https://doi.org/10.5664/jcsm.10878

JCSM | Journal of Clinical Sleep Medicine

EMERGING TECHNOLOGIES

A novel voice interactive sleep log: concurrent validity with actigraphy and sleep diaries

Daniel Lewin, PhD[1]; Claire M. Starling, MPH[2]; Eric S. Zhou, PhD[3]; Daniel Greenberg, BA[4]; Callen Shaw, BS[4]; Hannah Arem, PhD[2,5]

[1]Sleep Health and Wellness Center, Santa Barbara, California; [2]Healthcare Delivery Research, MedStar Health Research Institute, Washington, DC; [3]Dana-Farber Cancer Institute, Boston, Massachusetts; [4]Media Rez, Washington, DC; [5]Department of Oncology, Georgetown University, Washington, DC

This is a preliminary validation study of a novel approach to an interactive sleep data collection platform. We compared actigraphy, paper and pencil logs, and the novel voice interactive sleep log in a sample of 17 breast cancer survivors with insomnia symptoms and also report qualitative data on acceptability. We used correlation coefficients and Bland Altman plots to evaluate convergent validity across these measures and report means for acceptability ratings. The sleep log data collected via paper and pencil vs the voice interactive measure had comparable mean values and variable validity coefficients across key sleep variables compared to actigraphy except for wake after sleep onset, where the voice-interactive system had fair concurrent validity with actigraphy. The voice interactive sleep log has several advantages over pencil and paper logs and actigraphy as it reduces patient burden, automatically calculates sleep variables, documents the timeliness of response and provides daily feedback to respondents on calculated sleep metrics.

Clinical Trial Registration: Registry: ClinicalTrials.gov; Identifier: NCT05233800.

Keywords: insomnia, sleep log, actigraphy, assessment

Citation: Lewin D, Starling CM, Zhou ES, Greenberg D, Shaw C, Arem H. A novel voice interactive sleep log: concurrent validity with actigraphy and sleep diaries. *J Clin Sleep Med*. 2024;20(2):309–312.

INTRODUCTION

The evaluation of sleep metrics, such as sleep timing and sleep quality, is complex because objective and self-report subjective assessments have unique benefits and drawbacks. The 3 primary measures of sleep used in the evaluation and treatment of patients with insomnia are sleep logs or diaries,[1,2] sleep questionnaires,[3] and actigraphy (Mini-MotionLogger, Ambulatory Monitoring, Inc.). These yield raw data from which key variables are derived that contribute to the differential diagnosis of insomnia and other sleep disorders.

Self-administered paper and pencil sleep logs (PP-SLs) are the standard in clinical care, yet limitations include patient and provider burden. Paper logs may get misplaced and yield raw data that require calculations during appointments that could otherwise be used to interact with patients. Furthermore, clinicians have long questioned whether patients fill logs out daily or right before appointments, making the accuracy of reported sleep metrics somewhat suspect.

We developed a program that collects sleep log data using a voice-interactive sleep log (VIA-SL) on a home-based smart speaker to address some of the previously mentioned limitations of PP-SLs. This strategy to collect sleep data offers many potential advantages: first, voice-interactive technology is increasingly prevalent; second, the VIA-SL can auto-calculate important sleep metrics (eg, sleep efficiency) and provide daily feedback on sleep patterns; third, the VIA-SL can query erroneous responses, provide time limits on daily reporting, and give feedback in real time on adherence.

We hypothesized that the data quality and accuracy (measured by concurrent validity) of the VIA-SL would be comparable to the PP-SL and perform similarly to the PP-SL compared with actigraphy. We also hypothesized that users would find the overall interactive system to be highly usable and acceptable.

METHODS

As part of a larger project to provide a behavioral insomnia intervention to breast cancer survivors,[4] we evaluated the concurrent validity of actigraphy (Ambulatory Monitoring, Micro-Motionlogger, ACTI),[5] a standard PP-SL (the Consensus Sleep Diary),[1] and our newly developed VIA-SL.

Participants

We recruited survivors of stage I–III breast cancer or stage IV high-functioning breast cancer survivors. Included participants reported a score greater than or equal to 5 on the Pittsburgh Sleep Quality Index.[2] Exclusion criteria included undiagnosed or poorly controlled sleep and psychiatric disorders.

Sleep data collection

Participants were mailed an Amazon Echo Dot (third-generation smart speaker) and a smart phone with a hotspot to provide maximum privacy. Participants were instructed to run the VIA-SL daily within 30 minutes of bed and wake times, and the

program queried on key consensus sleep diary questions needed to calculate relevant sleep metrics. Participants were concurrently asked to complete PP-SL printouts daily. Actigraphs were set to collect sleep data at a 1-minute epoch length. Individuals were asked to indicate via an event button when they were going to sleep and when they were waking up. All study participants were asked to complete 10 days of concurrent data and a minimum of 4 days of data were required. Three of the actigraphs failed, resulting in exclusion of those participants.

Acceptability, appropriateness, and usability

Participants completed acceptability, usability, and appropriateness ratings on the overall treatment and diary program using Likert scales, where higher numbers indicate above average.[6,7]

Contiguous days of actigraphy data were included in analyses when there were concurrent data from the VIA-SL and PP-SL.

Data analyses

Descriptive statistics for sleep metrics included time lights out (TLO), time out of bed (TOB), total time in bed (TIB), sleep-onset latency (SOL), wake time after sleep onset (WASO), total sleep time (TST), and sleep efficiency. All data were normally distributed.

Concordance correlation coefficients (CCCs) were estimated by the variance components from linear mixed models, and Bland-Altman plots[8] were used to evaluate the agreement of the 2 sleep log measures compared with each other and with actigraphy. Altman suggested the following gradings of CCCs: < 0.2 = poor and > 0.8 as excellent (0.2–0.8 fair/moderate).

RESULTS

Sample characteristics

The study sample consisted of 17 breast cancer survivors, with an average age of 56.1 years (SD = 13.5 years). The racial distribution of our sample was 64.7% White, 23.5% Black, and 11.8% other. Sleep data were collected from participants an average of Actigraphy, 7.5 days (SD = 1.3); VIA-SL, 7.3 days (SD = 0.8); and PP-SL, 7.1 days (SD = 0.2).

Mean sleep variables

For all sleep variables there were minimal differences in means and variability between the PP-SL and the VIA-SL (**Table 1**), and in all cases, the VIA-SL values were between the PP-SL and actigraphy values. The PP-SL and VIA-SL underestimated actigraphy TST by 46 and 41 minutes, SE by 3%, and WASO

Table 1—Mean sleep variables.

Variable	Sample Observations (n = 17)	Units	Mean (SD)	CCC with Actigraphy[a]
TLO_PP-SL	105	Hours:minutes (hours)	11:22 (1.4)	0.45
TLO_VIA-SL	105	Hours:minutes (hours)	11:15 (1.4)	0.47
TLO_ACTI	105	Hours:minutes (hours)	10:50 (2.4)	—
TOB_PP-SL	104	Hours:minutes (hours)	7:32 (1.3)	0.81
TOB_VIA-SL	104	Hours:minutes (hours)	7:29 (1.3)	0.87
TOB_ACTI	104	Hours:minutes (hours)	7:15 (1.6)	—
TIB_PP-SL	105	Minutes	451.62 (82.7)	0.13
TIB_VIA-SL	105	Minutes	459.15 (74.0)	0.26
TIB_ACTI	105	Minutes	525.1 (77.9)	—
TST_PP-SL	105	Minutes	391.87 (80.7)	0.28
TST_VIA-SL	105	Minutes	396.81 (76.5)	0.22
TST_ACTI	105	Minutes	437.86 (64.4)	—
SE_PP-SL	105	Ratio TST/TIB	0.87 (0.11)	0.18
SE_VIA-SL	105	Ratio TST/TIB	0.87 (0.11)	0.17
SE_ACTI	105	Ratio TST/TIB	0.84 (0.10)	—
SOL_PP-SL	104	Minutes	23.41 (23.2)	0.18
SOL_VIA-SL	104	Minutes	23.78 (23.3)	0.12
SOL_ACTI	104	Minutes	13.30 (20.6)	—
WASO_PP-SL	104	Minutes	36.83 (40.0)	0.05
WASO_VIA-SL	104	Minutes	38.98 (39.0)	0.34
WASO_ACTI	104	Minutes	54.66 (47.1)	—

[a]CCC estimated by variance components from a linear mixed model. ACTI = actigraphy, CCC = concordance correlation coefficient, PP-SL = paper and pencil sleep log, SE = sleep efficiency, SOL = sleep-onset latency, TIB = time in bed, TLO = time lights out, TOB = time out of bed, TST = total sleep time, VIA-SL = voice-interactive sleep log, WASO = wake after sleep onset.

by 18 minutes and 16 minutes, and overestimated SOL by approximately 10 minutes relative to actigraphy.

Validity coefficients

CCCs showed considerable variability across sleep metrics, with the best overall agreement among the 2 sleep log methods and actigraphy for TLO and TOB; the CCC for TLO (PP-SL 0.45 and VIA-SL 0.47) and TOB (PP-SL 0.81 and VIA-SL 0.87) were in the moderate to excellent range for both log measures compared with actigraphy. The VIA-SL TIB CCC was only fair (0.26), although higher than the PP-SL (0.13). For TST, PP-SL and VIA-SL were just fair (0.28 vs 0.22, respectively). For SE and SOL the CCC for both logs was poor (SE PP-SL 0.18 and VIA-SL 0.17; SOL PP-SL 0.18 and VIA-SL 0.12). For WASO, we found an acceptable CCC for VIA-SL (0.34) and an exceedingly poor finding for the PP-SL (0.05). Comparing the 2 sleep logs, there was high concordance for TLO (0.91), TOB (0.92), SOL (0.97), and TIB (0.86), while there was moderate concordance for TST (0.70), SE (0.71), and WASO (0.63).

Bland-Altman plots suggest that a handful of extreme values in mean differences may account for some differences, particularly for WASO. Distributions by method appeared quite similar for SE and SOL.

Acceptability and usability

Participant ratings of the ease of use of the overall voice-interactive system were generally high, with ratings of 4.3/5 for acceptability, 4.2/5 for appropriateness, and 83.4 for system usability (exceeding average of 68).

DISCUSSION

There has been a proliferation of new technologies designed to measure sleep health. This study tested the validity of a novel approach to evaluating insomnia symptoms that could be used independently or as part of a program that diagnoses and treats insomnia. Overall, our findings offer preliminary evidence that the VIA-SL is comparable to the PP-SL in mean values of key sleep variables as well as patterns of concordance with actigraphy. Participant feedback suggested high acceptability and usability for the overall treatment and assessment components of the parent study.

Findings of high validity of the PP-SL and VIA-SL of sleep timing (TLO and TOB) were consistent with other studies comparing logs and actigraphy.[9,10] Overall, these findings suggest that the VIA-SL is at least comparable to PP-SL.

Limitations of this study include a small sample that had specific demographics and diagnoses that may limit generalizing these findings to other populations. The timing of daily PP-SL completion is also unknown.

CONCLUSIONS

Overall, the VIA-SL and the PP-SL demonstrate expected associations with actigraphy, a validated measure of sleep timing, sleep maintenance, and sleep duration. Next steps include testing the efficacy of delivering components of cognitive behavioral therapy for insomnia via the overall voice-interactive assessment and intervention program.

ABBREVIATIONS

CCC, concordance correlation coefficient
PP-SL, paper and pencil sleep log
SE, sleep efficiency
SOL, sleep-onset latency
TIB, time in bed
TOB, time out of bed
TST, total sleep time
VIA-SL voice-interactive sleep log
WASO, wake time after sleep onset

REFERENCES

1. Carney CE, Buysse DJ, Ancoli-Israel S, et al. The consensus sleep diary: standardizing prospective sleep self-monitoring. *Sleep.* 2012;35(2):287–302.
2. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res.* 1989;28(2):193–213.
3. Bastien CH, Vallières A, Morin CM. Validation of the Insomnia Severity Index as an outcome measure for insomnia research. *Sleep Med.* 2001;2(4):297–307.
4. Starling CM, Greenberg D, Zhou E, et al. Testing delivery of components of cognitive behavioral therapy for insomnia to breast cancer survivors by smart speaker: a study protocol. *BMC Med Inform Decis Mak.* 2022;22(1):163.
5. Schmidt-Nowara W, Beck A, Jessop C. Actigraphic assessment of a treatment trial of sleep restriction in chronic insomnia. *Sleep Res.* 1992;21:259.
6. Bangor A, Kortum PT, Miller JT. An empirical evaluation of the System Usability Scale. *Int J Hum-Comput Int.* 2008;24(6):574–594.
7. Weiner BJ, Lewis CC, Stanick C, et al. Psychometric assessment of three newly developed implementation outcome measures. *Implement Sci.* 2017;12(1):108.
8. Altman DG. *Practical Statistics for Medical Research.* New York: Chapman and Hall/CRC, 1990.
9. Thurman SM, Wasylyshyn N, Roy H, et al. Individual differences in compliance and agreement for sleep logs and wrist actigraphy: a longitudinal study of naturalistic sleep in healthy adults. *PLoS One.* 2018;13(1):e0191883.
10. Smith MT, McCrae CS, Cheung J, et al. Use of actigraphy for the evaluation of sleep disorders and circadian rhythm sleep-wake disorders: an American Academy of Sleep Medicine clinical practice guideline. *J Clin Sleep Med.* 2018; 14(7):1231–1237.

SUBMISSION & CORRESPONDENCE INFORMATION

Submitted for publication March 20, 2023
Submitted in final revised form October 18, 2023
Accepted for publication October 18, 2023
Address correspondence to: Daniel Lewin, PhD, D.ABSM, CBSM, Sleep Health and Wellness Center, 5672 West Camino Cielo, Santa Barbara, CA 93105

DISCLOSURE STATEMENT

All authors have reviewed and approved this manuscript. Work for this study was performed at Healthcare Delivery Research, Medstar Health Research Institute, Washington, DC. This study was funded by the National Cancer Institute (NCI) grant number R44CA232905. The design of the study; collection, analysis, and interpretation of data, and writing the manuscript are independent of the funding body. The study protocol has undergone full external peer review by the funding body as part of the peer-review process. Daniel Lewin, PhD, has no conflicts of interests, disclosures, or financial interests aside from those normally associated with Small Business Innovation Research. Claire M. Starling, MPH, has no financial interests' conflicts or disclosures. Eric S. Zhou, PhD, has received consulting fees from Samsung and has no other conflicts or financial interest aside from those normally associated with Small Business Innovation Research. Daniel Greenberg, BA, is Principal Investigator on the grant supporting this research and is a principal in Media Rez and has an interest consistent with the policy on Small Business Innovation Research. Callen Shaw, BS, is Co-Investigator on the grant supporting this research and is a staff member of Media Rez and has an interest consistent with the policy on Small Business Innovation Research. Hannah Arem, PhD, Principal Investigator on the grant has no conflicts of interests, disclosures/financial interests aside from those normally associated with Small Business Innovation Research.

EDITOR'S NOTE

The Emerging Technologies section focuses on new tools and techniques of potential utility in the diagnosis and management of any and all sleep disorders. The technologies may not yet be marketed, and indeed may only exist in prototype form. Some preliminary evidence of efficacy must be available, which can consist of small pilot studies or even data from animal studies, but definitive evidence of efficacy will not be required, and the submissions will be reviewed according to this standard. The intent is to alert readers of *Journal of Clinical Sleep Medicine* of promising technology that is in early stages of development. With this information, the reader may wish to (1) contact the author(s) in order to offer assistance in more definitive studies of the technology; (2) use the ideas underlying the technology to develop novel approaches of their own (with due respect for any patent issues); and (3) focus on subsequent publications involving the technology in order to determine when and if it is suitable for application to their own clinical practice. The *Journal of Clinical Sleep Medicine* and the American Academy of Sleep Medicine expressly do not endorse or represent that any of the technology described in the Emerging Technologies section has proven efficacy or effectiveness in the treatment of human disease, nor that any required regulatory approval has been obtained.