Published in final edited form as:

J Gerontol Nurs. 2012 April ; 38(4): 18–23. doi:10.3928/00989134-20120307-01.

Automated Technology to Speed Recognition of Signs of Illness in Older Adults

Marilyn J. Rantz, PhD, RN, FAAN[Curator's Professor],

Sinclair School of Nursing and Family and Community Medicine, Helen E. Nahm Chair and University Hospital Professor of Nursing, University of Missouri, Columbia, Missouri, 573-882-0258

Marjorie Skubic, PhD[Professor],

Electrical and Computer Engineering

Richelle J. Koopman, MD, MS[Associate Professor],

Curtis W. and Ann H. Long Department of Family and Community Medicine

Gregory L. Alexander, PhD, RN, FAAN[Associate Professor],

Sinclair School of Nursing

Lorraine Phillips, PhD, RN[Assistant Professor],

Sinclair School of Nursing

Katy Musterman, RN, BSN, MBA[Care Coordinator and Nursing Manager],

TigerPlace, Sinclair School of Nursing

Jessica Back, LMSW,

TigerPlace, Sinclair School of Nursing

Myra A. Aud, PhD, RN[Associate Professor],

Sinclair School of Nursing

Colleen Galambos, PhD, ACSW, LCSW, LCSW-C[Professor],

School of Social Work

Rainer Dane Guevara, B.S., and

Electrical and Computer Engineering

Steven J. Miller, MA[Research Associate]

Marilyn J. Rantz: rantzm@missouri.edu

Abstract

Our team has developed a technological innovation that detects changes in health status that indicate impending acute illness or exacerbation of chronic illness *before* usual assessment methods or self-reports of illness. We successfully used this information in a one year prospective study to alert health care providers so they could readily assess the situation and initiate early treatment to improve functional independence. Intervention participants showed significant improvements (as compared to control group) for the SPPB gait speed score at quarter 3 ($p=0.030$), left hand grip at quarter 2 ($p=0.02$), right hand grip at quarter 4 ($p=0.05$), and the functional ambulation profile of the GAITrite at quarter 2 ($p=0.05$). Technological methods such as these could be widely adopted in elder housing, long term care settings, and in private homes where elders want to remain independent as long as possible.

Keywords

Technology; elder independence; non-wearable sensors; gait speed; elder housing

Health care providers who care for older adults often become aware of subtle changes, almost developing a “sixth sense” that “something is wrong” or “something is about to happen” to a particular person. Many times, these early changes are beginning symptoms of acute illnesses or exacerbations in chronic illnesses. Our Eldertech Research Team, an interdisciplinary team of nurses, social workers, physician, informatics experts, and electrical and computer engineers, implemented a novel network of environmentally embedded sensors that generate data about older adults as they go about their normal living activities. Automated data processing methods developed by the team analyze data and alert clinicians that something “is different” and “potentially wrong” with a person in their care. The clinicians have a convenient way to visualize the data to interpret what may be occurring, within the context of the person’s health status (Alexander, Wakefield, Rantz, et al., 2011). Our team hypothesized from preliminary work (Rantz, Skubic, & Miller, 2009) that sensor data would provide cues of impending signs of illness earlier than traditional nursing assessments. We also hypothesized that patterns in the sensor data would emerge *before* older people become aware that something is “not right” with their health.

This article reports findings of this innovative research for early illness detection and proactive chronic disease management to detect changes in health status that indicate impending acute illness or exacerbation of chronic illness *before* usual assessment methods. Our team chose to use unobtrusive, inexpensive, non-wearable, infrared (PIR) motion sensors that monitor people continuously while they go about daily activities in their homes. Unobtrusive bed sensors collect data about each person’s pulse, breathing, and restlessness while they sleep. We developed methods of alerting health care providers and identified key outcome variables for future research with large scale testing of non-wearable sensor technology that enables aging in place through proactive early illness detection.

Methods

Retrospective and prospective qualitative and quantitative methods were used to 1) develop alerts based on sensor data and notify health care providers of potential illness; 2) refine a web-based interface to display sensor data in a format that is easy to use and interpret, readily available, and clinically relevant; and 3) prospectively evaluate the early illness sensor system to determine appropriate outcome variables and sample sizes for follow-up intervention studies.

This research was supported by several years of preliminary studies developing the integrated sensor network at TigerPlace, a 54 apartment assisted living facility with a research infrastructure and integrated sensor system (Rantz, Skubic, Alexander, Popescu, et al., 2010; www.agingmo.com and www.eldertech.missouri.edu)

To enable the development and refinement of the system, sensor data surrounding all significant health events (ER visits, hospitalizations, falls) were first viewed by the PI and aresearch associate with experience in aging research followed by the clinical research team (4 PhD prepared nurses, a family practice physician, and the TigerPlace RN care coordinator). A total of 104 health events from participating residents (n=20) from 2005 through 2008 were reviewed by the team. In 42% of the cases, the team observed patterns of changes in the sensor data about 10 to 14 days preceding a significant health event (Rantz, Skubic, Alexander, Aud, et al., 2010). Based on these analyses, a 14 day window was set for initial algorithms to calculate potential alerts from changes in the sensor data (Alexander, Rantz, Skubic, et al., 2011). It was necessary to set initial alert algorithms to conduct the prospective pilot study using early illness alerts.

Sample

Older adults living at TigerPlace were recruited for the prospective phases of this study. For the pilot study, a convenience sample of 42 people was recruited: 20 living with the sensor networks (intervention) and 22 without (control); one control participant died immediately after baseline. Table 1 displays demographics of the sample. Medical diagnoses that are typical for older adults were prevalent in both groups, including diabetes, hypertension, cardiovascular disease, osteoarthritis, osteoporosis, Parkinson's disease and some cancers.

Intervention

Intervention participants had data-driven alerts sent to the TigerPlace RN care coordinator when there were indicators of potential decline in physical function, and/or indicators of acute illness onset or chronic illness exacerbation. The alerts flag potential illness onset so the nurse can evaluate the residents health condition and intervene with early treatment. After receiving an alert, the nurse accessed a secure web site displaying the user interface so the resident's activity pattern could be interpreted; next, the nurse determined if there was a need for further evaluation of an imminent acute illness or exacerbation of a chronic illness. The nurse involved other health care providers as appropriate to the situation, and documented the alert receipt, the assessment of the potential health problem, and the actions taken in the resident's electronic health record.

Control participants (n=21) received usual care. As potential problems were detected, the nurse took appropriate nursing action, assessing the situation, involving other health care providers, and documenting the assessment and actions taken in the resident's electronic health record.

Outcome Measures

Outcomes were selected based on our model of early illness detection (Galambos, Skubic, Wang, et al., in review) and supporting literature (Boockvar & Lachs, 2003; Ridley, 2005). Baseline measures included a health history, medication use, and vital signs. Functional performance measures collected at baseline and quarterly included: 1) The Short Physical Performance Battery (SPPB) which assesses lower extremity function using measures of standing balance, gait speed, and lower extremity strength (Guralnik, Simonsick, Ferrucci, et al., 1994); 2) The GaitRite analysis (a portable carpet with sensors) which measures temporal and spatial parameters of gait including cadence, step length, and velocity (www.gaitrite.com; Bliney, Morris, & Webster, 2003).; 3) A hydraulic hand dynamometer measured grip strength of both the right and left hands of each participant. This measure has been commonly used for over 40 years and is recognized as a measure of frailty, disability, and mortality (Ali, O'Brien, Hoffman, et al., 2008; Ling et al., 2010); 4) Health event outcomes of emergency room visits, hospitalizations, and falls captured from existing documentation systems. These were totaled quarterly for the study duration; annual totals were used in analyses due to the infrequent occurrences of these events; and 5) Other measures routinely completed at TigerPlace including activities of daily living (ADLs), independent activities of daily living (IADLs), the Geriatric Depression Scale (GDS), Mini Mental Status Exam (MMSE), SF12 Health and Mental Health scales, and fall risk. Measures were collected at baseline, before the pilot study began, and at the end of each quarter for 1 year.

Data Analysis—The Wilcoxon rank-sum was used to compare the differences in quarterly change scores for each continuous variable. Logistic regression was used to compare the differences in dichotomous component scores. The Cochran-Mantel-Haenszel test was used to compare annual differences in ER visits, hospitalizations, or falls. Adjustments were made for multiple testing.

Web interface, Early Illness Sensor System Usability Measures—Research team members used the web interface as they received real-time alerts and offered suggestions for improving the interface. Based on this feedback, the interface was revised in an iterative fashion by engineering collaborators while clinicians continued to use it and provide feedback. Detailed weekly notes from the users were analyzed with usability methods for additional interface revisions (Alexander, Rantz, Skubic, et al., 2011). Each month throughout the study, clinicians anonymously completed 7 questions using Likert scales about their perspectives of the sensor system. Weekly, clinicians kept track of the time they spent reviewing each alert received from the system. These times were compiled and averaged for the team.

Results

Web interface, Early Illness Sensor System Usability Measures

End user confidence is crucial if in-home sensors, alert algorithms, and display interfaces are to be useful for clinicians as an early illness sensor system. Five of the Likert questions revealed shifts in overall confidence from 61% to 86%; ease of interpretation from 43% to 70%; clinical relevance of the sensor data from 52% to 83%; and confidence that the system would alert them to signs of potential decline in physical function, acute illness, or exacerbation of chronic illness improved from 26% to 71%. Ease of use is also important and improved from 50% to 85% and the availability of the interface improved from 85% to 92%.

To be successful, it was crucial for the sensor system to be efficient for clinicians to use. From the beginning, it was a goal of the engineering team to develop ways for the clinicians to access the data rapidly and reliably. Drilling through different screens to view the data from different perspectives can be time consuming. With interface refinements, interpretation time declined from an average of 4.26 to 2.01 minutes per alert by study end. Ideas for continued refinement of the interface will likely further reduce clinician reviewing time. An additional consideration for system efficiency is the number of alerts generated for the participants. By the end of the study alerts were being generated at a rate of about 3 per month per participant.

Algorithms were adjusted to improve effectiveness, accuracy and clinical relevance of alerts. Our goal was to reduce numbers of alerts that clinicians judged as not clinically relevant (Alexander, Rantz, Skubic, et al., 2011). For example, clinicians did not see increases in activity during the day time as particularly relevant, but time up at night as very relevant. In many cases, alerts that flagged increased frequency of time up at night resulted in early detection of urinary tract infections (Rantz, Skubic, Koopman, et al., 2011) or other acute infections such as pneumonia, upper respiratory infections, heart failure, pain post hospitalization, delirium, and hypoglycemia. Over the one year study, a total of 219 health events precipitated 32 ER visits, 23 hospitalizations, and 164 falls. In the last six months, after algorithm refinement, the intervention group (n=21) had 258 alerts generated by activity sensors and 43 breathing, 101 pulse, and 102 restlessness alerts for a total of 246 from the bed sensor.

A continuous feedback system was implemented so clinicians could rate alert relevance through an email link received with each alert. This enabled the engineering team to make continual adjustments in the algorithms to improve accuracy and relevance (Guevara, 2011). The three most clinically relevant alerts rated by clinicians during the final 9 months of the pilot study included recliner chair restlessness (63%), bed restlessness (75%) and slow pulse in bed (100%). An additional analysis of methods to maximize the accuracy of the alert algorithms revealed that for 100% of the clinically relevant alerts to be generated, the false

alarm rate would be about 30% (Guevara, 2011). For an early illness detection system, this false alarm rate was acceptable to the clinicians in this study.

Outcome Variables

Table 2 displays the outcome measures with statistically significant results ($p < 0.05$) and trends ($p < 0.10$); both will be considered in future studies. No statistically significant differences were found for the SF12, MMSE, GDS, ADLs, IADLs, fall risk, ER visits, hospitalizations or falls. The GAITrite Functional Ambulation Profile (FAP), a summary score reflecting an overall measure of walking (Nelson, Certo, Lembo, et al., 1999), was a significant finding; for comparison with FAP, velocity from the GAITrite is also included in Table 2, although not a significant result.

Intervention participants showed significant improvements for the SPPB gait speed score at quarter 3 ($p = 0.03$), left hand grip at quarter 2 ($p = 0.02$), right hand grip at quarter 4 ($p = 0.05$), and the FAP of the GAITrite at quarter 2 ($p = 0.05$). Trends in the positive direction for the sensor group occurred in both the 4 meter walk and second 4 meter walk in quarter 1 ($p = 0.08$ and $p = 0.06$); however, the sensor group trended worse in the 4 meter walk at quarter 3 ($p = 0.08$) while the control group remained the same. The control group did not improve for walking measures, but improved trends were observed for the semi-tandem stand at quarters 1 and 4 and repeated chair stand at quarter 4.

Discussion

Results are promising from this prospective pilot study using early warning sensors. Functional improvement was detected in both walking and hand grip in the intervention group compared to the control group. These two important functional abilities are critical for older people who want to remain independent and actively engaged in life. Walking ability is a key indicator of health and well-being in older adults (Viccaro, Perera, & Studenski, 2011). Changes in gait and gait speed are associated with functional and cognitive decline (Buracchio, Dodge, Howieson, et al., 2010; Wennie Huang, Perera, Van Swearingen, et al., 2010) and mortality (Studenski, et al. 2011). Grip strength is also recognized as a measure of frailty in older people and also associated with mortality (Ling et al., 2010). This new technological approach to identify illness onset earlier could lead to improved function and delay functional decline. The early illness sensor system with automated alerts enhanced assessment skills of clinicians; *using this system, health conditions were detected 1–2 weeks before traditional assessment and observation methods*. With earlier recognition, timely interventions are possible, and with those, clinical outcomes improve.

Importantly, the confidence in and clinical relevance of the early illness system improved throughout the study and clinician time to analyze each alert reduced more than 50%. A critical outcome was that the TigerPlace RN care coordinator and clinical social worker who had been actively involved in the study chose to adopt the early illness detection system with alerts as usual care for all residents who live with sensors. They were not willing to have the alert features “turned off” at the end of the study. Instead, they considered alerts from the sensor network to be a valuable part of clinical care for those who choose to live with them. They are encouraging all residents to enroll to have sensor networks installed in their apartments because the system helps them catch problems early, avoiding more severe conditions requiring residents to be hospitalized or moved to a less independent setting. Typically, about half of the people living at TigerPlace participate in the various technology studies and live with sensors embedded in their apartments. We have been told by families and residents moving into the facility, that one of the attractions for them is to participate in this cutting edge research.

It is important to point out limitations. Subjects were not randomly assigned and the sample was relatively small, although adequate for the exploratory nature of this study. The study did not control for interventions that may have helped some subjects improve function, such as physical therapy, occupational therapy, or surgery. The residents at TigerPlace are predominately Caucasian, thus a lack of diversity affects generalization to broader populations of elders.

Our research team is optimistic about future adoption of technological methods which we hope will be widely adopted in elder housing, long term care settings, and most importantly, in private homes where elders want to remain independent. We are in the planning stages for a follow-up intervention study that will use the early illness sensor system in a larger sample of elder housing to measure the clinical effectiveness and cost-effectiveness of using sensor data to detect early signs of illness or functional decline in older adults as compared to usual health assessment.

Acknowledgments

This article is based on results of NINR funded research, 1R21NR011197-02 (Rantz, PI, 2009-2012) Technology to Automatically Detect Early Signs of Illness in Senior Housing. Results and conclusions are the responsibility of the researchers, and not the opinion of NINR. Authors gratefully acknowledge the residents and staff of TigerPlace who graciously participate in our technology development research and the students and faculty of the Eldertech Research Team at the University of Missouri.

References

- Alexander GL, Rantz MJ, Skubic M, Koopman R, Phillips L, Guevara RD, Miller S. Evolution of an early illness warning system to monitor frail elders in independent living. *Journal of Healthcare Engineering*. 2011; 2(2):259–286.
- Alexander GL, Wakefield B, Rantz M, Aud M, Skubic M, Erdelez S, Al Ghenaimi S. Evaluation of a passive sensor technology interface to assess elder activity in an independent living facility. *Nursing Research*. 2011; 60(5):318–325. [PubMed: 21873920]
- Ali NA, O'Brien JM, Hoffman SP, Phillips G, Garland A, Findley JCW, Almoosa K, Hejal R, Wolf KM, Lemeshow S, Connors AF, Marsh CB. Acquired weakness, handgrip strength, and mortality in critically ill patients. *American Journal of Critical Care Medicine*. 2008; 178:261–268.
- Bliney B, Morris M, Webster K. Concurrent related validity of the GAITRite Walkway System for quantification of the spatial and temporal parameters of gait. *Gait and Posture*. 2003; 17:68–74. [PubMed: 12535728]
- Boockvar KS, Lachs MS. Predictive value of nonspecific symptoms for acute illness in nursing home residents. *Journal of the American Geriatrics Society*. 2003; 51(8):1111–1115. [PubMed: 12890074]
- Buracchio T, Dodge HH, Howieson D, Wasserman D, Kaye J. The trajectory of gait speed preceding mild cognitive impairment. *Archives of Neurology*. 2010; 67(8):980–986. [PubMed: 20697049]
- Galampos C, Skubic M, Wang S, Rantz M. The use of density mapping for early illness detection of dementia and depression in older adults. *Gerontechnology*. in review.
- Guevara, RDA. MS Thesis. Electrical and Computer Engineering, University of Missouri; Columbia, MO: 2011. Motion sensor network for early illness detection in the elderly.
- Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, et al. A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. *Journal of Gerontology*. 1994; 49(2):M85–94. [PubMed: 8126356]
- Ling CHY, Taekema D, de Craen AJM, Gussekloo J, Westendorp RGJ, Maier AB. Handgrip strength and mortality in the oldest old population: the Leiden 85-plus study. *CMAJ Canadian Medical Association Journal*. 2010; 182(5):429–435.

- Nelson AJ, Certo LJ, Lembo LS, Lopez DA, Manfredonia EF, Vanichpong SK, Zweick D. The functional ambulation performance of elderly fallers and non-fallers walking at their preferred velocity. *NeuroRehabilitation*. 1999; 13:141–146.
- Rantz MJ, Skubic M, Alexander GL, Aud MA, Wakefield BJ, Galambos C, Koopman RJ, Miller SJ. Improving nurse care coordination with technology. *Computers, Informatics, Nursing*. 2010; 28(6):325–332.
- Rantz MJ, Skubic M, Alexander G, Popescu M, Aud M, Koopman R, Miller S. Developing a Comprehensive Electronic Health Record to Enhance Nursing Care Coordination, Use of Technology, and Research. *Journal of Gerontological Nursing*. 2010; 36(1):13–17. [PubMed: 20047248]
- Rantz, MJ.; Skubic, M.; Koopman, R.; Phillips, L.; Alexander, GL.; Miller, SJ. Using sensor networks to detect urinary tract infections in older adults. *Proceedings, 13th IEEE International Conference on e-Health Networking, Application, & Services*; Columbia, MO. June 13–15, 2011; 2011. p. 142–149.
- Rantz, MJ.; Skubic, M.; Miller, SJ. Using sensor technology to augment traditional healthcare. *Proceedings from 31st Annual International Conference of the IEEE EMBS*; Minneapolis, MN. September 2–6, 2009; 2009. p. 6159–62.
- Ridley S. The recognition and early management of critical illness. *Annals of the Royal College of Surgeons of England*. 2005; 87(5):315–322. [PubMed: 16176687]
- Studenski S, Perera S, Patel K, Rosano C, Faulkner K, Inzitari M, Brach J, et al. Gait speed and survival in older adults. *JAMA*. 2011; 305(1):50–58. [PubMed: 21205966]
- Viccaro LJ, Perera S, Studenski SA. Is timed up and go better than gait speed in predicting health, function, and falls in older adults? *Journal of the American Geriatrics Society*. 2011; 59(5):887–892. [PubMed: 21410448]
- Wennie Huang WN, Perera S, Van Swearingen J, Studenski S. Performance measures predict onset of activity of daily living difficulty in community-dwelling older adults. *Journal of the American Geriatrics Society*. 2010; 58(5):844–852. [PubMed: 20406319]

Table 1

Sample Demographics

	Intervention (n=20)	Control (n=21)	Total (n=41)
Gender			
Male	6	8	14
Female	14	13	27
Mean Age (range)	84.5 (64–96)	83.9 (67–96)	84.6 (64–96)
Ethnicity			
Caucasian	20	20	20
Asian	0	1	1

Table 2

Results of Outcome Analysis

Outcome measure	Scoring for Measure	Means (SD) at Baseline and Quarter with Significant Results		Results & p-value
		Control (n=21)	Sensor (n=20)	
SPPB-total score	0-12 ¹	Baseline 6.86 (3.09) Q4 6.24 (3.66)	Baseline 5.40 (92.93) Q4 4.26 (2.54)	NS
Balance score	0-4 ¹	Baseline 2.14 (1.28) Q4 2.65 (1.27)	Baseline 2.10 (1.29) Q4 2.11 (1.48)	NS
Gait speed score	0-4 ¹	Baseline 2.96 (1.05) Q3 2.60 (1.35)	Baseline 2.25(1.12) Q3 2.41 (1.33)	p=0.03* Sensor got better, control worse
Chair stand score	0-4 ¹	Baseline 1.77 (1.45) Q4 1.5 (1.50)	Baseline 1.05 (1.32) Q4 0.27 (0.83)	NS
Repeated chair stands	Seconds to complete ²	Baseline 15.37 (5.69) Q4 15.79 (6.23)	Baseline 15.93 (5.32) Q4 21.43 (5.30)	p=0.08 sensor got worse; control same as baseline
4 meter walk	Seconds to complete ²	Baseline 6.60 (4.75) Q1 7.20 (6.68) Q3 6.62 (4.43)	Baseline 8.60 (5.49) Q1 8.35 (6.38) Q3 10.78 (11.37)	Q1 p=0.08 sensor got some better control got worse Q3 p=0.08 sensor got worse control same
2 nd 4 meter walk	Seconds to complete ²	Baseline 5.64 (2.91) Q1 5.79 (3.88)	Baseline 7.41 (3.84) Q1 6.27 (4.13)	p=0.06 sensor improved and control same
Hand Grip-Left	Pressure ¹	Baseline 19.84 (8.88) Q2 15.27 (10.34)	Baseline 16.55 (7.06) Q2 16.00 (7.75)	p=0.02* Control significantly declined, sensor stable
Hand Grip-Right	Pressure ¹	Baseline 21.71 (9.53) Q4 17.02 (8.57)	Baseline 17.38 (8.35) Q4 15.2 (9.32)	p=0.05* Control significantly declined more than sensor
Functional ambulation profile score (GAITrite)	Good score=>90, best 100	Baseline 54.11 (35.74) Q2 75.61(15.76)	Baseline 22.95(32.03) Q2 67.83 (17.39)	p=0.05* Intervention improved significantly more than control
Velocity (GAITrite)	cm/second	Baseline 73.10 (21.56) Q2 70.27 (30.92) Q4 72.70 28.09)	Baseline 55.23(19.82) Q2 60.16 (25.08) Q4 48.63 (50.24)	NS

¹ higher is better² faster is better