Use of Body Sensors to Examine Nocturnal Agitation, Sleep, and Urinary Incontinence in Individuals With Alzheimer's Disease

ABSTRACT

Nighttime agitation, sleep disturbances, and urinary incontinence (UI) occur frequently in individuals with dementia and can add additional burden to family caregivers, although the co-occurrence of these symptoms is not well understood. The purpose of the current study was to determine the feasibility and acceptability of using passive body sensors in community-dwelling individuals with Alzheimer's disease (AD) by family caregivers and the correlates among these distressing symptoms. A single-group, descriptive design with convenience sampling of participants with AD and their family caregivers was undertaken to address the study aims. Results showed that using body sensors was feasible and acceptable and that patterns of nocturnal agitation, sleep, and UI could be determined and were correlated in study participants. Using data from body sensors may be useful to develop and implement targeted, individualized interventions to lessen these distressing symptoms and decrease caregiver burden. Further study in this field is warranted. [*Journal of Gerontological Nursing, 44*(8), 19-26.]

More than 5.5 million individuals in the United States have Alzheimer's disease (AD) and the number of new cases of AD per year is expected to double by 2060 as the population of older adults continues to grow (Alzheimer's Association, 2017; Brookmeyer, Abdalia, Kawas, & Corrada, 2017). Family members provide much of the care for individuals with AD in their homes. As such, families undertake complex care regimens, including management of problematic behaviors, sleep disturbances, urinary incontinence (UI), and other activities of daily living. Many clinicians and families view these symptoms as being "just part of the disease" and seek either no treatment or conventional medical management, most often medications. Use of medications to address these symptoms has demonstrated limited effectiveness and increased unintended safety risks (Ballard et al., 2009; Drennan, Cole, & Iliffe, 2011; Hägglund, 2010).

As AD progresses, individuals may be unable to communicate their care needs (e.g., need for toileting),

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which can result in behaviors such as restlessness, agitation, and incontinence (Cohen-Mansfield, Dakheel-Ali, Marx, Thein, & Regier, 2015). Thus, restlessness, agitation, and UI may occur because of unmet needs. Faced with limited options for treatment of these distressing symptoms, increased stress and burden to caregivers, and increasing care need demands, many families seek long-term placement for their loved one with AD (Gaugler, Duval, Anderson, & Kane, 2007; Onishi et al., 2005).

Although each of these disturbances—nocturnal agitation, alterations in sleep, and UI—is recognized independently in individuals with AD, no research, to date, has studied the interrelationships of these distressing symptoms in community-dwelling individuals with AD. Wireless sensors hold promise as a means to measure these symptoms and determine their correlation, if any, to each other. With more knowledge about the relationships of these symptoms to each other, effective interventions for these distressing symptoms may be developed and could result in a higher quality of life for individuals with AD and their family caregivers.

...Restlessness, agitation, and urinary incontinence may occur because of unmet needs.

The purpose of the current study was to determine the correlates of nocturnal agitation, sleep, and UI in community-dwelling individuals with AD. The specific aims were to: (1) examine the feasibility and acceptability of the use of body sensors in individuals with AD and family caregivers; (2) describe patterns of nocturnal agitation, sleep continuity and duration, and nighttime UI in individuals with AD; and (3) examine the relationships among nocturnal agitation, sleep continuity and duration, and nighttime UI (e.g., timing, frequency) in individuals with AD. A secondary aim was to determine the influence of covariates (i.e., cognitive function, physical function, duration of dementia symptoms, and age) on primary study outcomes.

METHOD

A single-group, descriptive design with convenience sampling of participants with AD and their family caregivers was undertaken to address the study aims. Institutional Review Board approval was obtained prior to beginning the study. Informed written consent and assent (for individuals with AD who had significant cognitive impairment) were obtained before enacting the study protocol. All aspects of the study protocol were completed within participant homes.

Inclusion criteria for individuals with AD were: age 65 or older, confirmation of National Institute of Neurological and Communicative Disorders and Stroke and Alzheimer's Disease and Related Disorders Association criteria for probable or possible AD confirmed in writing by their physicians (McKhann et al., 2011); caregiver confirmation of at least two agitation behaviors occurring a minimum of several times per week in the individual with AD as measured by the Cohen-Mansfield Agitation Inventory-Community version (Cohen-Mansfield, 1995); caregiver confirmation of an average of two or more occurrences of nocturnal UI per week; all medications stable for at least 6 weeks prior to the study; community-dwelling; willingness to defer changes in medications (e.g., antidepressant, anxiolytic, psychotropic, sedative, and as-needed over-the-counter sleep medications); and fluent in English. For family caregiver participants, inclusion criteria were: age 21 or older; informal, unpaid caregiver who resides with the care recipient; willingness to defer changes in medications (as above) in the care recipient until completion of the study; and fluent in English. Exclusion criteria for individuals with AD included documented history of sleep apnea (untreated), periodic limb movements in sleep disorder, or restless legs syndrome; presence of acute illness; alcohol abuse or dependence within the past 2 years (criteria of the fourth edition of the *Diagnostic and Statistical Manual of Mental Disorders*); or history of significant psychiatric illness (e.g., schizophrenia). Participant recruitment occurred at several community-based organizations, including local caregiver support groups, adult daycare facilities, a university-based memory and aging care clinic, local neurology medical practices, and local public health fairs in the northeastern United States.

Study Procedures

Upon obtaining written consent to enroll in the study, screening surveys were administered to confirm that study inclusion and exclusion criteria were met. Following confirmation from screening criteria, a battery of surveys was administered to collect baseline data. A demographics form was completed for individuals with AD and their respective family caregivers to capture medical history, current medications, and other demographic data. Cognitive status for participants with AD was measured via the Modified Mini-Mental State

(3MS) examination (Teng & Chui, 1987). The 3MS provides a total score ranging from 0 to 100, with higher scores indicating less impairment. 3MS scores <79 indicate cognitive impairment, and scores <48 indicate severe impairment.

Because physical function and mobility play a large role in UI, the MDS 3.0 Section G mobility subscale was used to measure function (Centers for Medicare & Medicaid Services, 2008). This assessment rates bed mobility, transfer, walking in room, walking in corridor (home), locomotion in home, locomotion out of home, dressing, eating, toilet use, and personal hygiene. Physical function was rated for the past 7 days and activities were rated from independent to total dependence using a 5-point rating scale. Pain in participants with AD was measured each night by caregivers using the Pain Assessment in Advanced Dementia (PAINAD) scale (Warden, Hurley, & Volicer, 2003). These measures were used to provide additional insights into study findings, as these variables (i.e., physical function/mobility and pain) are known to affect agitation, sleep, and UI.

Noninvasive wireless sensors were used to measure agitation, sleep, and UI. Agitation was measured using wrist sensors/accelerometers, named TEMPO (technology-enabled medical precision observation) nodes, placed on participants with AD at bedtime by caregivers. TEMPO nodes capture wrist movements and have been validated in individuals with dementia as a measure of restlessness/physical agitation and serve as a proxy for sleep (Bankole et al., 2012). TEMPO nodes used in the current study are battery-powered devices updated from previous work in wireless inertial body sensors (Barth, Hanson, Powell, & Lach, 2009) capable of long-term data monitoring and file management up to 2 GB. TEMPO nodes capture triaxial accelerometer data in high sampling rate (128 Hz) for assessing the fine-grained wrist movement caused by dementia agitation.

Bed sensors also integrate two triaxial accelerometer sampling at 50 Hz. Data collection of bed sensors was conducted through the physical connection of a laptop beside the bed. Bed sensors were placed beneath the mattress pad to capture lower limb movements to measure restlessness and sleep. Bed sensors and wrist sensors were used to track sleep duration and continuity. Audio sensors were placed in participants' sleeping environments to detect verbal agitation (i.e., vocalizations).

A proprietary wetness sensor, DryBuddy™, was used to detect UI in participants with AD. Incontinence data were transmitted wirelessly through a small (2-inch) DryBuddy sensor worn in the participant's preweighed undergarment incontinence pad, held in place by a magnetic backing so that there was no belt or taping. Pads were weighed after use and before disposal to estimate volume of UI. Two data receivers that transmitted data from the DryBuddy device were placed on both sides of the bed and remained stationary throughout the study period. Data from TEMPO nodes, bed and audio sensors, and DryBuddy wetness sensors were transmitted wirelessly to a secured, remote database that could be monitored at the researchers' off-site workspace.

Audio and bed sensors were placed in participants' homes by study personnel. Family caregivers were provided in-person and written instructions regarding placement and maintenance of the TEMPO and DryBuddy sensors, as caregivers were responsible for placement of these devices for the 5 to 7 nights of the study duration. Written instructions were given to family caregivers to place the wrist sensors (TEMPO) and DryBuddy sensors each night on the care recipient going to bed for the night and to remove the devices each morning when the care recipient awakened for the day. Upon removal of the sensors, family caregivers placed the devices in chargers for use the following night. Study staff were available via telephone for troubleshooting problems or answering questions caregivers encountered.

Sleep diaries were completed by family caregivers each night to document bedtime, nighttime awakenings, and time of arising for participants with AD to cross-check measures of sleep obtained via sensors.

At completion of the study protocol, study staff interviewed family caregivers to obtain their perspectives on satisfaction and ease of enactment with the study components (i.e., body sensors) and their feedback on ways to improve their overall experience with the study. At the conclusion of the study, a summary of the timing and frequency of care recipients' data regarding agitation, sleep, and UI was provided to each family caregiver. Compensation of $20 was provided to all participants at completion of the study protocol.

Study Sample

Thirteen dyads (participant with AD [care recipient] and caregiver) were recruited to participate in the study. One dyad did not enroll in the study as the care recipient was hospitalized before the first study visit and later placed in a long-term care facility. Thus, the total number of care recipients and family caregivers was 24 (i.e., 12 dyads).

Data Analysis

Baseline survey data, daily pain assessments, sleep diaries, and post study feedback were entered by study personnel into the REDCap platform and were verified and cleaned for data analysis. All data were de-identified. SAS 9.4 software was used for data analysis. Descriptive statistics were calculated for all study variables. Data collected from the sensor system regarding nocturnal agitation, sleep, and UI were scored using threshold-based software developed by the study team. Data from audio sensors were not analyzed because of the large amount of environmental noise (e.g., television, radio).

TABLE

CHARACTERISTICS OF STUDY PARTICIPANTS

Variable	*n* (%)	
	Caregivers (*n* = 12)	Care Recipients (*n* = 12)
Gender		
Female	10 (83.3)	7 (58.3)
Male	2 (16.7)	5 (41.7)
Race		
Black	6 (50)	6 (50)
White	5 (41.7)	5 (41.7)
More than one race	1 (8.3)	1 (8.3)
Education		
Attended grade school	1 (8.3)	
Attended high school	1 (8.3)	2 (16.7)
High school degree	1 (8.3)	2 (16.7)
Attended college	2 (16.7)	3 (25)
Associate degree	2 (16.7)	
Bachelor's degree	4 (33.3)	1 (8.3)
Master's degree	2 (16.7)	3 (25)
Occupation		
Professional	9 (75)	6 (50)
White collar	1 (8.3)	1 (8.3)
Blue collar	1 (8.3)	3 (25)
Homemaker	1 (8.3)	1 (8.3)
None	1 (8.3)	
Employment status		
Full time	5 (41.7)	
Part time	2 (16.7)	
Retired	4 (33.3)	
Other	1 (8.3)	
Marital status		
Married	9 (75)	7 (58.3)
Widowed	4 (33.3)	
Divorced	2 (16.7)	1 (8.3)
Single	1 (8.3)	
Relationship with patient		
Wife	4 (33.3)	
Husband	2 (16.7)	
Daughter	5 (41.7)	
Niece	1 (8.3)	

Data from TEMPO sensors and bed sensors were used to detect nocturnal physical agitation and sleep. A 5-minute frame of Teager energy data was analyzed around each of the UI episodes (2.5 minutes before and after detection of a wetness event). The same agitation assessment techniques were adopted for TEMPO data and bed sensor data, as both are accelerometers. Variable-length Teager energy was calculated at every 1 minute throughout the night from the data from these two sensors. Agitation is indicated by significant increases in the average Teager value over brief periods of time, as the agitation instance surrounding UI typically appears for only a few minutes at a time.

Spearman's rho correlations were calculated to examine relationships among measures of wetness, sleep, and agitation, and relationships between characteristics of care recipients (i.e., cognitive function, physical function, duration of dementia symptoms, and age) and measures of wetness, sleep, and agitation.

RESULTS

The **Table** presents characteristics of participants. Cognitive function was categorized into three groups based on published cut-off scores for the 3MS instrument: normal (79 to 100); mild to moderate impairment (48 to 78); and extreme impairment (≤47). The participant with minimal impairment was rated by his physician as having a diagnosis of AD. For mobility function, care recipients were grouped into three categories based on scores on the MDS 3.0 mobility subscale: good (0 to 1), fair (2), and poor (3 to 4) mobility. The mean pain rating using the PAINAD instrument was 0.7, indicating that care recipients had no or minimal pain. Three care recipients were taking antipsychotic medications, two were taking diuretic medications, six were taking cholinergic medications specific for dementia, and four were taking moderate to high doses of anticholinergic medications. No care recipients were taking sedative medications.

Specific Aim 1

To examine the feasibility and acceptability of the use of body sensors, semi-structured, in-person interviews were conducted at the conclusion of the study protocol with each family caregiver. All caregivers stated that they encountered no difficulty applying and maintaining the TEMPO wrist and DryBuddy incontinence sensors. They stated the instructions were easy to understand and the graphics provided good reinforcement of the written directions. One participant indicated her care recipient was resistant to wearing the incontinence pad and DryBuddy incontinence sensor and became somewhat agitated when the wrist sensors were placed. Two care recipients removed the TEMPO wrist sensors at different times throughout the study, and family caregivers believed this was due to these participants sleeping on the side where the TEMPO device was placed. No skin breakdown was observed in either of these two cases. Caregivers offered several strategies to improve their experiences. They suggested making the TEMPO device smaller, decreasing the illumination emitted from the TEMPO devices, and providing a softer backing on the TEMPO devices to improve comfort. They suggested the DryBuddy could be altered to be a light or white color (as opposed to blue) so the care recipient would not see the device as easily, thus decreasing potential resistance to wearing the undergarment and device.

Although it was expected that verbal agitation could be detected from the acoustic sensors, many types of noise during the real-world deployments were merged with the recorded sounds, such as dog barking or sound from a television or radio. As such, these data were not used in analyses.

Data received from sleep diaries were used to validate the bed sensor (sleep) data. Because much of the sleep diary data were incomplete, those data are not reported. Further, the majority of family caregivers reported they were not sleeping in the same room as care recipients; thus, they were unable to provide accurate data regarding nighttime awakenings and time of morning awakening. Therefore, methods to estimate the temporal information regarding awakening were developed. Data captured by bed sensors provided adequate information to detect morning awakening. Once care recipients awakened and left the bed, the acceleration magnitude of bed sensors was determined to equal local gravity. Nighttime awakenings were indicated by the simultaneous agitation detected by the TEMPO nodes and bed sensors. When data from TEMPO nodes and bed sensors demonstrated potential agitation in the same time window, it was concluded that there was a nighttime awakening in this specific period. The **Figure** depicts data from sensors used to detect agitation and UI in one participant.

TABLE (CONTINUED)

CHARACTERISTICS OF STUDY PARTICIPANTS

Variable	*n* (%)	
	Caregivers (*n* = 12)	Care Recipients (*n* = 12)
Dementia diagnosis (per physician confirmation)		
Alzheimer's disease		6 (50)
Mixed dementia		3 (25)
Dementia-unspecified		2 (16.7)
TIA		1 (8.3)
Nocturnal UI nights per week		
1		2 (16.7)
5		2 (16.7)
7		8 (66.7)
Cognitive status (3MS)		
Minimal impairment		1 (8.3)
Mild-moderate impairment		5 (41.7)
Extreme impairment		6 (50)
Pain (PAINAD)		
No discernible pain		12 (100)
Mobility (MDS)		
Good		7 (58.3)
Fair		3 (25)
Poor		2 (17.7)

Note. TIA = transient ischemic attack; UI = urinary incontinence; 3MS = modified Mini-Mental State Examination; PAINAD = Pain Assessment in Advanced Dementia scale; MDS = Minimum Data Set.

Specific Aim 2

For UI, across care recipients, the mean number of wetness events per night was 2.8 (*SD* = 2.2), with a range of 0 to 7 events per night. For urine volume, measured via incontinence pad weights, the mean urine volume

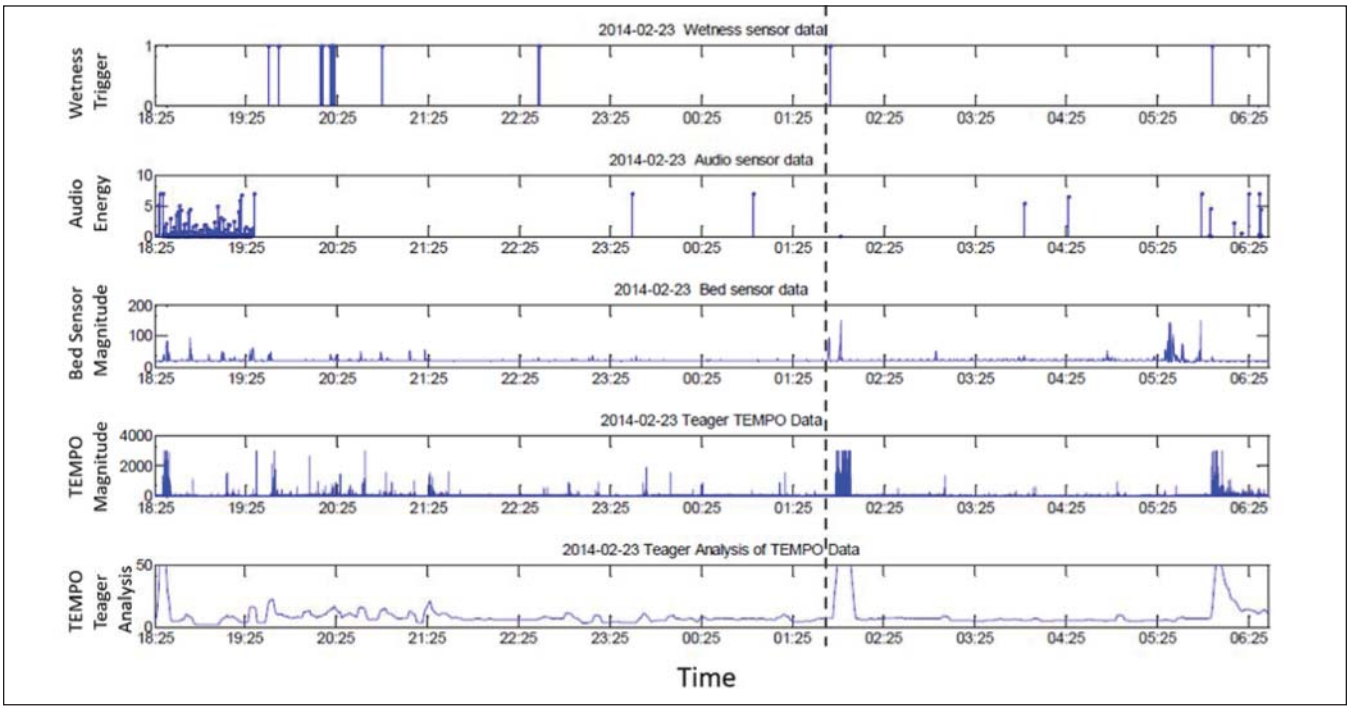

Figure. Illustration of the correlation inference process for data collected from a care recipient. The duration of the collected data is 12 hours, from 6:25 p.m. February 23, 2014 to 6:25 a.m. February 24, 2014. Wetness events detected from wetness sensor, short-term energy of audio sensor, sum of acceleration magnitude from bed sensor, sum of Teager energy from technology-enabled medical precision observation (TEMPO), and Teager analysis from TEMPO are plotted in rows, respectively. The salient time point of wetness event was 1:49 a.m. February 24. After searching a 10-minute window, the sleep agitation event detected from TEMPO was found at 1:57 a.m. of 12 minutes' duration, and another sleep agitation event detected from the bed sensor was found at 2:00 a.m. of 7 minutes' duration.

per night was 196.8 g (*SD* = 184.9 g), with a range of 1.4 g to 441.3 g per night across care recipients. The correlation between mean number of wetness events and urine volume per night was 0.94 ($p < 0.001$). These findings support the inclusion criterion for presence of UI as a prescreening measure for entry into the study and the accuracy of the DryBuddy to detect wetness. Care recipients were consistent across nights in the frequency and timing of wetness events, suggesting that patterns (i.e., frequency and timing) of UI are measurable and predictable for individuals with AD.

Specific Aim 3

To find the correlations among nocturnal agitation, sleep continuity, and UI, the UI events (i.e., wetness events) were used as salient time during the night, and then a search method was conducted in a short-time window (±2.5 minutes) around each salient time point. If agitation events were found in this short-time window, the wetness and agitation events were considered correlated. In addition, the correlated events were recorded in time order, indicating whether the agitation events happened before or after the wetness events. Because of the challenges in obtaining reliable data regarding verbal agitation, data related to wetness events and verbal agitation occurrences were not analyzed.

Measures of agitation and measures of wetness were inversely related. Number of agitation events had an inverse relationship with number of wetness events per night ($r_s = -0.57$, $p = 0.11$) and urine volume ($r_s = -0.60$, $p = 0.07$). Total agitation duration (combined TEMPO and bed sensors) also had an inverse relationship with number of wetness events ($r_s = -0.65$, $p = 0.04$) and urine volume ($r_s = -0.72$, $p = 0.02$). Across all care recipients, sleep awakenings, indicated by agitation events, occurred either before or after each wetness event, although the duration of these sleep awakenings varied. For two care recipients, no wetness events and no agitation or associated sleep awakenings were detected.

Secondary Aim

Agitation duration during the night was inversely related to physical function ($r = -0.64$, $p = 0.04$) and positively related to duration of dementia symptoms ($r = 0.71$, $p = 0.02$). Teager energy was inversely related to physical function ($r = -0.66$, $p = 0.04$). Additional nonsignificant moderate to high correlations ($r \geq 0.50$) were found between covariates of cognitive function, physical function, and duration of dementia symptoms and study outcomes of wetness, sleep, and agitation. No significant correlations >0.50

were found between care recipient age and any of the study outcomes.

DISCUSSION

The current study demonstrated that using wireless sensors to evaluate the relationships among nocturnal agitation, sleep, and UI is feasible and family caregivers could easily use them without undue burden. In the current study, caregivers reported high degrees of ease of use of passive body sensors. As others found in a systematic review of use of passive sensing, perceptions of willingness to use passive sensors, ease of use of technology, and privacy issues need to be continually addressed and enhanced to empower older adults in their care (Cornet & Holden, 2018).

Each care recipient in the current study had unique patterns of agitation and UI, although subgroups of patterns were identified. Some care recipients experienced agitation that preceded incontinence, whereas others were agitated post-UI. Findings from a recent scoping review revealed that agitation in AD was positively associated with younger age, younger age of dementia onset, and male gender (Kolanowski et al., 2017). Further, the authors concluded that agitation worsens as dementia progresses but responds to interventions that address unmet needs, such as UI (Kolanowski et al., 2017). The current study findings are consistent with these findings in that moderate correlations were found between decreased cognitive function and duration of dementia symptoms and measures of agitation. Although the current study findings were not significant, this may have been due to the small sample size. One difference in the current study findings from those in the scoping review is that the current study included only community-dwelling individuals with AD and examined nocturnal agitation only, whereas the work by Kolanowski et al. (2017) included individuals with AD who resided in any setting, including nursing homes. Although the current study found an inverse relationship between number and duration of agitation events to wetness events, more work in this area is warranted to further elucidate this relationship.

To date, UI in individuals with AD has not been treated aggressively; rather, the focus has been on containment, which has led to higher use of indwelling urinary catheters (Grant, Drennan, Rait, Petersen, & Iliffe, 2013; Hägglund, 2010). There is some evidence that toilet assistance at predicted times decreases incidence of incontinence episodes (Ostaszkiewicz, Johnston, & Roe, 2004). Recording the first wetness episode provides a guide for the timing of toileting for an individual with AD. Toileting in advance of that time could not only prevent wetness but also reduce agitation and improve sleep continuity at night. Thus, use of the wireless sensors can help identify the times this assistance would prevent incontinence episodes and provide a means to test empirically this intervention for efficacious treatment.

In the current study, sleep disruption and agitation were not found to precede or follow all UI events. Although no studies were found that examined these three symptoms simultaneously, work by others (Kim, Oh, & Richards, 2014) has determined that caregiver perceptions of nocturnal behaviors in individuals with dementia were associated with caregiver burden, although real-time, quantitative data on these associations were not associated with burden; rather, severe cognitive impairment and musculoskeletal/integument and neurological comorbidities were associated with higher caregiver burden (Kim et al., 2014).

LIMITATIONS

The current descriptive, correlational study has several limitations. Because the audio sensors captured a large amount of noise from participants' sleeping environments, such as that from television and radio, these data could not be used to examine verbal agitation. Thus, potentially important aspects of agitation were not available for analysis. Some care recipients were taking medications that could have confounded study outcomes; however, the authors chose not to exclude these participants if they had been stable on these medications for at least 6 weeks. Further, the small sample size limits generalizability of the study findings but serves as a first step in elucidating potential relationships among these distressing symptoms.

CLINICAL IMPLICATIONS AND CONCLUSION

The use of body sensors to detect agitation, sleep, and UI in individuals with AD is a reliable and feasible means to gather valid data regarding these distressing symptoms. Using data from sensors may provide the necessary information to develop individualized toileting schedules, which could reduce incontinence and agitation. Building upon and extending these data will enable researchers to develop and test interventions that may reduce incidence of agitation and UI, improve sleep, and have profound implications for improving the quality of life for individuals with AD.

REFERENCES

Alzheimer's Association. (2017). *2017 Alzheimer's disease facts and figures.* Retrieved from https://aanddjournal.net/article/S1552-5260(17)30051-1/pdf

Ballard, C.G., Gauthier, S., Cummings, J.L., Brodaty, H., Grossberg, G.T., Robert, P., & Lyketsos, C.G. (2009). Management of agitation and aggression associated with Alzheimer disease. *Nature Reviews Neurology, 5,* 245-255. doi:10.1038/nrneurol.2009.39

Bankole, A., Anderson, M., Smith-Jackson, T., Knight, A., Oh, K., Brantley, J.,...Lach, J. (2012). Validation of noninvasive body sensor network technology in the detection of agitation in dementia. *American Journal of Alzheimer's Disease and Other Dementias, 27,* 346-354. doi:10.1177/1533317512452036

Barth, A., Hanson, M., Powell, H., & Lach, J. (2009, June 3). *TEMPO 3.1: A body area sensor network platform for continuous movement assessment.* Paper presented at the Sixth International Workshop on Wearable and Implantable Body Sensor Networks, Berkeley, CA.

Brookmeyer, R., Abdalia, N., Kawas, C., & Corrada, M.M. (2018). Forecasting the prevalence of preclinical and clinical Alzheimer's disease in the United States. *Alzheimer's & Dementia, 14,* 121-129. doi:10.1016/j.jalz.2017.10.009

Centers for Medicare & Medicaid Services. (2008). *Minimum Data Set, version 3.0.* Washington, DC: Author.

Cohen-Mansfield, J. (1995). Assessment of disruptive behavior/agitation in the elderly: Function, methods, and difficulties. *Journal of Geriatric Psychiatry and Neurology, 8,* 52-60.

Cohen-Mansfield, J., Dakheel-Ali, M., Marx, M.S., Thein, K., & Regier, N.G. (2015). Which unmet needs contribute to behavior problems in persons with advanced dementia? *Psychiatry Research, 228,* 59-64. doi:10.1016/j.psychres.2015.03.043

Cornet, V.P., & Holden, R.J. (2018). Systematic review of smartphone-based passive sensing for health and wellbeing. *Journal of Biomedical Informatics, 77,* 120-132. doi:10.1016/j.jbi.2017.12.008

Drennan, V.M., Cole, L., & Iliffe, S. (2011). A taboo within a stigma? A qualitative study of managing incontinence with people with dementia living at home. *BMC Geriatrics, 11,* 75. doi:10.1186/1471-2318-11-75

Gaugler, J.E., Duval, S., Anderson, K.A., & Kane, R.L. (2007). Predicting nursing home admission in the U.S.: A meta-analysis. *BMC Geriatrics, 7,* 13. doi:10.1186/1471-2318-7-13

Grant, R.L., Drennan, V.M., Rait, G., Petersen, I., & Iliffe, S. (2013). First diagnosis and management of incontinence in older people with and without dementia in primary care: A cohort study using The Health Improvement Network primary care database. *PLoS Medicine, 10,* e1001505. doi:10.1371/journal.pmed.1001505

Hägglund, D. (2010). A systematic literature review of incontinence care for persons with dementia: The research evidence. *Journal of Clinical Nursing, 19,* 303-312. doi:10.1111/j.1365-2702.2009.02958.x

Kim, S.S., Oh, K.M., & Richards, K. (2014). Sleep disturbance, nocturnal agitation behaviors, and medical comorbidity in older adults with dementia: Relationship to reported caregiver burden. *Research in Gerontological Nursing, 7,* 206-214. doi:10.3928/19404921-20140512-01

Kolanowski, A., Boltz, M., Galik, E., Gitlin, L.N., Kales, H.C., Resnick, B.,...Scerpella, D. (2017). Determinants of behavioral and psychological symptoms of dementia: A scoping review of the evidence. *Nursing Outlook, 65,* 515-529. doi:10.1016/j.outlook.2017.06.006

McKhann, G.M., Knopman, D.S., Chertkow, H., Hyman, B.T., Jack, C.R., Jr., Kawas, C.H.,...Phelps, C.H. (2011). The diagnosis of dementia due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia, 7,* 263-269. doi:10.1016/j.jalz.2011.03.005

Onishi, J., Suzuki, Y., Umegaki, H., Nakamura, A., Endo, H., & Iguchi, A. (2005). Influence of behavioral and psychological symptoms of dementia (BPSD) and environment of care on caregivers' burden. *Archives of Gerontology and Geriatrics, 41,* 159-168. doi:10.1016/j.archger.2005.01.004

Ostaszkiewicz, J., Johnston, L., & Roe, B. (2004). Timed voiding for the management of urinary incontinence in adults. *Cochrane Database of Systematic Reviews, 1,* CD002802. doi:10.1002/14651858.CD002802.pub2

Teng, E.L., & Chui, H.C. (1987). The Modified Mini-Mental State (3MS) examination. *Journal of Clinical Psychiatry, 48,* 314-318.

Warden, V., Hurley, A.C., & Volicer, L. (2003). Development and psychometric evaluation of the pain assessment in advanced dementia (PAINAD) scale. *Journal of the American Medical Directors Association, 4,* 9-15. doi:10.1097/01.JAM.0000043422.31640.F7

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