Eldercare Technology for Clinical Practitioners

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Preface

Background: The majority of our increasing elder adult population requires some degree of formal and/or informal care because of loss of function as a result of failing health. According to the Centers for Disease Control (CDC), nearly three-quarters of elder adults suffer from one or more chronic diseases. Examples include arthritis, hypertension, and diabetes, to name a few. The cost and burden of caring for elder adults is steadily increasing.

Changes in the Medicare system led to a shift in the responsibility for care from institutions (nursing homes, etc.) to the community (individuals and families). The role of informal caregivers in providing care to the elder adult population has greatly increased in the past two decades. Consequently, informal caregivers have come to be viewed as an unpaid extension of professional caregivers, providing most of the care to elder adults requiring long-term care. In fact, national databases derived from different sources have provided unequivocal evidence that family and friends are the sole care providers for about three-quarters of all community-dwelling elder adults. Informal caregivers have experienced increased physical burdens and emotional strains because of this shift in long-term elder care responsibilities. Furthermore, healthcare providers are faced with a shrinking professional caregiving work force at the same time.

On the contrary, the proportion of the world's population of individuals over the age of 60 years is expected to double by 2030 to 20%. In the USA, the number of elder adults is expected to grow to 108 million over the next 15 years, which represents 45% of the adult population. Elder adults currently account for 60% of the overall healthcare spending in the USA. Appropriate management of chronic disease in older adults can reduce the US health care bill by up to 50%. Furthermore, 92% of these elder adults live alone in their own apartments, homes, independent living facilities, or assisted living facilities, including about 50% of those 75 years and older. Such statistics demonstrate an urgent need for innovative telehealth/telecare tools that enable elder adults to live independently and maximize caregivers' efficacy by providing timely health information and delivering more effective care. This change in the demographics and its potential economic impact on industrialized nations has prompted active research in automated systems for functional and health status monitoring and assistance, enabled by recent technological advancement.

In the meantime, advances in sensor, communication, and information technologies have created opportunities to develop novel tools enabling remote management and monitoring of chronic diseases, emergency conditions, and the delivery of health care. In-home health assessment and monitoring has the added benefit of measuring individualized health status and reporting it to the primary care provider and caregivers alike, allowing timelier and targeted preventive interventions. Health monitoring in home environments can be accomplished by a) ambulatory monitors that utilize wearable sensors and devices to record physiological signals; b) sensors embedded in the home environment and furnishings to unobtrusively collect behavioral and physiological data; or c) a combination of the two.

Aim and scope: This book addresses technologies targeted at the assessment, early detection, and the mitigation of common geriatric conditions including decline in functional abilities, gait, mobility, sleep disturbance, vision impairment, hearing loss, falls, and cognitive decline. This book not only describes the state of both embedded and wearable technologies, including technologies under research and on the brink of translation into products, but also focuses on research showing the potential utility of these technologies in the field.

Chapter 1 presents an introduction and reviews the statistics that make a compelling case for development and utilization of technologies for the geriatric care. Chapter 2 presents a comprehensive review of functional assessment instruments and promising technologies used in functional assessment of elders. Chapter 3 covers mobility and gait assessment technologies, whereas Chapter 4 reviews mobility aid technologies for the elderly. In Chapter 5, we review sleep disorders in older age and sleep assessment technologies, with emphasis on in-home assessment technologies. Chapter 6 presents a comprehensive review of age-related changes in vision and corrective technologies, whereas Chapter 7 addresses the management of hearing loss in older age. Chapter 8 is dedicated to falls, fall detection, and fall prevention technologies. Finally, Chapter 9 addresses emerging computer-based cognitive assessment technologies.

We believe, and hope, that this work will fill a gap in the knowledge and will be invaluable to Eldercare practitioners, as well as medical student studying Geriatrics and interested in gerotechnology, social studies, students studying gerontology and interested in gerontechnology, and nursing students interested in Geriatric Nursing, in addition to engineering students interested in Eldercare Technologies, and researchers from a broad spectrum of disciplines, particularly those interested in field experience and the end-user's perspective. This volume comes at a time when interest in Eldercare Technology and the need for effective and appropriate technologies especially are peaking.

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Chapter 2
Functional Assessment Technologies

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2.1 Importance of Functional Assessment for Older Adults

Functional well-being is a significant factor in the overall health of older people. The World Health Organization advisory group stated almost 40 years ago that the health of older adults was best measured in terms of function [1]. Generally speaking, function as an overall term can be divided into three categories: physical, psychological, and social function [2]. The three components interact closely and contribute to the overall construct of well-being. A comprehensive geriatric functional assessment is usually composed of these components. For example, Nelson and associates interchangeably used terms of function, functional health, and functional status as they conducted a complete functional assessment using separate measures of components, such as physical function, emotional status, role and social function, pain and social support [3].

The purpose of the comprehensive functional assessment among the elderly is to bridge the gap between people's actual abilities and the available resources [4]. A regular functional assessment can help clinicians easily identify older people's changes over time so that effective strategies can be implemented in a timely manner to prevent or reduce severe negative outcomes. Physical function is the key factor of functional assessment, and it is sometimes synonymous with functional status or functioning in current literature. The goal of this section is to examine the meaning of physical function as it relates to the overall functional assessment and to explore the significance of physical function to comprehensive geriatric functional assessment.

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2.1.1 Physical Function

Physical function is a commonly used term among researchers; however, there are few authors who have provided a clear definition of physical function. One example by Brach and VanSwearingen [5] states that physical function is associated with the ability to perform activities of daily living (ADLs), instrumental activities of daily living (IADLs), and mobility tasks, which are important for independent living without substantial risks of injury. McConnell and colleagues [6] referred to physical function as the degree of dependency in basic ADLs and discussed its importance on elders' quality of life. Similarly, Fitzpatrick et al. [7] regarded physical function as the physical ability to engage in daily activities related to personal care, socially defined roles, and recreational activities. These daily activities could be further classified into ADLs (basic self-care activities that include dressing, bathing, personal hygiene, toileting, walking, eating, etc.), IADLs (activities and skills needed to live independently in the community such as shopping, cooking, housekeeping, and handling finances), basic physical movements, and complex actions [8]. In contrast, Whetstone et al. [9] explained physical function as the dynamic changing status of dependency, difficulty, and preclinical changes across a wide range of activities.

Although most researchers did not specifically define the concept of physical function, their understandings of the term are demonstrated by their choices of measurement instruments. For example, Shimada et al. [10] examined physical function by evaluating subjects' balance, gait, and reaction time. Balance was evaluated by one-leg standing time and the Functional Reach Test (FRT); gait performance was measured by walking speed over a 10-m distance and the equipment of Whole Body Reaction Type-II was utilized to assess reaction time to an auditory stimulus (100 Hz). On the contrary, Furner and associates [11] used participants' self-report of performance on ADLs and IADLs to evaluate physical function. Some researchers choose to combine subjective and objective assessments to provide a comprehensive description of the status of physical function. For instance, subjective questionnaires, such as the physical functioning questionnaire (PFQ) and performance-based tests, which include a 6-min walk test, were used simultaneously to evaluate the status of physical function among a group of cardiac older people [12].

It seems that these authors have different understandings of physical function; however, they are concerned about the same construct. Most authors interpret physical function as people's actual physical performance abilities in simple movements, such as walking and standing, or their self-rated abilities on ADLs and IADLs. Additionally, most agree that the status of physical function at a certain time point in aging process could be affected by some physiological and pathological conditions. Therefore, it seems reasonable to conclude that physical function represents a person's current abilities to participate in daily activities relating to different social roles. Specifically, an older adult's actual performance and self reports in some basic daily life activities, ADLs and IADLs, can reflect the status of physical function.

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2.1.2 Significance of Physical Function for Older Adults

An appropriate level of physical function plays a significant role in active and independent living for the elderly, and regular assessments will make early detection and timely intervention possible to maintain reasonable or delay the deterioration of physical function. In the trajectory of aging, a person's quality of life is judged more often by the ability to maintain independence and physical function, than by any medical diagnosis [13]. However, lower level of physical function is also associated with significant negative health outcomes, such as hospitalization, nursing home admission, falls, and dependency [14]. Therefore, the assessment of physical function is not only a key component of functional assessment but an important part of comprehensive geriatric evaluation.

Physical function is closely associated with the other two components of functional assessments, social and psychological function, and some gerontological studies have confirmed such relationships. For example, Cronin-Stubbs and colleagues [15] conducted a population-based longitudinal study during a 6-year period in 3434 community-dwelling older people and found that mild depressive symptoms were associated with an increased risk of becoming physically disabled. Similarly, data from the MacArthur Studies of Successful Aging identified depression as a risk factor for physical disability, which was assessed by ADLs Scale. Results also suggested that depression and physical disability could initiate a spiraling decline in both physical and psychological function [16]. Consequently, clinicians should keep in mind that, while addressing the significance of physical function in gerontological care, social and psychological functions and their interactions should not be overlooked. Additionally, the contribution of pain to physical function and depression cannot be overlooked. Often, pain management is the key to improving physical function in older adults.

Some important clinical implications for elder care could be drawn. First, the assessments of physical function should be comprehensive and individualized. Clinicians should not only be familiar with the knowledge about physical function, but also accurately evaluate an older person's level of physical function on a regular basis. Secondly, because there are close interactions among physical, social, and psychological functions, progressive elder care programs should address physical activity involvement, social and intellectual engagement, and pain management among the elderly.

2.1.3 Common Health Conditions that Affect Functional Abilities

Because physical function significantly impacts the abilities of older adults to maintain independence, developing and implementing strategies to prevent or delay the onset of physical disability is a major priority for clinicians. Identifying contributing risk factors to the deterioration of functional abilities is an important step. This section will explore risk factors for declines of physical function and their close interactions with functional abilities.

The decline in functional abilities is not just dependent on chronological age, but is closely associated with other biological, psychological, and social risk factors [17]. For example, Stuck and associates [18] conducted a meta-analysis of 78 longitudinal studies exploring the risk factors for physical function decline in community-living older adults. Some conditions, such as cognitive impairment, depression, disease burden, poor self-rated health, low level of physical activity, and functional limitation, were identified as contributors with highest strength of evidence. The following sections describe key risk factors relating to health conditions and recent research findings in each area are discussed.

2.1.4 Cognitive Impairment

Cognitive function is an important factor for physical function or the abilities to maintain independence among older adults. Previous gerontological studies have confirmed the association between cognitive impairment and physical function. Greiner and associates [19] investigated the relationship of cognitive function to loss of physical function among a group of elderly Catholic nuns. Results showed that participants with low normal cognitive scores on Mini-Mental State Examination (MMSE) at baseline had twice the risk of losing independence in ADLs at follow-up compared with those with high normal scores. This close relationship between cognitive impairments and functional decline is also identified in other populations, such as non-disabled, community-living older adults and elderly Mexican Americans [20, 21].

Besides MMSE, which is an often used cognitive function instrument in aging studies, Moritz et al. [22] found consistent results utilizing another cognitive assessment tool, Pfeiffer's short portable mental status questionnaire (SPMSQ). This longitudinal study revealed persistent and incidental ADL limitations occurred more frequently in older persons with four or more errors on SPMSQ. The result not only confirmed the relationship between cognitive function and physical abilities in ADLs, but also suggested cognitive impairment might be a significant predictor of the onset of new ADL limitations. Conclusions could be made from these studies that cognitive impairment is an important contributor for declines in physical function and predicts the onset of ADL limitations, using a variety of assessment measures.

Accordingly, some implications can be drawn for geriatric clinicians. They should not only be familiar with cognitive impairment, which acts as a significant risk factor for functional decline, but also be aware of the knowledge that some cognitive functional tests can be used to forecast services needed and to plan interventions to delay the onset of ADL limitations or plan strategies to best deal with the limitations [22].

2.1.5 Depression

Although the prevalence of major depression is relatively small (2%) among older community-living persons, a high percentage (12–15%) of elderly community-dwellers suffer from minor depression or significant clinical depressive symptoms [23]. As a crucial contributor to older persons' well-being and functional status, the detrimental effects of depression on physical function have been investigated in numerous aging studies [24–26].

Penninx and associates [26] conducted a 4-year prospective cohort study exploring the impact of depressive symptoms on changes of physical performance among 1286 older community dwellers. After controlling for other conditions (such as baseline performance score, health status, and socio-demographic factors), they found that high levels of depressive symptoms [assessed by the Center for Epidemiologic Studies Depression Scale (CES-D)], could highly predict decline in physical function. These findings were consistent with research done by Everson-Rose et al. [25] substantiating a strong cross-sectional association between depressive symptoms and overall physical performance. Callahan and colleagues [27] also confirmed previous research findings that older persons with depression (evaluated by CES-D) reported greater functional impairment than those without depressive symptoms. Furthermore, a multi-site randomized clinical trial [24] revealed that effective treatment of depressive symptoms by a collaborative program improves physical function more than usual care.

The close relationship between depression and physical function can shed light on future clinical practice. Attention should be paid to the detrimental effects of depression on declines of physical function. Collaborative eldercare programs should be developed to address depression and interrupt the downward spiral of the deterioration of depression and physical performance.

2.1.6 Lack of Physical Activity

Lack of physical activity is also independently related with a higher risk for declines of physical function [18]. Studies have confirmed relationships between physical activity and functional impairment. For example, Seeman and colleagues [28] found a significant and independent association between better physical function and participation in moderate and/or strenuous exercise activity.

Abundant studies have examined the effects of exercise programs in helping improve physical function and maintain independence. Taylor-Piliae and associates [17] detected that Tai Chi exercise could significantly improve balance, upper and lower body muscular strength, endurance, and flexibility. Similarly, from a randomized and placebo-controlled trial, even among nursing home frail residents, a progressive resistance training was found to impressively increase muscle mass and improve functional performance in gait speed and stair-climbing abilities [29]. Frontera and associates [30] also demonstrated that regular resistance training could significantly promote the strength of extensor and flexor muscles in older participants. It is clear that physiological parameters, such as balance, gait performance, muscular strength, endurance, and flexibility are prerequisites to keep an appropriate level of physical function [31]. Increasing physical activity through exercise programs, such as Tai Chi and resistance training, can significantly improve physical function.

Another view of improving physical function is to *increase non-exercise physical activity* (NEPA). NEPA involves all forms of physical activity other than exercise. Most of a person's NEPA is associated with ambulation for practical purposes or movements not intended for health, including many forms of "puttering." Examples of NEPA that may be critical for preserving health and vitality include the thousands of light movements people associate with an independent and vibrant lifestyle, such as vacuuming, dusting, walking across the room to manually change the television channel, or adjust the blinds. Total energy expenditure is low in aging adults primarily because of less activity or NEPA, not a lower basal metabolic rate [32,33], and more time spent in sedentary activities involving sitting [34]. People over the age of 65 years take almost one-half as many steps per day as younger people. Remarkably, 20% of those aged above 65 years take less than 1000 steps per day, whereas only approximately 1% of middle-aged people less than 65 years take this few steps [35]. Taken together, these and other studies of aging adults with preclinical disability [36] have led to the belief that there is a vicious cycle linking inactivity with metabolic disorders and loss of mobility.

An emerging paradigm of great interest to the exercise physiology research community relates to how simply sitting instead of NEPA leads to increased risk for chronic diseases; the term coined for this new paradigm has been called "inactivity physiology" [37]. Simply put, the time spent standing in any weight-bearing activity (even NEPA) portends to be a determinant of multiple functional and disease endpoints relevant to successful aging. Low levels of high-density lipoprotein (HDL) cholesterol are associated with functional disability in the elderly [38]. In addition, bone health is related with the time one sits or stands [39–41].

Epidemiological correlations have associated daily sitting time with metabolic syndrome (low HDL cholesterol, high plasma triglycerides, hypertension, body fat, and insulin resistance or glucose intolerance [42–44]). For each hour less of daily television watching, there was a 12–26% reduction in the incidence of the metabolic syndrome [43]. The ill effect of sitting was independent of whether the person was engaged in traditional exercise [43, 45]. There are mechanistic explanations and interventional studies in animals for those associations. Components of the metabolic syndrome, diabetes, and cardiovascular disease have each been linked in large part to an enzyme called lipoprotein lipase (LPL). The inactivity found during aging is associated with significantly lower levels of LPL [46, 47]. The function of LPL is strongly suppressed to only 5% of normal levels after reduced standing and is preventable by increased standing and NEPA [48, 49]. NEPA measurements and interventions in the elderly or functionally impaired could thus be especially important to improve physical function.

2.1.7 Other Factors Affecting Functional Abilities

Some other factors, such as co-morbidities, few social contacts, poor self-perceived health, smoking, and vision impairment, have also been identified in current literature as strongly related to physical function decline [18]. Higher body weight has been recognized as an important risk factor for lower every day physical functioning [50]. Other researchers have also revealed that factors such as positive motivation and appropriate social roles can positively influence physical function in performance-based tests [51].

2.1.8 Summary, Functional Abilities

As an indispensable component of independent living while aging, physical function is and has always been the integral focus of clinical geriatric care. Some common health conditions, such as cognitive impairment, depression, and a lack of physical activity, which significantly contribute to the decline of physical function, have been reviewed. These significant contributing factors for declines of physical function should be identified regularly to prevent or delay severe deterioration and should be sufficiently addressed in comprehensive care programs.

Understanding the significance of physical function and risk factors for functional decline can help those interested in technology as a way to help older adults maintain or regain function. Technology should enhance the on-going assessment of physical function that is a major focus of clinicians. It is our belief that technology holds the capacity to enhance clinical effectiveness by early detection of changes in function, alerting clinicians and providing functional assessment information about functional performance of older adults in their care.

2.2 Common Measures of Functional Assessment

Physical function is the basis of overall well-being among the elders, and its accurate and sensitive measurement is a vital component in gerontological care. A variety of reliable and valid physical function instruments exist in current literature. There are three main kinds of instruments: self-report and proxy report, performance-based tests, and objective laboratory tests. This section will explore each category individually. Representative measures of each group will be discussed, and their characteristics will be examined and compared. Finally, the appropriate use of these instruments will be discussed.

2.2.1 Self-Report and Proxy Report

Self-report and proxy report assessments focus on self or proxy perception of physical function [14]. They are both relatively easy to administer and usually require little instruction for participants. Because self-report assessments are completed by subjects themselves, information about the overall perception of the individual regarding their health status and ability to perform certain activities are available [14]. In contrast, proxy reports are executed by family members or health professionals based on their observation of subjects' performance on certain tasks.

Measures that determine subjects' difficulty in performing ADLs and IADLs are often employed in various studies to monitor the changes in physical function. For example, there are direct ADLs and IADLs indices [52], as well as measures such as the functional status questionnaire (FSQ) that include specific sections addressing these aspects of physical function [53]. Similarly, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), a disease-specific measure, includes questions that focus on the subject's ability to perform ADLs and IADLs [54–56].

Assessment of pain and pain management strategies are often overlooked in self report and proxy report of physical function. Self report of pain and pain management strategies can be readily completed in simple perception-rating scales such as those recommended in research-based clinical practice guidelines [57]. As physical function is assessed, pain and pain management strategies should also be solicited.

2.2.2 *Performance-Based Tests*

Performance-based tests of physical function are ones in which subjects are asked to actually perform some specific tasks or activities and are evaluated using standardized criteria [13]. These tests are much more objective and psychometrically sound than self-reports and can offer more sensitive and accurate information.

Instead of measuring the whole construct of physical function, most performance tests are divided into subcategories and evaluate individual components of physical function, such as balance, gait, flexibility, and endurance [14]. Accordingly, the status of physical function can be drawn from overall performance on all or some of these subcategories. For example, Toraman and Sahin [58] used a Functional Fitness Battery to assess physical function. Components of this battery include lower and upper body strength, body flexibility, aerobic endurance, agility, and dynamic balance. Aerobic endurance and lower body strength are measured by simple activities, such as 6-min walk and chair-stand [58]. Similarly, Kenny et al. [59] used the short physical performance battery test (SPPB) to examine the efficacy of vitamin D supplementation among elders. Physical function in this battery is assessed from subjects' performance on rising from a chair, static balance, a 6-foot walk, the time up-and-go test, and the timed supine-to-stand test. Rekeneire and associates [60] also utilized a series of performance-based tests to study physical function. In this study, the timed repeated chair stand was used to assess lower extremity strength and 400 m as well as 2-min walk were used to measure endurance. Subjects' status of physical function was reflected from performance on these tests.

Table 2.1 Selected Instruments Comparisons

Instrument name	Author, Citation	Concepts measured	Scoring	Procedures, administration time	Limitation	Strength
Timed up and go test (TUG) (61)	Podsiadlo, D., Richardson, S. (1991). The timed "Up & Go": A test of basic functional mobility for frail elderly person. *Journal of the American Geriatrics Society* 39:142–8.	Physical mobility.	Time the whole performance. <20 sec: independently mobile of basic transfers; [20, 30]: varies in physical function and further assessment is needed; >30 sec: dependence on help for basic transfers and risk of falls.	Individuals stand up from a standard arm chair (approximate height of 46 cm), walk 3 m, turn, walk back to the chair and sit down again. 10 minutes.	It could not measure changes of functional mobility in either the freely mobile or the very dependent populations, although it could identify them.	It is easy and quick to administer and requires little training or equipment. An objective, reliable, and valid test for quantifying functional mobility.
Physical performance test (PPT) [62].	Reuben, D.B., Siu, A.L. (1990). An objective measure of physical function of elderly outpatients: the physical performance test. *Journal of the American Geriatrics Society* 38:1105–12.	Upper fine and coarse motor function, balance, mobility, coordination, and endurance.	Time individual tasks. The maximum score is 36 for the nine-item test and 28 for the seven-item test.	Nine-item scale: write a sentence, simulate eating, turn 360 degrees, put on and remove a jacket, lift a book, and put it on a shelf, pick up a penny from the floor, a 50-foot walk test and climb stairs. Seven-item scale: not include the stairs. 10 min.	Cannot differentiate from unmotivated from incapable persons and tasks included may not be complete measures of functional status.	Valid, reliable, and easy to administer.

(continued)

Table 2.1 (continued)

Instrument name	Author, Citation	Concepts measured	Scoring	Procedures, administration time	Limitation	Strength
Tinetti assessment tool (63)	Tinetti, M.E. (1986). Performance-oriented assessment of mobility problems in elderly patients. *Journal of the American Geriatrics Society* 34:119–26.	Balance and gait.	Maximum total score is 28. <19: a high risk for falls; [19, 24]: a risk for falls.	It is a task performance test. Participants are asked to perform specific maneuvers about balance and gait. 10–15 minutes.	The observations are crude and more variability among individuals could not be found.	A simple and practical performance test. Reliable and sensitive to significant changes used in normal daily living.
Berg balance scale (64)	Berg, K., Wood-Dauphinee, S., Williams, J.I., Gayton, D. (1989). Measuring balance in the elderly: Preliminary development of an instrument. *Physiotherapy Canada* 41(6):304–11.	Balance.	Maximum score is 56. <20: wheelchair bound; [21, 40]: walking with assistance; [41, 56]: independent.	14 performance-based measures. 10–15 min.	The observations are crude and small changes could hardly be detected.	Objective, valid, and reliable balance measure. Easy to administer and safe for older people.

Four widely used performance-based assessments are summarized in Table 2.1: Timed up and go (TUG) test [61], physical performance test (PPT) [62], Tinetti assessment tool [63], and Berg balance scale [64]. Specific information, such as subscales, scoring criteria, strength, and limitation concerning each instrument are identified and compared.

2.2.3 Laboratory Testing

Physical function and physical fitness are often used interchangeably; therefore, physical function can also be measured in objective laboratory tests that focus on physical fitness. For example, Rejeski et al. [12] combined an objective laboratory test of metabolic equivalent (MET) level with self-report questionnaire and a 6-min walk test to assess physical function in the elderly. Because physical fitness laboratory tests usually require expensive equipment and specially trained technicians, they are not practical for routine physical function assessments.

2.2.4 Summary, Common Measures of Functional Assessment

Appropriate measurement of physical function in the elderly requires multifaceted measurement that addresses the specific attributes of this population especially the close association of physical function with health status [14]. Three main kinds of measurements, self and proxy reports, performance-based tests, and laboratory tests are discussed. In addition, the four most widely used measurement tools are compared. Geriatric clinicians and researchers are encouraged to use a multifaceted approach to measure physical function by combining subjective measures, such as self or proxy reports and objective instruments, such as performance-based tests.

2.3 Overview of Home-Based Eldercare Technologies to Promote and Assess Function

Recent advances in sensor and information technologies have made an important contribution to the care of elderly people. A wide variety of technologies and devices have been developed to promote and support their independent and safe living. In general, these technologies can be classified into two basic categories: assistive devices and monitoring and response systems. These technologies and devices are often coupled together into a smart home environment so as to provide an integrated support for independent living of elderly people.

2.3.1 Assistive Devices

Functional decline in mobility makes it hard for older adults to operate many small appliances at home. At the Georgia Institute of Technology, computer vision researchers have prototyped the Gesture Pendant as a wearable device to control a variety of home appliances through simple hand gestures [65]. A recent study shows that computerized devices are able to help a person with severe dementia complete some ADLs, such as hand washing or using recorded voices for cueing [66]. For people with severe memory impairment, the technologies developed at the University of Michigan are able to remind an older person about his or her ADLs [67]. Medication compliance devices have also been developed to remind an older adult to take medication at the right time and in the right dose [68].

2.3.2 Monitoring and Response System

Individuals with mobility, cognitive, and sensory impairments may not be able to recognize and avoid unsafe conditions, or ask for help during a crisis situation; monitoring systems with sensors can help satisfy this need. Floor vibration monitors have been developed at the University of Virginia to detect possible falls of older adults [69]. Technologies are available to monitor ADL tasks in the home using a variety of sensing technologies. Sensors and switches attached to various objects, or optical and audio sensors embedded in the environment, are used to detect which task a person is performing [70,71]. The University of Virginia In-Home Monitoring System that uses a combination of wireless motion sensors to detect movement in areas of a person's living space can differentiate such ADL activities as showering or meal preparation. Inference of the ADL activities is done in a rule-based approach and has been validated in a community home with a healthy volunteer subject keeping detailed PDA-based time-stamped field notes [72, 73]. These same researchers have also developed a bed sensor for monitoring qualitative pulse and respiration, as well as sleep restlessness [74], which can provide basic indicators of health.

TigerPlace is an innovative independent living environment of 33 apartments built and operated by Americare of Sikeston, MO, USA, in affiliation with the University of Missouri (MU) Sinclair School of Nursing as a special facility where residents can truly age in place and never fear being moved to a traditional nursing home unless they choose to do so. With care provided by Sinclair Home Care and the TigerCare wellness center with registered nurse care coordination services, residents receive preventative and early illness recognition assistance that have markedly improved their lives. Links with MU students, faculty, and nearly every school or college on campus enrich the lives of the students and residents of TigerPlace. Research projects are encouraged and residents who choose to participate are enjoying helping with developing cutting technology to help other seniors' age in place. The Aging in Place Project at MU required legislation in 1999 and 2001 to be fully realized. Sinclair Home Care is an innovative home health agency initiated by the Sinclair School of Nursing specifically *to help older adults age in place in the environment of their choice.*

The residents of TigerPlace have embraced technology research to help them and others in the future age in place. Many of them are participating in on-going research with developing sensor technology to measure and interpret ADLs, detect falls, and early detection of illness or changes in chronic health conditions. As researchers with funding from the National Science Foundation and Administration on Aging, we are grateful to their willingness to help us as we pioneer this important area of elder care and the development of technology to help them improve and maintain function as they age in place in their homes.

At TigerPlace we have installed the University of Virginia monitoring system with bed, motion, and stove sensors wirelessly connected to a computer that sends the event information to a server. Counting the events provides useful information that indicates resident movement or absence of movement. In a sense, this provides continuous functional assessment because the resident's actions trigger events that are collected by the sensor and counted. The events are organized into a display of counts of the various sensors over a short period of time; typically the most convenient is an hour or several hours. Moreover, sensor firings could be grouped and activities could be inferred. The bed sensor activity counts per day are shown in Fig. 2.1; using daily graphs can reveal trends over time that may indicate changes in resident physical condition. From the bed sensor, greater activity may be due to a variety of factors including incorrect medicine dosage and impending change in health. By examining the data, a picture emerges of activities of the individual. By relating the histogram data for the resident to resident's comments about those events potential causes of events can be interpreted.

In the display of bed restlessness data in Fig. 2.1, a dramatic change in resident condition can be seen. This particular resident had a heart attack around December 20. For several days following the event, the resident was in the hospital and no events appeared. After returning, significantly higher restlessness levels indicate health-related problems. In later graphs in February, after the problems were addressed, the subject's restlessness levels returned to low levels similar to the graphs before the heart attack.

Clearly, this technology is potentially useful to health care providers. First, it provides additional information to health care providers by displaying a quick indication of the resident's well being, and possible deviations from their individual norm. It can provide loved ones access to activity information of their important elder family member (if the elder agrees) using relatively well-established communication systems such as web access. The data provide a longitudinal record of activity that can be examined for changes.

By relating the changes in sensor data to specific events of resident activity, a health care provider can obtain a picture of specific functional decline. Once identified, functional decline may be minimized or halted by appropriate interventions such as physical therapy, changes in medications, or others. Early detection and intervention by health care providers can extend the level of function of a resident and possibly even improve it. Modeling individual elder's activities with advanced computational intelligence techniques can enable interpretation of the baseline activity of individuals and alert health care providers of potential changes from baseline. Significant deviations from an individual's norm may indicate changes that require action.

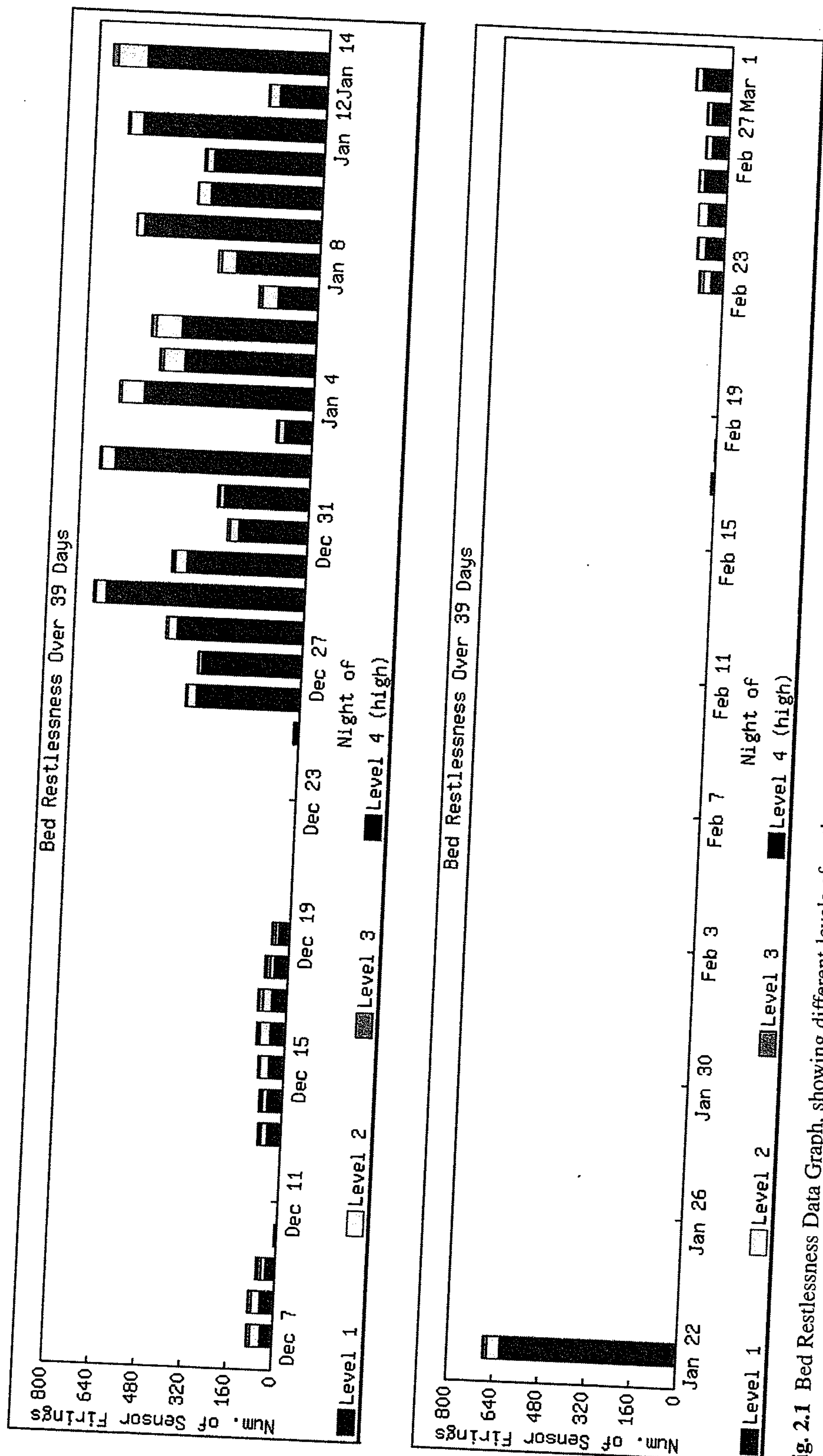

Fig. 2.1 Bed Restlessness Data Graph, showing different levels of restlessness from level 1 (least restless) to level 4 (most restless)

2.3.3 Smart Home Technologies

A smart home is a home that is able to proactively change its environment to provide services that promote an independent lifestyle for elderly users. Honeywell's Independent Lifestyle Assistant (ILSA) program is targeted at developing an intelligent home automation system to enable elders to live and function safely at home [75, 76]. The Living laboratory at MIT uses a portable kit of tape-on sensors and small switches to detect the movement of objects. They also studied how people respond to new proactive technologies [77]. In the Aware Home project at the Georgia Institute of Technology, a house with two identical independent living spaces is built for controlled experiments with technologies [78]. In France, a smart home called PROSAFE has been designed. Devices and sensors identify abnormal behavior that can be interpreted as an accident and collect representative data on a person's nocturnal and daily activity. The experimental room has been designed to accommodate patients with Alzheimer's disease. It is equipped with a set of infrared motion sensors connected to either a wireless or a wired network.

Realizing that visual information is very important in activity monitoring and analysis, researchers have developed various video camera systems and vision-processing algorithms for eldercare. In the Aware Home project at Georgia Institute of Technology, video cameras are used in a research laboratory to capture images of resident's daily activities, and a user-friendly interface, called Digital Family Portrait, is developed to efficiently visualize the activity data and resident's health status [78, 79]. In the CareMedia project at Carnegie Mellon University, a video camera system is developed to monitor patients' activity in nursing homes. Coupled with other types of sensor information and medical data, the video information is used to study the behavioral patterns of patients [80].

The University of Virginia In-Home Monitoring System has been installed in another assisted living setting ($n = 15$) and in another independent living setting ($n = 25$) (other than TigerPlace). In both settings, evaluations of Satisfaction with Life were obtained from the participating residents and modified Caregiver Strain Indexes as well as Caregiver Burden Interviews were obtained from the professional and informal caregivers [73, 81–83]. The only significant changes were that Satisfaction with Life improved in assisted living residents, and there was a statistically significant increase in informal care-giving but no increase in burden or strain. These same monitoring systems were installed in the homes of 13 home care clients [84] with similar results; clients had better perceived quality of life and informal caregivers had a perceived reduction in strain. From these preliminary results, it appears that using technology to monitor activity may have positive effects for elders in all three settings as well as some benefit for informal care givers. Cost-benefit in a sample of 21 assisted living residents has also been examined over a 3-month period as compared with a matched group by these same researchers with a significant reduction in health care costs such as hospital days, emergency room visits, and other primary care costs [85].

2.4 End User Interface Design for Functional Assessment Systems

Home-based functional assessment systems need to enable the processing and efficient display of information resulting from the sensor components. One of the challenges with the capturing of functional assessment, activity levels, and sleep patterns through sensor or other systems is the presentation of information to health care providers in a timely manner and with a display that does not burden providers with complex or redundant information but at the same time highlights situations that require attention or emergencies.

It is a widely accepted notion that user participation in the design and development of information systems increases the likelihood of successful implementation and utilization of these systems [86, 87]. Involvement of end users in system design is likely to result in increased user satisfaction [88], and an increase in the perception of usefulness of the application by the end user [89, 90]. Lack of communication and collaboration, on the contrary, between end users and designers is often linked to failure of information technology (IT) implementations [91].

In many cases, system failure is attributed to exclusion of end users from the system and interface design of monitoring systems. Organizations or agencies face the challenge to select the appropriate timing and extent of end user involvement in various phases of system development given, in many cases, limited resources and time constraints. Thus, understanding the nature of user participation and its implications on the utilization and ultimately the success of a system provides a useful roadmap for the implementation of both small- and large-scale applications.

2.4.1 Clinicians as End Users

In the TigerPlace project, nurses are one of the main user groups of the monitoring system. Additional user groups include residents, family members, and informal caregivers. To determine nurses' preferences and expectations of user interfaces that will enable the processing and efficient display of information resulting from the smart home components, we conducted focus group sessions with four gerontology nurses and one social worker [92]. The session was facilitated by a member of the TigerPlace research team. The focus group protocol included questions about participants' preferences in accessing patient-related data, their critique of suggested interfaces, and additional questions about types of display and alerts that will be useful in monitoring and caring for senior residents.

Specific examples of interfaces were displayed and comments were solicited in terms of advantages and disadvantages. Three of these examples were discussed in greater detail as they were perceived as essential to the display of activity levels and sleep patterns. Hard copies and large displays of the examples of user interfaces were provided to allow participants a careful examination before the discussion. The focus group facilitator followed a protocol of questions and took notes. Descriptive cues, examples, and explanations were provided, when necessary. Data codes were generated by using the data collected. The goal of the qualitative content analysis was a summary of the information gleaned from the analyses of data.

The clinicians who participated stated that non-emergency data sets should be available on a secure website allowing for providers to access them at their own discretion. Emergency alerts triggered by the system indicating a situation that requires immediate attention should be sent in *multiple formats*, such as email messages, pager messages, phone calls etc. The discussion whether this information should become part of the patient's medical record did not reach consensus. Some clinicians stated that that should be the case, whereas others expressed the concern that smart home technologies should move beyond the experimental phase before the datasets they produce become part of a legal document. Most participants stated that the interface should allow users to enter interpretations and other notes and provide a platform for communication with other health care providers.

Visual summaries and *overall trends* were perceived as very useful in managing large data sets. Participants showed preference for *interactive visual displays* that would allow zoom-in and zoom-out features, and ability to click for more information or enter comments. Furthermore, all participants agreed that they would like the interface to provide a "*print-version*" of the datasets so that they can easily create a hard copy for further review or archiving purposes. This study also highlighted the emphasis that clinicians place as end users on *internal* and *external consistency* of the interfaces and *interoperability* of this application with other applications and, specifically, the electronic medical record software (regardless of whether these datasets end up becoming part of the record system). All participants pointed out the need for consistency in choice of colors and symbols.

2.4.2 Interfaces between IT Systems

In a recent qualitative study using key informant interviews and focus group methods, 12 long-term care health care providers, administrators, and IT developers explored the use of advanced electronic technologies as it affects patient care, clinical support, and administrative activities [93]. The most important thread of information about IT sophistication emerging from these discussions regarded the need for more advanced interface development for IT systems to enhance system integration and connectivity. There was a recognized need for development of interfaces that support communication between different IT systems in order to build common data repositories and data warehouses. Interface operability was recognized as a vitally important issue.

Interfaces are important because they allow for the exchange of vital clinical information and contribute to the formation of relational databases that can combine distinct datasets into powerful reporting tools. Interfaces reduce the duplicative work required to keep separate IT systems current and facilitate a safer environment through more consistent data entry, faster retrieval of information, and improved reliability of data sources.

An important aspect of IT sophistication that is related to interface development is the usability of IT systems. Functional sophistication and integration of clinical decision support can be positively or negatively affected by the users' perceptions, accuracy of information input into the system, and the specificity of information guiding users' decisions. Increased levels of IT support and training personnel can improve usability, contribute to the design of sophisticated systems, keep the technology up and running smoothly, and are important for maintaining connections with users of IT. For clinical end users, integration of data with other clinical data sources is essential for rapid decision support that will ultimately improve quality of care for older adults.

2.4.3 Patients and Family Members as End Users

As stated earlier, end users include not only the clinicians and health care providers but also the actual residents or patients and their family members. A large portion of patients requiring functional assessment services are elderly and in some cases have functional limitations because of aging and/or their diagnosis. The Telecommunications Industry Association [94] describes a functional limitation as a "... reduced sensory, cognitive or motor capability associated with human aging, temporary injury, or permanent disability that prevents a person from communicating, working, playing or simply functioning in an environment where other people in the population can function." Although many argue that the Internet and advanced telecommunication technologies have the potential to empower patients and even revolutionize the process of health care delivery, the fastest growing segment of the US population (i.e., people over the age of 50 years) are at a disadvantage because software and hardware designers often fail to consider them as a potential user group.

Usability and accessibility issues are important quality criteria for web-based interventions, but are frequently ignored by designers and evaluators. The design of a usable web-based information system that will allow residents to monitor their own functional assessment data becomes a challenge when it targets users inexperienced with the technology and with possible functional limitations. Therefore, systems targeting older adults should have reached a high level of functional accessibility [95] and undergone rigorous usability tests. Several design considerations can be taken into account when developing systems for the elderly or other populations with functional limitations.

2.4.4 Privacy and Confidentiality

When designing systems that allow web access to patients, family members, and health care providers, the issues of privacy and confidentiality of individual health information have to be addressed. Information privacy is the patient's right to control the use and dissemination of information that relates to them. Confidentiality is a tool for protecting the patients' privacy. Thus, system designers need to take into consideration that the patient has the right to allow family members to access information about their activity level but may also choose not to. When discussing privacy, issues related to the video- and/or audio-recording and maintenance of tapes, the storage and transmission of still images, and other patient record data must be examined, and efforts must be undertaken to address them to the fullest extent possible. The transmission of information over communication lines such as phone lines, satellite, or other channels, is associated with concerns of possible privacy violations. An additional concern in some cases is the presence of technical staff assisting with the transmission procedure that could be perceived as a loss of privacy by the patients. Patients often are unfamiliar with the technical infrastructure and operation of the equipment which can lead to misperceptions of the possibilities of privacy violation.

Furthermore, ownership of and access to data must be addressed. In many web-based applications in home care, patients record monitoring data and transmit them daily to a web server owned and maintained by a private third party that allows providers to log in and access their patients' data. This type of application calls for discussion and definition of the issue of data ownership and patients' access rights to parts or all of their records.

2.4.5 Interdisciplinary Approach to System Design

An interdisciplinary approach is essential to design a home that is flexible and responsive to the needs and limitations of the residents. The value of interdisciplinary teams is not a new concept in gerontology. Such teams overcome the problems of the traditional health care organizational model, which reinforces functional specialties and silos of expertise. The interdisciplinary team approach promotes integrated and coordinated care for older adults so that all participants in the care-delivery process are focused on the older adult rather than their professional specialty. During both the design and the development phases of a smart home, experts from different disciplines need to be included. As Rogers [96] points out, we need to shift from a model of "technological determinism," namely that technology itself should be the impetus for change, to a model of the social construction of technology where technology is influenced by societal norms and needs.

The success of functional assessment systems or smart homes in general will depend on the level of compliance with universal design principles that are holistic and inclusive [97]. Many of the challenges that older adults face, whether functional or cognitive limitations, have been traditionally addressed by the utilization of mechanical adaptive devices, which allow the user to adequately function in their environment, but not necessarily actively participate in it. The use of adaptive and assistive technology that can be installed in the home environment has the potential to not only support but also enable and empower individual users.

2.5 End-User Perceptions of Home-Based Technologies for Functional Assessment

It is axiomatic that end-users' perceptions of an "elective" home-based technology for functional assessment are central to whether they accept and adopt it. Such perceptions contribute to, possibly determine, success in both the implementation and the sustained use of these technologies. Ideally, end-users of such information-based health-monitoring technologies work in partnership with their health care providers to "co-produce" the quality of their care and, ultimately, their health [98, 99]. Optimal management of chronic disease and functional decline demands such an approach.

Measures of end-user acceptance of, and satisfaction with, informatics technologies are often focused on an application's usability or user-friendliness and, for users with physical or cognitive limitations, its accessibility. Although these factors are important in other eldercare applications, they do not directly impact end-users of passive sensor monitoring devices like those at TigerPlace (except in the informational user reports these devices generate). A broader set of measures is necessary, especially for user perceptions of these technologies in the home environment.

People have different expectations of the personal space in their home or residence than of public spaces. We view health care monitoring and assessment technologies applied to us as a patient in a hospital (e.g., cardiac telemetry) differently than when they are applied in our home. Negative feelings associated with dependence may be especially strong in the home setting. Ruddick [100] explains how a person's "sense of self often changes with place, especially with place of residence (p. 20)." He goes on to compare the hospital patient's "sick self" to his or her self at home—"one's defining, natural, or 'telic' place (p. 20)."

The home telehealth literature, which includes functional assessment applications, recommends that such technologies be designed and implemented to minimize their obtrusiveness or intrusiveness to users in their home environments. However, these terms are not explicitly defined or consistently used [101]. In response, based on a review of the literature, Hensel et al. [102] proposed a model of obtrusiveness (Figure 2.2) with eight dimensions and twenty-two sub-categories. In this model, "obtrusiveness" in home-based technologies for functional assessment is an umbrella construct inclusive of "intrusiveness" and is defined as "a summary evaluation by the user based on characteristics or effects associated with the technology that are perceived as undesirable and physically and/or psychologically prominent (p. 20)." Although this model still must be validated, it provides a framework within which to examine older adults' perceptions of these technologies.

The model was developed to capture potential obtrusiveness across a comprehensive range of eldercare technologies, including those used in functional assessment. Some dimensions and categories may be more important to users of a passive sensor-based assessment system, such as at TigerPlace, than to users of different types of eldercare technologies. For example, within the physical dimension, users of a remotely monitored oxygen system may perceive it as obtrusive because they

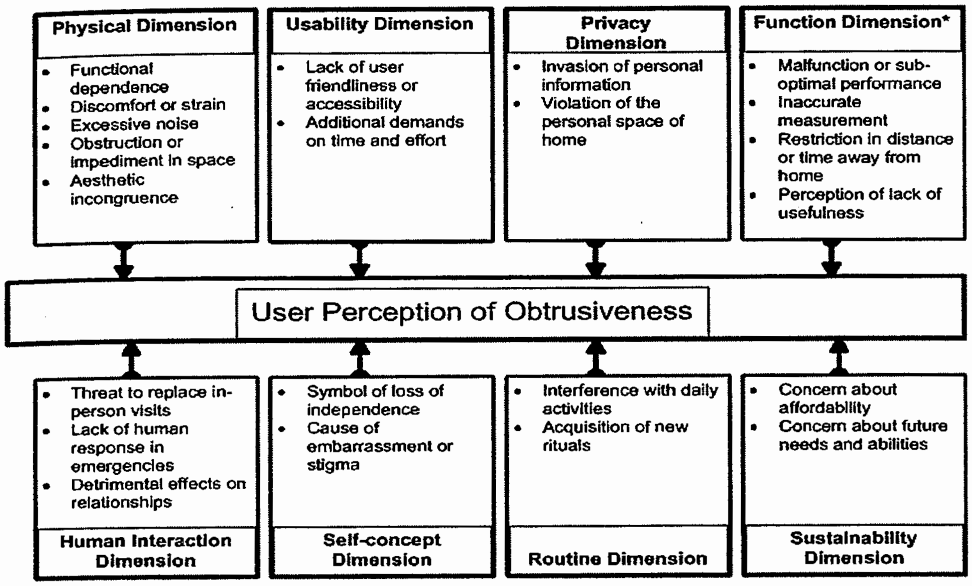

Fig. 2.2 Model of Obtrusiveness in Home-Based Technologies for Functional Assessment (reprinted with permission from the *Journal of the American Medical Informatics Association*) *Function dimension refers to function of the technology.

are functionally dependent on the technology. Conversely, TigerPlace residents are not, in a direct sense, functionally dependent on the sensors.

Consistent with this example, no participants of focus groups across two studies [103, 104] prospectively evaluated the TigerPlace sensors as potentially obtrusive because of physical *functional dependence*. On the contrary, comments were found in the focus group transcripts of each study expressing concerns that fit in the physical dimension subcategories of *obstruction or spatial impediment* and *aesthetic incongruence*. There were two dimensions in which concerns in each of the two studies included every subcategory: privacy and self-concept. Privacy was generally viewed in balance with health needs: greater health needs may mean sacrificing some privacy in terms of personal information and access to the personal space of home. Concerns expressed within the self-concept dimension reinforced that independence in relation to this technology is important not only in physical terms but also in psychological and even social terms (i.e., What will others think?).

In a third study [105] using focus groups, which broadly explored perceptions about these types of "smart home" technologies and was held before the selection of specific TigerPlace sensors, participants similarly voiced concerns about privacy. Consistent with the other studies, privacy concerns for some were heightened surrounding the use of cameras, although these apprehensions lessened when it was explained that video could be "anonymized" such that only gross movements, not individual features, would be depicted. Also consistent with the other studies, this earlier study found a focus on the function of technology in emergency response, especially in detection and response to falls.

Next steps at TigerPlace include examining the retrospective perceptions of residents who have sensors installed in their apartments. Potential future research questions include whether perceptions change to include the preventative utility of sensor monitors in detecting health problems earlier and thus facilitating earlier treatment. Another area of potentially fruitful research is the role of end-user control (e.g., the ability to turn off a sensor) in mediating perceived obtrusiveness, especially in the dimension of privacy.

An important qualitative finding across all three focus group studies was a general openness and favorability toward technologies that can help older persons maintain their independence. Moreover, simply because aspects of a technology are perceived as obtrusive by an individual does not necessarily mean he or she will not use it. Other factors such as perceived need undoubtedly greatly influence this decision. We do not know the generalized relationship between perceptions of obtrusiveness as defined in the dimensions and subcategories of the conceptual model and the adoption of a technology. Describing this relationship would necessitate a validated and reliable instrument for measuring obtrusiveness, applied in multiple large studies across different settings and populations. Obtrusiveness is conceptually defined as a "subjective" "summary evaluation," which may be based on "a number of characteristics or effects associated with the technology or one . . . that is especially important . . . to the user [102] (p. 22)."

Even though it is in an early stage of development, the model appears to provide a useful conceptual framework, with seventeen of the twenty-two categories found in at least one of the three focus group studies. Of course, different populations will emphasize different concerns. Participants in these focus group studies were relatively independent and lived within the monitored environment of an independent living facility.

This section intended to stress the importance of end-user perceptions of a functional assessment technology to their adoption of it and ultimate satisfaction with it. To assist in this assessment, a framework is provided to explore end-user perceptions of obtrusiveness of individual applications of these technologies.

2.6 Challenges for Technology Experts to Implement Functional Assessment Technologies in the Real World

There is remaining work to be done. It is not yet clear that data that are collected are complete in the sense of capturing functional assessment. It is unclear whether all the data that are needed or that all the events that are needed can be collected. It seems that activity of humans easily outstrips the ability of sensors to detect all the details that are needed for interpretation. There appears to be no perfect and specific set of sensors to capture all activity. Additionally, correlating activity with multiple sensors may not be sufficient and computational techniques may not adequately describe the activity nor sufficiently compute it for interpretation.

A major concern is that some technologies may be seen as obtrusive. Clearly, video technology requires means of assuring the residents that their images will be protected. Although video coupled with other imaging modalities have great usefulness as monitoring sensing systems, that usefulness must be tempered with the need to make the technology as unobtrusive as possible. Privacy is an important issue and one we believe *must be controlled by the individual resident.* Clearly, the resident must decide who sees their activity information and who does not. As long as technology is in the research stage, the institutional review board and human subject protection policies provide mechanisms to assure privacy. However, when the technology is released to the public for general use, it must be the elder resident who determines who gets what data. This concern will become acute as the resident's functional and cognitive abilities decline. Advanced planning will need to consider technologies and information just as treatment decisions are made in advance for medical care.

Technology has huge potential for the health and function of elders. It must be used wisely and always from the perspective of improving their independence, dignity, and function. Focus groups and interviews with elder users of technology and sensitivity to their needs by not only health care providers but also those developing the technology will go a long way to minimizing obtrusiveness of technology. The acceptance of technology by both health care providers and elders will help realize the promise that elders will achieve more independence and higher quality of life, and providers and loved ones will have more ready, useful, and accurate information about function and health status.

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