

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

Marilyn J. Rantz, PhD, RN, FAAN; Marjorie Skubic, PhD; Richelle J. Koopman, MD, MS; Gregory L. Alexander, PhD, RN, FAAN; Lorraine Phillips, PhD, RN; Katy Musterman, MBA, BSN, RN; Jessica Back, LMSW; Myra A. Aud, PhD, RN; Colleen Galambos, PhD, ACSW, LCSW, LCSW-C; Rainer Dane Guevara, BS; and Steven J. Miller, MA



© 2012 iStockphoto.com/Kosmitler

ABOUT THE AUTHORS

Dr. Rantz is Curator's Professor, Sinclair School of Nursing and Curtis W. and Ann H. Long Department of Family and Community Medicine, and Helen E. Nahm Chair and University Hospital Professor of Nursing, Dr. Skubic is Professor, and Mr. Guevara is a master's student, Electrical and Computer Engineering, Dr. Koopman is Associate Professor, Curtis W. and Ann H. Long Department of Family and Community Medicine, Dr. Alexander and Dr. Aud are Associate Professors, and Dr. Phillips is Assistant Professor, Sinclair School of Nursing, Ms. Musterman is Care Coordinator and Nursing Manager, and Ms. Back is Social Worker, TigerPlace, Sinclair School of Nursing, Dr. Galambos is Professor, School of Social Work, and Mr. Miller is Research Associate, University of Missouri, Columbia, Missouri.

The authors have disclosed no potential conflicts of interest, financial or otherwise. This article is based on results of research funded by the National Institute of Nursing Research (NINR) grant 1R21NR011197-02 (PI: Rantz, 2009-2012), Technology to Automatically Detect Early Signs of Illness in Senior Housing. The results and conclusions are the responsibility of the researchers and not the opinion of the NINR. The authors gratefully acknowledge the residents and staff of TigerPlace who graciously participate in their technology development research and the students and faculty of the Eldertech Research Team at the University of Missouri.

Address correspondence to Marilyn J. Rantz, PhD, RN, FAAN, Curator's Professor, S406 Sinclair School of Nursing, University of Missouri, Columbia, MO 65211; e-mail: rantzm@missouri.edu.

Posted: March 14, 2012

doi:10.3928/00989134-20120307-01

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 1-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 with the control group) for the Short Physical Performance Battery gait speed score at Quarter 3 ($p = 0.03$), hand grip-left at Quarter 2 ($p = 0.02$), hand grip-right at Quarter 4 ($p = 0.05$), and the GAITrite functional ambulation profile score at Quarter 2 ($p = 0.05$). Technological methods such as these could be widely adopted in older adult housing, long-term care settings, and in private homes where older adults wish to remain independent for as long as possible.

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 of chronic illnesses. Our Eldertech Research Team, an interdisciplinary team composed 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, 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 adults 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 identify 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, nonwearable, passive infrared (PIR) motion sensors that monitor people continuously while they perform 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 nonwearable sensor technology that enables aging in place through proactive early illness detection.

METHOD

Retrospective and prospective qualitative and quantitative methods were used to (a) develop alerts based on sensor data and notify health care providers of potential illness; (b) 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 (c) 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).

To enable the development and refinement of the system, sensor data surrounding all significant health events (e.g., emergency department visits, hospitalizations, falls) were first viewed by the principal investigator (M.J.R.) and a research associate (S.J.M.) with experience in aging research followed by the clinical research team (four PhD-prepared nurses [G.L.A., L.P., M.A.A., M.J.R.], a family practice physician [R.J.K.], and the TigerPlace RN care coordinator [K.M.]). 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 sensor data approximately 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, 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 group) and 22 without (control group). One control group participant died immediately after baseline measurements. **Table 1** displays the demographics of the sample. Medical diagnoses that are typical for older adults, including diabetes, hypertension, cardiovascular disease, osteoarthritis, osteoporosis, Parkinson’s disease, and some cancers, were prevalent in both groups.

Intervention

Intervention participants had data-driven alerts sent to the TigerPlace RN care coordinator when

TABLE 1**DEMOGRAPHICS OF THE SAMPLE**

Variable	Control Group (<i>n</i> = 21)	Intervention Group (<i>n</i> = 20)	Total (<i>N</i> = 41)
Sex, <i>n</i> (%)			
Women	13 (62)	14 (70)	27 (66)
Men	8 (38)	6 (30)	14 (34)
Ethnicity, <i>n</i> (%)			
Caucasian	20 (95)	20 (100)	40 (98)
Asian	1 (5)	0 (0)	1 (2)
Mean age (<i>SD</i>), range	83.9 (6.96), 67 to 96	84.5 (7.90), 64 to 96	84.6 (7.38), 64 to 96

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 resident's health condition and intervene with early treatment. After receiving an alert, the nurse accessed a secure website displaying the user interface so the resident's activity pattern could be interpreted. Next, the nurse determined whether 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 following in the resident's electronic health record: the alert receipt, the assessment of the potential health problem, and the actions taken.

Control group participants 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, & Rantz, 2011) 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:

- The Short Physical Performance Battery (SPPB), which assesses lower extremity function using measures of standing balance, gait speed, and lower extremity strength (Guralnik et al., 1994).
- GAITRite analysis (a portable carpet with sensors), which measures temporal and spatial parameters of gait including cadence, step length, and velocity (Bilney, Morris, & Webster, 2003).
- A hydraulic hand dynamometer (Jamar Hand Dynamometer, Sammons Preston Rolyan, Bolingbrook, IL) measured grip strength of both the right and left hands of each participant. This measure has been commonly used for more than 40 years and is recognized as a measure of frailty, disability, and mortality (Ali et al., 2008; Ling et al., 2010).
- Health event outcomes of emergency department visits, hospitalizations, and falls captured from existing documentation systems. These were totaled quarterly for the study duration, but annual totals were used in the analyses due to the infrequent occurrences of these events.
- Other measures routinely completed at TigerPlace, including the activities of daily living (ADLs) scale from the Minimum Data Set, the independent activities of

daily living (IADLs) scale from the Centers for Medicare & Medicaid Services' Outcome and Assessment Information Set, the Geriatric Depression Scale (GDS, Sheikh & Yesavage, 1986), Mini-Mental State Examination (MMSE, Folstein, Folstein, & McHugh, 1975), SF-12 Health and Mental Health scales (Resnick & Nahm, 2001), and fall risk (Hollinger & Patterson, 1992). Measures were collected at baseline, before the pilot study began, and at the end of each quarter for 1 year. No significant differences in baseline scores on these measures were found between the intervention and control groups.

Data Analysis

The Wilcoxon rank-sum test 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 emergency department 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. On the basis of this feedback, the interface was revised in an iterative fashion by engineering collaborators while the 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, et al., 2011). Each month throughout the study, clinicians anonymously completed seven 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.

TABLE 2

RESULTS OF OUTCOME ANALYSIS

Outcome Measure	Scoring for Measure	Mean (SD) at Baseline and Quarter with Significant Results		Results
		Control Group (n = 21)	Intervention Group (n = 20)	
SPPB total score	0 to 12 ^a	Baseline: 6.86 (3.09) Q4: 6.24 (3.66)	Baseline: 5.40 (92.93) Q4: 4.26 (2.54)	ns
SPPB balance score	0 to 4 ^a	Baseline: 2.14 (1.28) Q4: 2.65 (1.27)	Baseline: 2.10 (1.29) Q4: 2.11 (1.48)	ns
SPPB gait speed score	0 to 4 ^a	Baseline: 2.96 (1.05) Q3: 2.60 (1.35)	Baseline: 2.25 (1.12) Q3: 2.41 (1.33)	Intervention group improved; control group worsened (<i>p</i> = 0.03 [*]).
Chair stand score	0 to 4 ^a	Baseline: 1.77 (1.45) Q4: 1.50 (1.50)	Baseline: 1.05 (1.32) Q4: 0.27 (0.83)	ns
Repeated chair stand	Seconds to complete ^b	Baseline: 15.37 (5.69) Q4: 15.79 (6.23)	Baseline: 15.93 (5.32) Q4: 21.43 (5.30)	Intervention group worsened; control group remained the same as at baseline (<i>p</i> = 0.08).
4-meter walk	Seconds to complete ^b	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: Intervention group improved somewhat; control group worsened (<i>p</i> = 0.08). Q3: Intervention group worsened; control group remained the same (<i>p</i> = 0.08).
Second 4-meter walk	Seconds to complete ^b	Baseline: 5.64 (2.91) Q1: 5.79 (3.88)	Baseline: 7.41 (3.84) Q1: 6.27 (4.13)	Intervention group improved; control group remained the same (<i>p</i> = 0.06).
Hand grip-left	Pressure ^a	Baseline: 19.84 (8.88) Q2: 15.27 (10.34)	Baseline: 16.55 (7.06) Q2: 16.00 (7.75)	Control group declined significantly; intervention group remained stable (<i>p</i> = 0.02 [*]).
Hand grip-right	Pressure ^a	Baseline: 21.71 (9.53) Q4: 17.02 (8.57)	Baseline: 17.38 (8.35) Q4: 15.20 (9.32)	Control group declined significantly more than intervention group (<i>p</i> = 0.05).
GAITRite Functional Ambulation Profile score	>90 = good score; highest score = 100	Baseline: 54.11 (35.74) Q2: 75.61 (15.76)	Baseline: 22.95 (32.03) Q2: 67.83 (17.39)	Intervention group improved significantly more than control group (<i>p</i> = 0.05 [*]).
GAITRite velocity	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

Note. SPPB = Short Physical Performance Battery; Q = Quarter; ns = not significant.

^a Higher score is better. ^b Faster time is better.

^{*} Denotes statistical significance.

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 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 from 26% to 71%. Ease of use is also important and improved from 50% to 85%; 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 participants. By the end

of the study, alerts were being generated at a rate of about three per month per participant.

Algorithms were adjusted to improve the effectiveness, accuracy, and clinical relevance of the alerts. Our goal was to reduce the number of alerts that clinicians judged as not clinically relevant (Alexander, Rantz, et al., 2011). For example, clinicians did not consider increases in daytime activity as particularly relevant, but time up at night was considered very relevant. In many cases, alerts that flagged increased frequency of time up at night resulted in early detection of urinary tract infections (Rantz et al., 2011) or, according to the results of the current study, other acute infections such as pneumonia, upper respiratory infections, heart failure, post-hospitalization pain, delirium, and hypoglycemia. During the 1-year study, a total of 219 health events precipitated 32 emergency department visits, 23 hospitalizations, and 164 falls. In the last 6 months, after algorithm refinement, the intervention group ($n = 20$) 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 e-mail 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 slow pulse in bed (100%), bed restlessness (75%), and recliner chair restlessness (63%). 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 approximately 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 SF-12, MMSE, GDS, ADLs, IADLs, fall risk, emergency department visits, hospitalizations, or falls. The GAITRite Functional Ambulation Profile (FAP), a summary score reflecting an overall measure of walking (Nelson et al., 1999), was a significant finding; for comparison with FAP, GAITRite velocity is also included in **Table 2**, although there was not a significant result.

Intervention group participants showed significant improvements for the SPPB gait speed score at Quarter 3 ($p = 0.03$), hand grip-left at Quarter 2 ($p = 0.02$), hand grip-right at Quarter 4 ($p = 0.05$), and the GAITRite FAP 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 $p = 0.06$, respectively); however, the intervention group trended worse in the 4-meter walk at Quarter 3 ($p = 0.08$), whereas the control group remained the same. The control group did not improve for walking measures, but an improved trend was observed for the repeated chair stand at Quarter 4 ($p = 0.08$). The statistically significant and trend results in walking measures and hand-grip for the sensor group as compared to the control group are not only clinically and functionally relevant, but also relevant for use as research measures for future studies.

DISCUSSION

The results of this prospective pilot study using early warning sensors are promising. Functional improvement was detected in both walking and hand grip in the intervention group compared with the control group. These two important functional abilities are critical for older adults 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, Wasserman, & Kaye, 2010; Wen-nie Huang, Perera, VanSwearingen, & Studenski, 2010) and mortality (Studenski et al., 2011). Grip strength is also recognized as a measure of frailty in older adults and is associated with mortality (Ling et al., 2010). This new technological approach to identifying illness onset earlier could lead to improved function and delay functional decline. The early illness sensor system with automated alerts enhanced clinicians' assessment skills; using this system, health conditions were detected 1 to 2 weeks before traditional assessment and observation methods. With earlier recognition, timely interventions are possible, and with those, clinical outcomes improve.

Importantly, clinicians' confidence in and the clinical relevance of the early illness detection system improved throughout the study; in addition, clinician time to analyze each alert reduced more than 50%. A critical outcome was that the Tiger-Place 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 clinicians catch problems early, avoiding more severe conditions requiring residents to be hospitalized and/or moved to a less independent setting. Typically, approximately 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 such cutting-edge research.

It is important to point out limitations. Participants 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 participants improve function, such as physical therapy, occupational therapy, or surgery, or the presence of other comorbidities. The residents at TigerPlace are predominately Caucasian, thus a lack of diversity affects generalization to broader populations of older adults.

FUTURE DIRECTIONS

Our research team is optimistic about future adoption of technological methods that we hope will be widely adopted in older adult housing, long-term care settings, and most important, in private homes where older adults wish 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 older adult housing to measure the clinical and cost effectiveness of using sensor data to detect early signs of illness or functional decline in older adults compared with usual health assessment.

CONCLUSION

Technological innovations such as the early illness detection system developed and researched by our team hold much promise for developing new solutions to the persistent problems of functional decline and loss of independence in older adults. In this two-group intervention study, we learned that interpretation of continuously collected data from nonwearable sensors as people go about their everyday living can detect changes in health status, days and even weeks before typical clinical assessment or personal complaints. With early detection of changes in health status, early interventions have potential to

maximize independence and minimize functional decline typically associated with acute illness or exacerbations of chronic illness.

REFERENCES

- Alexander, G.L., Rantz, M., Skubic, M., Koopman, R.J., Phillips, L.J., Guevara, R.D., & Miller, S.J. (2011). Evolution of an early illness warning system to monitor frail elders in independent living. *Journal of Healthcare Engineering, 2*, 337-363.
- Alexander, G.L., Wakefield, B.J., Rantz, M., Skubic, M., Aud, M.A., Erdelez, S., & Al Ghenaime, S. (2011). Passive sensor technology interface to assess elder activity in independent living. *Nursing Research, 60*, 318-325. doi:10.1097/NNR.0b013e318225f3e1
- Ali, N.A., O'Brien, J.M., Jr., Hoffman, S.P., Phillips, G., Garland, A., Findley, J.C.W.,... Marsh, C.B. (2008). Acquired weakness, handgrip strength, and mortality in critically ill patients. *American Journal of Respiratory and Critical Care Medicine, 178*, 261-268. doi:10.1164/rccm.200712-1829OC
- Bilney, B., Morris, M., & Webster, K. (2003). Concurrent related validity of the GAITrite walkway system for quantification of the spatial and temporal parameters of gait. *Gait & Posture, 17*, 68-74.
- Boockvar, K.S., & Lachs, M.S. (2003). Predictive value of nonspecific symptoms for acute illness in nursing home residents. *Journal of the American Geriatrics Society, 51*, 1111-1115. doi:10.1046/j.1532-5415.2003.51360.x
- Buracchio, T., Dodge, H.H., Howieson, D., Wasserman, D., & Kaye, J. (2010). The trajectory of gait speed preceding mild cognitive impairment. *Archives of Neurology, 67*, 980-986. doi:10.1001/archneuro.2010.159
- Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). "Mini-mental state." A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189-198.
- Galambos, C., Skubic, M., Wang, S., & Rantz, M. (2011). *The use of density mapping for early illness detection of dementia and depression in older adults*. Manuscript in review.
- Guevara, R.D.A. (2011). *Motion sensor network for early illness detection in the elderly* (Unpublished master's thesis). University of Missouri, Columbia.
- Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G.,... Wallace, R.B. (1994). 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, 49*, M85-M94.
- Hollinger, L.M., & Patterson, P.A. (1992). A falls prevention program for the acute care setting. In S.G. Funk, E.M. Tornquist, M.T. Champagne, & R.A. Wiese (Eds.), *Key aspects of elder care: Managing falls, incontinence, and cognitive impairment* (pp. 110-117). New York: Springer.
- Ling, C.H.Y., Taekema, D., de Craen, A.J.M., Guskeloo, J., Westendorp, R.G.J., & Maier, A.B. (2010). Handgrip strength and mortality in the oldest old population: The Leiden 85-plus study. *CMAJ, 182*, 429-435. doi:10.1503/cmaj.091278
- Nelson, A.J., Certo, L.J., Lembo, L.S., Lopez, D.A., Manfredonia, E.F., Vanichpong, S.K., & Zwick, D. (1999). The functional ambulation performance of elderly fallers and non-fallers walking at their preferred velocity. *NeuroRehabilitation, 13*, 141-146.
- Rantz, M.J., Skubic, M., Alexander, G., Aud, M.A., Wakefield, B.J., Galambos, C.,... Miller, S.J. (2010). Improving nurse care coordination with technology. *Computers, Informatics, Nursing, 28*, 325-332. doi:10.1097/NCN.0b013e3181f69838
- Rantz, M.J., Skubic, M., Alexander, G., Popescu, M., Aud, M.A., Wakefield, B.J.,... Miller, S.J. (2010). Developing a comprehensive electronic health record to enhance nursing care coordination, use of technology, and research. *Journal of Gerontological Nursing, 36*(1), 13-17. doi:10.3928/00989134-20091204-02
- Rantz, M.J., Skubic, M., Koopman, R.J., Phillips, L., Alexander, G.L., Miller, S.J., & Guevara, R.D. (2011, June). Using sensor networks to detect urinary tract infections in older adults. *13th IEEE International Conference on e-Health Networking Applications and Services*, pp. 142-149. doi:10.1109/HEALTH.2011.6026731
- Rantz, M.J., Skubic, M., & Miller, S.J. (2009, September). Using sensor technology to augment traditional healthcare. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 6159-6162. doi:10.1109/IEMBS.2009.5334587
- Resnick, B., & Nahm, E.S. (2001). Reliability and validity testing of the revised 12-item Short Form Health Survey in older adults. *Journal of Nursing Measurement, 9*, 151-161.
- Ridley, S. (2005). The recognition and early management of critical illness. *Annals of the Royal College of Surgeons of England, 87*, 315-322.
- Sheikh, J.I., & Yesavage, J.A. (1986). Geriatric Depression Scale (GDS): Recent evidence and development of a shorter version. In T.L. Brink (Ed.), *Clinical gerontology: A guide to assessment and intervention* (pp. 165-173). New York: Haworth Press.
- Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M.,... Guralnik, J. (2011). Gait speed and survival in older adults. *Journal of the American Medical Association, 305*, 50-58. doi:10.1001/jama.2010.1923
- Viccaro, L.J., Perera, S., & Studenski, S.A. (2011). Is timed up and go better than gait speed in predicting health, function, and falls in older adults? *Journal of the American Geriatrics Society, 59*, 887-892. doi:10.1111/j.1532-5415.2011.03336.x
- Wennie Huang, W.-N., Perera, S., VanSwearingen, J., & Studenski, S. (2010). Performance measures predict onset of activity of daily living difficulty in community-dwelling older adults. *Journal of the American Geriatrics Society, 58*, 844-852. doi:10.1111/j.1532-5415.2010.02820.x