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Home Monitoring to Track Activity and Sleep Patterns Among Older Adults

A Feasibility Study

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Measuring changes in activity and sleep over time is important for research and practice. While commercially available home monitoring systems passively track these parameters, the feasibility, acceptability, and usefulness of new products need to be evaluated. We tested a commercially available system for providing long-term data on activity and sleep with 10 single women (mean age, 86.5 years) who were monitored in their homes. Motion detectors, a bed sensor, door sensor, and chair sensor were installed for 3 months to collect data. Other measures, objective actigraphy data from 1 week and self-report, provided data for comparison. Sleep and activity data were similar across measures; the most active participant had the highest scores on all activity measures including sensor data. Participants were generally positive about the monitoring system, but participants varied in their awareness levels of the presence of the equipment. Use of the sensor system was feasible in this pilot study and acceptable to participants. The study also illustrates challenges researchers can encounter when working with a commercial company.

KEY WORDS: Fear of falling, Frail older adults, Physical activity, Sensors, Sleep

Activity and sleep are important outcomes in aging research related to physical and mental health, and quality of life.[1,2] Accurately monitoring changes in these parameters over a long period is desirable to detect changes that might indicate illness onset or changes in health. Early identification of changes provides an opportunity to intervene and address problems. To make long-term monitoring easier, new technologies offer passive methods, such as sensors to track older adults in their homes. However, evaluation of new technologies with older adults to determine feasibility and acceptability is important.[3] This article describes a pilot study to evaluate a commercially available home monitoring system to track activity and sleep in community-dwelling older adults for use in future studies.

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BACKGROUND

Changes in activity, especially declines, may signal health events or problems amenable to interventions to keep older adults engaged in physical activity.[1] One such problem that may affect activity level is fear of falling. Concerns about falling can cause older persons to excessively restrict activity, resulting in social isolation, physical and functional decline, disability,[4] and ultimately an increased risk of falling.[5] Fear of falling is associated with declines in life-space mobility[6] and daily activity[7] in older people, but interventions are available to help older adults remain active if a problem is identified.

Similarly, poor sleep in older adults is associated with negative health outcomes including morbidity and mortality,[8,9] and affects up to 50% of older people.[2] Researchers[10] found changes in sleep patterns an early indicator of illness. In addition, sleep difficulty has been linked to anxiety,[11] functional decline in older adults,[12] and falls.[13] Therefore, understanding changes in sleep patterns over time is important for aging research and practice, so interventions can be implemented when needed.

Accurately measuring activity in older adults using self-report questionnaires has limitations. One issue is recall bias, considering the potential for short- or long-term memory changes. There is no consensus among researchers regarding how long the recall period should be to avoid problems.[14] When measuring activity, self-report questionnaires are often insensitive to changes in activity levels in older adults.[1] These questionnaires are often not helpful clinically, because they do not reflect changes in activity levels from high to low or measure restriction of activities. Early detection of changes in activity reflecting the onset of disability are especially challenging, because they are gradual and insidious.[15] Infrequent measurement can cause researchers or clinicians to miss the onset of activity changes and make it difficult to determine causes.

Finally, many activity questionnaires have a ceiling effect in sedentary older people. These questionnaires may ascertain moderate- and high-intensity activities but often leave out low-intensity activities.[14,16] Older people tend to be more sedentary and do more low-intensity activities because of declines in function.[17]

Self-report measures of sleep have similar limitations to activity measures. For example, the Pittsburgh Sleep Quality Index (PSQI) is a widely used measure of sleep.[18] However, the PSQI includes questions about sleep over the previous month, which has long been noted to create recall bias, making it difficult to use the measure to identify changes over time.[19] These limitations in measures of both activity and sleep support the need for objective measures to monitor for changes that may indicate early onset of illness, improve chronic disease management, and support aging in place.[10,20]

Actigraphs are wearable accelerometer-based devices that have been used in research and clinical settings to measure sleep and activity for decades.[21] Accurate objective data can be collected using accelerometry; however, there are limitations to using this method over long periods of time. Most researchers collect data over 7 to 14 days to obtain adequate information about sleep-wake patterns.[22] There are challenges with data collection,[23] even over these short periods of time. Wearing an actigraphy watch or device often requires participant vigilance. Study participants may forget to wear them, lose them, or get them wet, resulting in missing data or damaged equipment.[23] Some find the equipment uncomfortable. Often participants are asked to complete extra paperwork daily while using actigraphy, such as a daily sleep diary. As a result, use of accelerometers may be burdensome for study participants over a long period of time.

Passive sensors that monitor physiological and sociological data in the home have increasingly been used in aging research as technology has advanced.[24,25] Sensor-based measurements are popular because they are more accurate than self-report questionnaires in tracking activity and sleep data.[26,27] The passive nature of many sensor systems reduces participant burden so that data can be collected longitudinally, and researchers can explore changes in health outcomes in older populations over time.[28,29] However, even this approach has challenges such as cost, privacy issues, an overload of information, technical problems, and acceptability of systems to older adults.[24]

Previous studies have explored the feasibility and acceptability of sensor-based monitoring systems with older adults. In some studies, older adults reported concerns about being monitored, including privacy,[29] feeling controlled,[30] and skepticism about the usefulness of technologies, accuracy, and uncertainty about what was being done with their information.[31] However, researchers also reported positive views about being monitored. Some older adults liked the feeling of being monitored and the potential for improved safety, especially if they thought it would help them maintain their independence.[30,32-34] However, sensor systems may have different features, such as audio or video monitoring, motion detectors, and bed pads that may affect perceptions.[35] Research indicates that technologies need to fit easily into older adults' lives, and new systems should be tested with older adults to determine acceptability and feasibility.[3]

Given the limitations of prior measures of activity and sleep, using passive sensor systems to assess activity and sleep patterns over time is attractive. But new systems must be evaluated to determine acceptability and accuracy, as with any new measure.[3,24] As a result, this study was designed to evaluate the feasibility of using a new commercially available home monitoring system to collect passive data for future research and practice related to sleep, fear of falling, and activity restriction. The aims were to determine acceptability of the data collection system and feasibility based on our ability to recruit and retain older adults in a long-term study. We also explored the usefulness of the data from the sensor system to monitor activity and sleep patterns for future research.

METHODS

This pilot study was a single-group descriptive observational study to evaluate the feasibility of using a commercially available passive in-home monitoring system to track activity and sleep patterns among community-dwelling older adults over time. The sample was 10 older adults who lived alone in an apartment or home. Older adult volunteers were included if they were between the ages of 70 and 90 years, able to speak and read English, and independent in mobility, and had access to an electrical outlet for the monitoring system. Participants could not have significant visual problems, cognitive impairment, major medical conditions that would interfere with general activity, a large pet, or plans for travel more than a day or two during the study.

PROCEDURES

Participants were recruited from two senior apartment buildings and a community event. After obtaining institutional review board approval, we gave presentations and recruited attendees to participate in the study. Those interested were later visited to discuss the study, determine eligibility, and obtain informed consent. After agreeing to participate, we made another appointment to obtain baseline data and install the home sensors, which were left in place for 3 months. During this visit, we oriented the participant to the equipment and study and gave written instructions and contact information for the research team in case of questions or problems. Participants completed questionnaires and were given a 3-month calendar. They were instructed to maintain their usual activities and record falls or absences from the home due to hospitalization, travel, or other unusual activities on the calendar. A research assistant remotely checked an online dashboard regularly to monitor sensor functioning so that issues with the sensor equipment could be identified. Additional visits were made to address equipment issues at the participant's convenience.

We also collected standard actigraphy and sleep diary data for 1 week for comparison to the sensor data. Written and verbal instructions on wearing the actigraphy watch were provided by the research assistant to reduce participant-related data problems, such as removing the actigraphy watch and forgetting to use the watches' event marker to note bedtime and morning rising, as these events introduce artifact into data measurements. Finally, we interviewed participants when the data collection was completed. We provided a $25 monetary incentive at the end of the actigraphy data collection week and again after completion of the follow-up interview.

MEASUREMENT

Baseline data included demographic variables of age, gender, race and ethnicity, educational level, and number of chronic diseases. Participants were asked the amount of difficulty they had performing six activities of daily living and nine instrumental activities of daily living using a 4-point Likert scale from "no difficulty" to "unable to do the activity." Participants rated their fear of falling on a scale of 0 to 10, with 10 indicating the highest level of fear.

Health status was measured using the 12-item Short Form Health Survey (SF-12)[36] providing a mental health component score (MCS) and physical health component score (PCS).[36,37] The SF-12 questions are derived from the Short Form-36 Health Survey (SF-36) for measuring health-related quality of life.[37] Scores of 50 indicate population mean scores, with higher scores indicating better health. The SF-12 PCS and MCS subscales predict scores on the PCS-36 (R^2 = 0.911) and MCS-36 (R^2 = 0.918) in the general US population (N = 2333) with a 2-week test-retest reliability of 0.89 and 0.76 for the PCS and MCS subscales, respectively.[37]

To evaluate activity participation, we adapted the self-report Activity Checklist.[38] This questionnaire measures activity retention calculated as a proportion of the individual's current activity compared to their prior activities. This approach avoids penalties for activities not of interest. Due to the long length of the original checklist, the 55 items were compared to the activities in the Community Healthy Activities Model Program for Seniors Questionnaire.[39] In addition, responses on the checklist from prior studies were reviewed. The activities were reduced to a final list of 40 items including social, sports, leisure, home maintenance, and physical activities. From the list of activities, participants reported if they had ever done the activity and if so whether they continued to do it. Further, participants noted whether they do an activity more, less, the same, or if the activity had been discontinued. The activity score is a percent, comparing current activities to prior total activities.[38]

Self-reported sleep quality was assessed using the PSQI.[18] The PSQI, a self-administered questionnaire, includes 19 items to be answered using event-frequency and semantic scales. The instrument looks at seven areas: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency (the ratio of total sleep time to time in bed), sleep disturbances, the use of sleep-promoting medication, and daytime dysfunction. Scoring of answers is based on a 0- to 3-point scale, whereby 3 reflects the negative extreme on the Likert scale. A global sum of 5 or greater indicates "poor" sleep quality. The PSQI has internal consistency and a reliability coefficient (Cronbach's α) of .83 for its seven components.[18] The instrument takes approximately 5 to 10 minutes to complete.[40] For this analysis, we report on sleep quality and time in bed from the PSQI.

The MotionWatch 8 actigraphy (CamNtech, Boerne, TX) was used to measure sleep and activity patterns over 1 week using accelerometry. The MotionWatch 8 is a small waterproof device, approximately 36 × 28.2 × 9.4 cm, worn on the wrist. It contains a triaxial accelerometer sensor, an integral light sensor (0–64 000 lux), and 4-Mb nonvolatile memory. The sensitivity of the actigraphy is optimized for highly effective sleep-wake inference from wrist actigraphy, which has been previously validated and approved by the American Association of Sleep Medicine as an outcome measure for response to therapy among persons with insomnia.[41] Researchers found the MotionWatch 8 reliable and valid for examining sleep and activity in older adults.[42–44] Data were collected for 7 days at baseline and at the end of the 3-month monitoring period. While wearing the actigraphy watch, participants filled out a daily sleep diary, noting when they went to bed and when they got up to inform data analysis.

MotionWare Software, the companion software for the MotionWatch 8, was used to analyze actigraphy data to generate reports on a variety of activity and sleep variables. Variables were calculated for each day the participant wore the MotionWatch 8 and averaged across all days. The sleep variables selected for this study include total sleep time, sleep efficiency, and time in bed. The activity variable identified was the average daily total number of minutes per day spent in sedentary, moderate, or vigorous activity, which was used to calculate the average percent of the day the participant was active.

The commercially available home monitoring sensor system BeClose (Alarm.com, Tysons, VA) was developed to remotely monitor home activity by engineers, who consulted on development of this project. The system includes a base station that is plugged into an electrical outlet to collect and send data to the home company via cell phone lines (cell phone not required). Sensors included three motion detectors that were fastened to walls or doors using no-stick tape in the kitchen, bathroom, and hall or entrance to the living room area. A bed pressure sensor pad (12 × 18 inches) was placed under the mattress pad or sheets, and a chair pressure sensor pad was placed in the most-used chair under a cushion or pad. An exit sensor noted when the door to the apartment was opened and closed. We confirmed functioning of the sensors from an online dashboard three times per week. Activity variables generated by the sensors were provided as daily averages for the sensor triggers: kitchen activity, bathroom activity, hall activity, entry/exit activity, and a total daily activity measure (mean compilation of all triggers of motion detectors and door sensor). The chair sensor provided time on the chair in minutes. Sleep was provided as a time in bed variable based on time on the sensor pad, in minutes.

An experienced qualitative researcher conducted a brief structured follow-up interview with each participant to determine acceptability of the study. Using descriptive qualitative methods,[45] participants were asked about their perceptions of having the sensor system in their home and being monitored. Interviews were recorded and transcribed verbatim.

ANALYSIS

Baseline characteristics of the sample were compiled using descriptive statistics. We explored feasibility based on our ability to attain recruitment goals and retain participants for the 3 months of monitoring and research staff comments regarding the data collection process. Acceptability was determined by examining retention as well as input from follow-up interviews. Interview data were analyzed to describe participant awareness of the monitoring system during the study, including any positive or negative experiences with the system and any impact of being monitored.[45]

We planned to use algorithms with the sensor data to compute a variety of activity and sleep variables to compare these findings with self-report questionnaires and actigraphy data. However, the company providing the sensors and data was sold during the study, and staff from the new company deleted some data or moved the sensor data where it could not be retrieved. As a result, we were only able to obtain summary data on some of the sensors for five study participants (54 days of sleep data and 73 days of activity data). We used the data that we could obtain to identify variables to compare with our other data as a rough measure of convergent validity. A total activity variable was provided and visually compared with the two other activity variables with similar metrics: self-reported activity level (percent current activity) from the Activity Checklist and actigraphy-measured activity (percent of the day active). Time in bed was available from all three data sources, and self-reported (PSQI) time in bed was visually compared with the actigraphy report of average time in bed and the sensor-measured average time in bed.

RESULTS

Ten women were originally enrolled in the study. Nine were white and one was African American, with a mean age of 85.67 (SD, 5.10) years. One lived in a house, and the rest in apartments. One participant withdrew because she had to leave town for several weeks due to a family issue. Sensor data on four participants were not available, so five participants were included in the quantitative analysis (Table 1). These five remaining participants were white and female, and the mean age was 85.2 (SD, 2.17) years, and they lived in apartments. While participants had little difficulty with activities of daily living (ADLs), they noted greater difficulty with instrumental activities of daily living (IADLs). Four participants (80%) reported fear of falling, with a mean score of 5.6 out of 10 (SD, 1.34) indicating moderate fear. On average, the participants demonstrated above average mental well-being, but below average physical health status.

Activity and Sleep Characteristics

From the Activity Checklist, participants reported retaining 34 (75%) of their prior activities (Table 2). This indicates participants had given up a significant number of things they used to do. Activities most often given up were those that were more physically demanding, such as sports. The average activity per actigraphy was 343 minutes per day (5.7 hours). Most of the time was spent doing sedentary activities, which is characterized by energy expenditure ≤1.5 metabolic equivalents.[46] The sensor data provided total counts from triggers of

Table 1. Baseline Characteristics of Older Adults in the Home Monitoring Study

Variables	Results
Age, mean (SD) (y)	85.2 (2.17)
Gender	
Female, n (%)	5 (100%)
Race/ethnicity	
White, n (%)	5 (100%)
Educational attainment, mean (SD) (y)	14.4 (2.61)
Chronic diseases, mean (SD)	5.8 (2.95)
ADL, mean (SD)	7.5 (1.29)
IADL, mean (SD)	10.75 (2.87)
SF-12	
MCS, mean (SD)	57.38 (4.14)
PCS, mean (SD)	40.05 (10.08)
Fear of falling rating, mean (SD)	5.6 (1.34)

Note. ADL range 6–24, with a higher score indicating greater difficulty; IADL range 9–36, with higher score indicating greater difficulty; MCS range 0–100, with higher score indicating greater mental health status; PCS range 0–100, with higher score indicating greater physical health status.

Table 2. Activity and Sleep Characteristics of Participants

Participant	1	2	3	4	5	Average
Activity Measures						
Self-report						
Modified Activity Checklist	0.61	0.55	0.42	0.75	0.34	0.53
Actigraphy						
Average daily activity (min)	382	262	298	389	383	342
Percent of the day active	26.5	18.2	20.7	28.0	26.6	24
Daily sensor counts						
Kitchen activity	12.7	8.2	6.1	10.2	9.3	9.3
Bathroom activity	10.1	8.1	6.00	12.1	7.8	8.8
Entry/exit	9.0	7.3	7.4	13.9	6.3	8.8
Total activity (all sensors)	57.7	55.2	40.1	64.4	34.0	50.3
Sleep Measures						
Self-report						
PSQI total score	4	3	5	9	3	4.8
PSQI time in bed (min)	495	555	465	525	420	492
Actigraphy						
Total sleep time (min)	494	472	463	430	348	444
Sleep efficiency (%)	90.3	88.1	87.5	83.0	87.6	88.3
Time in bed (min)	547	536	529	517	490	523.8
Sensor data						
Time in bed (min)	40.4	555.5	556.8	461.7	561.5	435.2

Note. PSQI: a total score of 5 or greater is indicative of poor sleep quality. Modified Activity Checklist score percent represents present of prior activities retained.

the motion detectors in the hall, kitchen, and bathroom, and the door (entry/exit) sensor for a total activity count. The numbers were consistent across participants, as were the other activity measures.

Based on the PSQI, most participants reported that the quality of their sleep was good. Participant 4 had poor self-reported sleep quality (Global score = 9) and the lowest sleep efficiency (83%) by actigraphy, which may indicate that this person was staying in bed longer to try to get more sleep. The objective measures of sleep provided by actigraphy indicated that four of the participants had good total sleep time (>7 hours per night on average). The sensor data recording of time in bed were consistent across the participants, except one participant who removed the bed sensor because she found it uncomfortable.

Comparison of Self-report, Actigraphy, and Sensor Data

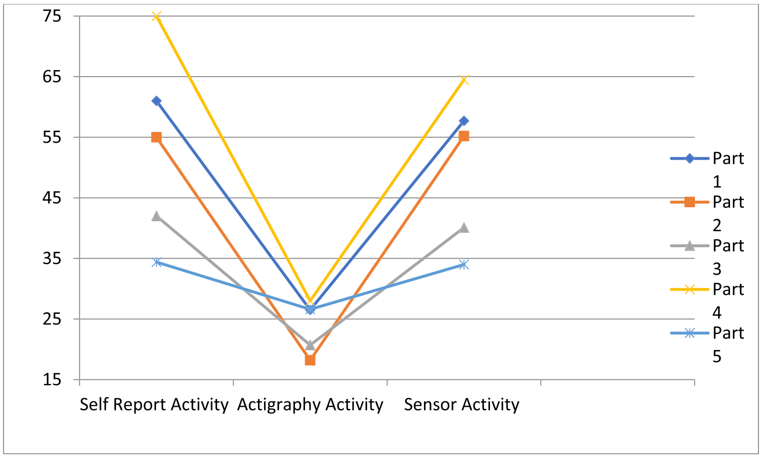
Visually examining the three activity scores for each participant (Figure 1), the most active participant had the highest scores on all three measures. This pattern was not consistent across all scores, but the sensor and self-reported activity scores were similar across participants, from highest to lowest. Actigraphy indicated that these participants were only active for 18% to 28% of the day. Participant 4, who retained the highest number of her prior activities, had the most minutes of activity and the highest total activity counts from the sensors.

When time in bed was compared across the three measures (Figure 1), the self-reported PSQI provided the longest time in bed for two of the participants (19 and 8 minutes) compared to actigraphy. The PSQI and actigraphy showed shorter time in bed for three participants compared to the sensor (range, 0.5-213.5 minutes). Participant 1 had very little time in bed as measured by the sensor because the bed pad was removed due to discomfort. In general, actigraphy provided lower estimates of time in bed when compared to sensor data in every participant.

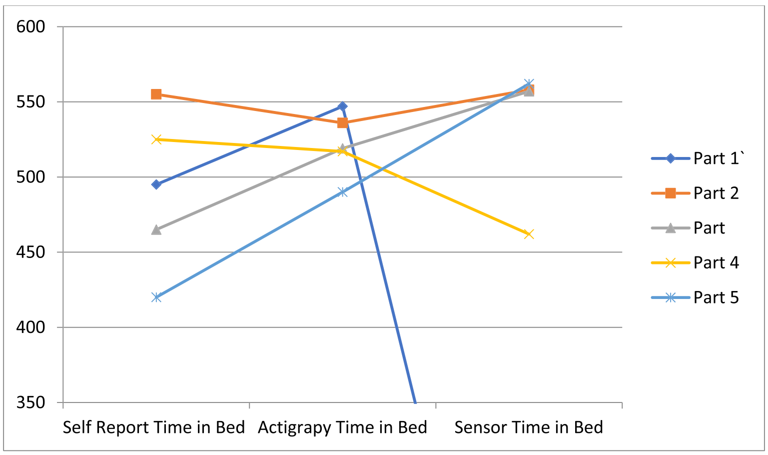
Feasibility

All but one of the 10 study participants completed the 3 months of sensor monitoring. She dropped out due to leaving town for an extended period because of a sick family member. Another participant was dropped before the final interview because she was hospitalized after the data collection and had no recollection of the study or monitoring equipment, possibly due to a delirium episode while hospitalized. The most successful recruitment method was presentations to groups in senior apartments and word of mouth at these facilities. Flyers were not effective. The installation of sensor equipment was simple, and we did not have any issues with wall damage from equipment due to the current availability of strong nonstick tape.

A few challenges were noted. We had to buy some additional equipment for the study, including surge protectors



Note: Self report activity = % of current activity/prior activity; Actigraphy activity = % of day active; Sensor score = average counts of motion detector activation



Note: Time in bed = PSQI self-report, actigraphy and sensor measured variables.

FIGURE 1. Average activity and sleep variables by participant.

to make additional electrical outlets available for the base stations. Other materials purchased included mattress pads to increase comfort of the bed sensor and chair pads for those whose chairs did not have a removable chair cushion. Tracking the sensor function was not difficult. The research assistant checked sensor functioning every 2 to 3 days via the dashboard and recorded any problems. A few participants had concerns or questions about equipment and equipment issues. We addressed issues when they came up, made home visits, and maintained a functioning monitoring system over 3 months with moderate effort.

Participant Experiences With the Monitoring System

Eight participants were interviewed about their experiences with the monitoring equipment to allow for evaluation of acceptability. Their comments diverged on whether or not they noticed the sensor equipment. Two participants reported that they quickly and easily forgot about the equipment. One participant did not notice the motion detectors on the walls after the first week or two but found the bed and chair pads "irritating" for the remainder of the study because they kept moving around and needed to be repositioned.

Those who remained aware of the system had a range of experiences from noticing the equipment most of or all the time and finding it bothersome, to noticing it but not finding it bothersome. One participant reported that she often thought about what the researcher would think about her frequent trips to the bathroom or kitchen, and she intentionally decreased trips to these locations. She said the monitoring system "was always on my mind" for the duration of the study. Another participant reported similar concerns and that she too changed behaviors and routines because of the monitoring equipment. For example, she reported, "I wouldn't sit on the bed to put on my shoes. I would sit on the end of the bed, so they wouldn't think I was in the bed" and "…I was just conscious that it was there and it would record every time I walked in and out of a room. You know, sometimes I would avoid it by not going into the room." For this participant, awareness of the equipment lessened after the first month.

Another participant found the bed pad to be uncomfortable. The first bed pad was replaced, but the discomfort continued, so finally the bed pad was removed. She reported she was aware of the remaining equipment but did not find it "disturbing" in any way. In another participant, the equipment served as a prompt to move more, which she saw as an "advantage." She reported, "I read a lot and I curl up with a book in a place for several hours at a time, and I think that knowing the monitor was there helped me to get up and do exercises and move around."

One participant was aware of the monitoring equipment the entire study but did not find it bothersome. It is worth noting that the participant who seemed to find the system the most bothersome reported she would do another monitoring study if asked because "it is time to give back. I think if they can learn something to help others, I'm there for them."

Several participants also reported concerns about potential compromises to the data with the presence of other individuals in their homes. One participant said, "The only time I was a little worried about it was when my three great grandchildren were here and I was watching them and they are rather active. They are 2 and 3." Another participant had a dog visit her. Adult children and other family members or friends also visited participants during the study. Some visitors noticed and inquired about the equipment, but this did not affect participants' interest in being part of the study.

DISCUSSION

The ability to track activity and sleep over time is an important goal for research and practice.[20] We found the home monitoring system feasible to use over 3 months and acceptable to participants with a few minor exceptions. The system was relatively easy to set up, use, and track functioning. We identified areas to enhance participant orientation to the system and follow-up procedures that would strengthen a future study. The data collection would have generated a significant number of person-days of data if we could have retrieved it all, but we only received a portion of the data. This limited our ability to examine the data from the sensor system or conduct a rigorous analysis of the findings. However, we could provide preliminary findings that suggest that the data obtained from the sensor system would generate scores that would be interpretable to evaluate changes in home activity and sleep over time. Our experiences may be helpful to researchers exploring new sensor systems.

The participants in this sample were somewhat frail with minimal average activity time each day as measured by actigraphy. We recruited mostly participants who lived alone in apartment buildings. These buildings provided meals, which may attract older adults with low functional levels who are seeking a supportive environment. We did find that participants spent a fair amount of time in their apartments. Further study with older adults in a range of living situations and more variable levels of activity would provide more information on the utility of this data collection method. If participants spent a lot of time away from home, this kind of system might not provide enough information. An important question to explore is whether a home-based system provides adequate activity data, or if a wearable device is needed that would capture activity outside the home as well as at home.

While one participant reported a high level of sleep difficulty, they all had adequate actual sleep of at least 7 hours[2] as measured by actigraphy that varied from time in bed. In interpreting our sleep findings, it is important to note that not all time in bed is spent asleep. Actigraphy estimates sleep from a lack of movement, not time lying down on the bed, which is measured by the sensor estimate and PSQI question. We found a difference between sensor-measured time in bed and actigraphy sleep, but differences between sensor time in bed and PSQI time in bed were only 3 to 7 minutes (although there was a substantial difference in one participant). This could be due to recall bias, yet the differences were close (minutes), indicating that the passive sensor measurement approach could be useful in the home environment. Although to our knowledge we are the first to compare time in bed across measures, these findings are consistent with those of other researchers who compared self-reported and objectively measured sleep time[46] and sitting time.[47] These findings suggest that time in bed may be best measured using a bed sensor.

During follow-up interviews, participants reported a range of perceptions of the monitoring equipment, with some aware of it for the duration of the study, others not as much. For example, researchers[30(p48)] found that participants "positively valued sensor monitoring equipment" as a safety mechanism that promoted ongoing independent living. Also, three themes emerged from a qualitative study of older adults' and caregivers' perspectives on home monitoring equipment in another study[35]: "feeling cared for," "feeling cared about," and "suggestions for change." One of the subthemes to "suggestions for change" was "do not use a monitoring system on me." A few participants preferred privacy to monitoring. Our study demonstrates that for some a monitoring system is intrusive and bothersome, and they too would likely not want a monitoring system used on them. We would strengthen participant orientation to the monitoring system, because some of their concerns were unfounded.

It is important to check back frequently with participants in the first weeks to ensure participant comfort and explore concerns. In addition, we would encourage participants to maintain their regular schedule.

There are challenges in using commercial products for research purposes. While these products are attractive because researchers do not need teams of engineers to build systems from scratch or create algorithms to analyze massive amounts of data, control over the system is limited. Products can be more lucrative in the commercial arena than research arena, so startup companies may be sold, as happened with our partner company. Based on the experiences from this study, we encourage further exploration of the usefulness of home sensor monitoring for research purposes. Also, caution is advised in determining which system to use for future research studies.

Overall, actigraphy monitoring using MotionWatch 8 was acceptable to participants in our study and has been successfully used by other researchers to estimate sleep[42] and activity.[43,44] As a result, intermittent actigraphy monitoring may be an alternative to using home sensors. Researchers could compare the benefits of quarterly activity and sleep monitoring with actigraphy compared to constant sensor monitoring to see if adequate information can be gained. New technologies are continuously being developed, and researchers will have to evaluate the pros and cons of various data collection methods to determine which will give them the information needed to answer the questions in their research studies.

Maintaining adequate levels of activity and sleep is an important goal for health and quality of life in our older population. Finding ways to track these parameters and intervene when problems are identified will continue to be goals for health professionals. Passive sensors show promise for monitoring of activity and sleep, and continued research is needed to find the best methods and systems to help researchers and clinicians promote healthy aging.

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References

1. Layne AS, Hsu FC, Blair SN, et al. Predictors of change in physical function in older adults in response to long-term, structured physical activity: the LIFE study. *Archives of Physical Medicine & Rehabilitation*. 2017;98(1): 11–24.e13.
2. Crowley K. Sleep and sleep disorders in older adults. *Neuropsychology Review*. 2011;21(1): 41–53.
3. Schulz R, Wahl HW, Matthews JT. Advancing the aging and technology agenda in gerontology. *The Gerontologist*. 2015;55(5): 724–734.
4. Choi K, Jeon GS, Cho SI. Prospective study on the impact of fear of falling on functional decline among community dwelling elderly women. *International Journal of Environmental Research and Public Health*. 2017;14(5).
5. Delbaere K, Close JC, Mikolaizak AS, Sachdev PS, Brodaty H, Lord SR. The Falls Efficacy Scale International (FES-I). A comprehensive longitudinal validation study. *Age and Ageing*. 2010;39(2): 210–216.
6. Auais M, Alvarado B, Guerra R, et al. Fear of falling and its association with life-space mobility of older adults: a cross-sectional analysis using data from five international sites. *Age and Ageing*. 2017;46(3): 459–465.
7. Hornyak V, Brach JS, Wert DM, Hile E, Studenski S, Vanswearingen JM. What is the relation between fear of falling and physical activity in older adults? *Archives of Physical Medicine and Rehabilitation*. 2013;94(12): 2529–2534.
8. Dean GE, Weiss C, Morris JL, Chasens ER. Impaired sleep: a multifaceted geriatric syndrome. *Nursing Clinics of North America*. 2017;52(3): 387–404.
9. Saccomano SJ. Sleep disorders in older adults. *Journal of Gerontological Nursing*. 2014;40(3): 38–45.
10. Rantz M, Phillips LJ, Galambos C, et al. Randomized trial of intelligent sensor system for early illness alerts in senior housing. *Journal of the American Medical Directors Association*. 2017;18(10): 860–870.
11. Zimmerman ME, Bigal ME, Katz MJ, Derby CA, Lipton RB. Are sleep onset/maintenance difficulties associated with medical or psychiatric comorbidities in nondemented community-dwelling older adults? *Journal of Clinical Sleep Medicine*. 2013;9(4): 363–369.
12. Spira AP, Kaufmann CN, Kasper JD, et al. Association between insomnia symptoms and functional status in U.S. older adults. *Journals of Gerontology, Series B*. 2014;69(suppl 1): S35–S41.
13. Min Y, Slattum PW. Poor sleep and risk of falls in community-dwelling older adults: a systematic review. *Journal of Applied Gerontology*. 2018;37(9): 1059–1084.
14. Jørstad-Stein EC, Hauer K, Becker C, et al. Suitability of physical activity questionnaires for older adults in fall-prevention trials: a systematic review. *Journal of Aging and Physical Activity*. 2005;13(4): 461–481.
15. Gill TM, Allore H, Holford TR, Guo Z. The development of insidious disability in activities of daily living among community-living older persons. *The American Journal of Medicine*. 2004;117(7): 484–491.
16. Hekler EB, Buman MP, Haskell WL, et al. Reliability and validity of CHAMPS self-reported sedentary-to-vigorous intensity physical activity in older adults. *Journal of Physical Activity & Health*. 2012;9(2): 225–236.
17. Tse AC, Wong TW, Lee PH. Effect of low-intensity exercise on physical and cognitive health in older adults: a systematic review. *Sports Medicine Open*. 2015;1(1): 37.
18. 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 Research*. 1989;28(2): 193–213.
19. Smith MT, Wegener ST. Measures of sleep: the Insomnia Severity Index, Medical Outcomes Study (MOS) Sleep Scale, Pittsburgh Sleep Diary (PSD), and Pittsburgh Sleep Quality Index (PSQI). *Arthritis Care & Research*. 2003;49(S5): S184–S196.
20. Rantz MJ, Skubic M, Miller SJ, et al. Sensor technology to support Aging in Place. *Journal of the American Medical Directors Association*. 2013;14(6): 386–391.
21. Ancoli-Israel S, Martin JL, Blackwell T, et al. The SBSM guide to actigraphy monitoring: clinical and research applications. *Behavioral Sleep Medicine*. 2015;13(suppl 1): S4–S38.
22. Martin JL, Hakim AD. Wrist actigraphy. *Chest*. 2011;139(6): 1514–1527.
23. Berger AM, Wielgus KK, Young-McCaughan S, Fischer P, Farr L, Lee KA. Methodological challenges when using actigraphy in research. *Journal of Pain and Symptom Management*. 2008;36(2): 191–199.
24. Kang HG, Mahoney DF, Hoenig H, et al. In situ monitoring of health in older adults: technologies and issues. *Journal of the American Geriatrics Society*. 2010;58(8): 1579–1586.
25. Reeder B, Meyer E, Lazar A, Chaudhuri S, Thompson HJ, Demiris G. Framing the evidence for health smart homes and home-based consumer health technologies as a public health intervention for independent aging: a systematic review. *International Journal of Medical Informatics*. 2013;82(7): 565–579.
26. Alexander GL, Wakefield BJ, Rantz M, et al. Passive sensor technology interface to assess elder activity in independent living. *Nursing Research*. 2011;60(5): 318–325.
27. Klenk J, Dallmeier D, Denkinger MD, Rapp K, Koenig W, Rothenbacher D; ActiFE Study Group. Objectively measured walking duration and sedentary

behaviour and four-year mortality in older people. *PLoS One*. 2016;11(4): e0153779.

28. Kaye JA, Maxwell SA, Mattek N, et al. Intelligent systems for assessing aging changes: home-based, unobtrusive, and continuous assessment of aging. *The Journals of Gerontology Series B*. 2011;66(suppl 1): i180–i190.
29. Demiris G, Oliver DP, Giger J, Skubic M, Rantz M. Older adults' privacy considerations for vision based recognition methods of eldercare applications. *Technology and Health Care*. 2009;17(1): 41–48.
30. Epstein I, Aligato A, Krimmel T, Mihailidis A. Older adults' and caregivers' perspectives on in-home monitoring technology. *Journal of Gerontological Nursing*. 2016;42(6): 43–50.
31. Demiris G, Hensel BK, Skubic M, Rantz M. Senior residents' perceived need of and preferences for "smart home" sensor technologies. *International Journal of Technology Assessment in Health Care*. 2008 Winter;24(1): 120–124.
32. Pol M, van Nes F, van Hartingsveldt M, Buurman B, de Rooij S, Kröse B. Older people's perspectives regarding the use of sensor monitoring in their home. *The Gerontologist*. 2016;56(3): 485–493.
33. Wild K, Boise L, Lundell J, Foucek A. Unobtrusive in-home monitoring of cognitive and physical health: reactions and perceptions of older adults. *Journal of Applied Gerontology*. 2008;27(2): 181–200.
34. Van Hoof J, Kort HS, Rutten PG, Duijnstee MS. Ageing-in-place with the use of ambient intelligence technology: perspectives of older users. *International Journal of Medical Informatics*. 2011;80(5): 310–331.
35. Bruce CR. Informed decision making for in-home use of motion sensor-based monitoring technologies. *The Gerontologist*. 2012;52(3): 317–324.
36. Ware JE. *How to Score Version 2 of the SF-12 Health Survey (With a Supplement Documenting Version 1)*. Lincoln, RI: QualityMetric Inc; 2005.
37. Ware J, Jr., Kosinski M, Keller SD. A 12-item Short-Form Health Survey: construction of scales and preliminary tests of reliability and validity. *Medical Care*. 1996;34(3): 220–233.
38. Everard KM, Lach HW, Fisher EB, Baum MC. Relationship of activity and social support to the functional health of older adults. *The Journals of Gerontology Series B*. 2000;55(4): S208–S212.
39. Stewart AL, Mills KM, King AC, Haskell WL, Gillis D, Ritter PL. CHAMPS physical activity questionnaire for older adults: outcomes for interventions. *Medicine and Science in Sports and Exercise*. 2001;33(7): 1126–1141.
40. Mollayeva T, Thurairajah P, Burton K, Mollayeva S, Shapiro CM, Colantonio A. The Pittsburgh Sleep Quality Index as a screening tool for sleep dysfunction in clinical and non-clinical samples: a systematic review and meta-analysis. *Sleep Medicine Reviews*. 2016;25: 52–73.
41. Morgenthaler T, Alessi C, Friedman L, et al. Practice parameters for the use of actigraphy in the assessment of sleep and sleep disorders: an update for 2007. *Sleep*. 2007;30(4): 519–529.
42. Landry GJ, Best JR, Liu-Ambrose T. Measuring sleep quality in older adults: a comparison using subjective and objective methods. *Frontiers in Aging Neuroscience*. 2015;7: 166.
43. Resnick B, Galik E, Boltz M, et al. Physical activity and function in assisted living residents. *Western Journal of Nursing Research*. 2018;40(12): 1734–1748.
44. Falck RS, Landry GJ, Brazendale K, Liu-Ambrose T. Measuring physical activity in older adults using MotionWatch 8 actigraphy: how many days are needed? *Journal of Aging and Physical Activity*. 2017;25(1): 51–57.
45. Kim H, Sefcik JS, Bradway C. Characteristics of qualitative descriptive studies: a systematic review. *Research in Nursing and Health*. 2017;40(1): 23–42.
46. Landry GJ, Falck RS, Beets MW, Liu-Ambrose T. Measuring physical activity in older adults: calibrating cut-points for the MotionWatch 8(©). *Frontiers in Aging Neuroscience*. 2015;7: 165.
47. Lagersted-Olsen J, Korshøj M, Skotte J, Carneiro IG, Søgaard K, Holtermann A. Comparison of objectively measured and self-reported time spent sitting. *International Journal of Sports Medicine*. 2014;35(6): 534–540.

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