

Evaluation of waist-worn actigraphy monitors for the assessment of sleep in older adults with and without Alzheimer's disease

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Abstract

Objectives: Evaluate differences in sleep characteristics between older adults with and without mild Alzheimer's disease using waist-worn actigraphy monitors.

Methods: Actigraph GT3X+ monitors and self-reported sleep and activity logs were used for one week and compared between older adults (N = 85) with (n = 35) and without Alzheimer's disease (n = 51).

Results: Participants with Alzheimer's disease had greater total sleep time and spent more time in bed than nonimpaired older adults. Estimates for sleep efficiency and total sleep time for the total sample were elevated compared to previous studies of wrist-worn devices in similar populations, while estimates of sleep onset latency and wake after sleep onset for the total sample were lower.

Conclusions: Actigraphy-based sleep studies in older adults with Alzheimer's disease should consider discrepancies between objective and subjective estimates of sleep and monitor placement to maximize the ability to measure both activity and sleep.

Keywords

Actigraphy, older adults, sleep, physical activity, Alzheimer's disease

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Introduction

Studies examining sleep in older adults have focused on the challenges this population faces in obtaining non-disrupted sleep. Some reasons for this difficulty include changes in sleep patterns, life situation (e.g. loss of partner or spouse, changes in housing, financial distress), and health status.^{1–3} The consequences of disrupted sleep for this population include decreased physical and psychological health and cognitive functioning.^{4–7} Poor sleep may be a prodromal symptom of cognitive decline and Alzheimer's disease (AD). In their review of animal and human research that investigated sleep disturbance and AD, Musiek et al.⁸ suggest that sleep disturbance (e.g. fragmented sleep, sleep deprivation, disrupted circadian rhythms) precedes the onset of AD symptomatology. Research examining the association between poor sleep and AD has demonstrated that older adults with AD have shorter total sleep

times (TSTs), spend less time in bed (TIB), have lower sleep efficiencies (SEs), spend more time awake after sleep onset (WASO), and have more nightly awakenings as compared to older adults without AD.⁹ Given the deleterious impact of poor sleep and its relationship to AD, researchers have investigated ways to improve sleep in older adults as a method to improve cognitive function. Increasing physical activity has been explored as a promising intervention to improve sleep and cognitive function due to its positive impact on both psychological and physical health.^{10–13}

According to multiple systematic reviews, physical activity interventions in middle-aged and older adults

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result in improvements in sleep quality, sleep duration, SE, and a reduction in the amount of time spent WASO.^{14–16} These improvements in sleep have been found to be comparable in size to pharmacological and behavior therapy interventions for disrupted sleep.¹⁴ Although the directional relationship between sleep and physical activity is believed to be reciprocal,¹¹ several mechanisms have been hypothesized by which physical activity may improve sleep, including increased metabolic activity, reduced pain, increased physical functioning, exposure to bright light, and improvements in mood.^{16–20}

As interest in the relationship between physical activity and sleep has grown, the use of waist-worn actigraphy monitors to measure both sleep and physical activity has been considered. Actigraphy monitors are small devices that use accelerometry to quantify sleep and physical activity. Whereas physical activity is defined by the actigraphy monitor as the presence of movement, sleep is defined by the actigraphy monitors as the absence or attenuation of movement.²¹ Although this conceptualization of sleep is parsimonious, it is difficult for actigraphy technology to distinguish sleep from an inactive wakeful state. In other words, wake is often misclassified as sleep.²² In their review of the validity and reliability of actigraphy monitors for evaluation of sleep, Martin and Hakim²³ determined that actigraphy can be biased toward overestimating TST because monitors assume that the lack of movement signifies sleep. This bias may be particularly problematic for older adults. Like those diagnosed with insomnia (and for whom actigraphy estimates of sleep differ greatly from sleep diary reports of sleep), older adults may experience disturbed sleep and lay motionless in bed at night trying to initiate sleep or stay asleep, but demonstrate nonfragmented “good” sleep with actigraphy. Given the increasing difficulty in initiating and maintaining sleep with increasing age, this scenario may be more common than not in this population.²⁴ Nevertheless, many clinicians and researchers have begun to rely on and primarily use actigraphy monitors to measure physical activity and sleep due to their low cost and low burden on older adult participants and patients; actigraphy monitors can be reused with multiple individuals and monitors are typically small and unobtrusive.²⁵ Additionally, actigraphy monitors allow for physical activity and sleep to be measured across various contexts and time points, allowing data to be collected longitudinally across multiple locations.²⁶ This is an important feature of actigraphy, to reduce the burden of making multiple lab visits or sleeping in a laboratory. Although wrist-worn actigraphy monitors are valid objective measures of sleep in older adults, waist-worn monitors are more sensitive and specific than wrist-worn monitors for measuring sedentary

and low-intensity activities that make up a majority of physical activity in this population.^{25,27} Waist placement of monitors, however, has been shown to overestimate TST and SE and poorly detect wakefulness in child and adult populations when compared to polysomnography and wrist actigraphy.^{28,29} However, they have not been well studied in healthy older adults (HOAs) and older adults with AD. This presents a dilemma for researchers who want to observe the relationship between physical activity and sleep in older adults.

As part of a larger study of physical activity in older adults with and without AD, the primary purpose of the present study was to evaluate differences in sleep classification and sleep characteristics estimated by waist-worn actigraphy. The secondary purpose was to explore the measurement properties of waist-worn actigraphy monitors to characterize sleep in this population. We were interested in comparing self-reported wake and sleep intervals to wake and sleep intervals classified by waist-worn actigraphy monitors. Based on previous research,^{8,30–32} we hypothesized that we would observe differences in actigraphy-estimated sleep parameters between groups such that older adults diagnosed with AD would demonstrate poorer sleep (e.g. lower TST and SE) compared to cognitively intact older adults. We also hypothesized that our waist-worn monitor derived estimates of sleep would, overall, be higher than actigraphy estimates of sleep previously reported in other studies using wrist-worn monitors due to the potential of waist-worn monitors to be less sensitive to movement during sleep than wrist-worn monitors.

Methods

Participants

Participants were recruited from the University of Kansas Alzheimer’s Disease Center Registry (KU-ADC), a large registry of well-characterized AD patients and older adult controls without cognitive impairment. KU-ADC recruitment and evaluation have been described previously.³³ Briefly, registry participants receive cognitive testing and clinical examinations annually. Experienced study clinicians trained in dementia assessment and clinical research provide consensus diagnoses through a comprehensive clinical research evaluation and review of medical records. Diagnostic criteria for AD follow NINCDS–ADRDA criteria.³⁴

Participants who had undergone full physical and neurological examinations and a review of medical history were recruited into this study. The study sample included individuals with mild AD based on a clinical

dementia rating (CDR) scale scores of 0.5 (very mild) or 1 (mild) or older adult controls with CDR scores of 0 (normal).³⁵ Participants with AD were required to have a study partner who spends at least 10 h/week with the participant, who would be with the participant every day during the data collection procedures (detailed below). Participants with mobility disability that confined them to a bed or wheel chair, as well as participants with sensory impairment, including those with inadequate visual or auditory capacity were excluded. The KU-ADC registry excludes individuals with active (<2 years) ischemic heart disease (myocardial infarction or symptoms of coronary artery disease) or uncontrolled insulin-dependent diabetes mellitus.

A total of 100 community-dwelling older adults with and without mild AD were recruited. Of those, $N = 86$ had valid sleep actigraphy data ($n = 35$ mild AD; $n = 51$ controls). Fourteen participants did not have sleep actigraphy data for the following reasons: monitor malfunction ($n = 1$), pilot study design with random assignment to one of two monitors ($n = 6$), discomfort with wearing the waist band to bed ($n = 6$), and withdrawal from the study ($n = 1$). Fifty-four percent were female and 91% were Caucasian. The mean age was 73.52 years ($SD = 7.04$) and the mean level of education was 16.56 years ($SD = 3.26$). A majority of participants did not work full time (94%) and a majority did not work or volunteer at all (82%) (Table 1). There was a statistical difference between older adults with and without mild AD with regards to gender: more women were in the group without mild AD than in the group with mild AD. There were no other statistically significant differences with regards to the characteristics of the sample. The study protocol was approved by the KU Medical Center Human Subjects Committee. Participants, and/or their legally acceptable representative, provided written, informed consent.

Procedures

Physical activity and sleep were recorded using an Actigraph GT3X+ accelerometer worn on the

dominant hip. Hip dominance was determined by participants' hand dominance (e.g. if they were right-hand dominant then the monitor was worn on the right hip). The GT3X+ is a compact, lightweight, and unobtrusive triaxial accelerometer that has been validated for measuring physical activity and sleep across a range of community-dwelling older adult samples.^{36,37} Hip placement was chosen because this placement has greater sensitivity and specificity for measuring sedentary and low-intensity activities compared to placement on the wrist, which were the primary focus of the larger study from which these data are derived.²⁷ Instructions for how to complete the diaries and how to wear the units were given to participants and, if applicable, their study partners. Participants were instructed to wear the unit on their dominant hip, secured by an elastic waist belt, 24 h a day for seven days. Participants kept a diary recording their activities in 30 min intervals throughout the day. This included writing down when participants fell asleep and woke up (e.g. 10:00 p.m. and 7:00 a.m.). For participants with mild AD, study partners were asked to assist with completing the diaries and compliance with wearing the unit as needed. It also included wear-time reports used to determine compliance (identifying periods of device removal) as well as wake and sleep time. After the data collection period, participants attended a follow-up visit where they returned the monitors, reviewed activity logs, and completed additional questionnaires.

Participants had an average of 6.87 ($SD = 0.96$) valid nights of actigraphy data. A valid night of data was defined as a night where the participant wore the watch for at least 10 h. Wear-time validation was calculated using the Choi algorithm.³⁸ A majority of valid nights were weekdays (71.4%). Data were processed using ActiLife V6.10.4 software and the Cole-Kripke algorithm.^{39,40} The Cole-Kripke algorithm is commonly used in actigraphy studies (see Ancoli-Israel et al.²⁵) and has been validated against polysomnography in the detection of sleep and wake.⁴⁰ Self-reported sleep logs were compared against ActiLife defined bed and wake times, lux, and movement data to set

Table 1. Characteristics of sample and by Alzheimer's disease status.

	Total sample		Older adults without AD		Older adults with AD	
	n		n		n	
Age (mean years, SD)	86	73.52 (7.04)	51	73.43 (6.51)	35	73.66 (7.85)
Sex (% female)	86	54	51	69	35	31
Race (% Caucasian)	86	91	51	96	35	86
Education(mean years, SD)	86	16.56 years (3.26)	51	17.23 (3.34)	35	15.55 (2.90)

AD: Alzheimer's disease.

nighttime sleep intervals. If self-reported sleep and wake times were within 30 min of ActiLife-defined sleep data, the sleep interval was set according to the participants' self-reported sleep and wake times. If self-reported sleep was missing or appeared invalid, the ActiLife-defined sleep interval was used. Outcomes were sleep onset latency (SOL; amount of time it takes to fall asleep), TST, TIB, SE ((TST/TIB) × 100), WASO (amount of time spent awake after falling asleep), and average number of awakenings. Daytime sleep/nap intervals were excluded from analyses of nighttime sleep. Nighttime sleep intervals were excluded when examining daytime waking activities that were categorized as sleep intervals.

Statistical analyses

Data were analyzed using IBM SPSS Statistics version 24 software.⁴¹ All participants included in these analyses provided data (e.g. wore monitors and completed diaries) for a minimum of five days. From these participants with at least five nights of data, we used data for days where both sleep diaries and accelerometry data were available. One-way analysis of variance tests were performed to determine if there were differences in actigraphy-derived sleep parameters and monitor-classified intervals of nighttime wake between individuals with AD and HOA. A chi-square test was performed to determine if the congruence between self-reported and actigraphy-derived wake and sleep times differed between AD and HOA.

Results

Individuals with AD had greater actigraphy-derived nighttime TST (HOA $M(SD)=475.37 (60.86)$; AD $M(SD)=542.23 (113.91)$, $F(1, 83)=12.44$, $p<.001$, $\eta^2=0.13$) and spent greater TIB at night (HOA $M(SD)=495.57 (59.98)$; AD $M(SD)=568.83 (106.21)$, $F(1, 83)=16.61$, $p<.001$, $\eta^2=0.16$)

compared to HOA (Table 2). The AD group had marginally more monitor-classified intervals of nighttime wake during which they reported being asleep (HOA $M(SD)=0.17(0.38)$; AD $M(SD)=0.64(1.61)$, $t(41.1)=1.79$, $p=.081$, $\eta^2=0.01$). Self-report and actigraphy-derived wake and sleep times agreed more consistently in the HOA group (79% of self-reports were within 30 min of actigraphy-derived estimates), compared to the AD group (68% of self-reports were within 30 min of actigraphy-derived estimates; $\chi^2(1)=7.98$, $p<.01$, $w=0.01$). Overall, we observed that the monitors incorrectly categorized several waking activities as sleep for both groups, including reading, TV, lying in bed, eating, driving, and phone/computer use.

Discussion

Compared to cognitively intact older adults, older adults with AD in our sample slept more and spent more TIB. Although the older adults with AD had higher WASO, more nightly awakenings, lower SOL, and marginally lower SE compared to the HOA group, these results were not statistically significant. Our findings contradict previous studies. In both HOA and AD groups, nighttime SE and TST were elevated compared to previous studies of wrist-worn devices in similar populations,^{20,24,42,43} while estimates of SOL and WASO were lower. Our results demonstrate that older adults with AD slept more and spent more TIB, whereas other studies have demonstrated a reduced amount of TST and TIB in this population when compared to cognitively intact older adults.⁹ The present study is derived from a study primarily focused on physical activity, thus, these contrary findings may be due to our use of waist-worn actigraphy as opposed to the wrist-worn actigraphy monitors used in studies primarily focused on sleep. Differences not only in the placement of monitors, but the brand of monitors and how the sleep data are processed (e.g. algorithms

Table 2. Actigraphy sleep parameters for sample and by Alzheimer's disease (AD) status.

Sleep parameter	Total sample		Older adults without AD		Older adults with AD		F (1,83)	p	η^2
	n	M (SD)	n	M (SD)	n	M (SD)			
SOL (min)	86	2.45 (4.17)	51	3.02 (5.00)	35	1.63 (2.35)	2.34	.13	0.03
TST (min)	86	502.89 (92.48)	51	475.37 (60.86)	35	542.23 (113.91)	12.44	<.001	0.13
TIB (min)	86	525.38 (89.10)	51	495.57 (59.98)	35	568.83 (106.21)	16.61	<.001	0.16
SE (%)	86	95.60 (5.41)	51	95.98 (5.02)	35	95.04 (5.95)	.62	.43	0.01
WASO (min)	86	20.35 (26.95)	51	17.18 (24.03)	35	24.97 (30.17)	1.75	.19	0.02
Number of awakenings	86	4.41 (4.27)	51	4.04 (3.93)	35	4.94 (4.73)	.93	.34	0.01

SE: sleep efficiency; SOL: sleep onset latency; TIB: time in bed; TST: total sleep time; WASO: wake after sleep onset.

used to score sleep data) could also explain why we observed different results compared to previous studies. Notably, Spira et al.,²⁰ McCrae et al.,⁴² Kay et al.,²⁴ and van den Berg et al.⁴³ used different wrist-worn monitors than those used in the presented study (SleepWatch-O,²⁰ Actiwatch-L,⁴² Actiwatch 2,²⁴ and Actiwatch AW4⁴³). Different lengths of monitoring and exclusion criteria than the presented study were also utilized in these studies. Spira et al.²⁰ monitored participants for approximately four consecutive 24 h periods, McCrae et al.⁴² monitored participants for 14 consecutive 24 h periods, Kay et al.²⁴ monitored participants for seven consecutive 24 h periods, and van den Berg et al.⁴³ monitored participants for an average of six 24 h periods. McCrae et al.⁴² excluded participants if they self-reported or were diagnosed with any sleep disorder except for insomnia whereas Kay et al.²⁴ included participants with and without insomnia. McCrae et al.⁴² also excluded individuals with cognitive impairment. Spira et al.²⁰ excluded individuals that self-reported AD or who were taking AD medications. These were not exclusion criteria for the presented study. Our findings may also demonstrate the heterogeneous nature of sleep in older adults with and without AD, and suggest that further research is needed to comprehensively characterize sleep patterns in this population.

These findings highlight the need for careful evaluation of sleep/wake actigraphy classification algorithms used in older adults with and without AD. Our data demonstrate that waist-worn actigraphy monitors classify intervals of sleep as wake more often in individuals with AD than in HOA. In addition to more impaired sleep, individuals with AD or their caregivers may have had difficulty accurately reporting sleep. Differences between individuals with AD and HOA may also relate to the way that activity monitors estimate sleep based upon the presence and absence of movement, with the presence of movement indicating wakefulness and the absence of movement indicating sleep. Because individuals with AD in our sample spent more TIB, it is possible that the longer amount of TIB contributed to the discrepancies in identifying wake and sleep more so in the AD than the HOA group. For example, if people with AD spent more TIB without being asleep, there would be more movement that could be misrepresented. Although there was not a statistically significant difference between the AD and HOA group regarding WASO and nightly awakenings, a review of previous research studies⁹ demonstrated that older adults with AD have more fragmented sleep due to nightly awakenings. These nighttime awakenings could be interpreted as waking periods by actigraphy if numerous awakenings occur or last for extended periods of time. The position of monitors at the hip may have also

influenced the estimation of the presence and absence of movement during sleep, as arms may be more likely to move during sleep than hips. Future studies should investigate the patterns of physical movement in older adults with and without AD during both waking and sleeping periods to determine whether there is a difference in levels of physical movement between the two groups (e.g. arm versus hip movements) and how these differences impact actigraphy sleep measures.

The purpose of our study was to evaluate the use of a waist-worn actigraphy monitor for assessing sleep and to consider the benefits and challenges of using a waist-worn actigraphy monitor for assessing sleep and low-intensity physical activity simultaneously. These data confirm previous reports that waist-worn actigraphy monitors overestimate sleep and underestimate wakefulness,²⁸ and demonstrate over and underestimation in an older adult and AD patient population. The most common method for estimating sleep is to use wrist-worn actigraphy monitors. Wrist-worn monitors provide estimates of sleep that are not significantly discrepant from self-reported sleep in older adults and can also be used to monitor physical activity.⁴⁴ However, there are limitations of using wrist-worn monitors for measuring physical activity in older adults. For example, it is difficult to obtain accurate measures of walking using an assistive device when actigraphy monitors are placed on the wrist.⁴⁵ Additionally, wrist monitors have poor sensitivity to low-intensity activities, which comprise the majority of activities in which older adults engage.^{25,27} Therefore, future studies should validate waist-worn actigraphy monitors for the measurement of sleep to allow recording of sleep and physical activity with one monitor. If the over- and underestimation of sleep parameters is consistent, statistical models could be used to adjust sleep parameter estimates to allow better comparability with wrist-worn monitors. Using waist-worn monitors would allow accurate and easy study of unexplored areas of sleep and physical activity, such as determining the intensity of physical activity needed for sleep benefit and investigating the impact of daytime sedentary behavior on sleep patterns in older adults. Accurately capturing sleep and physical activity patterns using one device would allow researchers to conserve resources and reduce participant burden (e.g. one device versus two).

Our study has several limitations. The study sample was racially homogenous and was high functioning, thus, not representative of all older adults with and without AD. We did not collect data using wrist-worn and waist-worn actigraphy simultaneously or compare our results to polysomnography data due to our study being a secondary analysis of data collected for a study that only used waist-worn monitors. Future studies

should also compare differences and similarities in polysomnography sleep data and waist-worn and wrist-worn actigraphy sleep and physical data that are collected simultaneously in older adults with and without mild AD. This would allow researchers to explore how the three differ in quantifying sleep and differentiating between sleep and wake and how waist- and wrist-worn monitors differ in quantifying physical activity in older adults with and without mild AD. Use of polysomnography and both waist- and wrist-worn actigraphy monitors would further the understanding of how the type of sleep measurement (polysomnography versus actigraphy) and placement of monitors in older adults with and without AD impacts the estimates of sleep and activity. We used paper logs to collect self-reported sleep diaries to validate sleep/wake times and assess compliance. Modern technological methods such as phone reminders may increase accuracy and reduce recall bias that may occur from delayed reporting of sleep times, although it is difficult to accurately record activity by any method when individuals are planning to sleep.

Conclusion

Despite potential over and underestimation of sleep using waist-worn actigraphy, we found differences in TST and TIB between older adults with and without AD. We observed differences in the number of sleep intervals misclassified as wake—people with AD had more sleep intervals categorized as wake than those without AD. More research is needed to understand disease-related sleep changes that occur in AD and discrepancies between objective and subjective measures of sleep. Our results highlight the importance of considering placement of monitors when evaluating sleep patterns among older adults with and without AD. Future studies might use both wrist- and waist-worn monitors simultaneously to assess the biases associated with placement for accurate estimation of both sleep and physical activity.

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Contributorship

CSK, BR, & AW conceived the study. CSK and BR conducted that analyses and wrote the paper. AW secured the funding for the study. All authors reviewed and edited the manuscript and approved the final version.

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