Productivity and Activity Impairment questionnaire.

[a] Outcome assessment scales are explained in the Measurements subsection of the Methods section.

[b] Highest-ranked impairment.

Reported Adverse Effects

There was 1 serious adverse event reported, which was unrelated to the intervention. The event was reported to the University of Oxford Medical Sciences Inter-Divisional Ethics Committee. Participants who received dCBT reported a higher occurrence of difficulty remembering things, headache and/or migraine, fatigue and/or exhaustion, extreme sleepiness, difficulty with concentration and attention, reduced motivation and/or energy, and irritability attributed to the insomnia improvement program at week 8 (eTable 4 in Supplement 2).

Discussion

It is well established that CBT is the first-line treatment for people with chronic insomnia[14,17-19,21,22] and that sleep-related outcomes, whether on index measures of insomnia or on derivations from sleep diaries, show sustained improvement.[17] The findings from this study confirm large effects on insomnia symptoms. However, we primarily addressed whether CBT for insomnia affects functional health, psychological well-being, and sleep-related quality of life. We used dCBT instead of face-to-face CBT to facilitate an adequately powered scientific inquiry of explanatory processes.

Our findings provide strong support for the hypothesis that dCBT improved participants' functional health relative to sleep hygiene education. At 24 weeks, effect sizes were small for functional health and psychological well-being (Cohen *d*, 0.31 and 0.38) and large for sleep-related quality of life (Cohen *d*, −1.46). The greater effect on sleep-related quality of life, measured with the GSII, likely occurs because the GSII specifically asks participants to define areas of impairment attributed to poor sleep, whereas functional health and well-being were assessed with global measures (PROMIS-10 and WEMWBS). Improvements in all 3 primary outcomes were mediated by insomnia improvements associated with dCBT. These mediation effects were substantial: 51% mediation of functional health, 47% of well-being, and 46% of sleep-related quality of life at 8 weeks, and 84% of functional health, 75% of well-being, and 66% of sleep-related quality of life at 24 weeks' follow-up. To our knowledge, this is the first large-scale study demonstrating a causal relationship between CBT-mediated reduction in insomnia symptoms and perceived health status and quality of life.

A report of a parallel study (Oxford Access for Students Improving Sleep [OASIS]) exploring mental health symptoms as the outcome variable of interest and likewise demonstrated a causal relationship between insomnia improvement and reductions in mental health symptoms.[33] Together, the mediation analyses in these 2 studies (with a total of 5466 participants) provide novel and convincing evidence that insomnia may be a legitimate and important target for mental health and well-being. Consideration of the secondary variables in the present study yields further data on the generalized effects of insomnia improvement on symptoms of depression, anxiety, fatigue, sleepiness, and cognitive failures and productivity, with mediation in substantial part through changes in insomnia.

Limitations

We are mindful of limitations of this research. Although participant demographic characteristics were typical of clinical populations (eg, typically female, middle-aged) and had some similar characteristics (eg, two-thirds reported diagnosed health comorbidities), participants were not drawn from patient groups or health care services and therefore reflect individuals who experience insomnia in the general population. This difference may reduce the generalizability to the insomnia patient group but increases the generalizability to those experiencing insomnia symptoms in the general population. As is typical of digital programs, and indeed of CBT in general, there was a substantial dropout from treatment (58% of participants completed ≥4 dCBT sessions); however, intention-to-treat analyses still identified significant improvements. Sensitivity and missing data analyses did not change the study conclusions. In addition, the instrument used to measure insomnia symptoms includes items around daytime functioning because these items are part of the *DSM-5* insomnia disorder diagnosis; these items may have inflated the mediation effects. Finally, we note that attributed adverse effects were more common in the group receiving dCBT than in the control participants. Despite widespread generalized benefits, dCBT can have adverse effects; we hypothesize that these effects might result from the sleep restriction component that is introduced in week 3. Potentially, these adverse effects were short lived; at weeks 8 and 24, sleepiness, fatigue, cognitive failures, and mood symptoms were more common in participants receiving SHE than in those receiving dCBT.

Conclusions

The results of this definitive trial suggest that dCBT not only is effective in improving insomnia symptoms but also demonstrates positive effects around the clock by improving the functional health, psychological well-being, and sleep-related quality of life of people with positive screening results for insomnia disorder. In addition, improved insomnia is a mediator of these benefits. These findings indicate that dCBT improves both daytime and nighttime aspects of insomnia, lending further weight to the clinical guideline recommendation of CBT as the treatment of choice for insomnia.

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Author Affiliations: Sleep & Circadian Neuroscience Institute, Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford, United Kingdom (Espie, Kyle, Foster, Luik); Big Health Ltd, London, United Kingdom (Espie, Cape, Luik); Biostatistics & Health Informatics Department, Institute of Psychiatry, Psychology & Neuroscience, King's College London, London, United Kingdom (Emsley); Susan Wakil School of Nursing and Midwifery, The University of Sydney, Sydney, Australia (Gordon); CIRUS Centre for Integrated Research and Understanding of Sleep, Woolcock Institute of Medical Research, University of Sydney, Sydney, Australia (Gordon); Department of Sleep Disorders and Research Center, Henry Ford Health System, Detroit, Michigan (Drake); School of Health and Social Care, University of Lincoln, Lincoln, United Kingdom (Siriwardena); Division of Psychology and Language Sciences, Faculty of Brain Sciences, University College London, London, United Kingdom (Cape); Feinberg School of Medicine, Northwestern University, Chicago, Illinois (Ong); Sleep & Circadian Neuroscience Institute, Department of Psychiatry, University of Oxford, Oxford, United Kingdom (Sheaves, Freeman); Department of Health Policy, The London School of Economics and Political Science, London, United Kingdom (Costa-Font); Centre for Biostatistics, School of Health Sciences, The University of Manchester, Manchester, United Kingdom (Marsden).

Author Contributions: Dr Espie had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Espie, Kyle, Gordon, Drake, Siriwardena, Cape, Ong, Sheaves, Foster, Freeman,

Costa-Font, Luik.
Acquisition, analysis, or interpretation of data: Emsley, Kyle, Gordon, Drake, Costa-Font, Marsden, Luik.
Drafting of the manuscript: Espie, Emsley, Kyle, Marsden, Luik.
Critical revision of the manuscript for important intellectual content: Espie, Emsley, Kyle, Gordon, Drake, Siriwardena, Cape, Ong, Sheaves, Foster, Freeman, Costa-Font, Luik.
Statistical analysis: Emsley, Marsden.
Administrative, technical, or material support: Kyle, Gordon, Siriwardena, Sheaves, Freeman, Luik.
Supervision: Espie, Gordon, Costa-Font.

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