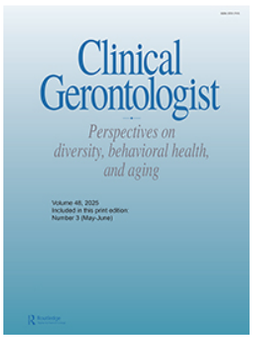

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In-Home Assistive Technology May Help Protect Dementia Caregivers from Declining Sleep Efficiency: A Randomized Control Trial

Julian A. Scheffer PhD[a,b], Darius T. Levan BA[a], Jenna L. Wells PhD[c], Dolores Gallagher-Thompson PhD[d], Kevin J. Grimm PhD[e], Kuan-Hua Chen PhD[f], Casey K. Brown PhD[g], Breanna M. Bullard MA[a], Claire I. Yee PhD[h], Scott L. Newton BA[a], Enna Y. Chen BA[i], Jennifer J. Merrilees PhD[j], David Moss BS[k], Gene Wang BS[k], and Robert W. Levenson PhD[a]

[a]Department of Psychology, University of California, Berkeley, California, USA; [b]Department of Psychology, University of Western Ontario, London, Ontario, Canada; [c]Department of Psychology, Cornell University, Ithaca, New York, USA; [d]Department of Psychiatry and Behavioral Sciences and School of Medicine, Stanford University, Stanford, California, USA; [e]Department of Psychology, Arizona State University, Tempe, Arizona, USA; [f]Department of Neurological Sciences, University of Nebraska Medical Center, Omaha, Nebraska, USA; [g]Department of Psychology, Georgetown University, Washington, DC, USA; [h]Department of Quantitative and Health Sciences, Mayo Clinic, Scottsdale, Arizona, USA; [i]Department of Psychology, Stanford University, Stanford, California, USA; [j]Department of Neurology, Memory and Aging Center, San Francisco, California, USA; [k]People Power Company dba Care Daily Company

ABSTRACT

Objectives: Caregivers for people with dementia (PWDs) often experience sleep problems due to stressors associated with their role (e.g. concern about PWDs' nighttime wandering). We investigated whether a technology system, People Power Caregiver (PPCg), that helps monitor the caregiver's home would benefit caregivers' sleep.

Methods: Primary caregivers of PWDs (Study 1: $N = 70$, Age $M = 64.54$, SD = 11.82, range = 35–84; Study 2: $N = 92$, Age $M = 62.73$, SD = 11.10, range = 32–89) were assigned to a fully activated PPCg condition or control condition (Study 1: partially active PPCg; Study 2: waitlist control). Caregivers completed the Pittsburgh Sleep Quality Index at baseline, three-months, and six-months.

Results: Caregivers in the control conditions reported significantly worsening sleep efficiency whereas in comparison, those in the active conditions reported improving sleep efficiency.

Conclusions: Given how critical sleep is both for caregivers' health and the care they provide, these findings underscore potential benefits of in-home technologies for protecting caregivers' sleep.

Clinical Implications: Technology-based interventions that help monitor the home may support caregivers' sleep. Protecting caregivers' sleep may also preserve their ability to provide high-quality care as their loved one's disease and associated functional decline progresses.

KEYWORDS
Intervention; latent growth modeling; longitudinal

As the population ages, the number of people diagnosed with age-related neurodegenerative disease is increasing dramatically. Recent estimates (Alzheimer's Association, 2024) indicate that 6.7 million people in the U.S. currently live with Alzheimer's disease (AD), the most common cause of dementia. People with dementia (PWD) often exhibit impairments in cognitive, physical, and emotional functioning (Mega et al., 1996), which can increase their dependence on caregivers for assistance with instrumental activities of daily living (e.g., managing their finances and accessing health care; Schulz et al., 2020). Family members often take on these kinds of informal (i.e., nonprofessional and typically unpaid) caregiver roles, providing the PWD with psychological, functional, and financial support.

The impact of informal caregiving is substantial, with more than 11 million people in the U.S. providing nearly 18 billion hours of informal caregiving for PWDs (Alzheimer's Association, 2024). Despite caregiving being a positive and meaningful experience for many individuals (Doris et al., 2018; Lloyd et al., 2016; Quinn & Toms, 2019), the associated stressors and unpredictability of this role can increase caregivers' rates of depression, seeking treatment for anxiety, suicidal ideation, and use of psychotropic medications compared to similarly aged non-caregiving adults (Collins & Kishita, 2020;

CONTACT Robert W. Levenson, PhD boblev@berkeley.edu Department of Psychology, University of California, 2121 Berkeley Way, Berkeley, CA 94704

A subset of caregivers from Study 1 was included in a study which documented that caregivers with the fully activated People Power Caregiver (PPCg) system reported lower anxiety compared to caregivers with a partially activated system (Levenson et al., 2024).

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Kaddour & Kishita, 2020; Pinquart & Sörensen, 2003; Richardson et al., 2013; Schulz et al., 2020; Victor et al., 2021; Vitaliano et al., 2003). Moreover, caregivers often have trouble maintaining healthy sleeping routines due to worry and concern that the PWD may become restless or agitated, wake up, and possibly wander during the night. These difficulties and concerns can further exacerbate caregivers' health risks and impede their ability to meet caregiving demands and provide high-quality care (e.g., poor sleep can worsen processing speed and multitasking ability; Brewster et al., 2022, 2024; Gao et al., 2019; Peng et al., 2019). Thus, there is a clear need to develop effective, scalable, and affordable interventions that reduce stress and improve sleep for caregivers.

Sleep problems among dementia caregivers

There are conflicting theories concerning sleep problems in dementia caregivers. According to the *perceived sleep need view*, as caregivers age, they may perceive less sleep as sufficient because the impact of additional sleep becomes less restorative, and the effects of reduced sleep become less detrimental to physical, mental, and cognitive health (Scullin, 2017). Similarly, the *caregiver empowerment model* suggests that the positive and enriching aspects of the caregiving experience should lead to sleep quality that is either unchanged or even improves (Jones et al., 2011). In contrast, the *environmental stressor view* proposes that caregivers will experience greater sleep problems due to the unavoidable external stressors related to their role (e.g., increasing needs and disruptive behaviors on the part of the PWD; Pinquart & Sörensen, 2007).

Numerous studies have supported the environmental stressor view compared to other sleep theories, documenting greater reports of sleep problems in caregivers. Many caregivers report needing to sleep with "an open ear" or sleep "lightly" (Peng & Chang, 2013; Rowe et al., 2010) reflecting increased vigilance to PWD's needs, whereabouts, safety, and nighttime behaviors (e.g., bathroom use). Tellingly, approximately 60% of AD caregivers fit clinical criteria for insomnia, characterized by difficulty falling asleep, waking repeatedly through the night, experiencing daytime fatigue, and having depressed mood (Bentley et al., 2022). Consistent with this, a recent meta-analysis of 35 studies with 3,268 dementia caregivers found that caregivers averaged 2.42 to 3.50 fewer hours of sleep per week and lower sleep quality compared to age-matched non-caregiving adults (Gao et al., 2019). Clearly interventions are needed that target factors contributing to caregivers' sleep problems (e.g., reducing the need for constant vigilance). Such interventions, if successful, could help caregivers address their sleep demands, reduce downstream health risks, and improve the quality of care they provide.

Interventions to address dementia caregivers' sleep problems

Interventions that do not require prescription medications (e.g., benzodiazepines) are often preferred for dementia caregivers given the troublesome side-effects (e.g., daytime impairments in cognition, risk of falls) that these medications can have in middle-aged and older adults (Bentley et al., 2022). Consequentially, there is increasing interest in evaluating the benefits of technology-based interventions for older adults and dementia caregivers (Beattie et al., 2020; Miller et al., 2022) including task reminders, behavioral management strategies, cognitive aids, fall alerts, wandering alerts, interactive telecommunication devices, and in-home monitoring using embedded and wearable sensors. These interventions can reduce caregiver stress and burden, while improving PWD safety (Xiong et al., 2018, 2020). For example, in a randomized controlled trial (RCT), our research group found that caregivers who received an in-home assistive technology system (People Power Caregiver, PPCg) consisting of embedded sensors (e.g., to detect motion, door openings), artificial intelligence (AI) bots that recognized unusual patterns of activity, and a phone app (to control the system and provide information) had lower anxiety compared to a control condition at the six-month assessment (Levenson et al., 2024).

Moreover, a systematic review (Pignatiello et al., 2022) of 15 studies of sleep interventions (including physical, cognitive, collaborative, and environmental) found that caregivers in studies who were

given in-home monitoring systems experienced better sleep quality (Spring et al., 2009), lesser wakefulness after sleep onset (Rowe et al., 2010), and increases in sleep time (Thomas et al., 2019) compared to caregivers who did not receive monitoring systems. Of the available non-pharmacological interventions that help alleviate caregiver burden and reduce the need for vigilance, in-home monitoring and warning technologies offer considerable promise (Levenson et al., 2024; Miller et al., 2022). Yet, despite the promise of these technologies, there have been few implementations of RCTs to test the incremental benefits of this technology in dementia caregivers with adequately powered sample sizes (Austrom et al., 2015; Guerra et al., 2013). Further, a critical review of caregiver interventions emphasized that assessments of technology-based interventions were often characterized as pilot studies or proof of concept demonstrations (Butler et al., 2021). Therefore, research is needed that systematically examines the benefits of technology-based interventions, particularly using RCTs, to evaluate their incremental effectiveness and feasibility.

The current project

We conducted two RCTs evaluating the ability of a new system of in-home assistive technology (People Power Caregiver; PPCg) to reduce sleep problems in people living with and serving as the primary caregiver for a PWD. Study 1 recruited a West Coast sample and was limited to caregivers for a person diagnosed with dementia. Study 2 recruited a larger national sample and included caregivers for a person diagnosed with dementia or mild cognitive impairment. Both studies had an active condition (participants received the fully activated PPCg system) and a control condition (Study 1: participants received PPCg with only limited features activated; Study 2: participants were placed on a waiting list and received the fully activated PPCg at the end of the study period). In both studies, caregivers completed a well-validated measure of sleep at baseline and then again at three-month intervals (Study 1 lasted for 9 months; Study 2 lasted for 6 months). We hypothesized that across the two studies, caregivers in the active condition would report better sleep over time compared to those in the control condition.

Methods

Participants

In Study 1, we recruited 76 people living with and serving as the primary caregiver for a person who had received a diagnosis of dementia from a medical professional (we had originally planned to recruit a larger sample, but recruitment was halted by the onset of the COVID-19 pandemic). In Study 2, we recruited 222 people living with and serving as the primary caregiver for a person who had received a diagnosis of dementia or mild cognitive impairment from a medical professional.

In Study 1, the system was installed by the research team and in Study 2 it was self-installed by the caregivers. In both studies, we excluded participants who encountered installation issues (Study 1: $N = 6$ homes; Study 2: $N = 113$ homes).[1] In addition, in Study 2 we excluded participants who did not have the system installed for the expected duration at the six-month assessment ($N = 17$).[2] After exclusions (see Figure 1), we analyzed data from 70 caregivers in Study 1 and from 92 caregivers in Study 2 (total N across both studies = 162; 76 active and 86 control; see Table 1 for demographic details). Across studies, most of the caregivers were spousal caregivers (70.37%) caring for a person with Alzheimer's Disease (see Supplemental Table S1 for diagnosis details).

Recruitment

Study 1. In Study 1 (conducted between 2018 and 2020), caregivers were recruited via local advertisements, clinic referrals, community caregiver networks, and a professional recruitment company (Recruitment Partners). An initial screening was conducted to determine the following eligibility criteria: (a) the caregiver was the primary adult family caregiver living with the care recipient; (b) the care recipient had received a diagnosis of dementia from a medical professional (people diagnosed with mild cognitive impairment were not included); (c) their home had wireless internet connectivity (e.g., WiFi); and (d) the caregiver had an iPhone with cellular service. Eligible caregivers who indicated interest in the study were asked to

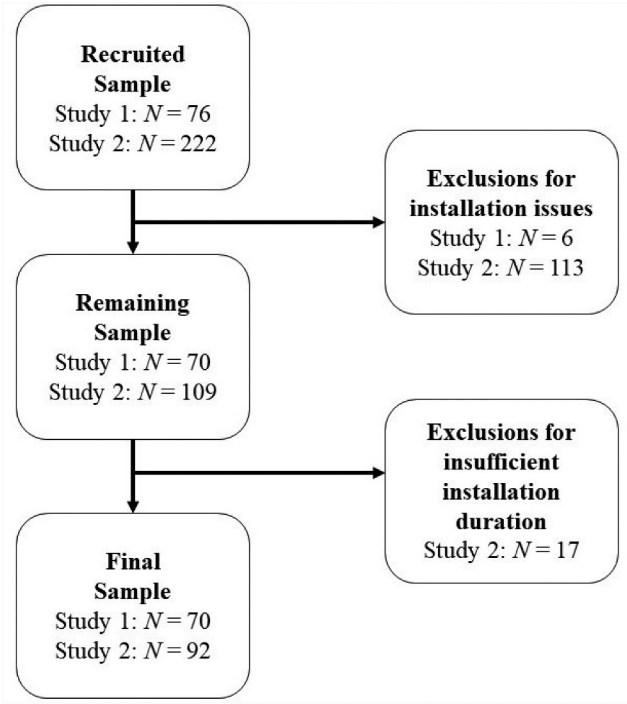

Figure 1. Caregiver-care recipient dyad exclusion flow chart.

complete a consent form (PWD consent was obtained from a surrogate when necessary) and baseline questionnaire package online and an appointment was scheduled with one of our technicians to install the PPCg system in their home.

Study 2. In Study 2 (conducted between 2020 and 2021), caregivers were recruited using an online marketing campaign using mailing lists provided by national dementia organizations. Applicants were directed to a website where they were screened for their eligibility based on the following criteria: (a) the caregiver was the primary adult familial caregiver living with the care recipient; (b) the care recipient had received a diagnosis of dementia or mild cognitive impairment from a medical professional; (c) their home had wireless internet connectivity (e.g., WiFi); and (d) the caregiver had either an iPhone or Android device with cellular service. Thus, Study 2 criteria differed from Study 1 by including diagnoses of mild

Table 1. Caregiver demographic information with comparison statistics.

	Study 1		Study 2		
	Control $N = 34$	Active $N = 36$	Control $N = 52$	Active $N = 40$	Condition Test
Age	66.18	63.03	64.90	59.95	$F = 5.01$,
M (*SD*)	(10.74)	(12.69)	(9.78)	(12.16)	$p = .027$
Sex					
Female	28	12	14	12	$\chi^2 = 1.21$,
Male	5	24	37	28	$p = .272$
Ethnicity					
Black, Afro-Caribbean, or African American	1	4	3	2	$p = .787$
East Asian, Southeast Asian, or Asian American	–	2	3	1	(Fisher's
Latino or Hispanic American	2	2	4	3	Exact
Native American or Alaskan American	–	–	–	1	Test)
South Asian or Indian American	1	1	–	–	
Non-Hispanic White or European American	26	24	40	30	
Other	3	3	1	3	
Education					
High school/GED	1	2	2	2	$F = 0.01$,
Some college experience	4	4	9	4	$p = .919$
2-year college	7	8	7	4	
4-year college	8	10	14	18	
Technical/trade school certificate/degree	1	–	3	1	
Master's degree	7	6	12	9	
Ph.D., M.D., or other professional degree	5	5	4	2	
Income					
Less than $20,000	1	2	–	4	$F = 0.27$,
$20,000–$35,000	3	1	6	–	$p = .870$
$35,001–$50,000	5	4	5	2	
$50,001–$75,000	5	9	7	11	
$75,001–$100,000	5	7	18	8	
$100,001–$150,000	7	3	9	8	
Greater than $150,000	5	6	4	4	
Caregiving Relationship					
Spouse/partner	25	22	41	26	$p = .008$
Significant other	1	–	–	–	(Fisher's
Child	5	12	8	13	Exact
Grandchild	–	1	–	1	Test)
Sibling	1	–	–	–	
Parent	1	–	1	–	
Other	–	1	1		

There was a small percentage of missing demographic data within a given category from caregivers when broken down by study and condition (range: 2.94% - 11.11%).

cognitive impairment and users of Android phones. Caregivers were contacted via phone by a member of the research team to: (a) obtain consent (PWD consent was obtained from a surrogate when necessary); (b) convey information about the study requirements; (c) inform participants of study; (d) ask caregivers to complete a baseline questionnaire online.

Apparatus

The PPCg system was developed by Care Daily in collaboration with the Berkeley Psychophysiology Laboratory with support from a Small Business Innovation Research Grant from the National Institute on Aging. PPCg consists of a set of wireless devices and sensors that are installed in the home to monitor motion, door openings, temperature/humidity, and water leaks. A gateway device connected to the home's internet router communicates with the sensors and uploads sensor data to Care Daily's cloud where machine learning algorithms learn typical patterns of activity within each home over the course of roughly 1 week. PPCg alerts caregivers via SMS text messages and notifications pushed to an associated smartphone app when it detects worrisome and potentially dangerous situations (e.g., door openings at unusual times, levels of motion in locations and at times that differ from the home's typical patterns). If the caregiver does not respond to these notifications, the alerts can be delivered to their designated family members and friends. In this way, PPCg serves as a resource that can take on tasks that would otherwise require constant caregiver vigilance. The app also provided features intended to maintain social connections and reduce caregiver isolation. In Study 1, this was app-based family photo sharing. In Study 2, this was a Care Daily blog that provided educational materials regarding caregiving. In both studies, an in-app forum called "Community" allowed caregivers to communicate with each other.

PPCg hardware

Study 1. In this study, PPCg consisted of: (a) five motion sensors, (b) three entry sensors, (c) two temperature sensors, (d) one water leak sensor, (e) six battery-operated motion sensing night lights, (f) a Google Home Mini smart speaker, (g) an Apple iPad tablet, and (h) a wireless gateway device. Once installed, the gateway device communicated with the sensors via a Zigbee wireless protocol. Figure 2a displays this system.

Study 2. In this study, PPCg had a simpler setup: (a) three motion sensors (versus five in Study 1), (b) two entry sensors (versus three in Study 1), (c) no temperature sensors (versus two in Study 1), (d) one water leak sensor (similar to Study 1), (e) two motion sensing night lights (versus six in Study 1), (f) an Amazon Alexa Dot (versus a Google Home Mini and Apple iPad in Study 1), (g) one push-button that could be used to initiate emergency services (versus none in Study 1), and (h) a wireless gateway device (similar to Study 1). Figure 2b displays this system.

Procedures

Study 1

The study lasted for nine months, with questionnaires administered at baseline, 3 months, 6 months and 9 months. At each assessment, the questionnaires were identical except that the demographic questions were only administered at baseline and a set of user satisfaction items were added to the last two assessments.

The only contact participants had with the research team was during assessment periods and if they encountered a problem with the system, in which case technical support was provided by Care Daily or the Berkeley Psychophysiology Laboratory. At the end of the study, participants in the control condition were offered the opportunity to have their PPCg systems fully activated for an additional nine-month period without charge and to continue completing the questionnaires every 3 months (data from this period were not included in the current study). All participants were paid $175 for participating in the nine-month study (prorated if all questionnaires were not completed). Participants in the control condition who had their systems fully activated and completed the additional questionnaires were paid an additional $75 (prorated if all questionnaires were not completed).

Random assignment. All participants provided informed consent prior to the in-home installation appointment with the installation team. Installers and participants were blind to the condition assignment, and simple randomization occurred after the

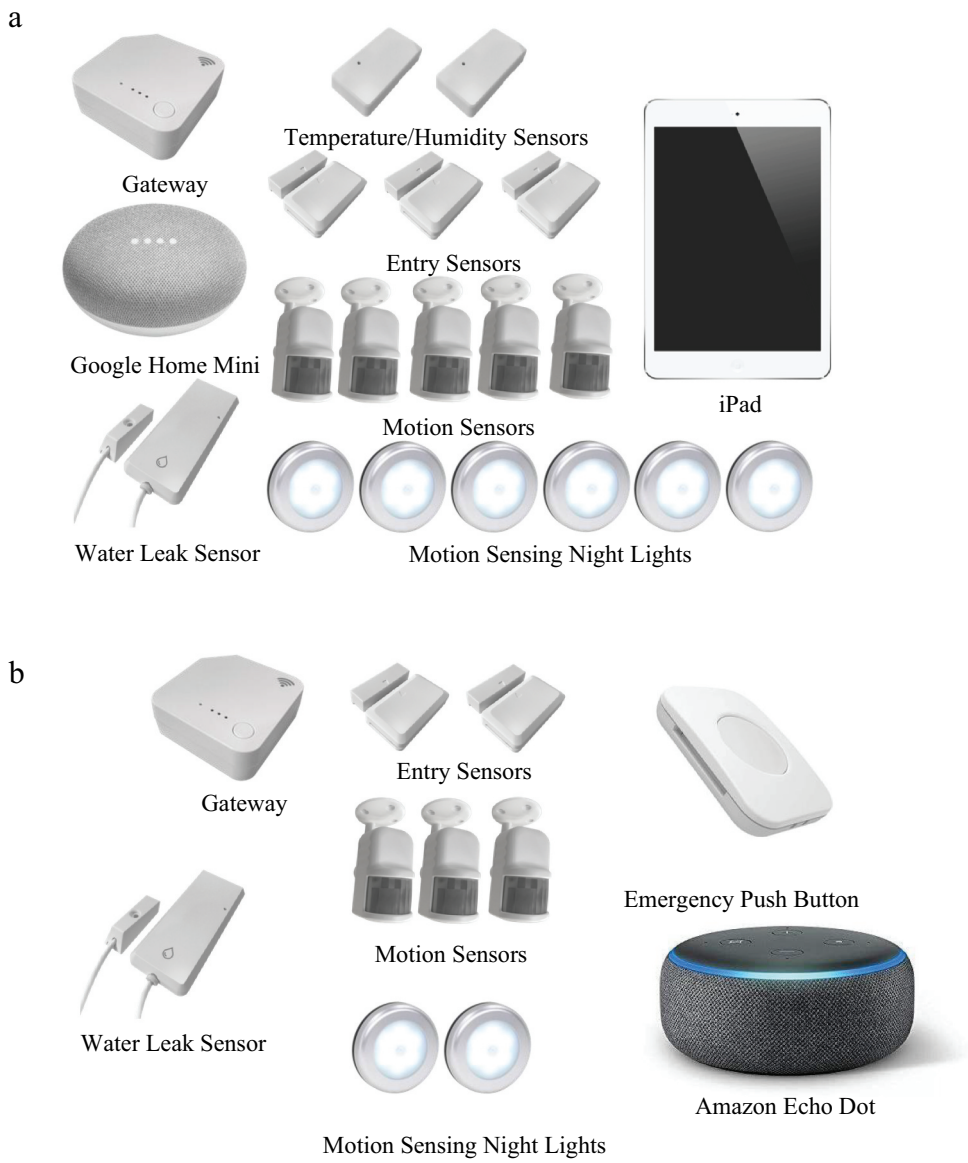

Figure 2. People power caregiver setup for study 1 (a) and study 2 (b).

appointment concluded (i.e., a research team member not involved in the installation randomized participants after the installers notified them that installation had been completed). Homes were randomly assigned to either: (a) the fully activated condition (all sensors and associated alerts were active); or (b) the control condition (only the water leak and moisture sensors and associated alerts were active).

Study 2

The study lasted for 6 months, with questionnaires administered at baseline, 3-months, and 6-months. At each assessment, the questionnaires were identical except that the demographic questions were only administered at baseline and a set of user satisfaction items were added to the last two assessments.

The only contact participants had with the research team was during assessment periods and if they encountered a problem with the system, in which case technical support was provided by Care Daily or the Berkeley Psychophysiology Laboratory. At the end of the study, participants in the control condition were offered the opportunity to have a fully activated PPCg system shipped

to them without charge and to continue completing the questionnaires every 3 months (data from this period were not included in the current study). All participants were paid $75 for installing PPCg and $25 for each completed questionnaire (including the additional questionnaires offered in the control condition).

Random assignment. At the time of indicating interest in the study, simple randomization was conducted by a Care Daily staff member. Research team members who obtained informed consent were blind to the condition assignment as were participants at the time of completing their initial questionnaires. Caregivers' homes were assigned to one of two conditions: (a) the fully activated condition (all sensors and associated alerts were active); or (b) the control condition (participants were told that they would receive a fully activated PPCg system at no charge after a six-month waiting period). In the fully activated condition, PPCg was shipped to the participant's home and participants were offered a virtual installation session with a person from Care Daily who led them through the installation procedures and verified that the system was correctly installed. The target ratio for random assignments in this study was 3:1 for the active-to-control conditions (the actual ratio was 2.17:1).

Measures

Sleep quality

Caregivers completed the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), an 18-item self-report measure that assesses problems with seven components of sleep: (C1) subjective quality, (C2) latency, (C3) duration, (C4) efficiency, (C5) sleep difficulty, (C6) medication usage, and (C7) daytime dysfunction. Individual components were scored from 0 to 3 based on the scale's guidelines, with higher numbers indicative of poorer sleep (see Supplemental Material). The PSQI total score is derived by summing the component scores, with scores higher than 5 indicative of poor sleep quality. The PSQI has shown strong reliability and validity in a variety of samples (Mollayeva et al., 2016) and has been used frequently with dementia caregivers to assess sleep quality (Gao et al., 2019) and the effectiveness of interventions to improve sleep (Pignatiello et al., 2022). For a detailed description of the measure, see Supplemental Material.

Analytical approach

To make the two studies comparable in length, we only analyzed the first three assessments from each. Latent growth modeling (LGM) was used to estimate a latent intercept (i.e., starting point) and a latent linear slope (i.e., growth or decline) based on the three observations: T1 = baseline, T2 = three-months, T3 = six-months. Compared to other within-subject analytic approaches (e.g., repeated measures analysis of variance), LGM has the advantage of accounting for individual variation in the intercept and slope.

To determine whether there was invariance across the two studies on the PSQI total score and within the individual PSQI components (Grimm et al., 2016; Liu et al., 2017), we examined the differences in the latent variables by separately regressing the latent intercept and slope of the study variable, which was dummy coded (i.e., Study 1 = 0, Study 2 = 1; see Supplemental Figure S1A). Our primary analysis examining the effect of PPCg on caregiver sleep (i.e., on the PSQI total followed by the individual PSQI components) was conducted by regressing the latent intercept and slope on condition, which was dummy coded (i.e., control = 0, active = 1; see Supplemental Figure S1B). To correct for multiple comparisons, we report false discovery rate (FDR) adjusted thresholds using a q-value of .05 (Benjamini & Hochberg, 1995).[3] Any findings that pass alpha levels of .05 but not the false discovery rate threshold are indicated as "suggestive" findings (see Table 2).

In analyses using LGM with continuous outcome variables (i.e., PSQI total score), we used full information maximum likelihood estimation (FIML) to account for missing data ($N = 5$ caregivers) in the model (Jeličić et al., 2009). This approach estimates parameters based on all observed data points and their interrelationships. In analyses using LGM with ordered variables (i.e., individual PSQI components), we used pairwise deletion methods for missing data

Table 2. Latent intercept and linear slope comparison by study and by condition.

	Model Fit			Intercept			Slope		
Study Models (Study Invariance)	**χ^2**	***p***	**CFI**	**b**	***p***	**i/m(Q)**	**b**	***p***	**i/m(Q)**
PSQI Total Score	2.07	.355	1.000	0.47	.421	—	0.17	.490	—
C1 – Quality	3.26	.776	1.000	−0.46	.203	.014	0.17	.444	.029
C2 – Latency	0.32	.999	1.000	0.75	.051	.007	−0.06	.701	.036
C3 – Duration	10.60	.101	.992	0.40	.271	.029	−0.21	.222	.021
C4 – Efficiency	6.64	.356	.994	0.19	.453	.043	−0.05	.731	.043
C5 – Sleep Difficulty	1.14	.980	1.000	−0.24	.419	.036	0.30	.105	.007
C6 – Medications	0.91	.989	1.000	0.52	.233	.021	0.46	.185	.014
C7 – Daytime Dysfunction	1.09	.982	1.000	−0.20	.583	.050	0.01	.943	.050
Condition Models (Main Analyses)	**χ^2**	***p***	**CFI**	**b**	***p***	**i/m(Q)**	**b**	***p***	**i/m(Q)**
PSQI Total Score	3.48	.175	.994	−0.32	.586	—	−0.23	.354	—
C1 – Quality	3.51	.742	1.000	0.02	.950	.050	0.04	.839	.036
C2 – Latency	1.57	.954	1.000	−0.43	.239	.014	0.06	.696	.021
C3 – Duration	1.39	.967	1.000	0.13	.715	.043	−0.29	.102	.014
C4 – Efficiency	5.85	.440	1.000	0.20	.461	.029	−0.34	.038	.007
C5 – Sleep Difficulty	2.88	.823	1.000	−0.37	.238	.007	0.06	.743	.029
C6 – Medications	0.47	.998	1.000	−0.18	.682	.036	0.02	.939	.050
C7 – Daytime Dysfunction	1.68	.947	1.000	−0.35	.321	.021	0.02	.894	.043

(i/m)*Q provides an adjusted significance threshold based on the false-discovery rate (FDR). The Q-value was set to .05. The symbol "b" refers to the raw coefficients obtained in the model.

($N = 4$ caregivers). We inspected the χ^2 test of model fit and the standardized root-mean-square residual (SRMR) as measures of absolute fit and examined the comparative fit index (CFI) as a measure of incremental fit. Adequate model fit is generally considered to be indicated by: (a) non-significant χ^2 values ($ps < .05$), and (b) CFI values greater than 0.95 (Hu & Bentler, 1999).

Statistical power

For LGM analysis determining whether PPCg benefitted caregivers' sleep, power calculations are notably complex (Wolf et al., 2013). Using the semPower package in R (Moshagen & Bader, 2023), an a priori power analysis indicated that for a condition effect on a linear slope in the model of .05 (small) with 80% power and alpha of .05 with 145 degrees of freedom in the model, we would require 133 participants. Thus, analyses within individual studies were underpowered.

Ethical considerations

These studies received ethical approval by the Office for Protection of Human Subjects at the University of California, Berkeley (2010-02-861). All caregivers reviewed and completed a consent form (PWD consent was obtained from a surrogate when necessary) at Time 1 before completing the study materials.

Results

Study invariance

There were no significant differences in the latent intercept (range of b = −0.46–0.75, $p \geq .051$) and slope (range of b = −0.21–0.46, range of $p \geq .105$) across the two studies for total sleep quality and the seven components of the PSQI (see Table 2). Therefore, we combined the two studies for analyses (Liu et al., 2017).

Baseline differences between experimental conditions

Analyses of variance comparing the active and control conditions on the PSQI total score and PSQI individual components revealed no significant differences at baseline between the two conditions (see Supplemental Table S2). A χ^2 test of the percentage of caregivers reporting significant sleep problems at baseline on the PSQI total score (i.e., a sum of 5 or

greater out of 21; control condition: $M = 7.76$, $SD = 3.84$; active condition $M = 7.22$, $SD = 3.68$) revealed no differences between the two conditions (active: 72.37%, control: 75.58%, $N = 2$ missing; $\chi^2(1) = 0.30$, $p = .583$).

Did caregivers' sleep benefit from the PPCg system?

We examined each of the seven component scores on the PSQI to determine whether caregivers' sleep benefited from the PPCg system. All models indicated appropriate fit $\chi^2(6)$ range = 0.47–5.85, $p \geq .175$, CFI range = .994–1.00 (see Table 2). We did not obtain any significant condition effects on the latent intercept (i.e., baseline) on the PSQI total score or on any of the PSQI individual components, further verifying no baseline or starting point differences between conditions on these self-reports of sleep in the caregivers (range of b = −0.43–0.20, range of $p = .238$–$.950$). We additionally did not obtain any significant condition effects on the latent slope (i.e., assessing sleep improvements or declines) on the PSQI total score or on the individual components that assess sleep quality, latency, sleep difficulty, use of sleep medications, and daytime dysfunction (range of b = −0.23–0.06, range of $p = .354$–$.939$; see Table 2).

However, we did obtain a significant effect of condition on the latent slope for sleep efficiency (i.e., total number hours that caregivers were asleep compared to the total number of hours that they were in bed; b = −0.34, $p = .038$) such that the control condition reported worse sleep efficiency over time (i.e., growing sleep efficiency problems, b = 0.23) whereas by comparison, the active condition reported better sleep efficiency over time (i.e., declining sleep efficiency problems, b = −0.12; Cohen's d of the difference = −0.76 or a moderate effect size, see Table 2 and Figure 3). However, this condition effect on the linear slope for sleep efficiency did not pass the FDR-adjusted threshold of .007, which accounts for multiple comparisons.

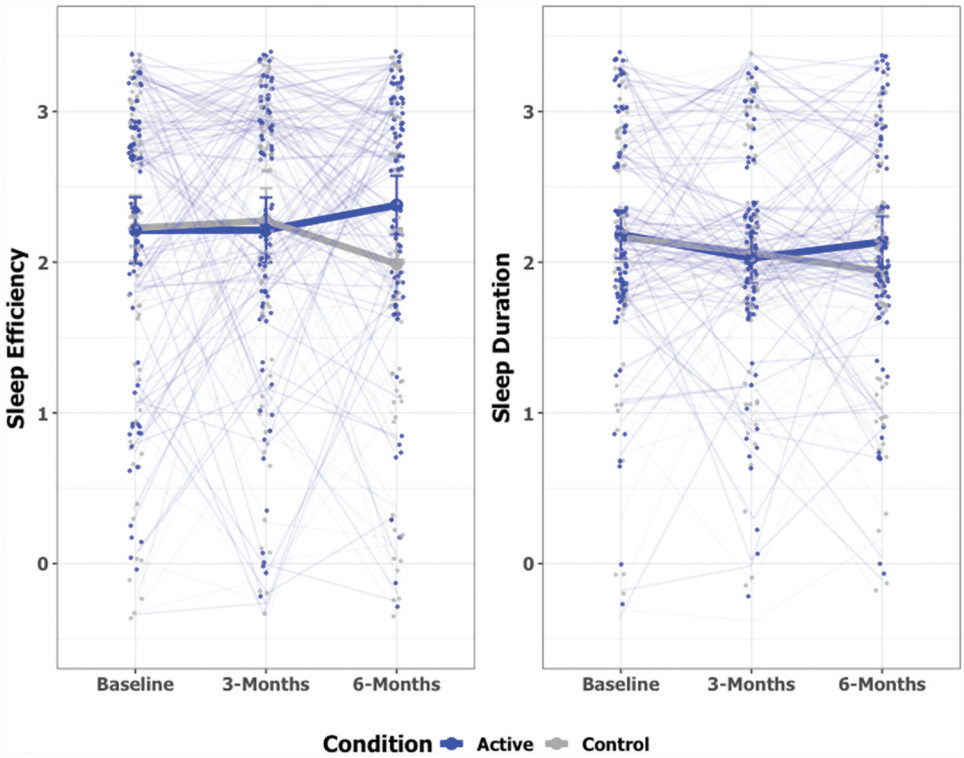

Figure 3. Caregiver sleep efficiency and duration by condition and assessment. The PSQI sleep efficiency (left) condition slope effect was statistically significant at the .05 level ($p = .038$; but did not survive FDR threshold). The sleep duration (right) condition slope effect was only a nonsignificant trend ($p = .102$). Scores are reversed for ease of display (higher scores indicate better sleep). Individual raw scores are jittered in position to avoid overlap of dots, individual trajectories are displayed (transparent lines), with the active group (blue) and control (gray) group means and 95% confidence intervals displayed.

Given this finding, we conducted a post-hoc power analysis using Monte Carlo Simulation with 500 simulations of the results obtained for sleep efficiency. Power is indexed by the proportion of these simulations in which the condition effect on the latent intercept or latent slope yielded a significant result. Our power to detect the condition effect on the latent intercept was 0.09 and on the latent slope was 0.33. Therefore, the analyses reported may be underpowered for results with smaller effect sizes. Given this post-hoc power analysis, we interpret the findings of PPCg's benefit on caregiver sleep efficiency with some caution.

Other than sleep efficiency, the only other individual sleep component that showed indication of benefits for the PPG system was sleep duration. Although not statistically significant at the .05 level, the effect of condition on the latent slope for sleep duration (b = −0.29, $p = .102$) was in the direction of the control group reporting declining sleep duration over the 6-month period (i.e., growing sleep duration problems, b = 0.38) compared to the active condition (i.e., lesser growth in sleep duration problems, b = 0.09 Cohen's d of the difference = −0.56 or a moderate effect size; see Table 2 and Figure 3). See Supplemental Figures S2 and S3 for additional information on the sleep efficiency and duration findings.

Discussion

In this project, we conducted two longitudinal randomized controlled trials and found that caregivers in the fully activated PPCg system conditions received some protection from the worsening sleep efficiency that was observed in caregivers in the control conditions (partially activated PPCg in Study 1, waiting list control in Study 2). When comparing theories of sleep, our results do not support the caregiver empowerment (Jones et al., 2011) or perceived sleep need (Scullin, 2017) models. However, they do support the environmental stressor model (Pinquart & Sörensen, 2007) given PPCg's benefits on caregiver sleep efficiency (i.e., addressing environmental stressors by helping monitor the PWD). We also found support for prior findings that caregivers often experience sleep problems due to the multiple external stressors related to their role. This took the form of high levels of caregivers' reported sleep issues within each condition at baseline (i.e., >70%) and caregivers reporting worsening sleep efficiency in the control condition. Our findings also demonstrate that PPCg protects caregivers against declines in sleep efficiency. Although we cannot identify with certainty the mechanism responsible for this effect, we believe that PPCg's monitoring features may lessen caregivers' need for constant vigilance (Peng & Chang, 2013; Rowe et al., 2010) at night and reduce associated disruptions in sleep (e.g., fewer awakenings to make sure the PWD has not fallen or left the house; Bentley et al., 2022; Brewster et al., 2022, 2024; McCurry et al., 2007). Moreover, this beneficial effect on sleep efficiency may have broader downstream benefits given the relationship that sleep problems have with other health problems (Gao et al., 2019; Peng et al., 2019) and declines in cognitive functioning (H. Ikeda et al., 2022; Y. Ikeda et al., 2022). Although we were not able to identify the exact mechanism by which PPCg protects sleep efficiency, we speculate that it may result from the reduced vigilance required by caregivers as they offload some of their monitoring of their PWD to the PPCg system while in bed at night.

We were surprised that none of the other PSQI components other than sleep efficiency showed significant benefits and that only one (sleep duration) showed changes (non-significant) that were in that direction. However, each of these components by design measures somewhat different aspects of sleep. Sleep efficiency is a direct measure of the ratio of sleep time to the caregiver's overall time in bed and may benefit from PPCg allowing the caregiver to "let go" and trust PPCg to detect and provide alerts for worrisome situations. Consistent with this, concerns about the PWD's whereabouts and activities during the night have been found to increase the time that caregivers lie in bed with "an open ear" (Gao et al., 2019; McCurry et al., 2007; Rowe et al., 2010). These factors may also have contributed to the trend findings that PPCg also benefitted sleep duration.

Prior research has reported that non-technology-based sleep interventions such as Cognitive-Behavioral Therapy for Insomnia (CBT-I) show improvements on sleep efficiency (Bei et al., 2015; Jacobs et al., 2004; Sivertsen et al., 2006). Considering the costs of technology-based interventions for caregivers, it is important to consider

whether insurance will subsidize their purchase, installment, and maintenance. Mobile apps are also available to help improve sleep (e.g., Insomnia Coach, Headspace, Calm) but do not require additional extensive hardware. Rigorous research is needed to examine the merits of using various technological and non-technological interventions (e.g., CBT-I; emotional, psychological, and physical support; environmental changes; Cheng et al., 2019, 2020) separately and together to help improve caregiver sleep.

Strengths and limitations

This research has several strengths including: (a) conducting two longitudinal RCTs with different recruitment geographies, expert and self-installation, and different control conditions, thus testing the robustness of the PPCg intervention; (b) recruiting caregivers who varied in whether they were caring for someone with a diagnosis of either mild cognitive impairment or dementia, geographic location, and socioeconomic status (i.e., income and education; Adler & Snibbe, 2003); and (c) evaluating a technology-based intervention for dementia caregivers with adequate statistical power after combining data across studies. The research also had several limitations: (a) recruitment for Study 1 was ended early due to the onset of the COVID-19 pandemic (Levenson et al., 2024); (b) the majority of the sample was white female spousal caregivers for male partners; (c) we were not able to determine the mechanism underlying the observed sleep benefit associated with PPCg; (d) we did not have objective sleep measures (e.g., actigraphy, polysomnography) in addition to self-report; and (e) the sleep efficiency finding did not survive corrections for multiple comparisons. Additionally, the desired recruitment ratio of 3:1 active-to-control condition home assignments in Study 2 fell slightly short with simple randomization (i.e., 2.17:1). Future iterations of this type of randomized control trial may consider using block randomization to help achieve the desired ratio. Nonetheless, given the lack of prior randomized control trials evaluating the utility of in-home assistive technologies, we believe these findings are sufficiently encouraging to support future implementations and evaluations of technology-based solutions for addressing caregiver sleep problems.

There is no doubt that gender, relationship, and diversity factors influence caregivers' response to a myriad of interventions (Diverse Elders Coalition, 2021; Gallagher-Thompson et al., 2023). Thus, future research should consider the impact of these factors on the efficacy and effectiveness of interventions for caregivers. In sum, we believe that there is considerable potential value in developing and evaluating in-home assistive technologies that can help caregivers deal with the challenges of caregiving and protect against sleep problems that represent significant risks to their health and well-being.

Notes

1. For caregivers excluded for installation issues, there were no statistically significant differences on the sleep outcomes at baseline for those who were excluded versus included (*p*s = .228–.877).
2. For caregivers excluded for insufficient duration with PPCg in the active condition of Study 2, there were no statistically significant differences on the sleep outcomes at baseline for those who were excluded versus included (*p*s = .091–.993).
3. (i/m)*Q, where i = rank of given uncorrected *p*-value (lowest-to-highest), *m* = total number of comparisons, Q = false discovery rate (.05, meaning our false discovery rate is 5%). This correction was applied to the individual PSQI components but not to the PSQI total score.

Clinical Implications

- In two randomized controlled trials, we found that caregivers who received a fully activated PPCg technology system received some protection against declines in sleep efficiency compared to caregivers in the control conditions. We believe this results from the system's in-home monitoring features lessening the level of caregiver vigilance during the night and associated disruptions in sleep (e.g. less need to check to make sure the PWD has not fallen or left the house).
- We believe that these findings should encourage caregivers to seek out information about technology-based assistive methods (e.g. PPCg, wearables, apps) that may help protect their sleep efficiency.
- Additionally, caregivers and clinicians can hopefully stay informed about the rapidly evolving state of the art technology-based products and services.

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Disclosure statement

David Moss and Gene Wang are employees and own stock in Care Daily, which developed and sells People Power Caregiver (PPCg). No other conflicts of interest are reported by the other authors.

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ORCID

Dolores Gallagher-Thompson PhD http://orcid.org/0000-0001-5321-3403

Data availability statement

Data, syntax, and analytic code are available at https://osf.io/csruy/. This study was not pre-registered

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