Biomechanical activity devices to index wandering behavior in dementia

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Abstract

Valid and reliable measures of wandering are needed to study this troubling behavior. Although researchers have used various perspectives, definitions, and approaches to study wandering, spontaneous ambulation is a key characteristic across all views. Biomechanical activity devices for capturing movement provide one way to index wandering. This study examined four devices with ambulatory nursing home residents with dementia (N = 178) who wore devices simultaneously during four observations. Among the Actillume, StepWatch, Step Sensor, and TriTrac-R3D, the StepWatch yielded data from the highest proportion of observations, explained the most variance (63.9 percent) among all instruments, and was acceptable to nursing staff. Although the Step Sensor was the staff's preferred device, its performance was least acceptable for research purposes. Results support use of the StepWatch in future studies of wandering.

Key words: biomechanical activity devices, dementia, wandering behavior

Introduction

Measurement is a key issue in advancing our understanding of wandering among persons with dementia and in evaluating the impact of interventions to modify this challenging behavior. Most studies of wanderers, or of wandering behavior, have relied on simple classification of persons as wanderers or nonwanderers based upon caregiver judgments that lack clear or consistent criteria. Although several other measurement approaches have been used in more recent studies,[1] none have been sufficiently evaluated for acceptability as the "gold standard" or emerged as the most commonly employed means.

An important reason for this lack of a generally accepted measurement approach is ambiguity across various conceptions and definitions of wandering. However, one universal characteristic of wandering is spontaneous ambulation.[1-3] A standard approach to quantifying this aspect of wandering would be highly beneficial across diverse theoretical frames of reference. Thus, the purpose of this study was to determine the extent to which biomechanical activity devices can accurately and acceptably assess wandering in nursing home residents with dementia.

Biomechanical devices are often superior to subjective measures,[4] and this may be particularly important when subjects' abilities for self-report are questionable, as is often the case in dementia. Biomechanical measures of activity have been advocated for studying a variety of phenomena (e.g., sleep-wake patterns, locomotor activity, and motor behavior[5-7]) and applied to diverse populations (e.g., children, healthy and obese youth, elderly, insomniacs, and Parkinson's, Alzheimer's disease (AD), and neuropsychiatric patients[8-14]). Biomechanical measures of activity are highly reliable in laboratory and field settings[15] and have been validated against direct observation and activity and sleep diaries.[15-17]

Scientists studying wandering have noted the potential usefulness of biomechanical activity devices for

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some time,[16,18-21] Identified benefits include potential cost savings over direct or videotaped observations and requisite coding procedures, absence of rater bias or interpretation, and elimination of the need for time sampling strategies,[20] which can affect reliability and validity of observations. However, studies to evaluate these devices have had small samples, and approaches used to validate these measures against observed parameters of wandering have varied widely.

The earliest use of such devices in studies of wandering was reported in 1988 by Algase,[18] who employed large-scale integrated (LSI) activity meters. Originally designed for epidemiological studies of activity, exercise, and energy expenditure, these devices employed a mercury switch inside a plastic housing to count any three-degree tilt in vertical axis and aggregated counts into units representing 16 tilts. An LED display, powered by a hearing-aid battery and activated by application of a magnet to the side of the housing, provided a reading in increments of 10 units or 160 tilts.[15] In subsequent studies using these same devices, the 24-hour distribution of wandering was mapped, and stability of wandering over a three-day interval was evaluated.[19,22] Although useful for demonstrating the value of activity meters in the study of wandering, the value of LSI was limited because the display was difficult to access and read accurately while being worn by subjects, and the device was prone to damage from moisture. Application over extended time periods was necessary to obtain the best reliability, and manufacture and support of the LSI were eventually discontinued in favor or newer computer-driven technology.

Based on the concept of a pedometer, Madsen[16] designed and evaluated the Step Sensor as a means to objectively quantify amount or frequency of wandering. Designed in consideration of gait characteristics of the elderly (e.g., shuffling) that are problematic for the use of pedometers by this age group, the Step Sensor is a pressure-sensitive switch embedded in a foam heel pad and connected by thin wires to a small plastic box. The box clips to the outer aspect of the subject's shoe and contains an LCD display. Though the only activity meter designed specifically to measure wandering, the device was initially evaluated by comparison to observed step counts of cognitively intact individuals under varying speeds and controlled conditions.

Cohen-Mansfield and associates[20] were the first to evaluate multiple activity devices as measures of wandering using the Step Sensor, a pedometer, the ActiGraph (Ft. Walton Beach, FL), and the Personal Activity Meter (PAM). Ten nursing home residents identified as having a high degree of "pacing" wore each device separately for one 12-hour period; subjects were observed hourly for 10 minutes while wearing each device, during which time all steps taken were counted. Observations occurred on four sequential days. Overall correlations between observed steps and devices were all significant ($p < 0.01$). The ActiGraph and the PAM had r values over 0.95, whereas the Step Sensor and pedometer had correlations of 0.638 and 0.796, respectively. All devices had drawbacks with regard to both the subject (fidgeting, removal attempts, initial and sustained responses to wearing the instrument) and the researcher (difficulty applying or removing, malfunctions or failures, and ease of data retrieval and analysis). Because data regarding any one device were all obtained on one day, observations cannot be regarded as independent, and a high degree of correlation would be expected. Further, devices were not evaluated simultaneously; thus, although compared over the same general time frame, they were compared on the basis of different observations. Another limitation of this study is that the small sample was nonrandom and drawn from a single facility; it also was biased in favor of subjects with a high degree of ambulation. Nonetheless, the study represented an improvement over Madsen's work, in that the sample was composed of wanderers—per staff ratings on the Cohen-Mansfield Agitation Inventory (CMAI)—and multiple devices were evaluated. However, though "steps taken" could be expected to correlate highly with activity devices, "steps" were not well justified as the criterion variable for wandering. Steps alone fail to account for the effect of ambulatory ability on wandering or to differentiate between wandering and nonwandering ambulation. Other criteria, such as frequency of wandering episodes or the time spent wandering, may be a more relevant standard both theoretically and clinically.

Therefore, this study was undertaken to further advance the evaluation of biomechanical activity devices as proxies for direct observation in quantifying wandering. The following research questions were posed:

1. How do biomechanical activity devices compare on their ability to yield meaningful data in a general sample of cognitively impaired, ambulatory nursing home residents?

2. How do biomechanical activity devices compare on clinical acceptability from the standpoint of nursing home staff?

3. Which biomechanical activity device best indexes wandering behavior conceived as time ambulating in a random, lapping, or pacing pattern?

Methods

Design

This study used a cross-sectional survey design within which subjects simultaneously wore four biomechanical activity devices for two four-hour time periods on each of two nonconsecutive days, and observation for wandering behavior occurred for the duration of these same observation periods.

Sites and subjects

Subjects were drawn from 23 randomly chosen nursing homes and assisted living facilities within a three-county metropolitan area of one midwestern state. Because subjects were cognitively impaired, consent was obtained from proxies authorized to make medical decisions. In accord with required protections for human subjects, nursing home personnel identified and contacted proxies of potential subjects and determined their willingness to hear about the study. Only willing proxies were approached for consent. Some potential subjects were ruled out when their proxies revealed a subject's failure to meet inclusion criteria. Owing to methods required to meet human subjects' standards for consent, an accurate consent rate for all eligible subjects cannot be computed.

All assenting subjects for whom informed consent was obtained and who met inclusion criteria were then studied. Inclusion criteria were: having a medical diagnosis of dementia by DSM-IV criteria, being independently ambulatory, speaking English, and scoring less than 24/30 on the Mini-Mental State Examination (MMSE).[23] Because of the needs of a concurrent study, all subjects were also right-handed and educated through eighth grade. Because we were interested in persons with widely variable degrees of wandering behavior, subjects were not required to be identified wanderers.

The 178 subjects were 75.3 percent female and 85.48 percent white, with an overall mean age of 85.3 (SD = 6.31) years. Males and blacks were slightly younger (83.68 and 84.56 years, respectively). While all subjects met DSM-IV criteria for dementia, only 86 percent had a dementia diagnosis documented in their medical record. Of these, 77.5 percent were diagnosed with AD, 10.7 percent with multi-infarct dementia (MID), 9.0 percent with mixed AD and MID, and 2.9 percent had a nonspecific diagnosis such as senile dementia or organic brain syndrome.

Measures

Biomechanical activity devices were used to capture movement indicative of wandering behavior. Initially, these were the LSI activity meter, the Actillume, the TriTrac-R3D, and the Step Sensor. Part way through the study, a fifth instrument, the StepWatch, was added to replace the LSI. The LSI, described earlier, is a very small and lightweight mechanical accelerometer that continuously aggregates units of movement. About 1 x 3/4 x 1/2 inches in size, the black plastic housing has rounded corners and was affixed using a cloth strap applied to the ankle on the leg corresponding to the dominant arm and hand. An initial reading is made at the time the LSI is applied to the subject, and at whatever subsequent interval the researcher desires, by applying a magnet to the device to activate the LED display. Research staff document a reading by hand on a written log sheet. For this study, readings were taken at one-hour intervals. After five subjects were studied, the LSI failed and suitable manufacturer's support could not be obtained. Therefore, we abandoned the LSI, and data from it were not used in any analyses.

The Step Sensor (Motion Research of Iowa, Inc.), a step counter, also described earlier, was worn in the shoe under the heel on the same side as the LSI. The rigid plastic housing, about 2 x 1 x 1/2 inch in size, which records step counts, was attached to the outer aspect of the shoe. Similar to the LSI, readings on the Step Sensor were taken hourly by hand although no magnet is required to activate the display.

The Actillume (Ambulatory Monitoring, Inc., Ardsley, NY) is an accelerometer that measures movement in three planes using a piezoelectric sensor (the same as the ActiGraph) while recording ambient light level. The size of a large diver's watch, the Actillume can be set to aggregate counts over any predetermined time period using the manufacturer's software. There is no external display on the Actillume; data are stored electronically within it and uploaded to a computer for processing. As readings were being compared to direct observations made in real time, we selected a one-minute epoch. Subjects wore the Actillume on the same leg as the other instruments.

The TriTrac-R3D (Hemokinetics, Madison, WI) is an improved version of the CalTrack (Glass Lantern, LLC, Washington, DC) used to estimate physical activity levels. Like the Actillume, the TriTrac-R3D is a triaxial accelerometer programmed via computer that can be preset for start times, stop times, and epochs. Unlike the Actillume, the TriTrac-R3D is a larger device, about the size of a small transistor radio. Set for a one-minute interval, the TriTrac-R3D was worn in a pouch placed around the subject's waist and positioned over the hip.

The StepWatch (Cyma, Seattle, WA) is a step counter developed initially for studies of activity in amputees.

Table 1. Percentages of observations (N = 712) with and without data by device and source of data loss				
	Actillume (%)	**TriTrac-R3D (%)**	**Step Sensor (%)**	**StepWatch* (%)**
Data available	52.95	43.54	46.35	57.98
Equipment failure	4.35	3.93	4.92	0.69
Project/staff problem	9.41	8.71	8.85	0.00
Setting issue	2.67	2.81	2.53	1.48
Subject issue	29.78	40.03	36.52	28.80
Other	0.84	0.98	0.84	11.00
* n = 288 for StepWatch.				

About 2 1/2 inches square and 1/2 inch thick, the StepWatch housing has a concave surface designed to fit comfortably against the lower calf and held in place with two elastic straps. The StepWatch interfaces with a Macintosh computer by infrared light; the manufacturer's software allows for individual settings related to the gait characteristics of the wearer and can be set to any predetermined epoch to aggregate step counts. As for the Actillume and TriTrac-R3D, the StepWatch was set for a one-minute epoch, and data were uploaded electronically after each observation day. The StepWatch was worn on the same leg as other instruments.

As the criterion measure, *wandering* was timed and coded by trained data collectors from subjects' ambulation episodes. All ambulation episodes occurring in any public space of the nursing home or assisted living facility were documented using a MacSema BestWand bar code reader (MacSema Inc., Bend, OR) with an internal clock, light-emitted diode signal, programmable memory, and ability to retain 512K in a computer-readable format. The MacSema wand, which can be programmed to any predetermined coding system and has full transmission capabilities, was used to swipe a standardized coding sheet for the start, stop, and pattern for each ambulation episode observed. Use of the bar coder reduces measurement error associated with stopwatches by eliminating steps in timing, recording, transferring, and entering data.

Two dimensions of wandering were quantified by this method: episode pattern and duration. Episode pattern (random, lapping, pacing, and direct) was discerned based on a typology developed by Martino-Saltzman and associates.[24] Accordingly, random is haphazard locomotion having many hesitations and direction changes; lapping is circuitous locomotion following a repetitive route or path; pacing is back-and-forth locomotion between two points; and direct is an undiverted path between a start point and a destination. From several thousand videotaped episodes of ambulation displayed by nursing home residents, they developed definitions and diagrams of each pattern. On a subsample of 231 of these ambulation episodes, they obtained a kappa of 0.79 ($z = 13.2$, $p < 0.0001$) with this typology. In our study, these four patterns were used to categorize each ambulation episode. Although all ambulation was observed and recorded, wandering comprised only ambulation episodes with a random, lapping, or pacing pattern. Because the direct pattern is considered efficient for travel,[24] episodes with a direct pattern were not considered wandering even though they were counted and coded. Episode duration was determined as the time elapsed from the onset to the cessation of each walking episode. Duration for all wandering episodes was summed within an observation period and converted to a percentage of the total duration for that observation period. Since the proportion of episodes that were coded as lapping or pacing was small, no analyses by pattern were attempted.

Data regarding acceptability of biomechanical activity devices were obtained in two ways. First, data collectors kept field logs during all observation periods to document the devices worn, any issues in subjects' acceptance, equipment failure or malfunction, site interference, or project staff errors or problems. Second, devices were also examined and rated independently by individual nursing staff of each unit where study subjects resided using a scale anchored at 0 and ranging from highly acceptable (+5) to highly unacceptable on nine characteristics: appearance, concealment, body placement, safety, size, weight, comfort, ease of cleaning, and ease of application.

Procedures

Subjects were randomly assigned to two of three four-hour observation periods (0800-1200, 1200-1600, and

Table 2. Nursing staff ratings of four devices on nine criteria for clinical acceptability (N = 70)*								
Criterion	Actillume		TriTrac-R3D		Step Sensor		StepWatch*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Appearance	2.59	0.75	3.06	0.83	3.24	0.75	3.50	0.76
Comfort	2.29	1.04	3.14	0.77	3.24	0.66	3.47	0.80
Concealment	2.51	1.07	2.74	0.97	2.76	1.15	3.74	0.61
Easy application	2.76	0.82	3.18	0.73	3.19	0.79	3.19	0.98
Ease of cleaning	2.73	0.73	3.17	0.72	3.19	0.75	3.25	0.92
Location	2.77	1.07	2.91	0.88	3.14	0.71	3.76	0.55
Safety	2.61	1.00	3.27	0.72	3.35	0.86	3.71	0.59
Size	2.31	0.99	2.83	0.82	3.29	0.77	3.53	0.79
Weight	2.63	0.90	3.41	0.71	3.54	0.61	3.76	0.49
* n = 17 for StepWatch								

1600-2000) and observed 1:1, twice at each assigned time period, for a total of 16 scheduled hours each. Observations for the same time period were separated by a period of at least 48 hours. During observation times, subjects were continuously monitored by data collectors operating from a distance of 30-50 feet from the subject.

Data collectors completed 12 hours of training in the programming, application, and reading or data interface for activity devices and in using the MacSema bar code reader to code episode frequency, duration, and pattern. For devices, training methods included demonstration and return demonstration. For wandering observations, training included observation and coding of videotapes of wandering obtained during a previous study and field practice on simulated and actual wandering in the nursing home setting. Data collectors' reliability in identifying direct versus all wandering patterns was equally high, while their reliability in distinguishing among wandering pattern was somewhat lower, ranging between 70 and 80 percent.

Data analysis

Data from the Actillume, TriTrac-R3D, StepWatch, and MacSema wand were downloaded to a computer and converted to SPSS files for analysis. Because each biomechanical device was tolerated differently by each subject, the file for each device was paired to the corresponding MacSema wand file separately and trimmed as necessary to create a matching time period, minute for minute. Because the Step Sensor did not have a computer interface, raw data were entered and matched to a MacSema wand file, which was then trimmed to correspond to the time period encompassed by the Step Sensor readings. Except for the Step Sensor, the proportion of time in motion was calculated for all devices and for observed wandering episodes. For the Step Sensor, actual step counts were used in analyses since proportion of time in motion could not be derived from step counts.

Results

Ability to yield meaningful data

To examine the amount of usable data, tables were created to show the number of cases for which data had been obtained during one or more observation periods. Another table was constructed to demonstrate the number of subjects for which data from one, two, three, or four devices were available for analysis. Tables revealed that the Actillume was worn successfully by 24.6 percent of subjects for all four periods, whereas the StepWatch was so worn by 29.2 percent. By comparison, subjects accepted other devices for all four periods at rates of only 11 to 12 percent. The percent of subjects accepting a device for *any* period was also highest for the Actillume and StepWatch

Criterion	Worst			Better
Appearance	TriTrac-R3D	StepWatch	Actillume	Step Sensor
Comfort	TriTrac-R3D	Actillume	StepWatch	Step Sensor
Concealment	Actillume	TriTrac-R3D	StepWatch	Step Sensor
Easy application	TriTrac-R3D	StepWatch	Actillume	Step Sensor
Ease of cleaning	TriTrac-R3D	Actillume	StepWatch	Step Sensor
Location	TriTrac-R3D	Actillume	StepWatch	Step Sensor
Safety	TriTrac-R3D	Actillume	StepWatch	Step Sensor
Size	TriTrac-R3D	Actillume	StepWatch	Step Sensor
Weight	TriTrac-R3D	StepWatch	Actillume	Step Sensor

Note: Bars between devices indicate significant differences between mean ratings for devices appearing on either side of the bar; no bar between devices indicates that mean readings were not significantly different between devices.

Figure 1. Rank order and significant differences using general linear modeling.

(82.1 percent and 83.3 percent, respectively); rates for other devices were somewhat lower at 76 to 79 percent. In regression analyses conducted to evaluate whether cognitive impairment or age affected acceptance of any device, neither MMSE nor age predicted the number of observation periods during which subjects accepted any device.

Reasons for the absence of device data were culled from field notes of data collectors and classified as problems with equipment failures, project or staff, setting, subject, or other. Results are shown in Table 1. Subject problems, largely refusals to wear or removals of devices, were the largest source of data loss. Overall, the StepWatch had the least missing data related to equipment failures, project or staff errors, and setting issues but the most missing data in the "other" category. It should be noted that the StepWatch was introduced into the study for only the last 72 cases and, therefore, encompasses only 288 total observation periods compared to 712 for other instruments.

Clinical acceptability

Nursing staff ratings of each device on nine criteria are shown in Table 2. Ratings on each criterion were evaluated using a general linear modeling approach. Results of tests for within-subject contrasts are shown in Figure 1. The Step Sensor was consistently rated best, but ratings were significantly better than all other instruments on only six of nine characteristics: appearance, concealment, body placement (location), safety, size, and weight. The StepWatch was rated as the second best instrument on six characteristics: comfort, concealment, ease of cleaning, body placement, safety, and size. It was a significant improvement over the TriTrac-R3D on five criteria, and rated as good as or better than the Actillume on all criteria.

Valid index of wandering behavior

Because each device was accepted by each subject for varying numbers (0-4) of observations, separate analyses were conducted by device. Each device was evaluated using data from all subjects who wore the device for one or more periods. This resulted in different and uneven subsamples by device. Before these analyses were computed, resulting subsamples were compared on MMSE, age, sex, and race to evaluate group equivalence. No significant differences were found. Nonetheless, age, sex, and MMSE were used as control variables in regression analyses. To maximize the number of cases available for analysis, an MMSE score of -1 was assigned to subjects who were too impaired to complete the test and earn a "true" 0.

First, devices were examined for their ability to

explain variance in proportion of time spent wandering. The Step Sensor (n = 107) did not predict any significant amount of variance in proportion of time observed wandering ($f = 1.326$; $p = 0.252$). The Actillume (n = 136) predicted 20.9 percent of the variance ($f = 32.225$; $p < 0.001$). The TriTrac-R3D (n = 113) predicted 24.1 percent of the variance ($f = 31.848$; $p < 0.001$). The StepWatch (n = 40) predicted 63.6 percent of the variance ($f = 81.011$; $p < 0.001$). Next, proportion of time during which motion was detected by each device was compared to the proportion of time during which wandering was detected in corresponding observation periods. Both the Actillume and TriTrac-R3D detected much higher percentages of time in motion, 63 percent and 49 percent, respectively, compared to a corresponding estimate of 11 percent assessed through direct observation, reflecting a substantial overestimation of wandering. However, the StepWatch and direct observation produced similar estimates, 16.8 percent and 15.4 percent, respectively.

Reliability assessment

Reliability analysis was done by correlating meter readings from two corresponding time periods occurring three days apart. Correlations for only the StepWatch ($r = 0.71$) and Actillume ($r = 0.84$) were significant at $p < 0.001$.

Discussion

These results indicate that the StepWatch and Actillume were able to yield the largest amount of meaningful data; they were best tolerated (i.e., worn by the largest percent of subjects for the greatest number of observation periods) among all devices tested. However, failure mode analyses did not reveal an advantage for any device. Further, neither age nor MMSE had an effect on the acceptance rate for any device.

Staff ratings revealed that the Step Sensor was the most clinically acceptable device, rating significantly better than all other devices on six of nine characteristics. The Tritrac-R3D was clearly the least acceptable device, receiving the lowest ranking on all criteria except concealment.

The StepWatch was superior to all other devices in terms of its ability to index wandering. It explained more than two and one-half times the variance (63.6 percent) of the next best performing device, the TriTrac-R3D (24.1 percent) for percent of time wandering. The StepWatch produced the closest estimate of time spent wandering, whereas the Actillume and TriTrac-R3D made substantial overestimates, indicating that they were oversensitive to movement that is not wandering behavior.

Although this study was conducted primarily for evaluating measurement approaches to wandering for research purposes in nursing homes, its results may also have clinical merit in these settings. The StepWatch may be useful in assessing the amount and daily distribution of wandering behavior, which can point up risk for weight loss, foot problems, or other concerns associated with high levels of or excessive wandering. The StepWatch may also be useful as a means to evaluate the effectiveness of interventions aimed to reduce or redistribute wandering behavior.

In conclusion, this study indicates that one device, the StepWatch, is clearly the best overall for use in future studies of wandering. It is the best tolerated and most accurate biomechanical activity device for this purpose. Among all devices with any ability to significantly index wandering, its clinical acceptability is as good as or better than the Actillume and is significantly better than the TriTrac-R3D.

Acknowledgments

Research conducted under funding from the National Institutes of Health, National Institute on Aging, 1 RO1 AG11501, PI Donna L. Algase.

Authors acknowledge contributions of Gwi-Ryung Son, PhD, RN, and Lan Yao, doctoral student, to revisions of this manuscript.

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