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In-home Use of Home-based Sensor Technology for Monitoring Mobility in Community-
Dwelling Korean American Older Adults

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Abstract

In-home Use of Home-based Sensor Technology for Monitoring Mobility in Community-Dwelling Korean American Older Adults

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The growing population of older adults faces many health challenges, including mobility limitation. Mobility limitation leads to reduced participation in physical and social activities and threatens quality of life and well-being. However, the current understanding of mobility and the ability to assess mobility limitation in older adults are often restricted to a limited set of variables measured sporadically. An alternative approach is to bring monitoring through sensor-based technology into the home setting. This monitoring could be performed continuously with less intrusion on the daily lives of residents and reduced reliance on self-reporting and memory recall of past events. Recent developments in sensor technologies have shown that they could provide the key to early detection of mobility limitation and prompt intervention to prevent adverse health events due to mobility limitation. Despite demonstrated successes of sensor technologies, no attempts have been made to explore mobility and activity patterns of Asian American older adults. Also, there still remains a challenge in increasing acceptance and usage of these technologies among older adults, particularly in those from racial and ethnic minority groups, or who have lower income or poor literacy.

The dissertation includes three papers that covered two areas, 1) mobility limitation in community-dwelling older adults and 2) home-based sensor technologies for continuously monitoring older adults' mobility and activity levels. The first paper is a systematic review of instruments to measure mobility limitation among community-dwelling older adults. A search of PubMed, CINAHL, and psycINFO databases identified studies that were published from 1990 to 2012 and included the topics of definitions of mobility limitation, empirical constructs of elderly mobility and types of mobility measurement tools (either self-report or performance-based). A total of 103 articles were included in this systematic review. The review provides a broader overview of what types of mobility measures are commonly used and included a thought discussion of the inconsistencies in mobility measurement, which limit the comparison across studies.

The second paper seeks to understand perceptions of home-based monitoring technologies in the context of culture among older Korean immigrants and older adults living in Korea. This study is a qualitative analysis of three focus groups and four individual interviews (N = 21) and focuses on cross-national differences in perceptions and intention to use of home-based monitoring technologies among the Korean ethnic group. We identified several cultural and contextual factors affected the acceptability of home-based monitoring technologies among participants, such as weakened filial tradition, immigration, cultural norms around the living situation of an older adult, health insurance system, and national policy initiatives for technology adoption for older adults. Results of the study indicates the need for considering cultural differences to better understand the complexity embedded in the construction of perceptions of and preferences for home-based monitoring technologies among older adults from various ethnic groups.

The third paper is a feasibility study to test an integrated home-based monitoring system that utilizes innovative sensor technologies to assess aspects of Korean American older adults' daily activities with an emphasis on mobility. An exploratory multiple case-study methodology was used. The sensor system was deployed in four homes of Korean American older adults (N = 6). Study procedures included 1) data collection from the sensors, 2) administration of self-report instruments to measure mobility and health, and 3) individual interviews at midpoint and study completion. Sequence plots for every area of the home show variable natural fluctuation in activity trends. Most participants did not have any decrease or increase, but one participant's overall activity in each area was increased after her granddaughter's visit. Participants had different 24-hour occupancy patterns in the bathroom, bedroom, kitchen, and living room. Interview data indicated that the home-based sensor system was acceptable for all participants. However, some participants reported privacy concerns related to a motion sensor in the bathroom at an initial stage.

Results from these papers suggest that sensor technologies could lead to understanding of aging, allowing for identification of patterns in elder mobility. Despite some challenges related to sensor deployment and data analysis, continuous sensor-based monitoring of activity patterns in the home will provide a useful tool to detect deviations from normal activity and mobility patterns that could be an early sign of functional decline. Finally, findings from the dissertation indicate that technology applications could be successfully performed in the minority population of older adults. Future efforts are necessary to develop linguistically and culturally appropriate technology-based interventions to prevent functional limitation and enhance healthy aging among older adults from racial and ethnic minority groups.

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DEDICATION

To my inspiring husband Dong Won Yoon and my family in Korea

A circle of strength and love, kept by God, together forever.

CHAPTER 1: Introduction

Significance of the Problem

The growing population of older adults faces many health challenges, including limitations in their mobility. It is estimated that more than 40% of individuals aged 65 or older living in the community have difficulty in walking or climbing stairs (Shumway-Cook, Ciol, Yorkston, Hoffman, & Chan, 2005). Mobility is broadly defined as the ability to move independently from one location to another (Vasunilashorn et al., 2009). Maintaining mobility is fundamental to independence and healthy aging among older adults. Many forms of daily activity are related to mobility, such as transferring from a bed to a chair, climbing up stairs, walking and traveling inside and outside the home (Prohaska, Anderson, Hooker, Hughes, & Belza, 2011). Mobility is viewed as a dynamic condition (Blain et al., 2010), and even at a same age range older people show differing levels of mobility. Loss of mobility results in reduced participation in physical and social activities, and therefore threatens quality of life and well-being (Webber, Porter, & Menec, 2010). A number of studies have shown that mobility limitation is a main cause of loss of independence and physical disability and ultimately leads to adverse health outcomes such as falls, institutionalization, and death (Gill, Allore, Hardy, & Guo, 2006; Montero-Odasso et al., 2009; Tiedemann, Shimada, Sherrington, Murray, & Lord, 2008; C. Y. Wang, Yeh, & Hu, 2011). In an effort to address the public health concern, the Centers for Disease Control and Prevention (CDC) Healthy Aging Program, the National Association of Chronic Disease Directors, and the Healthy Aging Research Network (HAN) have been working together to develop approaches to promoting mobility among community-dwelling older adults (CDC, 2013).

While it is important to investigate barriers and facilitators to mobility for older adults, such an inquiry can benefit from a narrow contextual focus where community characteristics such as ethnicity or culture are explored. Korean Americans, for example, are such an ethnic minority and they are the fourth largest Asian immigrant subgroup and the fastest growing subgroup in the United States (Park, Roh, & Yeo, 2012). Previous research revealed that physical inactivity is a major health risk in Korean American elderly (Sohng, Sohng, & Yeom, 2002). Environmental factors, cultural beliefs and attitudes, and health status are known to be affecting behavioral changes for increasing the level of physical activity in Korean American elderly (Lim, Kayser-Jones, Waters, & Yoo, 2007; Sin, Belza, LoGerfo, & Cunningham, 2005; Sin, LoGerfo, Belza, Cunningham, & Belza, 2004). However, little is known about the mobility of Korean American older adults, so there is a need to understand trends, preferences, and patterns in the mobility of the Korean American elderly population.

As part of prevention approaches to addressing the risk of mobility limitation in the population of older adults, both clinicians and researchers have made considerable efforts to identify reliable and valid tools that could assess changes in mobility as well as have developed a new instrument for measuring mobility. However, the methodologies are lacking that capture varied development of mobility limitation and cover a breadth of underlying components of mobility such as physical, functional, cognitive, environmental and social parameters. Thus, the current understanding of mobility and the ability to assess and manage mobility limitation in older adults are often restricted to a limited set of variables measured at a few discrete time points.

An alternative approach is to facilitate monitoring through sensor-based monitoring technologies in the home environment of older adults. The idea of using sensor technologies in

the home setting to monitor elder activity levels is not a novel idea and has been tested by multiple research groups (Hayes et al., 2008; Reeder et al., 2013; Skubic, Alexander, Popescu, Rantz, & Keller, 2009). This monitoring could be performed continuously with less intrusion on the daily lives of residents (Kaye et al., 2011). The continuous assessment of physical function can overcome the limitation in the current mobility assessment. Sensor technologies, designed to detect and record individuals' activities and status in their living spaces, make it possible to reduce reliance on older adults' self-report and memory recall of past events and changes in their health status. Therefore, these technologies can generate an objective record of activity patterns and provide a fully valid perspective of elderly mobility. Also, because sensor-based monitoring does not require older adults to use computers, it can benefit various populations of older adults with chronic conditions, such as dementia or memory loss, while avoiding problems caused by incorrect use of wearable devices to measure activities (Alwan, 2009; Mahoney et al., 2007). Recent developments in sensor technologies have shown that they could provide the key to monitoring mobility in older adults, early detection of mobility limitation, and prompt intervention to prevent adverse health events resulting from limitations in mobility. That way, home-based sensor technologies can support older adults to maximize their health and allow them to age at home independently as long as possible (Chan, Estève, Escriba, & Campo, 2008; Kang et al., 2010). Based on this assumption, this study will apply a home-based sensor system to Korean American older adults to monitor their daily activities with an emphasis on mobility.

The fact that older adults prefer living independently in their homes for as long as possible recognizes the necessity of adopting technology solutions into the home or community settings. Adoption is critical to increasing the usage and diffusion of technology proven to be effective (A. Wang, Redington, Steinmetz, & Lindeman, 2011). However, despite the increased

interest focusing on the adoption of home-based sensor technologies for older adults, there still remains a challenge in increasing acceptance and usage of these technologies among older adults.

Older adults' acceptance of home-based monitoring technologies would be different from the acceptability of other types of technologies (Mahoney, 2011), because implementing the sensor technologies in the home setting could be intrusive to residents and might bring privacy and obtrusiveness concerns. In order to adequately design and implement sensor technology solutions to address the specific needs of older adults, facilitators of and barriers to the adoption and utilization need to be examined. Researchers have examined what factors influence older adults' perceptions of sensor technologies. These include perceived usefulness, privacy concerns, or an unobtrusive feature of the technology (Demiris, Hensel, Skubic, & Rantz, 2008; Reeder et al., 2013). However, we do not know much about what factors increase technology adoption in other cultural groups of older adults and whether older persons respond differently to new technologies according to cultural or other parameters. Many technology systems have targeted the general population but feasibility and acceptance in underserved or minority populations have not been systematically examined. There is a lack of studies that have examined the linkage between technology adoption and culture. Previous research exploring the cultural influences on the technology acceptance has been conducted in highly developed Western countries. It is difficult to apply this knowledge to other cultural groups because different cultural groups have different cultural values and belief systems that influence user perceptions of technologies (Hofstede, 1980; Wilkowsk, Ziefle, & Alagöz, 2012). To our knowledge, there is no published study that explored older adults' acceptance of sensor technologies in the context of culture. Since user acceptance is predicting for the usage and successful implementation of sensor

technologies, it is necessary to understand which factors contribute to user acceptance of sensor technologies and how cultural differences can determine the level of sensor technology adoption in the population of older adults. An understanding of older adults' technology experiences in the context of culture can provide insights into the knowledge about how to help the elderly population from diverse cultures overcome technological challenges and accept new technologies proven to be useful. Therefore, we sought to address this limitation through the examination of sensor technology acceptance in the cultural context among samples of older Korean immigrants and older adults living in Korea.

Statement of the Study Purpose

There are three main objectives to this study:

1. To systematically review the relevant literature of instruments that are designed to measure mobility limitation among community-dwelling older adults.
2. To conduct a qualitative study to explore attitudes toward and perceptions of sensor technologies in the cultural context among Korean American older adults and older adults living in Korea. This study focuses on factors influencing the acceptability of sensor technologies, such as perceived usefulness, obtrusiveness, and any potential privacy concerns.
3. To conduct a feasibility study of home-based sensor monitoring by pilot-testing the installation of the sensor technology in actual residential settings of community-dwelling Korean American older adults.

Content of the Dissertation

The dissertation consists of three parts. In the first part (Chapter 2), findings from a systematic review on the literature of instruments to measure mobility limitation among

community-dwelling older adults are presented. The Nagi model of the pathway from disease to disability is used as an underlying theoretical framework to better understand elements included in mobility assessment. This paper includes a balanced discussion on the current state of mobility measures as well as suggestions to identify appropriate mobility measures for older adults living in the community.

Part two (Chapter 3) of the dissertation reports findings from a qualitative analysis of three focus groups and four individual interviews conducted with Korean and Korean American older adults to examine their perceptions of home-based sensor technologies. This study provides insight into factors that can increase technology adoption of Asian older adults both in the U.S. and internationally.

Part three (Chapter 4) presents findings from a feasibility study to test an integrated home-based monitoring system that utilizes innovative sensor technologies to assess aspects of Korean American older adults' daily activities with an emphasis on mobility. In this chapter, data obtained from the sensors is compared with responses measured by psychometric instruments of activities of daily living and mobility to see whether the system allows for measuring mobility. Also, changes in activity patterns are explored by examining data obtained from sensors over the two-month period of monitoring and by comparing baseline data with 2-month follow up data.

Finally, a brief summary of all the studies is included in Chapter 5. This chapter concludes with an in-depth discussion on challenges and opportunities in using home-based sensor technologies to support aging in place among older adults and recommendations for future investigations.

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CHAPTER 2

Instruments to Assess Mobility Limitation in Community - Dwelling Older Adults:

A Systematic Review¹

Abstract

Mobility is critical in maintaining independence in older adults. This study aims to systematically review the scientific literature to identify measures of mobility limitation for community-dwelling older adults. A systematic search of PubMed, CINAHL, and psycINFO using the search terms “mobility limitation”, “mobility disability”, “mobility difficulty” yielded 1,847 articles from 1990 to 2012; a final selection of 103 articles was used for the present manuscript. Tools to measure mobility were found to be either self-report or performance-based instruments. Commonly measured constructs of mobility included walking, climbing stairs, and lower extremity function. There was heterogeneity in ways of defining and measuring mobility limitation in older adults living in the community. Given the lack of consistency in assessment tools for mobility, a clear understanding and standardization of instruments are required for comparison across studies and for better understanding indicators and outcomes of mobility limitation in community-dwelling older adults.

Keywords: mobility limitation, instrument, screening, community.

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Introduction

Mobility, broadly defined as the ability to move independently from one location to another (Vasunilashorn et al., 2009), is fundamental to healthy aging and quality of life in older adults. Many forms of daily activity are related to mobility, such as transferring from a bed to a chair, climbing up stairs, walking and traveling inside and outside the home (Prohaska, Anderson, Hooker, Hughes, & Belza, 2011). In their concept analysis, Rush and Ouellet (1998) conceptualized mobility as a functional ability and suggested that measuring mobility can determine the level of independence and health care needs in the elderly population. Mobility is viewed as a dynamic condition (Blain et al., 2010); such that older individuals demonstrate varying levels of mobility even within the same age range. Thus the evaluation of mobility in older adults is a critical component of assessment. Tinetti (1986) suggested that mobility assessment has multiple purposes including identifying components of mobility difficulty related to performing daily activities, reasons for difficulty with specific tests, and possible health risks caused by immobility (e.g., falls).

More than 40% of individuals aged 65 or older living in the community have difficulty in walking or climbing stairs (Shumway-Cook, Ciol, Yorkston, Hoffman, & Chan, 2005), both of which are commonly measured constructs of mobility. Mobility limitation makes it difficult for older adults to be fully involved in their activities of daily living and reduces social participation. Previous studies have shown that older adults' mobility limitation is a marker for risk of adverse outcomes, such as physical disability and injuries, loss of independence, institutionalization, and death (Blain et al., 2010; Gill, Allore, Hardy, & Guo, 2006; Studenski et al., 2011; Tiedemann, Shimada, Sherrington, Murray, & Lord, 2008; Wang, Yeh, & Hu, 2011). To prevent these health outcomes, a population-based prevention approach targeting older adults at increased risk of

mobility limitation is needed. In order to identify at-risk older individuals, reliable and valid tools are necessary to guide development of preventive therapeutics by focusing on modifiable risk factors.

To date, both clinicians and researchers have made an effort to identify accurate and objective tools for capturing mobility changes in older adults. Also a number of studies have focused on testing existing assessment tools or developing new instruments for measuring mobility limitation. Although many single element or composite tools are currently being used to measure changes in mobility, there is a lack of consensus over which tool to use; and many of these instruments have not been fully validated for measurement of mobility (Abellan van Kan et al., 2009). Some instruments have limitations in differentiating a spectrum of mobility limitation in the elderly population due to either a ceiling effect, floor effect, or inadequate scale width (de Morton, Berlowitz, & Keating, 2008). Moreover, tools are lacking that capture varied patterns of development of mobility limitation or cover a breadth of underlying components of mobility such as physical, functional, cognitive, environmental and social parameters (Prohaska et al., 2011; Webber, Porter, & Menec, 2010). Thus, the current understanding of mobility and the ability to assess and manage mobility limitation in older adults is often restricted to a limited set of variables measured at either a single or a very few points in time. To inform effective interventions that could prevent adverse consequences of mobility limitation and improve mobility and physical performance in older adults, it is necessary to identify available instruments that have been developed based on sound conceptual definitions and operationalized constructs of mobility. Further, it is essential to examine what types of mobility measures are commonly used to make recommendations regarding the need for further validation.

Although several studies have examined measures on mobility limitation for older people, reviews to date have focused only on one type of measurement, such as the one-leg standing test (Michikawa, Nishiwaki, Takebayashi, & Toyama, 2009) or gait speed (Abellan van Kan et al., 2009), or else included elderly subjects across diverse settings [e.g., community, long-term care and acute care] (Scott, Votova, Scanlan, & Close, 2007). To date, there is no published review that has examined how mobility limitation of older adults is defined and measured within community settings. Because the majority of older adults live in the community and mobility is important to independent living and quality of life, there is a need for a thorough review on measures of mobility in the specific context of community-dwelling elderly persons.

In an attempt to fill existing gaps in the literature and to provide an update on instruments of mobility limitation in community-dwelling older adults, we conducted a systematic review of published studies. The Nagi model of disability was used as an underlying framework for organizing constructs included in mobility identified in the reviewed articles. The model provides a conceptual framework that consists of four central concepts: pathology, impairment, functional limitation, and disability. It helps to understand how pathology (disease) is distinguished from impairment (abnormalities or loss) as well as differences between functional limitations and disability (Nagi, 1976; Verbrugge & Jette, 1994). Specific aims of this systematic review were to: 1) identify available mobility assessment tools, 2) synthesize the results of definition and measured constructs of mobility limitation as well as types of mobility measures, and 3) summarize characteristics and relevant psychometric properties of the included instruments according to the measurement type to assist clinicians and researchers to identify appropriate mobility measures for older adults living in the community.

Methods

A systematic search of the literature was conducted using the following databases: PubMed, CINAHL and psycINFO from January 1990 through December 2012. The search terms included “mobility limitation”, “mobility disability”, “mobility difficulty”, “mobility” (for CINAHL), “older adults,” combined with the terms “human” and “English.” Articles were included if (1) the study described a research design in which data had been collected in at least one time point, (2) the authors explicitly addressed the way in which mobility had been defined and measured (e.g., mobility limitation defined as the inability to climb a flight of stairs or walk a half-mile without assistance; defined mobility as the ability to move independently around the environment), and (3) mobility was measured as a predictor or an outcome variable, and not simply used to indicate inclusion criteria of older adults (e.g., obesity and fatigue in older adults with mobility limitation). Exclusion criteria included studies that (1) did not focus on community-dwelling adults aged 65 or older, (2) did not have a primary focus on mobility (e.g., examined assistive technologies) or (3) samples consisted of subjects based on specific medical diagnosis, such as Parkinson’s disease, arthritis, or hip fracture.

The initial database search yielded 1,847 articles, of which 499 articles were then excluded because they were duplicates. Titles for the 1,348 articles were screened for relevance. Then 401 abstracts were identified as potentially relevant after title review. One researcher reviewed all abstracts, applying the inclusion/exclusion criteria. One hundred and thirty eight candidate publications were excluded during abstract review, thus decreasing the total to 263. Full text articles were retrieved for these 263 publications for further evaluation. After full text review, 163 articles were further excluded leaving 100 articles for inclusion in the final review. Hand search of the reference lists of the articles was also performed in order to obtain additional

studies that fit the inclusion criteria. Three additional publications were identified for inclusion, for a final total of 103 articles (See Figure 2.1).

During full text article review, a second researcher independently reviewed 26 randomly selected articles from the downloaded full text results and applied the inclusion/exclusion criteria for testing inter-rater reliability. The two researchers met to reconcile differences through discussion until agreement was reached about application of the inclusion/exclusion criteria. Initial agreement before reconciliation was 84.6%, and agreement after reconciliation was 100%.

A data-extraction table was used to document study design, original epidemiological study if necessary, sample size, participant characteristics, inclusion and exclusion criteria, definition of mobility limitation, and specific information on mobility instruments, such as type, measured constructs, cut-points, psychometric properties and response options. This table was initially constructed by a single researcher, and then underwent review by all authors and agreement was reached prior to final analysis.

Once studies were identified, constructs of mobility included in those articles were analyzed and categorized according to the Nagi model of the pathway from disease to disability to better understand elements included in mobility assessment. Noteworthy, this article does not provide an exhaustive list of instruments to assess elderly mobility. We focused on a comprehensive analysis of existing studies that describe various types and characteristics of assessment tools based on a clear definition of mobility limitation.

Results

Study Characteristics

Among the 103 articles included in this review, 74 were prospective cohort studies, 24 were cross-sectional studies, 4 were randomized controlled studies, and 1 was a retrospective

cohort study. Eighty-five (82.5%) studies analyzed data that were a part of larger longitudinal cohorts, such as the ACTIVE study, Established Populations for Epidemiologic Studies of the Elderly (EPESE), Health, Aging, and Body Composition (Health ABC) study, Invecchiare in Chianti, Aging in the Chianti area (InCHIANTI) study, Cardiovascular Health Study, and Women's Health and Aging Study (WHAS), etc. Overall, 242,480 older adults in community settings were followed for the investigation of mobility limitation (range: 36 – 31,568). Study participants were mainly female, and the average age of study participants was generally considered “middle old” and ranged from 72 to 84.2 years across studies. Forty-four studies (42.7%) had inclusion criterion of independent ambulation. Thirty-five studies (34.0%) recruited cognitively intact older adults, while most did not report inclusion criteria regarding cognitive status of participants. Cognitive function of older adults was measured by either using the Mini-Mental Status Examination (MMSE) (n = 22) or other measures of cognitive function (e.g. modified MMSE) (n = 1).

Definitions and Measured Constructs of Mobility Limitation

Mobility limitation was most often operationally defined as difficulty in walking a certain distance (e.g., one quarter of a mile, half mile, 2km, 10km or 2-3 blocks) or difficulty in climbing a flight of stairs. In seven studies (6.8%), gait speed was used as an indicator of mobility limitation. There were several terms that were interchangeably used with mobility limitation (n = 31) across the studies, including mobility disability (n = 35), mobility difficulty (n = 4), mobility dependency (n = 1), mobility-related functional limitation (n = 1), mobility impairment (n = 6), mobility deficit (n = 1), life-space mobility (n = 3), lower-extremity functional limitation (n = 1), walking difficulty (n = 2).

Based on the types of mobility measures, we identified several empirical constructs included in mobility. These were categorized into core concepts of the Nagi model of the pathway from pathology to disability (Table 2.1). Many of the constructs fit into the functional limitation category, while there was no construct applicable for the first concept of the model: pathology.

[Table 2.1 about here]

Among these constructs, walking (n = 66) and climbing stairs (n = 37) were most commonly used across studies. While forty one studies (39.8%) focused only on one aspect of mobility (e.g., walking or climbing), sixty-two studies (60.2%) measured two or more aspects. Several studies define elderly mobility in a broader context, with a focus on difficulty in performing social roles due to functional limitation or community mobility (environmental aspects of mobility, or an area and frequency of movement into various levels of spaces), which is categorized in the disability in the Nagi model.

Instrument Characteristics according to the Type of Mobility Measure

Many studies depended solely on self-report (n = 68) or performance-based measures (n = 17), while others employed both types of instruments (n = 18). Table 2.2 summarizes types of mobility measurement tools as well as the number of studies in which the tools were used. Forty-five studies (43.7%) used only one to two questions to measure mobility limitation, mainly asking participants whether they had difficulty or limitation in walking or climbing stairs (Table 2.1). The Rosow-Breslau Scale and the Life-Space Assessment of Mobility (LSA) were the two most frequently used tools, which were used in five (4.9%) and four (3.9%) studies respectively. On the other hand, the types of performance-based tests varied across the studies in the review, including usual or fast gait speed, the ability to walk 400m, Timed Up and Go Test (TUG),

balance test, and the Short Physical Performance Battery (SPPB) (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). The latter was used most frequently (10 studies, 9.7%).

[Table 2.2 about here]

Self-Report Single Item Mobility Measures. Self-report tools assessed walking, climbing, or non-walking mobility tasks (Table 2.3). There was variability in distances assessed for walking (e.g., one quarter of a mile, half a mile, 500m, 1km, or 2km) or the number of steps climbed (e.g., a flight of stairs or 10 steps) to determine mobility limitation across studies. Although the same question was asked about difficulty walking or climbing, scaling methods differed across studies, which were either dichotomous (e.g., Hung, Ross, Boockvar, & Siu, 2012; Wang et al., 2011) or ordinal scale based on the level of difficulty of the task (e.g., Hardy, Kang, Studenski, & Degenholtz, 2011; Manty et al., 2009; Stenholm et al., 2009). Moreover, the specific questions varied across studies even though they measured the same domain of mobility. For instance, studies assessing self-reported difficulty walking, some studies asked about perceived difficulty in walking or the ability to walk (e.g., “do you have difficulty walking?” or “are you able to walk?”), while others assessed the need for help with walking (e.g., “do you need special equipment or aids to help you with walking?”).

[Table 2.3 about here]

Self-Report Instruments of Mobility Limitation. Table 4 lists all standardized instruments for mobility limitation that were found during the review that consist of several items. These instruments are designed to measure walking, climbing, spatial movement, driving space, community mobility, or functional activities. All of the instruments identified during the current review are self-report measures (Table 2.4).

[Table 2.4 about here]

Performance-Based Single Item Mobility Measure. Specifics of performance-based functional assessment tools are presented in Table 2.5. These performance-based measures include single item tools as well as composite tools. As a single item measure, gait speed was the most commonly measured parameter across multiple studies; in these studies, participants were asked to walk a certain distance either at usual or fast pace. Variability was also found in walking distances of gait speed tests across studies, ranging from 2.4m to 400m. Walking as a domain of mobility was measured differently in two studies, namely, either as the loss of the ability to walk 400m within a limited time (Vestergaard et al., 2009), or the distance a participant could walk within three (Shumway-Cook et al., 2003) or six minutes (6MW) (Wang et al., 2011). Several cut-off points for gait speed have been suggested as predictors of mobility disability depending on severity of mobility limitation or distance traveled. Step-mounting test was another single item tool which measures the ability to climb stairs (Sakari et al., 2010).

[Table 2.5 about here]

Performance-Based Composite Measures of Mobility. Several lower and upper extremity function tests were performed in fourteen studies as part of a composite measure of mobility, such as SPPB, Berg Balance Scale (BBS), TUG, chair stands, one-leg stand, functional reach, or grip strength. In two studies, participant's trips that required ambulation were videotaped in order to evaluate whether participants avoided or encountered environmental challenges to community ambulation (Shumway-Cook et al., 2002; Shumway-cook et al., 2005).

Some studies provide detailed information related to how to apply the performance measures. However, variability was found in the instructions given to study participants across studies. For example for the 400m walk test, participants were asked to walk 20 laps of 20

meters (Chang et al., 2004; Simonsick et al., 2008), 10 laps of 40 meters (Marsh et al., 2011), or four laps of 100 meters (Sayers et al., 2004).

Psychometric Properties of Mobility Measures. Reliability and validity of performance-based measures for mobility limitation were examined in several studies. Rivera et al. (2008) compared the degree of agreement between each mobility outcome and the composite outcome of mobility difficulty (gait speed and self-reported mobility limitation) as a latent construct. Kappa coefficients indicate comparability, with 0.62 for usual gait speed of 0.5m/s or less, 0.65 for self-reported difficulty walking or inability to walk across a small room, and 0.74 for dependence on a walking aid. In the study by Simonsick et al. (2008), sensitivity, specificity, and positive predictive value were examined for three mobility measures (self-reported difficulty walking 1 mile, a short walk test, and long distance corridor walk). In both men and women, self-report of ability to walk 1 mile had the highest sensitivity but lowest specificity and positive predictive value for identifying persons with mobility limitation (defined as two consecutive semi-annual reports within 2 years of difficulty walking one-quarter mile or climbing one flight of stairs), while gait speed less than 1.0m/s had the lowest sensitivity but highest specificity. Poor performance on the 400-m walk test had intermediate sensitivity and specificity. In a study of Sayers et al. (2004), three questions among 18 items assessing walking habits and ability were found to be compatible with the ability to walk 400m and predicted a 91% probability of inability to walk 400m with a sensitivity of 46% and a specificity of 97%. Khokhar et al. (2001) reported validity, with kappa coefficient of .44 for self-reported mobility and physician rating in the Barthel Index and kappa coefficient of .36 for self-reported mobility and neurological assessment of gait.

In addition, two self-report instruments were tested for psychometric properties. Shumway-Cook et al. (2005) examined the test-retest reliability and concurrent validity of the Environmental Analysis of Mobility Questionnaire (EAMQ). Intra-class correlation coefficients (ICC) for the EAMQ over one-week period ranged from 0.81 to 1.0. Spearman rank correlation coefficients (r) with mobility observed in the environment were significant, with $r = 0.63 - 0.66$ for the encounter summary score and $r = -0.58 - -0.63$ for the avoidance score. The LSA has high test-retest reliability, with $ICC > 0.86$, and it is highly correlated with measures of physical function and performance. Spearman correlation coefficient was the highest between the LSA and physical performance ($r = .60, p < .01$) while the lowest correlation was found with comorbid conditions ($r = -.19, p < .01$). The LSA had acceptable correlations with the physical component of short form-12 question survey ($r = .44$), the Geriatric Depression Scale ($r = -.41$), activities of daily living (ADL) difficulty ($r = -.40$), and instrumental activities of daily living (IADL) difficulty ($r = -.39$) (Baker et al., 2003).

Discussion

This article summarizes mobility assessments of mobility and its limitations of community-dwelling older adults. This systematic review identified a total of 103 articles that used one or more measures to examine the magnitude of mobility limitation in elderly persons in the community. Prior literature (Webber et al., 2010) has already discussed that elderly mobility can be broadly defined and should be examined in a holistic way. This review provides evidence to support their concept of mobility, demonstrating that the current state of mobility limitation measurement lacks consistency. There is a great deal of heterogeneity in its definition, empirical constructs of mobility and types of instruments used across studies. For instance, some studies viewed walking and climbing as key constructs of mobility, while others focused on the ability to

perform physical performance tests. Furthermore, even if the same domain of mobility was measured in studies, the focus of assessment would not always be the same. In an example of walking as a construct, some studies measured gait speed for assessing mobility limitation, while others asked older adults whether they were able to walk a certain distance. On the other hand, Vestergaard et al. (2009) assessed participants' need to rest during the 400m walk test based on the assumption that greater numbers of rest stops is related to a greater risk of mobility limitation. This may be due to the fact that mobility itself is dynamic and multidimensional (Blain et al., 2010; Webber et al., 2010) and that there is a lack of clear conceptual understanding of mobility that should be a basis of research questions to examine its limitation in community-dwelling older adults. Given the lack of a consistent conceptualization of elderly mobility, further inquiry will be necessary to approach mobility in an integrative and interdisciplinary way. Then it will be possible to compare findings on the prevalence of mobility limitation as well as its determinants and health outcomes across studies.

The choice of tool in the community setting may depend on researchers or clinicians' preferences, feasibility of using the instrument and/or clinical characteristics of study population. The current review demonstrates that there are various mobility assessment tools. These instruments have fallen into two broad categories: self-report and performance-based measures. We found that self-report measures were preferred in most studies (n = 86) since they are generally more feasible, less time-consuming and are cost-effective as a result (Simonsick et al., 2001; van den Brink et al., 2003). Research has suggested that both types of measures should be used in a complementary manner, as they do not examine the same construct of mobility (Hoeymans, Feskens, van den Bos, & Kromhout, 1996). Some researchers argue that self-report measures are less accurate because they focus on perception, not on actual performance (Brach,

VanSwearingen, Newman, & Kriska, 2002) and they are easily influenced by recall bias and other factors, such as cognitive ability, culture, education and language (Faber, Bosscher, & van Wieringen, 2006; Hoeymans et al., 1996; Wang et al., 2011). For example, Vasunilashorn et al. (2009) found that, in a case of asking the ability to walk 400m, older adults who do not regularly walk that distance might misgauge distance. Some discrepancy has also been reported between self-report of mobility limitation and actual performance of mobility-related tasks despite the evidence for reliability and validity of self-report measures for community-living older adults (Manty et al., 2007; Sayers et al., 2004). However, self-report instruments have been also found to be predictive of mobility disability (Sayers et al., 2004) or associated with performance-based limitation (van den Brink et al., 2003). These indicate a need for further validation of self-report measures of mobility limitation that are commonly used for community-dwelling elders.

Comparing self-report tools to performance-based measures like the SPPB, physical performance tests appear to require more training and equipment than self-report tools, which can be a burden both for researchers and subjects. To be practically used in community-dwelling older adults, the assessment of mobility should be easy to administer especially when sufficient time and/or space are unavailable. The current review found that there was a variation on the allowable use of assistive devices, such as canes, crutches, or walkers, during administering performance-based tests (Table 2.4). For example, the use of assistive device was allowed for gait speed test in nine studies while two studies did not permit walking aids (Sayers et al., 2004; Vestergaard et al., 2009). Considering that 6.2% to 9% of older adults use assistive walking devices (Carbone et al., 2013; Wolff, Agree, & Kasper, 2005), administration of mobility tests should accommodate people with assistive devices or frailty. If older adults are not allowed to use their assistive devices during mobility tests, we would not capture mobility limitation in a

certain number of older adults. It is also important to note that performance-based measures should be more feasible at home as well as in clinical settings and less complex so that clinicians other than physical therapists, like home health nurses can easily use. For example, asking individuals whether they can walk one mile (self-report) or administering a short distance walk test (e.g., 2.4 meter walk) would be an easier method to examine mobility than 400m corridor walk test in older adults, as multivariate analyses showed that each of these measures predicted newly developed mobility limitation (Simonsick et al., 2008).

There were similarities in domains of mobility measured either by self-report instrument or performance-based tools. The most commonly assessed parameters of mobility limitation were walking, climbing and physical performance. However, we found that there are inconsistencies in mobility measurements, which made it difficult to compare across studies even using similar measure. These included the number of questions asked, the type of questions, scaling methods, the length of track or the number of steps, and administering instructions within a tool, regardless of whether it was self-report or performance-oriented. For instance, even though gait speed was assessed, the distance required for the test varied widely (8-foot distance, 4m, 10m, 15.24m, 300ft, or 400m). Given the lack of consistency in the way of measuring mobility in community-dwelling older adults, standardization of instruments is necessary for comparison across studies and for future comparative effectiveness research. In addition, as expected, inconsistent cut-off points of a tool were also found across studies, depending on age and gender of the population and the walking distance. Although there is a criticism that a varied range of cut-off points may limit generalization (Abellan van Kan et al., 2009), defining population-specific cut-off points can allow for better comparison of mobility problems in a target population.

Eight self-report instruments were found in this review, which are not condition specific and consist of several items. Noteworthy, this article does not provide an exhaustive review of mobility instruments. While about half of the mobility instruments have evaluated walking, climbing and functional abilities as a parameter of mobility, we found that the Environmental Analysis of Mobility Questionnaire, LSA, Life-Space Questionnaire, and Driving Habits Questionnaire have addressed a broader spectrum of elderly mobility and the importance of contextual factors in mobility limitation. A person's mobility level is determined by an interaction among intrinsic and extrinsic factors, such as cognitive, environmental, financial, physical and psychosocial factors (Tinetti, 1986; Webber et al., 2010); reduced social interactions or limited access to transportation may lead to a spatial constriction in elderly mobility (Auger et al., 2009). Therefore, it is necessary to further consider socio-ecological parameters to measure various aspects of mobility.

This review has provided an important contribution to knowledge by comprehensively examining existing measures of mobility limitation that can be used for community-dwelling older adults. However, there were limitations of the present review. First, only studies published in English were eligible for inclusion in this review. Second, this review does not provide an exhaustive list of mobility measures because of the inclusion/exclusion criteria. There is the possibility that our search strategy constrained the yield of mobility instruments and is not an exhaustive list of existing measures of mobility that identify older adults at risk of mobility limitation. For example, none of the studies identified in this review used measures of peripheral nerve function which may influence mobility limitation, likely due to our explicit definition requirement. Similarly, other tests such as the 6-minute walk test (6MW) was used in one only study (Wang et al., 2011) identified in this review although the 6MW is applied clinically across

different settings. Third, psychometric information regarding the identified mobility measures may not be exhaustive due to the inclusion/exclusion criteria, although the information may be available for instruments in other published articles not identified in this review. Lastly, the search strategy and study identification process could have the potential for selection bias.

Conclusion

The review demonstrated that most measures focused on the physical aspects of mobility limitation. We found there is lack of consistency in definitions used and operationalized constructs of mobility limitation as well as question types, administration process, setting, scaling, and cut-off points. The lack of consistency reflects the fact that we still need to focus on developing an accepted conceptual framework of mobility for this population. Only then will it be possible to identify items required to screen for the level of decline in mobility in which health care professionals and gerontologists have reached consensus. We propose a combined approach to choosing mobility measures within a community setting. For example, assessment of self-reported difficulty walking at two or three distances –short (walking across a room) and long (one-quarter of a mile) distances – may be necessary to accurately identify older adults at risk of mobility limitation. Performance measurement that either combines a gait speed at 4 meters and a long-distance walk test (e.g., 400m or 6MW) or use a more comprehensive lower physical performance battery, such as the SPPB or TUG, may have also greater success in assessing mobility limitation than use a single assessment. In order to foster more meaningful clinical decision making and patient-centered care in the future, this work needs to also incorporate the values and preferences of older adults themselves.

References for Chapter 2

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Figure 2.1. Process Flow for Literature Review

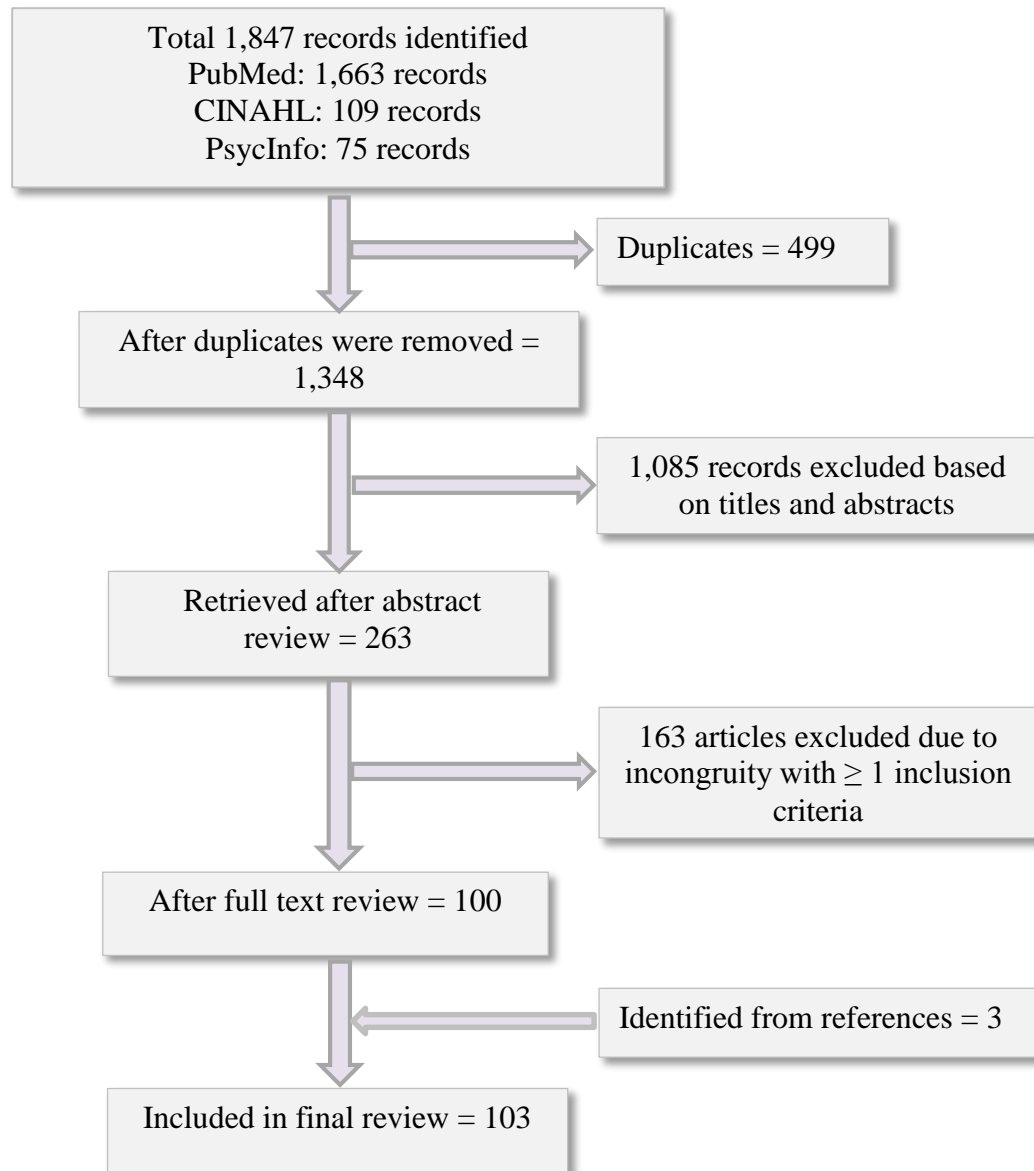


Table 2.1

Categorization of Empirical Constructs included in Mobility according to the Nagi Model

Concept in the Nagi Model	Definition	Empirical constructs of mobility limitation
Pathology	A condition of mobilization of the organism's defenses in the event of disease and injuries	None
Impairment	An anatomical, physiological, intellectual, or emotional abnormality or loss	Grip strength
Functional Limitation	Limitation in physical, emotional, and mental performance	Balance, bed/chair rise, climbing, crouching, functional reach, kneeling, lifting and carrying a heavy object, stooping, transferring, walking
Disability	Limitation in performing socially defined roles	Activity limitation, community mobility, doing heavy household work, dressing, driving, getting on a bus, spatial movement, task modification,

Note. Definitions above are simplified from the work of Nagi (1976).

Table 2.2

Self-Report and Performance-Based Instruments to Measure Mobility Limitation in Older Adults

Instrument	Used alone	Used in combination with other tools
	N (%)	
Self-report		
One question or two questions about “perceived difficulty in walking or climbing stairs”	43 (41.7)	12 (11.7)
More than three questions about “perceived difficulty in walking or climbing stairs”	6 (5.8)	3 (2.9)
Rosow-Breslau Scale	2 (1.9)	3 (2.9)
Life-Space Assessment of Mobility	3 (2.9)	1 (1.0)
Life-Space Questionnaire	2 (1.9)	1 (1.0)
Driving Habits Questionnaire	0	1 (1.0)
Others	1 (1.0)	3 (2.9)
Performance-based		
Single performance tests		
Gait speed	6 (5.8)	18 (17.5)
Ability to walk 400m	0	3 (2.9)
Distance over walked	0	2 (1.9)
Timed Up and Go Test	0	2 (1.9)
Chair rise	0	2 (1.9)
Berg Balance Test	0	2 (1.9)
Other	0	5 (4.9)
Instrument		
Short Physical Performance Battery (SPPB)	4 (3.9)	6 (5.8)
Observation & Videotaping		
Frequency of environmental encounters	0	2 (1.9)

Table 2.3

The Types of Questions to Measure Self-Reported Mobility Limitation and Distance or Activities Measured in Studies

Construct	Question	Distance walked/climbed or Specific activities	First Author and Year
<i>Functional limitation</i>			
Walking	Do you have difficulty walking (a certain distance)	400 yards	Ayis, 2006
	Are you able to walk (a distance)?	1/4 mile	Bannerman, 2002; Boudreau, 2009; Cappola, 2003; Cesari, 2005, 2012; Chaves, 2002; Davison, 2002; Fredman, 2008; Gray, 2011; Hardy, 2010a, 2010b; Hoffman, 2007; Houston, 2009, 2013; Jylha, 2001; Keeler, 2010; Kim, 2010; Koster, 2005, 2007, 2008; Lee, 2005; Leveille, 2007; Lihavainen, 2012; Manini, 2007, 2009; Patel, 2007; Penninx, 2004; Seino, 2012; Newman, 2006; Nordstrom, 2007; Stenholm, 2009, 2010; Shumway-Cook, Ciol, 2005; van den Brink, 2003; Visser, Goodpaster, 2005; Visser, Simonsick, 2005
		1/2 mile	Brach, 2012, 2007; Chaves, 2000; Clark, 2009; Gray, 2006; Gregory, 2011; Guralnik, 1993; Melzer, 2003; Mendes de Leon, 2006; Newman, 2008; Ostir, 1998; Salive, 1994; Visser, 1998; Wang, 2011; Weiss, 2007
		1 mile	Freire, 2012; Simonsick, 2008
		500m	Hirvensalo, 2007; Manty, 2009; Rantakokko, 2009
		1km	Fujita, 2006
		2km	Manty, 2009; Rantakokko, 2009
		1 block	Hung, 2012
	walking indoors and outdoors		Khokhar, 2001

		small room	Hung, 2012; Mendes de Leon, 2006; Rivera, 2008; Simonsick, 2005
	How much difficulty do you have walking (a distance)?	1 mile	Chang, 2004
	Have you had a change in your ability to walk?	1/2 mile	Brach, 2012
	Do you need help for walking?	1/4 mile 1/2 mile	Gill, 2006, 2012 Strawbridge, 1992
	How many blocks walked in the previous week?		Chang, 2004
	Can you walk outside during 5 minutes without stopping?		Melzer, 2005
	The maximum distance walked without difficulty		Ferrucci, 2004
	Do you need special equipment or aids to help you with walking?		Hoffman, 2007; Rivera, 2008; Shumway-Cook, Ciol, 2005
	How easy is it for you to walk (a distance)?	1/4 mile	Thorpe, 2011
	Do you get out of the house as much as you would like?		Fairhall, 2012
	Self-reported limitation in moving outdoors		van den Brink, 2003
Climbing	Do you have difficulty climbing stairs?	a flight of stairs 10 steps	Bannerman, 2002; Cappola, 2003; Freire, 2012; Fujita, 2006; Gray, 2006; Gregory, 2011; Houston, 2013; Hung, 2012; Khokhar, 2001; Manini, 2007; Newman, 2006; Nordstrom, 2007; Ostir, 1998; Salive, 1994; Stenholm, 2009; van den Brink 2003 Boudreau, 2009; Cesari, 2005, 2012; Davison, 2002; Fredman, 2008; Gray, 2011; Houston, 2009; Kim, 2010; Koster, 2005, 2007, 2008; Lee, 2005; Leveille, 2007; Patel, 2007; Seino, 2012; Stenholm, 2010; Visser, 1998; Visser, Goodpaster, 2005; Visser, Simonsick, 2005

		15 steps	Melzer, 2005
	How easy is it for you to climb (stairs)?	10 steps	Thorpe, 2011
	Ability to walk up and down stairs independently		Ayis, 2006; Clark, 2009; Guralnik, 1993; Keeler, 2010; Mendes de Leon, 2006; Wang, 2011
	Do you need help from another person to climb?	A flight of stairs	Gill, 2006; Strawbridge, 1992
Others	Self-reported limitation in non-walking mobility tasks	Carrying a heavy object	Davison, 2002; Hung, 2012; van den Brink, 2003
		Getting in and out of a bed or chair	Davison, 2002; Gregory, 2011; Khokhar, 2001
		Stooping, crouching, or kneeling	Davison, 2002
		Transferring	Abizanda, 2012; Weiss, 2007
Disability			
Activity limitation	Self-reported limitation in performing daily activities	Crossing streets	Khokhar, 2001
		Disembarking from a train or bus	Khokhar, 2001
		Doing heavy housework	Gregory, 2011
		Dressing	Weiss, 2007
		Driving	Gill, 2012
		Getting on a bus	Ayis, 2006; Chaves, 2000
Task modification	Have you changed the way you do the task?		Gregory, 2011

Note. Studies that used 3 items of the Rosow-Breslau Scale (difficulty in walking a quarter of mile, climbing stairs, and doing heavy work around the house) were not included in this table. Complete references for all included articles are available as a supplementary file.

Table 2.4

Characteristics and Psychometric Properties of Instruments to Measure Mobility Limitation

Instrument (First author, year)	Measured construct	Type	Example items or content	Other information
Environmental Analysis of Mobility Questionnaire (Shumway-Cook, 2003; Shumway-Cook, Patla, 2005)	Communit y mobility	Self- report	The effects of the physical environment on community mobility; 24 features of the physical environment were grouped into 8 dimensions; every feature is assessed with an encounter question (How often do you..?) or avoidance question (How often do you avoid...?)	5-point ordinal scale
Life-Space Assessment (Al Snih, 2012; Baker, 2003; Fairhall, 2012; Peel, 2005)	Spatial movement	Self- report	Range (bedroom, home, neighborhood, town and outside the town), frequency of movement and independence	Score range: Different scoring methods: maximal life-space, life-space using equipment, independent life- space, dichotomized measure and composite life-space
Life-Space Questionnaire (O'Connor, 2010; Sartori, 2012; Shah, 2012)	Spatial movement	Self- report	Questions asking about whether or not they have been to certain zones: period – in the past week and 2 months (Sartori, 2012); in the past week (Shah, 2012)	Score range: 0 - 6 (Shah, 2012), 0 - 9 (O'Connor, 2010; Sartori, 2012); larger scores indicate greater life space
Driving Habits Questionnaire (O'Connor, 2010)	Driving, spatial movement	Self- report	6 items assessing driving space (property, neighborhood, town, region, state, or country), the number of dates (0-7) that participants personally drove during a typical week	Dichotomous (yes/no); total score ranging from 0 to 6; larger scores indicate more driving space
Mobility-Help (Mob- H) Scale (Avlund, 2003)	Walking and climbing	Self- report	the need for help to transfer, walk indoors, go outdoors, walk outdoors in nice weather, walk outdoors in poor weather, and climb stairs	Score range : 0-6 according to the degree to which the participant manages the activities with or without need of help

Rosow-Breslau Scale (Buchman, 2010; Penninx, 1999; Shah, 2011; Whitson, 2007)	Walking, climbing, and activity limitation	Self-report	walking up and down a flight of stairs, walking one-half of a mile, and doing heavy housework like washing windows, walls, or floors	Response option: no help, help, and unable to do (Buchman, 2010); dichotomous (Whitson, 2007)
Walking performance interview (Sayers, 2004)	Walking	Self-report	18 item; asking how far and for how long the participant walked during normal walking behavior, and how easy and how difficult various walking tasks were	N/A

Note. Complete references for all included articles are available as a supplementary file.

Table 2.5

Types, Cut-Points, Scoring Methods, and Measuring Instructions of Performance-Based Tools

Construct	Test (First author, year)	Cut-point or scoring	Equipment requirements/ Instructions for the test
Walking	8-foot walk (2.4m) (Buchman, 2010; Mendes de Leon, 2005; Shah, 2011)	<ul style="list-style-type: none"> ▪ Gait speed of 0.4m/s for severe disability (Shah, 2011) ▪ Gait speed of 0.55m/s for mobility disability (Buchman, 2010) ▪ Scores from 1-5 assigned with higher indicating faster (Mendes de Leon, 2005) 	
	Fast gait speed (3m) (Melzer, 2005)	<ul style="list-style-type: none"> ▪ Gait speed of 0.4m/s for poor mobility performance 	
	Usual gait speed (4m) (Fairhall, 2012; Ferrucci, 2004; Rivera, 2008; Simonsick, 2005; Stenholm, 2009)	<ul style="list-style-type: none"> ▪ Gait speed of 0.5m/s for moderate to severe disability (Rivera, 2008) 	<ul style="list-style-type: none"> ▪ Home setting (Rivera, 2008) ▪ Use of a cane or walker permitted (Ferrucci, 2004; Rivera, 2008; Stenholm, 2009)
	Fast gait speed (4m) (Simonsick, 2005)		<ul style="list-style-type: none"> ▪ Use of a cane or walker permitted
	Usual gait speed (6m) (Blain, 2010; Thorpe, 2011)	<ul style="list-style-type: none"> ▪ Decline in gait speed defined as a 4% reduction in speed per year (Thorpe, 2011) 	<ul style="list-style-type: none"> ▪ Walking aids permitted at follow-up visits only (Thorpe, 2011)
	Number of steps taken over a 6-m course at usual pace (Blain, 2010)		
	The distance an individual can walk in 6 minutes (6MW) (Wang, 2011)		<ul style="list-style-type: none"> ▪ A 30-m long corridor; performed only once to avoid fatigue
	Maximal gait speed (10m) (Sakari, 2010)		<ul style="list-style-type: none"> ▪ Laboratory corridor

Gait speed at usual (Rolita, 2010) and fast pace (Choquette, 2010; Rolita, 2010)	<ul style="list-style-type: none"> ▪ gait speed $\leq 70\text{cm/s}$ is considered incident mobility disability (Rolita, 2010) 	<ul style="list-style-type: none"> ▪ Computerized walkway with embedded pressure sensors (GAITRite) in a quiet hallway wearing comfortable footwear and without any attached monitoring devices (Rolita, 2010)
Usual and fast gait speed (15.24m) (Wang, 2011)		<ul style="list-style-type: none"> ▪ Usual gait speed always preceded fast gait speed to ensure safety and comfort
Usual and fast gait speed (20m) (Thorpe, 2006)		<ul style="list-style-type: none"> ▪ Unobstructed corridor; walking aids permitted
Self-paced gait speed over a 91.4m (300ft) (Shumway-Cook, 2002)		<ul style="list-style-type: none"> ▪ Participants asked to walk for 3 minutes at usual pace in indoor course that contained 4 turns. Distance measured
The loss of ability to walk 400m within 15 minutes (Vestergaard, Nayfield, 2009)		<ul style="list-style-type: none"> ▪ The number and duration of rest stops recorded in intervals of <30 seconds and 30-60 sec. Sitting and assistive device use not allowed
400m walk test at fast pace (Simonsick, 2008; Vasunilashorn, 2009)	<ul style="list-style-type: none"> ▪ Gait speed $< 1.0\text{m/s}$; unrecognized mobility deficit > 7 minutes to walk 400m (Simonsick, 2008) 	<ul style="list-style-type: none"> ▪ 20 laps of 20 meters; 2-min warm-up walk, then 400-m walk as quickly as possible (Simonsick, 2008) ▪ Photo-based chronometer used (Vasunilashorn, 2009)
400m walk test (Patel, 2006)		<ul style="list-style-type: none"> ▪ Assistive device allowed; verbal encouragement, two standing rests permitted for < 2 minutes each
400m self-paced walk (Chang, 2004; Marsh, 2011; Sayers, 2004)		<ul style="list-style-type: none"> ▪ 20 laps of 20 meters, heart rate monitored (Chang, 2004) ▪ Assistive device not allowed; standardized verbal encouragement and 60 seconds rest allowed. 4 laps

			of 100m corridor (Boston) and a 20-m course marked by cones at each end, with 10 laps constituting 400m (Pittsburgh) (Sayers, 2004)
	400m walk test at usual pace (Vestergaard, Patel, 2009)		<ul style="list-style-type: none"> 10 laps of 40 meters; Standing rest stop allowed not exceeding 60 seconds per stop (Marsh, 2011)
	Distance walked over 3 minutes and velocity for self-paced gait (Shumway-Cook, 2003)		<ul style="list-style-type: none"> Standing rest stop allowed not exceeding 60 seconds
Balance	Berg Balance Test (Shumway-Cook, 2003; Shumway-Cook, 2002)		
	Timed Up and Go (TUG) (Karttunen, 2012)	<ul style="list-style-type: none"> 13.5 sec or inability for mobility limitation 	<ul style="list-style-type: none"> Standard armed chair used; participants wore regular footwear; usual ambulatory device allowed; support from the arms rests of the chair if necessary
Climbing	Step-mounting test: the maximum height that subjects could mount unsupported (Sakari, 2010)	<ul style="list-style-type: none"> The results were scored from 0cm to 50cm. 	<ul style="list-style-type: none"> 5 boxes of dimensions 60cm (length) x 60cm (width) x 10cm (height); use of either leg allowed
Community mobility	Community mobility (Shumway-Cook, 2002; Shumway-Cook, Patla, 2005)	<ul style="list-style-type: none"> Encounter scores range from 8 (low frequency of encounter) to 24 (high frequency of encounter) (Shumway-Cook, Patla, 2005) 	<ul style="list-style-type: none"> Subjects were observed and videotaped during trips into the community requiring ambulation.
Multiple constructs	TUG, chair stand, and one leg stand (Choquette, 2010) TUG (3m), chair stand, one leg stand, functional reach, and grip strength (Wang, 2011)		<ul style="list-style-type: none"> Testing sequence was randomly determined.

Short Performance Physical Battery (walking speed, repeated chair rises, and standing balance)

- walking distance: 2.4m (Guralnik, 1995; Ostir, 1998; Shumway-Cook, 2003; Shumway-Cook, 2002), 4m (Bean, 2011; Milaneschi, 2010, 2011; Patel, 2006; Sayers, 2006), not specified (Reid, 2008; Simonsick, 2005)

- Score range: 0-12 (Bean, 2011; Sayers, 2006; Shumway-Cook, 2003) or 1-11 (Ostir, 1998)
- 0 to 4: severe mobility limitation, 5 to 9: mild to moderate mobility limitation, and 10 to 12: good mobility (Milaneschi, 2010)
- Poor mobility performance ≤ 10 (Milaneschi 2011)
- Moderate mobility impairment >7 ; severe mobility impairments ≤ 7 (Reid, 2008)

- Carried out in the home by trained interviewers (Guralnik, 1995)

Note. Complete references for all included articles are available as a supplementary file.

Chapter 3.

The Role of Culture on Older Adults' Acceptability of Home-Based Monitoring Technologies²

Abstract

Home-based monitoring technologies have the potential to support healthy aging among older adults. Despite the increasing use of these technologies by older adults, there is a lack of studies examining older adults' acceptance of home-based monitoring technologies, especially for people from diverse cultural groups. The purpose of this study was to explore Korean older adults' and immigrant Korean older adults' attitudes toward and perceptions of home-based monitoring technologies in a cultural context. A qualitative analysis of three focus groups and four individual interviews using a constant comparative approach for emerging themes was conducted. Participants perceived that sensor technologies would be useful if health risks were to increase. There were several cultural factors determining the acceptability of home-based monitoring technologies. Most notably, the necessity of living alone due to loosened filial tradition and immigration was a main motivator for adopting these technologies for both Korean and Korean immigrants. The level of satisfaction with the health care system or therapeutic interaction affected their perceived need for technologies. Compared to the Korean immigrant group, Korean older adults regarded the government's roles as important in wide adoption and use of new technologies. Findings indicate the need for considering contextual factors when

² This manuscript has been submitted for review in the *Journal of Cross-Cultural Gerontology* and written to meet their publication guidelines.

explaining acceptance of home-based monitoring technologies among older adults from various ethnic groups and developing diffusion strategies according to end users' attitudes, experiences and cultural backgrounds.

Keywords: culture, home-based monitoring technologies, older adults, perceived usefulness, technology acceptance

Introduction

The global population of older adults is growing rapidly. Older adults prefer living independently in their homes for as long as possible (American Association of Retired Persons, 2012). In order to promote independence or prevent emergencies, efforts exist to support the adoption of technology solutions into the home or community. Home-based monitoring technologies have been developed as tools to address many of the healthcare challenges faced due to the worldwide aging of the population, such as lack of high-quality, efficient and accessible care (Lindeman, Wang, Steinmetz, & Redington, 2011). Passive remote monitoring systems installed in the residential infrastructure and the utilization of wearable sensors are becoming widely available. Examples of home-based monitoring technologies include 1) activity monitoring that employs wireless motion sensors, in-kitchen temperature sensors, door contact sensors and/or pressure mats (Kaye et al., 2011; Rantz et al., 2013), 2) sleep monitoring that can be achieved by detecting postural changes or cardiorespiratory function (Rantz et al., 2013) and 3) safety monitoring with fall detection (Chaudhuri, Thompson, & Demiris, 2014).

Despite the increased interest in home-based monitoring technologies for older adults, there are some unique challenges to the adoption and use of these technologies. Older adults' acceptance of home-based monitoring technologies is different from that of other types of technologies (Mahoney, 2011). Also, implementing monitoring technologies in the home setting can be intrusive to individuals and might also bring privacy concerns. In order to adequately design and implement sensor technology solutions to address the specific needs of older adults, facilitators and barriers to its adoption and utilization need to be examined. Although researchers have examined older adults' perceptions of home-based sensor technologies (Boise et al., 2013; Chung et al., 2014; Demiris et al., 2008; Reeder et al., 2013), much of the research among older

adults has focused on non-Hispanic whites. There is a lack of studies that have explored the acceptability of technologies among other cultural groups such as Korean older adults where perceived filial duty of children and other cultural norms tend to affect how aging models and interventions are perceived. It is questionable whether the knowledge on home-based monitoring technology acceptance of primarily white older adults in Western countries as documented in scientific studies, can be transferred to groups of older adults in non-Western countries or other ethnic, racial or broadly cultural groups in the US. We address this gap through the examination of home-based monitoring technology acceptance in a cultural context among older Korean immigrants and older adults living in Korea. The qualitative study aimed to explore attitudes toward and perceptions of home-based monitoring technologies among immigrant Korean older adults and Korean older adults.

Technology Acceptance in Older Adults

Over the past several decades, the Technology Acceptance Model (TAM) has been widely used to predict and explain an end user's response to new technology (Davis, 1989). According to the TAM, perceived usefulness and perceived ease of use predict technology acceptance. Several studies, mostly conducted in Western countries, have identified various factors influencing an end user's technology acceptance, including 1) user characteristics (age, education, or socioeconomic status), 2) user attitudes, needs, and preferences, 3) features of the technology, and 4) management support (Olson, O'Brien, Rogers, & Charness, 2011; Schulz et al., 2013; Venkatesh & Morris, 2000; Wu, Shen, Lin, Greenes, & Bates, 2008). However, how to increase technology adoption among older adults is still a pressing issue.

Furthermore, to address unique characteristics of the elderly population, some researchers have made an effort to develop a theoretical framework specifically focused on older adult

technology acceptance. For instance, Mahoney (2011) proposed the Adoption of Technology Model (ATM) that recognizes special features of passive remote monitoring technology for daily activities of older adults. The ATM considers pre-disposing factors of end-user adoption such as: a user's socio-demographic background, potential roles of multiple stakeholders and social-system setting. The model emphasizes a critical influence of the social-system setting, such as context and compatibility of technology with target user's culture, on determining the acceptability of the technology among older people. Similarly, the Accelerating Diffusion of Proven Technologies (ADOPT) model regarding home and community-based technology for older adults (Wang et al., 2011) addresses two contextual factors that affect older adult perception of technology: 1) technology-related policy including reimbursement, interoperability, privacy considerations, and regulation; 2) economic and other logistical resources or access. However, these two models have not been validated.

Many studies report that seniors are motivated to use new technology by utility and perceived benefits (Courtney, 2008; Melenhorst, Rogers, & Bouwhuis, 2006; Mitzner et al., 2010). Czaja et al. (2006) explained that older adults' cognitive abilities, computer self-efficacy, and anxiety related to using a computer had a mediating effect on technology adoption. Additional challenges to technology acceptance identified in the literature include fear of losing control (Lorenzen-Huber, Boutain, Camp, Shankar, & Connelly, 2011), privacy concerns (Courtney, 2008), and lack of confidence and familiarity (Czaja et al., 2006). The samples in these studies were primarily non-Hispanic white, African American and Hispanic seniors. Very little is known about the user attitudes, needs and preferences of Asian and Asian American older adults.

Cultural Context of Technology Acceptance in Older Adults

There has been considerable interest in culture theories to explain an end user's behaviors related to technology adoption and usage. Culture is manifested through certain artifacts including art, technology, and visible and audible behavior patterns (Leidner & Kayworth, 2006). Culture plays a critical role in forming basic assumptions among a group of people and it is manifested as attitudes, beliefs, customs, norms, and other psychological constructs. Therefore, it can affect users' attitudes toward and perceptions of technology (Lee, Choi, Kim, & Hong, 2007; Leidner & Kayworth, 2006).

Given that technology is not culturally neutral, people's responses to technology can vary according to their culture. For example, in a study on adoption of biotech for agriculture in sub-Saharan Africa (Ezezika et al., 2012), consideration of the role of women and men in agriculture is critical for its development and integration. Although the majority of farmers are women, in this cultural context they are not encouraged to participate in decision making and is therefore an important consideration. Therefore, examination of cultural issues is necessary to facilitate better informatics research that aims to support the application and dissemination of technology in culturally diverse groups.

With the increased attention to aging in place initiatives (Rantz et al., 2013; Vasunilashorn, Steinman, Liebig, & Pynoos, 2012), it is becoming important to recognize the importance of cultural factors in achieving greater acceptance of needed technologies among various groups of older adults. However, we do not know much about the relationship between cultural differences as constituted by a geographic locality and technology adoption in older adults. Walsh and Callan (2011) suggest the importance of contextual factors in constructing the acceptance of technology for community care, such as care sector, preference for person-to-

person contact, and context of place. The role of cultural factors thus should be noted to understand consumer demands and reduce barriers to necessary technologies for seniors from multiethnic groups.

To date, there have been few studies that investigated the linkage between the acceptance of health information technologies and culture in groups of older adults, even fewer among older Asians. Jen and Hung (2010) investigated which factors affected Taiwanese family's intentions to adopt technology for their older adult family members. This study showed that Taiwanese family's attitude was a significant determinant of the adoption of mobile healthcare services by older Taiwanese individuals. In a more recent study, one of the factors contributing to the high acceptance of telehealth technology among Korean American older adults was their respect for learning as well as respect for the professionals providing videoconference healthcare services (Jang et al., 2014).

The current study was designed to address the gaps in the existing literature by conducting an in-depth qualitative exploration of the acceptability of home-based monitoring technologies among older Korean immigrants in the United States and older adults living in Korea. In Korean culture, Confucian-inspired notions, such as filial duty of children and respect for older adults are considered important (Sohn, 2010). Provision of care for older parents at home has been the norm among Korean families. However, societal changes, including the increase in the number of working women and changes in family structure have influenced the way older adults are cared for both in Korea and the United States. Older adults thus may need to accept an alternative form of care, for example, innovative technology-based solutions. In this regard, it is important to examine what factors could increase technology acceptance and diffusion in a Korean older adult group. This investigation focused on the comparison of

participants' attitudes toward and perceptions of these technologies between these two groups.

Materials and Methods

Study Design

We conducted focus groups and individual interviews with older Korean immigrants in the United States and older adults living in Korea to solicit responses to questions regarding the acceptability of home-based monitoring technologies. A qualitative analysis of in-depth individual interviews and focus groups using a constant comparative approach for emerging themes was conducted (Polit & Beck, 2008). The study protocol was approved by the Human Subjects Division at the University of Washington, Seattle.

Participant Recruitment

The participants for this study comprised of 11 older Korean immigrants and 10 older adults living in Korea. Inclusion criteria for older Korean immigrants were (a) community-dwelling individual residing in the greater Seattle metropolitan area, (b) born in Korea and immigrated to the United States, and (c) aged 65 or older. Inclusion criteria for older adults living in Korea were (a) community-dwelling individual (b) born in Korea and currently living in Korea, and (c) aged 65 or older. Exclusion criteria for both groups included inability to speak or read Korean and to provide written informed consent. Participants were recruited through convenience and snowball sampling methods. For the group of Korean immigrants, access to study participants was facilitated through staff members of Korean American senior associations and non-profit organizations for Asian older adult immigrants in the Pacific Northwest. Recruitment of Korean older adults was conducted using the following strategies: churches and in-person contacts in the Seoul metropolitan area in Korea. All potential participants were screened before the interview to assess whether they were eligible for study participation.

Data Collection

Data were collected between March 2013 and March 2014. Demographic data was collected on participants except for the first focus group. Open-ended semi-structured interview questions were used. Three focus group sessions (2 for Korean immigrants and 1 for Koreans) and four individual interviews were conducted in Korean with 21 individuals, lasting approximately an hour. Eleven Korean immigrant older adults comprised two focus groups; individuals in the first group were members of the Korean American senior association while those in the second group were residents of an independent retirement community. Participants in Korean focus group were members of a church located in Incheon, Korea. While one researcher moderated the focus group session, another researcher took field notes to document contextual information and non-verbal expressions for later data analysis and interpretation. Four individual interviews were carried out via phone with older adults living in Korea, each lasting 30-40 minutes. Each focus group and individual interview was conducted in Korean language using an open-ended semi-structured interview protocol. Because most participants were not familiar with home-based monitoring technologies, the moderator provided participants with a handout containing photos of various sensors and sample data visualization (Figure 3.1). The moderator explained each page of the handout during the session to enhance understanding and facilitate discussion. Individual interviews via phone were conducted with older adults living in the Seoul metropolitan area in Korea. For individual interview participants, the handout was provided via email or in person. All focus groups and interviews were audio-recorded and transcribed verbatim. All the transcripts were translated into English and verified by another translator who is fluent in both Korean and English to check the accuracy of translation.

[Figure 3.1 about here]

Data Analysis

Audiotapes were transcribed verbatim and then compared with the audio recording to ensure accuracy. The transcripts were translated into English and then manually coded for initial themes. Two coders independently conducted initial coding of the first two transcripts for focus groups to create a code book. Coders met to standardize codes and reconcile disagreements until consensus was reached. Codes from the code book were reviewed for content validity by another researcher after several transcripts were coded. Subsequently, three trained investigators coded all the transcripts independently and further revised the code book. Coders met weekly to reconcile disagreements until consensus was reached about code application. Final results were summarized by the first author with assistance from the other coders.

Results

Demographics

A total of 21 older adults over the age of 65 participated in focus group sessions (17 participants) or individual interviews (4 participants). These focus groups included a Korean American senior association group (5 participants), a lower-income independent retirement community (6 participants), and a senior group of a church in Incheon, Korea (6 participants). Eight of 21 participants were male. Table 3.1 summarizes demographic characteristics of study participants.

[Table 3.1 about here]

Perceptions of Home-based Monitoring Technologies

Knowledge of Home-based Monitoring Technologies. When participants were asked about the use of home-based monitoring technologies for health before any explanation was provided, many older Korean immigrants reported that they did not know about such

technologies, leading to a lack of concern about their use, exemplified by the comment: *“If we faced unexpected consequences, then we would worry, but at this point I don’t have any concerns beforehand”*. On the contrary, several Korean older adults were aware of home-based monitoring tools such as *“some kinds of chips... placed in a body”*, or devices *“that let other people know you fell down”*. Their information source was mainly media. Both older Korean immigrants and Korean older adults perceived it as a novel idea and showed their interests in using these technologies.

Understanding of How The Technology Works. As part of the interview, participants were presented an explanation of different types of home-based monitoring technologies, their functions, data transmission mechanism, and a sample visual display of data to facilitate their understanding of how these technologies work and how data can be generated and transmitted. Nevertheless, there were some instances in which several participants questioned if a monitoring system installed in home would take a photo of a resident or function like a closed-circuit television (CCTV). This view was observed mainly among Korean participants, such as *“they are not taking pictures like smart phones, are they?”*. The reasons for this need further exploration, but one potential reason may be the ubiquitous use of CCTVs in communal areas of Korea, such as streets, stores, hallways, and elevators. Interestingly, it appears that Korean participants seemed to get a clear idea of the functionality of home-based monitoring technologies by comparison it with a camera or CCTV. For example, one man commented that *“(they are) not a camera, and it detects my movement only”*.

Perceived Usefulness of Home-Based Monitoring Technologies. Although participants reported that they do not have sufficient information on home-based monitoring technologies, both Korean older adults group and immigrants group responded positively toward the idea of

using these technologies for older adults. Participants foresee the potential value of these technologies for managing health. For example, participants stated, “*It could monitor my health status remotely*”, or “*it would teach me*”. In addition, one Korean participant emphasized a preventive purpose of health monitoring, “*It can be used for prevention of disease progress. Before you get so ill and face big problems, you could benefit from health care services*”. Convenience was also considered one of the benefits of utilizing sensor technologies at home.

Cultural Factors Affecting Home-Based Monitoring Technology Adoption

Independent Living due to Immigration and Loosened Filial Tradition. Some Korean participants pointed out that older adults living in Korea are facing an issue of living alone or at distance from their children. One woman described the lack of support from children compared to tradition of filial piety in Korea: “*more and more parents are not well served by their children*”, which seems to be a motivator for adopting home-based monitoring technologies for health. Furthermore, one Korean participant provided contextual information to explain why these technologies would be useful for those living alone without family. He introduced the term ‘*go-dok-sa*’, which literally means *lonely death* in Korean and is used to describe what has become a serious social issue among Korean older adults living alone. He explicitly stated that:

*“Those sensors seem to target ‘dok-go-no-in’ [*This Korean word has a literal meaning of older adults who live alone, but Korean people sometimes use the word to indicate elders living alone with low income or being abandoned]... Older adults who have family would be fine, but it must be hard for ‘dok-go-no-in’ to deal with things by him/herself. I think it would be necessary to install these sensors in homes of ‘dok-go-no-in’. Many dok-go-no-in were found several months after they had passed away”.*

Immigrant Korean elders seemed to accept their current situation – living alone or separately from children after their immigration into the U.S. Also, their living situation made them more independent in their decision making, “*my family lives far away, so they aren’t involved...*”,

which could also affect their decisions regarding the use of technologies in the home setting. One participant stated,

“There aren’t many (older Korean immigrant) individuals who live together with their children in the U.S. They live separately from their children. (Therefore), I think people older than 90 years desperately need sensors.”

However, some Korean immigrant elders who live alone in a retirement community where they are “receiving assistance from (home care) helpers” did not perceive that these technologies are necessary.

Satisfaction with Health Care Services. Based on the comparison of both groups, the level of satisfaction with the current health care services seemed to be related to perceived usefulness of home-based monitoring technologies. Although several Korean people perceived that “(health insurance) is going well in our country”, they expressed their disappointment toward physician-patient interaction and the quality of health care services compared to the past. Consequently, Korean participants dissatisfied with health care services were receptive to the idea of using innovative technologies for their health at home. By contrast, many immigrant Korean elders were satisfied with the U.S. health care system, and some of them were less enthusiastic about adopting these technologies.

“I am not experiencing much inconvenience. (I don’t have an urgent need for any help or assistance), because we have all the benefits... I am very satisfied.”

IT Capacity Building by the Government. Korean participants, in particular, and some older Korean immigrants discussed that government’s interest in adopting technologies for older adults determines the level of diffusion of technologies, supported by this comment: “I hope the government has a plan for this kind of technology. If there is support from the government, who would refuse it?”.

Korean older adults were interested in the role of market and government's policy to expand the accessibility and affordability. They further discussed that these technologies are not actively being introduced due to lack of profitability. Consequently, they recognized an active role of a private sector in developing and implementing home-based monitoring technologies in order to ensure competitive market economy so that low-cost technologies are available. Also, they expressed their expectations of the Korean government's efforts to improve accessibility to health information technologies for older adults. Interestingly, they seemed to regard expanded access to home-based monitoring technologies targeting older adults as an indicator of technological capabilities for developed countries, leading to this comment: "*I feel like these things should be widely used if we would say that Korea is a developed country*". Furthermore, focus group participants in Korea identified a lack of public policy related to senior housing and long-term care benefits as a challenge to expanding older adults' access to technology. One participant commented that due to high cost, it is hard for older adults to choose to live in an apartment that is a preferred housing type in Korea, and thus government should make an effort to make sure that "*these technologies should be installed in houses or small homes like studios*".

Perceptions of Need for Home-Based Monitoring Technologies

Socio-demographic Characteristics. While recognizing the usefulness of home-based monitoring technologies, some Korean immigrant elderly and Korean older adults shared their opinions in common that these technologies are useful for individuals older than them. This was exemplified by the remark: "*when I become very old, I want to have a system like that... Now, we are healthy, so we are probably okay*". Several Korean immigrants emphasized that they are not that old, such as "*I feel like I am still fine. We are just 70s, right?*", so they did not feel the need for these technologies until they get older. On the contrary, some Korean older adults in late 60s

and early 70s expressed a desire to use those technologies earlier than they become older, partly because it looks useful for purposes of prevention.

“It can be used for prevention of disease progress. ... Since looking at your data (obtained from technologies) is the first step in a trajectory of health care, I think it seems to be very helpful.”

The current living situation of older adults was mentioned as one of the factors affecting participant perceptions of home-based monitoring technologies. This theme applies to both Korean and Korean immigrant groups. Specifically, several people who acknowledged the potential usefulness of such technologies did not see themselves as the main beneficiaries of these technologies, but thought that older adults who live alone would benefit the most from home-monitoring systems, exemplified by the comment *“that looks good for an elderly person who is living alone”*. Some Korean immigrant elders identified other individuals or instances to explain why such technologies would be useful for those who live alone, such as: *“one of our members had a fall at home and stayed several days alone. He could not reach anyone... This (technology) could be very useful for him”*.

Changes in Health Status. Older adults in this study had mixed opinions about usefulness of home-based monitoring technologies with regard to health status. This theme also applied to both Korean and Korean immigrants groups. While some older adults explicitly expressed their desire to use such technologies at home, others did not seem to feel an immediate need for using these technologies, exemplified by the comment *“I don’t feel like I need it, for the present”*, because their perceived health status is good. In many cases, participants appeared to perceive home-based monitoring technologies as useful if health risks were to increase across focus groups and interviews. For example, one participant commented that *“well, when I start to have some troubles in my memory, or even have a dementia or Alzheimer’s disease and live*

alone, I think I would want to have a full automatic sensor system". Mobility limitation was considered another reason by several participants for adopting the technology, such as *"if I had difficulty with mobility or something, I would want sensors, but now (I don't need it)"*. Similarly, one Korean participant stated that he would not adopt the technology if he is independent and cognitively intact, even if he gets older.

Preferences for Home-Based Monitoring Technologies

Uses for Specific Health Applications. Both Korean older adults and older Korean immigrants identified potential uses for home-based monitoring technologies and personal activity data, such as an alarm system in emergencies, monitoring symptoms (e.g., wandering behavior of dementia patients), or a tool for prevention or disease management. Among several possibilities, a fall detection function was rated to be the most useful technology by most participants, because they were worried about a situation in which they could not get help from anybody after they fell down: *"that might be good if we were in a bad condition"*. Similarly, one woman thought a pressure sensor placed under the door mat *"that knows somebody coming in and out"* is *"the most necessary thing"* because its function being activated when someone is at the door can extrapolate health information as to whether an individual is ambulatory or not due to fall events. Moreover, one participant who was skeptical about home-based monitoring technologies due to a privacy concern shared his interest in fall detection sensors. Here is his remark:

"The fall sensor looks great. I heard from my aunt that she fell once because she felt dizziness. Because of the fall, her face got bruised and she was bleeding from the injury. Luckily, somebody noticed the injury and helped her to get up from the ground. In this case, if we had this fall sensor, we could press the button to contact family right after the fall."

Participants reported preferred features from a system design perspective. Several immigrant Korean elders noted a need to “*contact health care professionals or 911 in case of emergency, especially if we have falls*”, and added “*otherwise it is useless.*” Also, one man preferred a button in a fall sensor to send an alarm to a designated family member or informal caregiver.

Privacy Concerns. Privacy issues resulting from instrumenting monitoring technologies in the home setting were discussed by both Korean older adults and older Korean immigrants. Some older Korean immigrants stated that they might be worried because “*I used to walk around in my undies at my home, but if I had something then... (it would bother me)*”. Additionally, participants across groups and interviews perceived that some features of home monitoring technologies including recording sounds, taking photos, or videotaping would be a potential risk of privacy invasion. One participant living in Korea further commented that users should be careful about using sensors and “*decide clearly about whom we tell about this*”. He was concerned that “*sensors could be used in a bad way*” if users disclose the presence of sensors to others besides family and health care providers. Here is his comment:

“I might be concerned about confidentiality issues, such as a breach of my personal information or potential harms due to my information being exposed to others. For example, there would be a possibility that a burglar could see my data accidentally and come along after I go out. That would be my concern.”

On the other hand, when asked if technologies installed at home would affect their behaviors, most participants reported that “*it would not bother me. I would do things naturally*”. One of the reasons for this response is that “*we are already old (so, there is nothing to hide)*”. Interestingly, two Korean older adults acknowledged the obtrusive feature of the technology having a positive effect on their behavior change for health, exemplified by the remark: “*I could*

be aware of it being there, so I might try not to stay at one place for a long time and I might be able to try to become active for my health”.

Management of Technology and Data. A few Korean and Korean immigrant participants voiced that the issue of system management should be resolved prior to adopting home-based monitoring technologies. Korean participants mentioned that installing technologies at home should be accompanied by technical support for managing a system and data, exemplified by the quote: *“I am wondering who is responsible for managing the system. The government? Or police station? I think that, in reality, this system should be connected to children”*. He additionally commented that this issue would not affect older individuals who live in nursing homes or senior housings because there is likely to be a centralized system to manage devices and data as opposed to private housing. In addition, a few older Korean immigrants addressed the importance of developing a reliable system, because equipment malfunction during the data collection could be a potential harm for older adults who are frail and dependent on the system.

Low-Cost Technologies. For many older Korean immigrants, the high cost of technology systems was described as a main barrier to obtaining necessary monitoring technologies, exemplified by the following quotes: *“People cannot afford it”* and *“Maintaining it also costs money”*. Therefore, they wanted the government to establish a plan for improve the affordability of these technologies. An interesting thing to note is that one Korean participant mentioned a cost issue with regard to the possibility of theft: *“about being stolen, if the price of the sensor system is high”*.

Discussion

The study findings indicated that there are several cultural factors affecting the acceptability of home-based monitoring technologies among older Korean immigrants and Korean older adults. It is notable that Korean older adults who felt a lack of support from their children were motivated to adopt new technology. The population of older adults in Korea has experienced changes in family structures because economic development has changed the expectation for filial obligation by their children (Ko & Hank, 2014; Yoon, 2013). Korean older adults who were obligated to take care of their older parents by filial tradition do not expect their children to provide support to them. The sociocultural change in modern Korea found in this study was a distinctive factor determining Korean older adults' acceptance of home-based monitoring technologies. Compared to Korean older adults, Korean immigrant participants already accepted their living circumstances – living alone or separately from their children. It was partly due to American cultural norms that respect independence between parents and children. Regardless of the reasons, this study supports findings from previous studies that a user's living situation is associated with perceptions of home-based monitoring technologies and intention to adopt a new technology (Courtney, Demiris, Rantz, & Skubic, 2008; Essen, 2008).

Older adults' satisfaction with the current health care services seemed to influence their acceptance of home-based monitoring technologies. A difference was found in the level of satisfaction between Korean and Korean immigrant elderly groups even though we did not quantify participant satisfaction levels. Notably, some Korean older adults perceived a lack of physician-patient contact compared to the past even though they were satisfied with the Korean national health insurance system. Therefore, they recognized the potential of home-based monitoring technologies that is supplementary to existing methods for health management. This

view is aligned with the recent movement in European countries where health information technologies serve a complementary role in existing elder care (Walsh & Callan, 2011). Compared to the Korean participants, most Korean immigrant participants were from lower income communities, which made them dually-eligible for Medicare and Medicaid. Because of their dual eligibility, older Korean immigrants were generally satisfied with health care they receive and thus were less interested in using home-based monitoring technologies. Further examination is needed to better understand the relationship between older adults' experience of health care services and health service utilization and technology adoption.

Previous work on older adults' adoption of home-based monitoring technologies has less focused on exploring contextual variables that affect whether one chooses the technology solution (Courtney et al., 2008; Essen, 2008; Mihailidis, Cockburn, Longley, & Boger, 2008; Mitzner et al., 2010; Reeder et al., 2013; Wild, Boise, Lundell, & Foucek, 2008). Walsh and Callan (2011) emphasizing the necessity of considering a sociocultural context when explaining older adults' adoption of information and communication technologies, such as poor resources, lack of coordinated care, less spending on long-term care, and lack of prioritization. In this study, older adults provided unique insight into the role of the government and health policy in determining technology adoption. This was found primarily in a Korean older adult group, and some older Korean immigrants. Study participants voiced that it is necessary to make public policy at the national level to maximize the benefits of these technologies especially for those of low income and who are living alone. The areas for improvement identified by both groups include affordability, a centralized system of technology management, and housing infrastructure. Furthermore, the cost issue, perceived as one of the barriers to technology adoption, was discussed by study participants in relation with policy initiatives that provide

subsidies and make sensing infrastructure in home available to older adults in need of the technology. According to one study, a national subsidy program in the United Kingdom played a partial role in increasing the adoption of personal emergency alarm systems by 15% in contrast to the adoption rate of less than 5% in the non-subsidized US (Lau, 2006). Our study participants also called for the government's effort to develop policies expanding accessibility to these technologies to ensure adoption by the older population. This indicates that the role of the government is considered important by both Korean immigrant elderly and Korean older adults in achieving technology adoption. The findings suggest that factors affecting older adults' acceptance of home-based monitoring technologies extend beyond just the personal realm.

For the majority of immigrant Korean participants living in the US, using home-based technologies for monitoring health was considered a novel idea, while about a half of Korean participants reported their previous exposure to the information about various sensor technologies. Also, most Korean participants were open to the idea of using innovative home-based sensors while a fewer number of their counterpart expressed their desire to use these technologies at home. It seems that participants' previous exposure to IT-related information determines their intention to use of novel technologies. This information gap between these two groups might be explained by the sociocultural context to which two groups of participants belong. In accord with previous research (Rhee, Chi, & Yi, 2013), Korean immigrant elders seemed to be separated from the US culture due to limited English proficiency. Their social activities were restricted to the Korean community, and had social networks with Korean immigrants only. Because of their limited acculturation level characterized by separation as well as a linguistic barrier, they might not be easy to obtain health-related information including health information technologies as opposed to older adults living in Korea which is considered a

tech-savvy society (Shin & Jung, 2012). This finding could also be supported by the theory of diffusion of innovation proposed by Rogers (Rogers, 2003), which explicates the process by which new technologies are adopted by users. The results indicate the need for developing diffusion strategies depending on a target group's level of knowledge and experience related to technologies. That way, we can guide older people who are in need of tools for health monitoring and management to make decisions regarding adopting innovative technologies.

IT evaluation studies have addressed the importance of technology acceptance among users, because acceptance is the first step to diffusion of technology that is proven to be effective (Wang, Redington, Steinmetz, & Lindeman, 2011). In this study, those who recognized the potential value of using home-based monitoring technologies considered the technology acceptable. Although we did not directly assess older adults' intention to use a home-based monitoring technology, some expressed their interest in purchasing one, if available. This finding is supported by previous studies explaining the relationship between perceived usefulness and a user's intention to adopt a new technology (Davis, 1989; Venkatesh & Davis, 2000). However, this should be viewed cautiously as intention does not necessarily lead to their purchasing behavior or actual use of technologies (Lim et al., 2011). Functionalities that generated positive attitudes towards innovative home-based monitoring included convenience, remote health monitoring, prevention of adverse health outcomes, and a tool for understanding one's activity patterns. The literature supports our findings of features that affect older adults' positive perception of a new technology (Essen, 2008; Marschollek et al., 2009; Mihailidis et al., 2008; Mitzner et al., 2010). The finding suggests a need for research to understand what specific home-based monitoring features generate positive or negative perceptions among community-dwelling older adults.

In addition to cultural factors, this study identified several other factors influencing older adults' perceptions of home-based monitoring technologies, such as age, current living situation, perceived health, privacy concerns, and system functionality. It should be noted that participants who perceived themselves as healthy and not that old did not feel the urgent need for using these technologies, although they still had a positive view regarding these technologies. This finding is supported by prior literature. For example, Reeder et al. (2013) reported that older study participants lacked perceived need for in-home sensors because they thought they maintained good health. In contrast, in a study by Essen (2008), older adults who were aware of their frailty expressed a need for a telemonitoring device. Furthermore, both Korean older adults and Korean immigrant elderly had a keen awareness of fall detection technologies. The level of participant interest in fall detection sensors was higher than their interest in other types of home-based monitoring technologies. Even some participants who were skeptical about using in-home technologies for health monitoring due to privacy concerns showed willingness to adopt fall detection devices. Their intention to use this type of technology appears to be associated with older adults' fear of not being able to get help or fall-related injuries. Follow-up studies are needed to think about how home-based technology solutions best fit with older adults' fall-related challenges.

This study had several limitations that need to be acknowledged. First, the sample was purposively selected from one geographical location in the US and one in Korea, and may limit generalizability of the study findings. Second, participants' reactions towards technological solutions may be biased or limited by the explanation given during the interview introduction, as no participant had previous experiences with home-based monitoring technologies. Thus, their opinions may not represent perceptions or opinions of Korean older adults or Korean immigrant

elders who have used in-home health monitoring technologies. Third, despite the criticism that heterogeneity among individuals from a country is sometimes greater than heterogeneity among a group of people from different countries (Lee, Choi, Kim, & Hong, 2007), this paper examines culture at the national level, assuming that individuals in one country may represent similar cultural profiles.

Despite the aforementioned limitations, this study has strengths. This study explored Korean older adults and older Korean immigrants' perceptions of home-based monitoring technologies in a cultural context. To our knowledge, this is the first study to examine older adults' acceptability of home-based monitoring technologies in such a cultural context. In addition, we focused cross-national differences in perceptions and intention to use of home-based monitoring technologies among the Korean ethnic group. This study contributes new knowledge to the literature on technology adoption among various cultural groups of older adults, particularly with regards to Asian and Asian Immigrant populations which have been neglected in prior research. Without considering cultural differences, it may not be possible to understand the complexity involved in the construction of perceptions of and preferences for home-based monitoring technologies in older adult populations who are from various cultural backgrounds. With the emergence of the concept of person-centered care, it is becoming important to develop a new theoretical model addressing the importance of cultural factors in achieving greater technology adoption. This model could help to better recognize consumer demands and reduce barriers to necessary technologies for seniors from multiethnic groups as well as provide guidelines for design and implementation of home-based monitoring technologies for Asian older adults both in the US and internationally.

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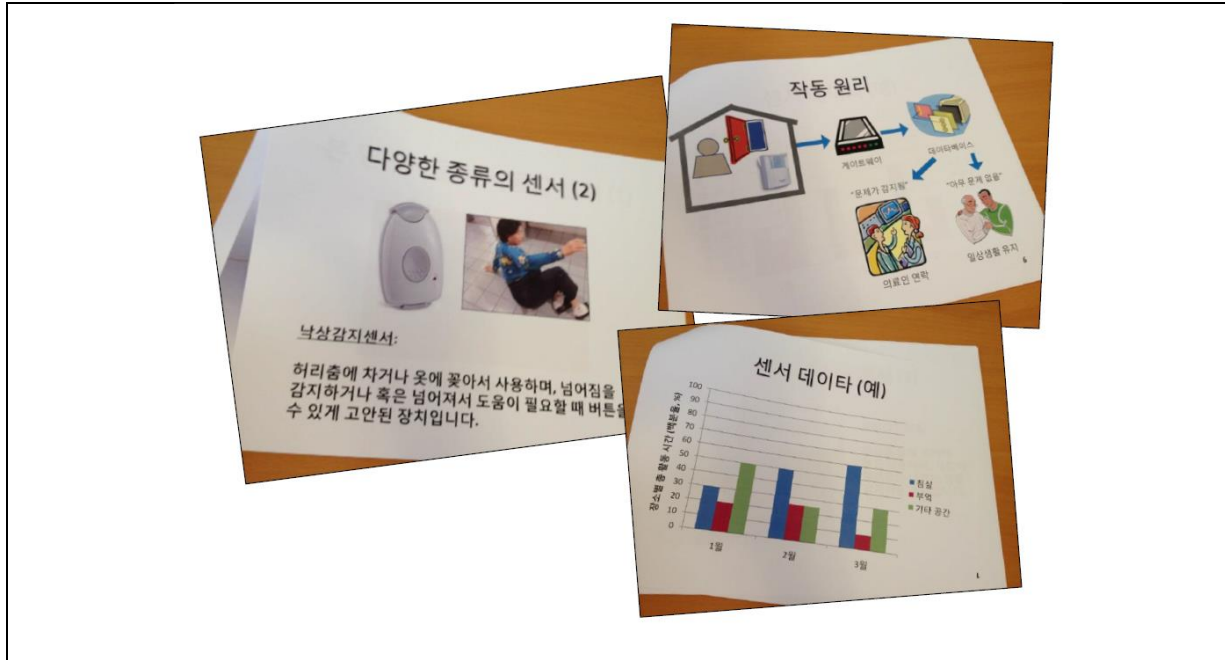
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Figure 3.1. Photos of a Handout Provided During the Interview



Note. Left: An example of fall detection sensor. Upper right: Mechanism of how the technology works and transmits data. Lower right: An example of data visual display

Table 3.1

Demographic description of study participants (n = 15)

	Korean immigrants (n = 5)*	Korean (n = 10)	Total (n = 15)
Age (years), M (SD)	74.8 (4.7)	67 (2.2)	69.6 (4.9)
Marital status, %			
Married	80.0	60.0	66.7
Divorced	20.0	10.0	13.3
Widowed	0	30.0	20.0
Highest education completed			
<High school	0	10.0	7.1
High school graduate or GED ¹	75.0	40.0	50.0
Some college, technical or vocational	0	20.0	14.3
≥ College degree	25.0	30.0	28.6
Chronic disease			
Yes	60.0	50.0	53.3
No	40.0	50.0	46.6

Notes: ¹GED = General Educational Development.

*Data were collected from 5 of 11 older Korean immigrants.

CHAPTER 4.

Use of an Environmental Sensor System to Monitor Mobility and Daily Activities in Korean American Older Adults: A Feasibility Study

Abstract

Despite an increasing interest in adopting home-based sensor technology for older adults, there have been limited attempts to apply this technology to communities of ethnic minority older adults. This article presents a case study in implementing a home-based sensor system in homes of Korean American older adults living in the community to monitor activity levels with a focus on mobility. The sensor system was deployed for about two months in four homes of community-dwelling Korean American older adults (N = 6). Study procedures included 1) data collection from the sensors, 2) administration of self-report instruments to measure mobility and health, and 3) individual interviews at midpoint and study completion. To explore changes in mobility and activities of each home over time, line graphs and sequence plots for each area of the home were applied to data obtained from a set of sensors. These plots show natural daily patterns in some individuals and also variability in others during the study period. Most participants did not have any decrease or increase except for one participant whose overall activity in each area was increased after her granddaughter's visit. Interview data indicated that the home-based sensor system was acceptable for all participants, but privacy concerns related to a motion sensor in the bathroom were observed in some participants. Despite some challenges related to sensor deployment and data analysis, continuous sensor-based monitoring of activity patterns in this study supports that sensor technology applications could be successfully performed in a sample of minority older adults.

Introduction

The incidence of mobility limitations and disability increases with age and chronic disease (Centers for Disease Control and Prevention (CDC), 2013). Mobility is broadly defined as the ability to move independently from one location to another (Vasunilashorn et al., 2009) and is critical for maintaining independence and promoting healthy aging. Older adults with chronic conditions are at increased risk of mobility limitation that is often defined as “self-reported difficulty walking one-quarter mile or climbing 10 steps” (Stenholm et al., 2010). This mobility limitation leads to reduced participation in activities of daily living (ADL) and other adverse health outcomes (Hardy, Kang, Studenski, & Degenholtz, 2011; Lo, Brown, Sawyer, Kennedy, & Allman, 2014; Montero-Odasso et al., 2009). Thus, mobility limitation threatens quality of life and well-being among older adults (Webber, Porter, & Menec, 2010).

There have been great efforts to explore patterns, risk factors, and health outcomes of mobility limitation among community-dwelling older adults at the community and societal level. Despite the importance of these public health efforts, such inquiry is also needed in a more narrow contextual focus where characteristics such as ethnicity or culture are considered. Korean Americans, for example, are such an ethnic minority and they are the fourth largest Asian immigrant subgroup and one of the fastest growing subgroups in the United States (Park, Roh, & Yeo, 2012). Previous research revealed that physical inactivity is one of the major health concerns in older Korean Americans (Kim, Ahn, Chon, Bowen, & Khan, 2005; Sohng, Sohng, & Yeom, 2002). Environmental factors, cultural beliefs and attitudes, and health status are known to affect the level of physical activity in Korean American elderly (Lim, Kayser-Jones, Waters, & Yoo, 2007; Sin, Belza, LoGerfo, & Cunningham, 2005; Sin, LoGerfo, Belza, Cunningham, & Belza, 2004). However, little is known about the mobility of Korean American older adults, so

there is a need to understand trends, preferences, and patterns in the mobility of the Korean American elderly population.

As part of prevention approaches to identify older adults at risk of mobility limitation, there have been considerable efforts to assess changes in mobility and to develop a new instrument for accurately measuring mobility. However, there are still limitations in the assessment and measurement of mobility for older adults (Abellan van Kan et al., 2009; Chung, Demiris, & Thompson, 2014; CDC, 2013; Prohaska, Anderson, Hooker, Hughes, & Belza, 2011). Although mobility function among older adults variably declines over time, it is generally only captured at a few discrete time points by self-report or performance-based measurements (Hayes et al., 2008). There is a need for continuous measurement of mobility and activities to better understand normal variability in daily functioning and to detect changes before they impact quality of life.

One innovative approach to facilitate monitoring is through the use of an environmental sensor system in the home. This monitoring can be performed continuously with less intrusion on the daily lives of individual elders (Kaye et al., 2011). Home-based sensor technologies, designed to record activities of individuals and health status in their living spaces, can help to intervene promptly to prevent adverse health events resulting from mobility limitation by detecting changes in activity patterns. Monitoring multiple aspects of functional performance through sensors and intervening based on these data sets can be used to support older adults to maximize their health and manage their chronic conditions (Kang et al., 2010). That way, home-based sensor technologies can allow older adults to age at home independently as long as possible (Chan, Estève, Escriba, & Campo, 2008; Kang et al., 2010). Sensor functionality and network devices allow continuous collection of physiologic and activity data, transmission of

data to a remote server, and recognition of abnormal patterns in collected data. The continuous monitoring of motor and physical function can overcome the limitation in the traditional assessment of older adults' health status that are often restricted to a limited set of variables sporadically. Therefore, passive monitoring through sensor technologies has the potential to greatly assist older adults with disease management and prevention of adverse health outcomes (Kaye, 2008). Also, sensor-based monitoring does not require older adults to use computers or directly deal with technological issues. Thus, older adults with chronic conditions such as dementia or memory loss can benefit from these technologies while avoiding problems caused by incorrect use of wearable devices to measure activities and mobility (Alwan, 2009; Mahoney et al., 2007). Thus, sensor technologies have the potential to overcome the limitation in the current mobility assessment (Hayes et al., 2008). Based on this assumption, this study applies a home-based sensor system to older Korean Americans to monitor their daily activities with an emphasis on mobility.

The idea of using sensor technologies at home to identify an older individual's general activity is not a novel idea as it has been tested by multiple research groups (Chen, Harniss, Patel, & Johnson, 2013; Kaye et al., 2011; Rantz et al., 2013; Reeder et al., 2013; Sixsmith et al., 2007; Wang et al., 2009). Despite a growing interest in using home-based sensor technologies for community-dwelling older adults, no specific attempts have been made to use this type of technology to explore activity patterns of Asian American older adults.

The purpose of this study is to test feasibility of a multi-sensor monitoring platform that is designed to assess mobility and daily activity patterns among older adults. In this paper we aimed to see how feasible it is to install the sensor system in real residences of Korean American

older adults and whether the system generates meaningful data. We also explored the acceptability of the home-based sensor system among Korean American older adults.

Methods

Design

An exploratory multiple case-study methodology (Yin, 2002) was used in this study with a focus on examining activity trends and mobility over time. We chose the case study research to investigate how the multi-sensor monitoring system is utilized within real-life context and how it is accepted by a minority group of older adults (Yin, 2002). The sensor system was deployed in four homes of Korean American older adults (N = 6) living in the community. The monitoring period ranged from 8 to 12 weeks. The study protocol was approved by the Human Subjects Division at the University of Washington, Seattle.

Participants

The participants for this study comprised of six older Korean immigrants. To be included in the study, participants needed to be 1) community-dwelling individual residing in the greater Seattle metropolitan area, 2) born in Korea and immigrated to the United States, 3) aged 65 or older and 4) able to speak and read Korean. Exclusion criteria included having 1) a known life expectancy of 6 months or less, 2) inability to provide written informed consent or 3) inability to install the sensor technology in the home. We did not apply exclusion criteria based on their type of residence or home environment; rather, we wanted to deploy the sensor system in real residences of older adult participants. Participants were recruited through convenience and snowball sampling methods. Information sessions were held at regular membership meetings of Korean immigrant senior associations and churches to explain the study. At the information

sessions, interested individuals identified themselves to the principal investigator for later initial eligibility screening via phone. All presentations and screening were conducted in Korean.

Sensor System Description

The system consisted of a study laptop, a wireless 4G router, and two different types of sensors including a set of motion sensors and a water consumption sensor (hydro sensor) (Figure 4.1). These sensors capture various events in which a participant may be involved. First, motion sensors used in this study were wireless passive infrared sensors (MS 16A, X10.com) and they were placed in rooms frequently trafficked by participants (bedroom, bathroom, kitchen, living room, dining room, and hallway, etc.). These sensors fire every 6 seconds as long as motion is sensed. Second, a hydro sensor was installed by screwing the pressure and flow sensors onto an exterior hose pipe, water heater drain valve, or utility sink faucet. The hydro sensor measures different activities involving water usage, such as taking a shower, using a toilet, and dishwashing, etc. The hydro sensor was developed by an engineer partner at the University of Washington. All data were time-stamped at the computer and automatically uploaded once at night through a secured Internet connection back to the secure university server. During the study, the laptop was left on all the time for buffering and processing the sensor data.

[Figure 4.1 about here]

Data Collection

Daily Activities and Mobility. Multiple data collection techniques were used to explore participants' ADL and mobility. First, we collected activity data through the sensor network. Second, participants filled out activity logs over two weeks in which they were asked to record where they were and what they were doing every 30 minutes during 24 hours. Third, we used self-report instruments to assess ADL and mobility. For ADL, this study used the Korean-

version of Katz ADL, which was translated and slightly adapted from the original version (Sohn, 1998). It has three ratings, from 1 (unable to do) to 3 (no help). A higher Katz ADL score means greater independence in performing ADL. Cronbach's alpha of the Korean Katz ADL ranged from .71 to .88 (Sohn, 1998; Yoo, 2007). In addition, the Rosow-Breslau scale (RB scale) (Rosow & Breslau, 1966) and Nagi disability scale (Nagi, 1976) were used to measure gross mobility and difficulty performing tasks, respectively. The RB scale consists of three items, with response options ranging from 1 (very easy) to 4 (very difficult). The Nagi scale has five response options, ranging from 1 (no difficulty at all) to 5 (unable to do it). Higher scores for both RB scale and Nagi scale indicate greater disability. Finally, life-space mobility was assessed by the Life-Space Assessment (LSA) (Baker, Bodner, & Allman, 2003). The LSA is designed to assess the space through which a person moves over the last four weeks preceding the assessment, ranging from within one's home (level 1) to outside one's town (level 5). A composite score ranges from 0 (mobility restricted to the bedroom) to 120 (independence enabling travel to out of town). The RB scale, Nagi scale, and LSA were translated into Korean by the author.

Falls. A monthly fall calendar was used to assess whether participants experienced falls during the month. Participants were asked to mark on this calendar on a daily basis using an "X" to denote a day that they experienced a fall, and use "*" to denote a day that they experienced a fall that resulted in an injury.

Psychosocial Aspects of Health. Participant's perceived health and well-being was assessed by the Korean-version of Short Form 12-item Survey version 2 (SF-12v2), which has a Cronbach's alpha of .81 (Lee, 2010). SF-12v2 consists of two domains; physical component summary measures (PCS) and mental component summary measures (MCS). The score of each

domain ranges from 0 to 100, with higher score indicating better health. Fear of falling was measured by the Modified Falls Efficacy Scale (FES) (Tinetti, Richman, & Powell, 1990). We used the Korean version FES (J. Choi, 2002), which has 10 items with an 11-point rating scale from 0 (not confident at all) to 10 (completely confident). The Korean FES showed high test-retest reliability (Cronbach's alpha = .91 - .92) (H. Choi, 2002). Depression was measured by the Geriatric Depression Scale-Short Form – Korean (GDSSF-K) (Ki, 1996), which has 15 items with “yes” or “no” response options. The composite score ranges from 0 to 15, and a point equal to or greater than 5 suggests depression. Reliability of GDSSF-K has been documented extensively (Cronbach's alpha = .88 - .92) (Ki, 1996; Kim, Yun, & Sok, 2006). Social support was assessed by the Medical Outcomes Study Social Support Survey (MOS-SSS) (Sherbourne & Stewart, 1991). We used a 19-item Korean version of MOS-SSS with scores ranging from 19 (lower social support) to 95 (greater social support). The reliability of the Korean version of MOS-SSS has been supported by several studies, with Cronbach's alpha of .98 (Kim & Oh, 2011; Park, 2011).

Cognitive Ability. Cognition was assessed by the Mini-Cog test (Borson, Scanlan, Brush, Vitaliano, & Dokmak, 2000). The score ranges from 0 to 5, with scores between 0 and 2 indicating possible cognitive impairment. The Korean version of Mini-Cog has been supported for screening dementia, with the sensitivity and specificity, 90% and 95.8%, respectively (Y. M. Choi, Lee, & Lee, 2006).

Perceptions of Home-Based Sensor Technologies. At exit we conducted a short interview regarding perceptions of using sensor technologies at home using a series of semi-structured open-ended questions.

Procedures

Residents in each household were enrolled in the study for 8-12 weeks. The first visit occurred at baseline. While one member was consenting the participant, another member measured the floor plan of the house and deployed the sensor system. We tried to install motion sensors in minimally intrusive places. Study participants were trained to use activity logs to collect information on daily activities. The logs were filled out continuously for two weeks on a row. In the second visit, activity logs and a completed fall calendar were retrieved. Also, we administered questionnaires on daily activities and mobility. In an exit visit, the same questionnaires used at baseline were administered again to measure ADL, mobility and other health parameters. We conducted an individual interview with the participant to ask about their perceptions of technologies. Then the sensor system was removed from the home.

Data analysis

The goals of this analysis were to characterize participants' mobility and activity trends in each area of the home over 2-3 months of follow-up.

Data Preparation. The dataset used in this study was released in a CSV format to us by our engineer partner. Activity data were acquired from six to nine motion sensors located at each room of the participant's home. The motion sensor dataset includes an activity time stamp, location stamp, and status ("on" or "off"). The hydro sensor dataset have information regarding which water source was turned on, start-time stamp, end-time stamp, duration, and confidence levels. The dataset for each home consisted of a set of daily files. As part of data preparation, the daily files were merged to one sheet per home and then cleaned to remove invalid values. Two variables indicating the day of week and time of day, respectively, were created. We did not exclude days in which there was no motion detection from analysis. Sensor data were first

aggregated to a minute level. Then we also aggregated the data to an hourly level by counting the number of minutes in the hour with at least one sensor “on” event in that minute. All data cleaning and analyses were performed with SPSS, version 19 (SPSS Inc., Chicago, IL).

Estimates of Mobility and Daily Activity Patterns. We were less interested in comparing one participant’s activity pattern to that of another participant than exploring changes in mobility and activities of each home over time. For this aim, the line graphs and sequence plots have been applied to data obtained from hydro and motion sensors. These plots are used to display motion sensor events in each space and at the whole home level, which were aggregated to a daily level. Therefore, activity trends can be visualized or tracked for pattern changes over time.

Results

More than 6,000 home-hours of continuous activity data were collected during this study. Participant homes were followed for up to 84 days (mean = 64.8 ± 14.3) to detect changes in activity patterns. All study participants were ambulatory and cognitively intact at baseline. Table 4.1 describes housing types and the number and types of sensors deployed in each home. Table 4.2 summarizes participant demographic at baseline and functional characteristics assessed at each measurement point. Four case studies are provided in the following sections.

[Table 4.1 about here]

[Table 4.2 about here]

Four Case Studies

Case 1. First home

A 79-year-old female living alone in her house is physically active. She immigrated to the United States five years ago to live near her son after her husband passed away. She was diagnosed with diabetes and has pain in her both knees. She reports feeling a little bit depressed and sometimes takes sleeping pills because of insomnia. The motion sensor in her bathroom detected visits to bathroom during the night (Figure 4.2 (a)). Also, she has a history of falls before study enrollment, but did not experience any falls during the study period. She manages quite well to avoid falls, but expresses her fear of falling. Her psychometric data indicate that although she is living independently indicated by her ADL and mobility scores, she has depressive symptomatology and mild cognitive decline.

As seen in Figure 4.2 (b), she occupies her living room more at night than day time, and thus it has an increasing trend when averaged over 24 hours. Based on her activity logs, the participant regularly goes out during the day for her exercise class or senior meetings and usually watches TV in the living room during the evening until she gets in bed. Overall, sensor data in each room presented that her activity trend has natural fluctuation over time without any decrease or increase (data not shown).

[Figure 4.2 about here]

A hydro sensor deployed in her bathroom inferred real-world water usage activities in her home. We collected a total of 2,768 labeled water events across all valves. Here, an event is one occurrence of a valve open. Table 4.3 shows a breakdown of valve activity by fixture. By using a hydro sensor, we extrapolated what types of water-involving activities were conducted during when a motion sensor in kitchen or bathroom fired. Specifically, there were cases in which a

toilet use was detected 1-2 minutes after a movement was captured by the motion sensor in the bathroom. Similarly, the fact that either a laundry or kitchen sink use was detected by a hydro sensor allowed us to infer what specific activity was conducted in kitchen when the participant's activities were sensed by a motion sensor in kitchen.

[Table 4.3 about here]

Case 2. Second Home

A 75-year-old woman who lives alone in her apartment and has no diagnosed clinical conditions. She has very active life style leaving the apartment quite frequently every day. During the study period, she did not experience any falls. She regularly attends community-based exercise sessions and senior meetings. Her granddaughter visited her during the study period and stayed several days. Sensor data detected the increased activity due to a guest. Also, the sensor data show that her overall activity in every area was increased after her granddaughter returned back home (Figure 4.3). Her activity logs indicate variability in her activity patterns over the 2-month follow-up period. For example, she had irregular sleep duration, time to get in bed or get up from the bed, and meal time. This variability in her life pattern is well detected by the in-home sensors. Figure 4.3 shows daily counts of minute with at least one sensor firing events in the bathroom and living room over two months.

[Figure 4.3 about here]

Case 3. Third home

This is a couple living independently in a 2-bedroom house. The husband has hypertension, high cholesterol, and nocturia, and took four medications, while the wife has high cholesterol only requiring one medication. This couple is physically active and enjoyed hiking almost every day in the morning. They did not report any falls during the study period. They are

patterned individuals. Their activity logs indicate that different days have similar routines. For example, the wife gets up at 3AM to go to church except for Sunday. After she returns home, the couple goes hiking for physical fitness. Figure 4.4 (a) indicates that they usually use the living room early in the morning, during lunch and in the evening over the week, even though different days have different peak points. Similarly, the kitchen activity was quite patterned, with increased sensor events during the breakfast, lunch, and dinner times (Figure 4.4 (b)). However, in Figure 4.4 (b), 2 of 7 days (Monday and Thursday) every week show different patterns from other days. Sequence plots for every areas of the home show variable natural fluctuation in activities over time, meaning that there was no increase or decrease in an overall mobility level and activity trend (graphs not shown).

[Figure 4.4 about here]

Case 4. Fourth home

The couple who lives in a two-story house is cognitively intact. The husband has Parkinson's disease and mobility limitation, so he is mostly home-bound and uses a walker or a cane when he goes out. Even though, he did not experience any falls during the study period, his fall risk has increased, indicated by a decrease in fall efficacy and ADL scores assessed at an exit point. The wife has diabetes and a visual problem, but she is physically active. Because the husband has to use the bathroom frequently during night and the wife had insomnia, the couple uses separate bedrooms and bathrooms. Figure 4.5 (a) shows that the couple has different levels of bedroom activities over time. The wife's activity levels were consistently higher than those of her husband. Figure 4.5 (b) indicates that the husband's 24-hour occupancy pattern as well as its level in bedroom are totally different from those of the wife. He hardly uses his bedroom from 11am to 6 pm while there were more activities captured by a motion sensor in her bedroom

during the same time frame. This may indicate that the husband has a decreased mobility level because of his chronic condition compared to his wife.

[Figure 4.5 about here]

Acceptability of Home-Based Sensor Technology

When asked about the sensor technology installed in their homes, participants felt that sensors were acceptable to them. In general, participants reported no inconvenience caused by the technology because they did not have to do anything with the system. Except for one participant, most people perceived the system was not obtrusive to their daily lives. However, two participants mentioned that they had to pay attention not to touch sensors while cleaning their counter top in a kitchen or a shelf in a living room where a motion sensor was installed. They also reported that visitors noticed the sensors. When asked about any concerns related to sensors, three participants stated that a motion sensor in the bathroom bothered them sometimes at an initial stage, but later they felt comfortable with the sensor system.

Discussion

Findings from these cases demonstrate successful deployment of a home-based sensor system for monitoring mobility and daily activities among Korean American older adults. By continuously monitoring older adults by using unobtrusive home-based sensor technologies, we have been able to observe multiple parameters of activity and mobility patterns of individuals, for example, 24-hour activity pattern or long-term changes in activity trends. The activity data obtained from the sensor system show the natural daily patterns in some individuals and also variability in others during the study period. In addition, the data indicate that no one experienced decline in their activity levels or mobility over the data collection period. This is likely due to the inclusion criteria and also partly because our study period was relatively short to

observe meaningful changes in health parameters. These results support further testing of the sensor technology with a larger cohort of older adults during an extended period of time or in those at high risk of mobility limitations to detect changes in activity patterns and physical functioning. It could allow to capture meaningful trend changes caused by natural aging process or environmental influences (Kaye et al., 2011).

Installing hydro sensor in addition to motion sensors was an innovative, non-obtrusive approach to monitoring older adults' movement in the home setting. The motion sensor itself has a limitation that the data are often ambiguous. While it is designed to detect whether there is a movement in one location, it does not identify specifically which activity was conducted. The hydro sensor used in this study allowed us to infer activities based on water usage patterns. This innovative sensor technology has the potential to support aging in place by monitoring real-world activities of daily living in the home (toilet use, bathing, cooking, etc.) (Fogarty, Au, & Hudson, 2006). Furthermore, one potential benefit of using this sensor is that it is possible to collect detailed log of daily activities from an unobtrusive single installation point. In many studies, an extensive home-based sensor network was deployed throughout a home. Even though the size of each sensor is small, the sensors can be intrusive to residents (Courtney, Demiris, & Hensel, 2007), leading to rejection of a sensor technology despite the perceived usefulness. Given that some participants expressed their concerns about privacy with regard to the motion sensor in bathroom, the hydro sensor showed the potential to monitor older adults' activities without an intrusive feeling compared to a motion sensor. Future work should address privacy issues related to the different types of sensors in real world contexts with various groups of community-dwelling older adults.

This sensor-based monitoring system was found to be acceptable to all six participants despite the privacy concerns about the bathroom sensor. All participants were retained to study completion though the study protocol might have been intrusive and burdensome to participants. The high retention of the participants may be because of multiple factors, including the availability of research staff in the client's native language and the convenience of home visits to participants. When they wanted to know how the system works and if there is a risk of privacy invasion, research staff was able to address those concerns by providing detailed information in their native language. By communicating efficiently through their native language, it could be possible to motivate them to remain in the study. Given the growing population of racial and ethnic minority older adults (CDC, 2013), this suggests the need for linguistically appropriate interventions for older adults who are linguistically isolated or feel more comfortable with their native language. There should be an effort to identify adoption and utilization barriers as well as facilitators and to develop models of care delivered through sensor-based monitoring technologies among older adults from racial and ethnic minority groups.

Recent studies have suggested that seniors are motivated to use an innovative technology by utility and perceived benefits (Chung, Reeder, et al., 2014; Melenhorst, Rogers, & Bouwhuis, 2006; Mitzner et al., 2010; Tomita, Mann, Stanton, Tomita, & Sundar, 2007). This study confirms prior findings that technologies that do not meet the needs of older adult users are unlikely to be adopted by older adults. Study participants who considered them healthy were not enthusiastic about using sensor technologies following study completion for monitoring their health. Further studies should focus on understanding how to increase the adoption of novel technologies among those who are at risk of mobility limitation and disability.

As mentioned previously, there was a privacy concern particularly regarding the motion sensor in the bathroom among several participants. This recognized concern seems to be related to the installation method. The motion sensors were installed on the toilet bowl or furniture at a height of 2 to 5 feet. Therefore, when participants were taking a shower or using a toilet, they noticed the presence of the sensor and perceived it as violation of privacy unconsciously even though they reported understanding of how the technology works. One participant reported having an intrusive feeling due to a red light of the sensor that is activated when motion is detected. From participant responses, we confirm the importance of unobtrusive minimally designed technologies for monitoring activities, like the hydro sensor used in this study. The issues should be considered a part of equipment design recommendations for older adults.

We found that there are challenges to sensor data analysis. Due to technical issues, activity data some days were not transmitted to the server. Also, there is an issue of labeling the data from multiple residents in the home. We recruited participants without restriction based on their living arrangements because we wanted to see the feasibility of the system in real-life settings. Motion and water consumption sensors in homes where a couple reside do not tag for personal identification. Therefore, different activities from different persons in one home were recorded into the same data set. This would be important because we are not able to figure out whether there is a signal from a couple's sensor data that indicates the risk of deteriorating health or abnormal life patterns. For example, in our third case, the activity pattern from the sensors does not allow us to discern when she goes to bed as her data are conflated with her husband's data. Therefore, we cannot determine if sleep is an issue for the wife given she gets up very early. Previous studies reported similar challenges in data analysis (Kaye et al., 2011; Pavel,

Hayes, Adami, Jimison, & Kaye, 2006; S. Wang & Skubic, 2008). The reliability in recognizing different persons will be improved when algorithms to disambiguate the data are fully available.

In addition, we identified challenges related to sensor deployment. One participant touched a sensor in her kitchen, resulting in the sensor facing a different direction. Therefore, her data incorrectly showed that the level of activities in kitchen was decreased significantly after the event. Future work should consider where to install and how to fasten sensor technologies to obtain reliable data over time from in-home sensor systems.

As a feasibility study, this study has several limitations. First, our activity measures pertain to indoor activity only, although most subjects were active outside the home. Second, the generalizability of the findings is limited because we included a small number of participants from one ethnic group. Third, we found that when water usage activities were detected, there was no corresponding motion sensor firings. It suggests a need for a method to improve the sensitivity and minimize false negatives. Finally, the two-months of sensor-based monitoring period was not enough to detect meaningful changes in activity levels. Despite these limitations, to the best of our knowledge, this is the first study targeting use of in-home technology assessment in ethnic minority older adults.

The results strongly suggest that continuous monitoring of activity patterns in the home, and variance in daily activity or 24-hour activity pattern, might provide a useful tool to detect deviations from normal activity patterns that could be an early sign of functional decline. Furthermore, the combination of activity logs and assessment of various health parameters would allow to validate the accuracy of sensor data. Finally, the results of the current study suggest that technology applications could be successfully performed for a long-term period in the minority population of older adults that is often less considered for the use of sensor technologies. Given

the feasibility demonstrated in this study, future research needs to involve a greater number of participants in an extended period of time to assess the important role of home-based sensor technologies on achieving proactive patient-centered health care for community-dwelling older adults.

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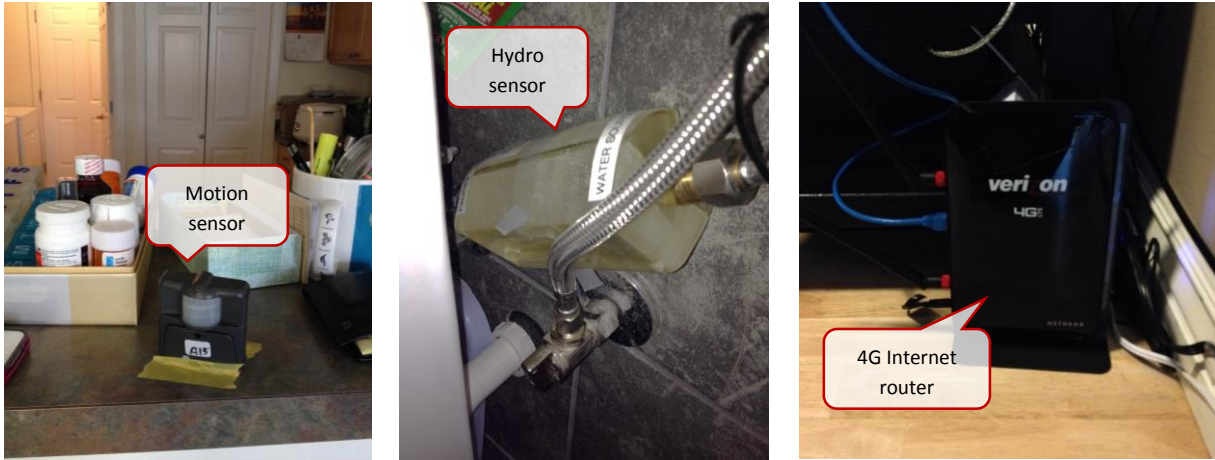
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Figure 4.1. Home-Based Sensor System



Note. (Left) motion sensor in a dining room; (middle) hydro sensor in a bathroom; (Right) Internet router in a living room

Figure 4.2. Sensor Data for the First Home

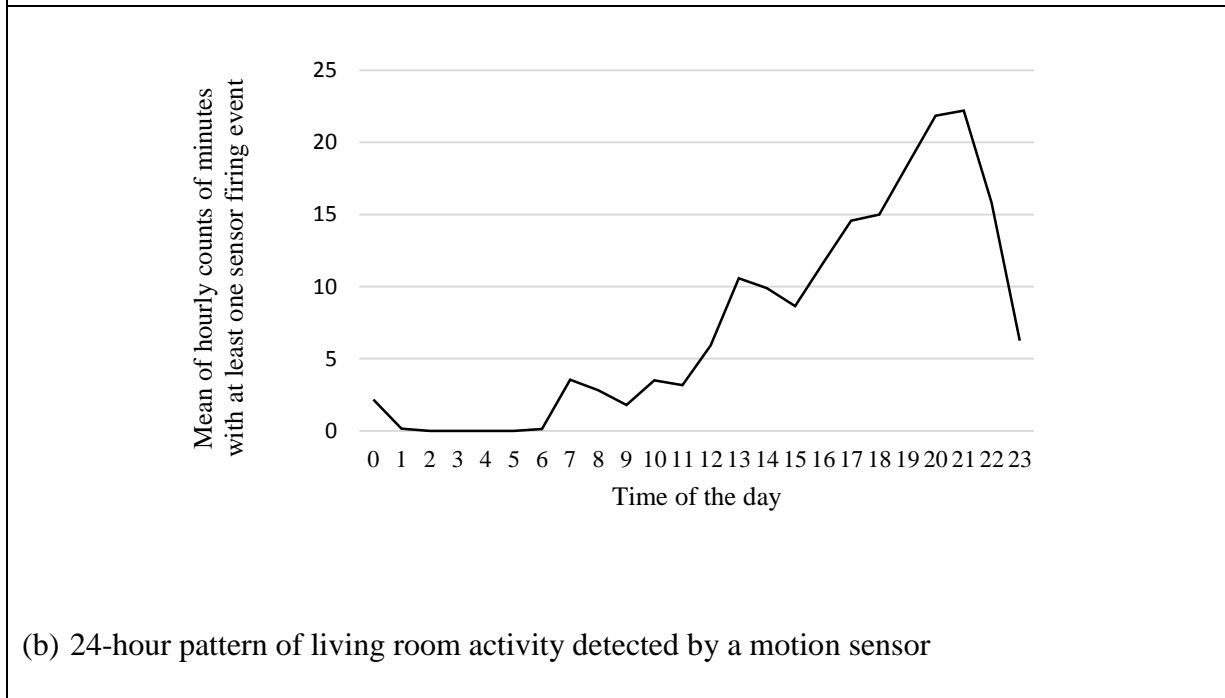
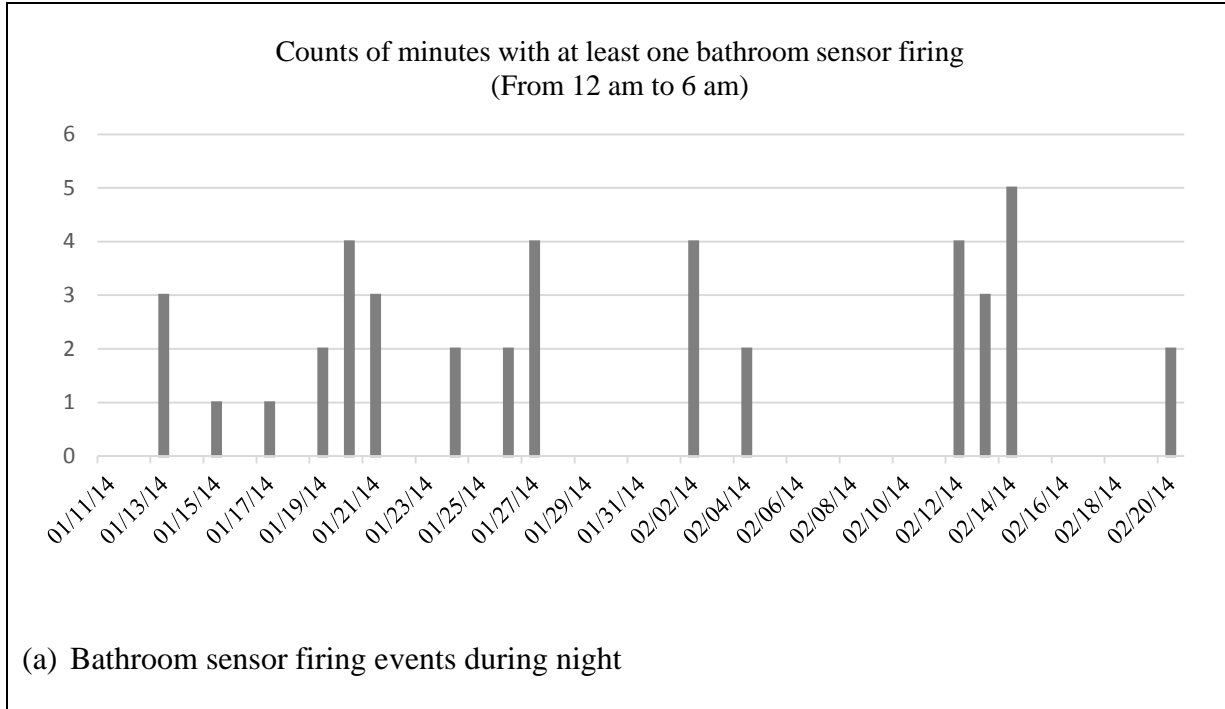


Figure 4.3. Sensor Data for the Second Home (Kitchen and Living Room)

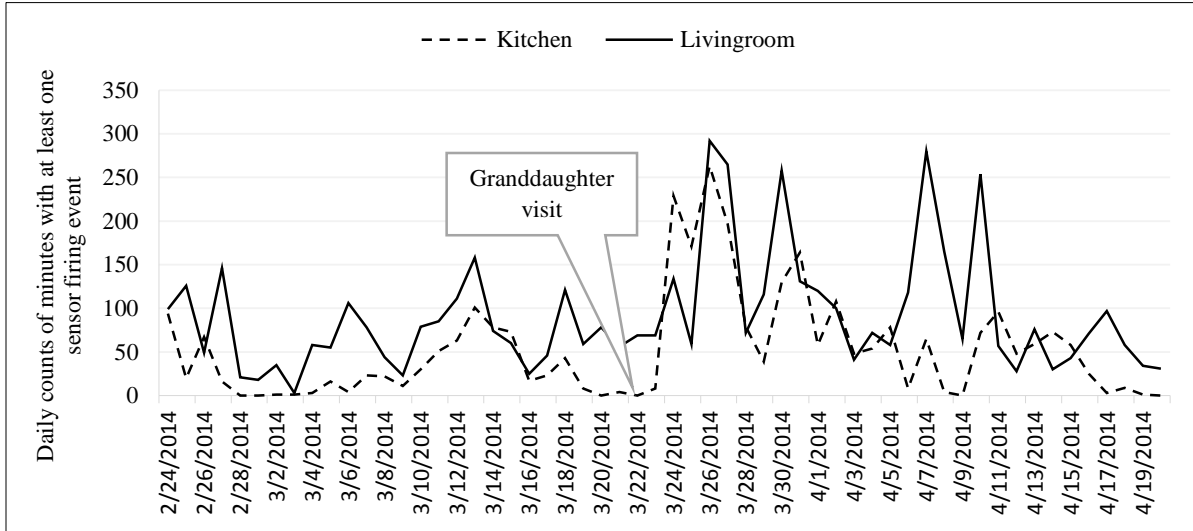
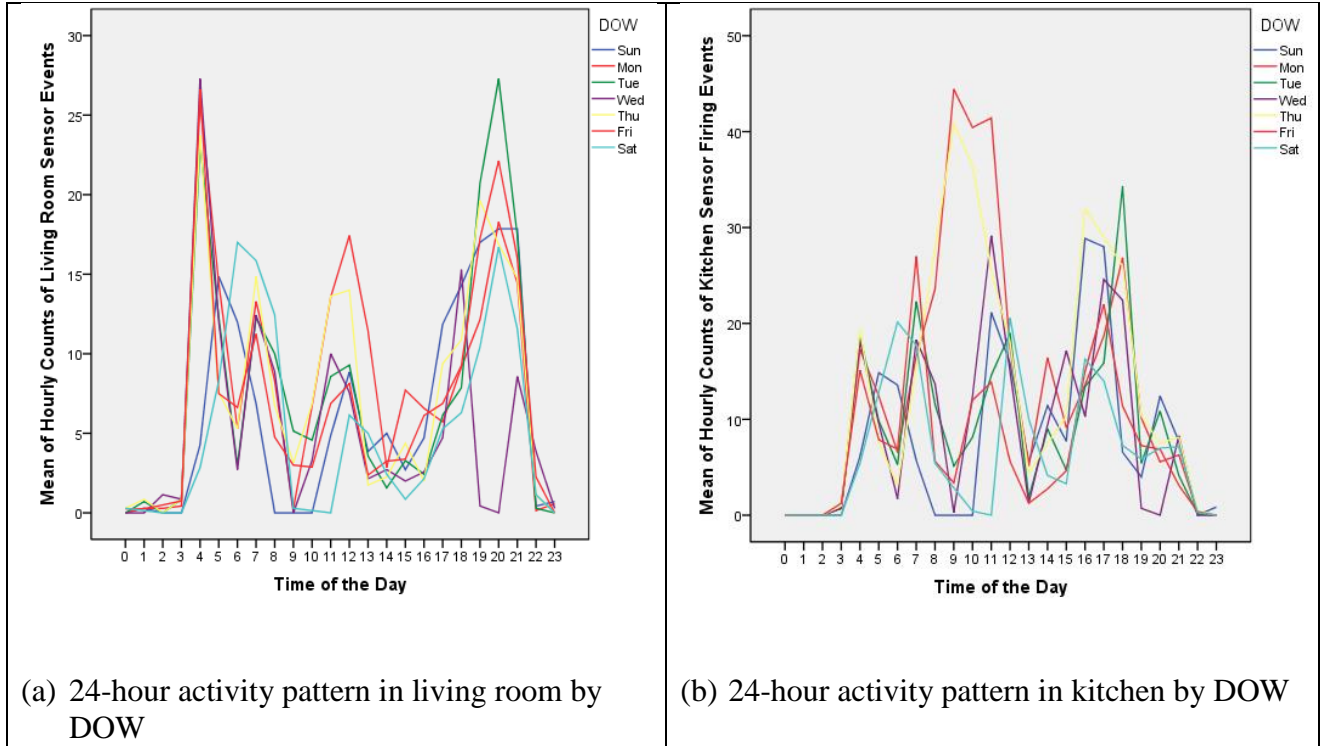
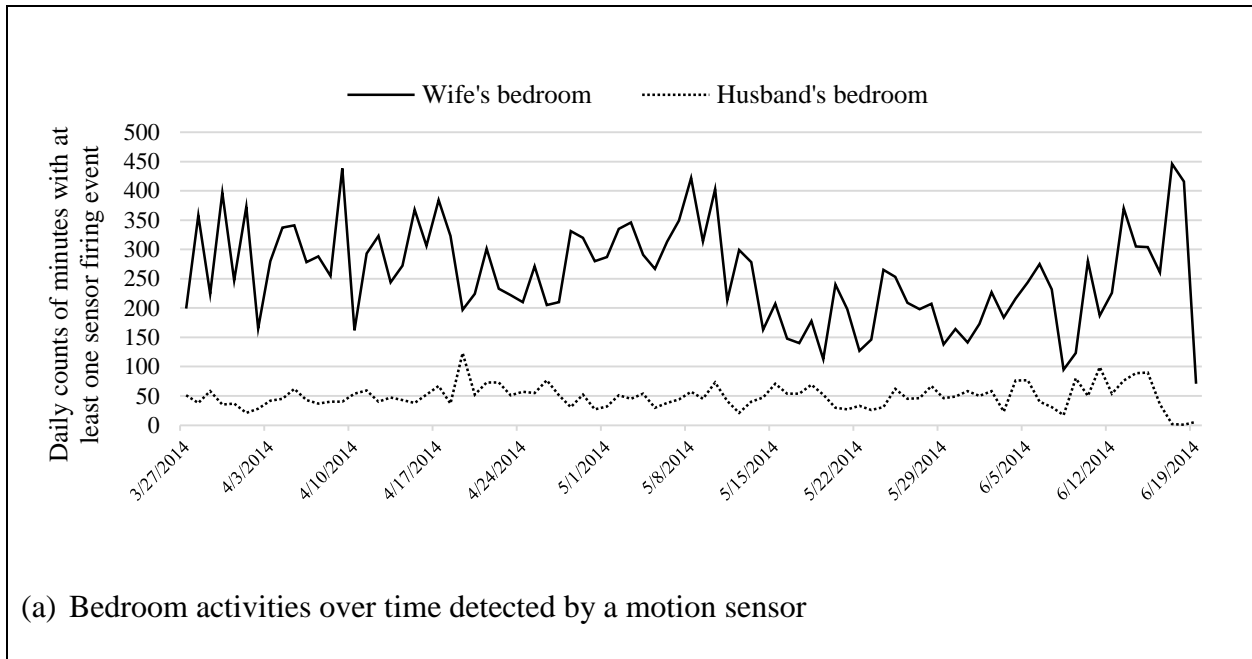


Figure 4.4. 24-Hour Activity Pattern Detected by Motion Sensors in the Third Home

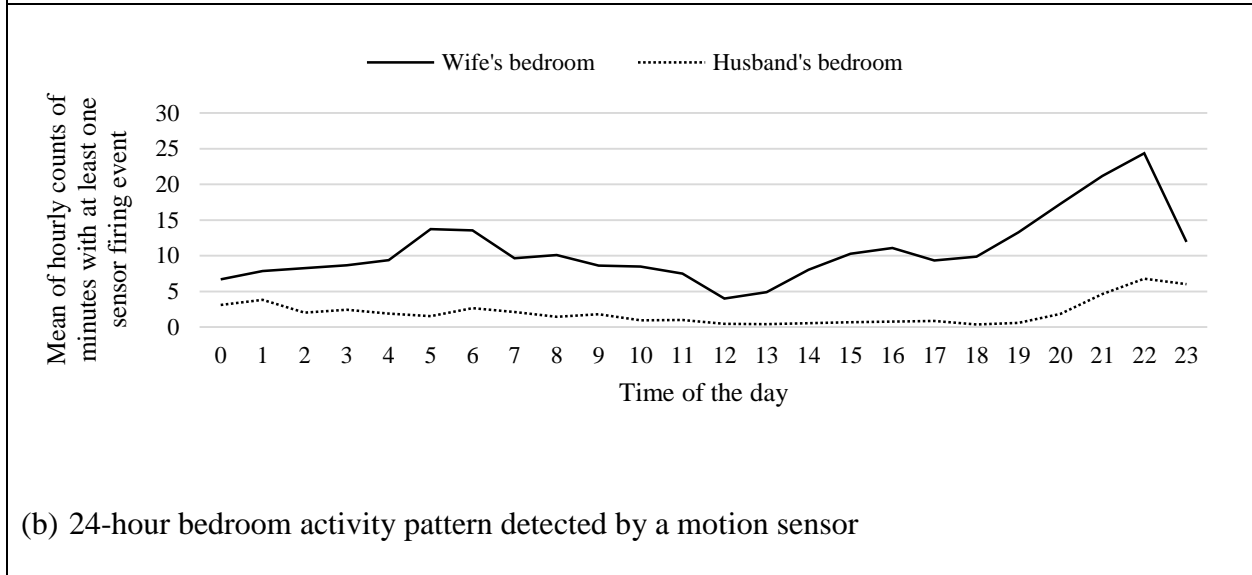


Note. DOW = day of the week

Figure 4.5. Comparison of Mobility and Activity Levels between Wife and Husband in the Fourth Home



(a) Bedroom activities over time detected by a motion sensor



(b) 24-hour bedroom activity pattern detected by a motion sensor

Table 4.1

Housing characteristics and sensors deployed

Home ID	Subject ID	Sex/Age	Housing Type	Sensors	Monitoring Period (days)	Total events
Home 1	1	F/79	House (1 bedroom, 1 bathroom)	1 Hydro sensor; 7 motion sensors ¹	67 ²	120091 (motion); 2768 (hydro)
Home 2	2	F/75	Senior apartment (1 bedroom, 1 bathroom)	6 motion sensors	56	62735
Home 3	3 & 4	F/68; M/74	Town home (2 bedrooms, 2 bathrooms)	8 motion sensors	52	231608
Home 4 ³	5 & 6	F/69; M/79	2-story house (3 bedrooms, 3 bathrooms)	9 motion sensors	84	613827

Note. ¹A motion sensor in the bathroom was installed later. ²Water usage data was collected for 26 days. ³Couple used separate bedrooms and bathrooms.

Table 4.2

Demographic and baseline functional characteristics of participants

Subject ID	Assessment	ADL	RB	Nagi	LSA	SF-12		FES	GDS	MOS -SSS	Mini-Cog
						PCS	MCS				
1	Baseline	12	9	12	90	28.8	39.6	89	6	44	3
	Midterm	12	10	11	84	-	-	-	-	-	-
	Exit	12	9	16	102	21.4	53.6	69	4	57	4
2	Baseline	12	6	7	74	41.1	66.2	94	2	70	4
	Midterm	12	6	8	92	-	-	-	-	-	-
	Exit	12	5	9	100	37.8	67.3	89	0	88	4
3	Baseline	12	4	8	72	52.9	58.2	100	1	95	5
	Midterm	12	6	6	112	-	-	-	-	-	-
	Exit	12	4	5	80	51.3	58.7	100	0	77	5
4	Baseline	12	6	5	72	55.1	62.5	100	0	94	5
	Midterm	12	6	6	120	-	-	-	-	-	-
	Exit	12	6	5	80	46.6	66.6	96	1	92	5
5	Baseline	12	5	8	78	42.1	58.0	100	0	94	5
	Midterm	12	4	8	80	-	-	-	-	-	-
	Exit	12	5	9	74	44.2	44.9	100	0	64	4
6	Baseline	11	9	15	63	29.5	49.9	97	1	95	4
	Midterm	10	10	19	46.5	-	-	-	-	-	-
	Exit	9	9	17	55	36.0	42.7	63	4	64	5

Note. ADL = Korean version Katz Activities of Daily Living; RB = Rosow Breslau Scale; Nagi = Nagi Disability Scale; LSA = Life-Space Assessment of Mobility; SF-12 PCS = Korean Short form 12-item Survey Physical Component Summary Measure; SF-12 MCS = Korean Short form 12-item Survey Mental Component Summary Measure; FES = Korean Fall Efficacy Scale; GDS = Korean Geriatric depression scale; MOS-SSS = Korean Medical Outcomes Study Social Support Survey.

Table 4.3

A summary of water involving activities detected by the hydro sensor in the first home

Fixture	Total	Daily Average
Bathroom sink	2134	82.1
Dishwasher	6	0.2
Kitchen sink	265	11.5
Shower	24	0.9
Toilet event	334	12.9
Washing machine	5	0.2

Note. Daily averages were calculated based on 26 days.

CHAPTER 5. Conclusion

Summary

Mobility is a key factor in maintaining independence and achieving healthy aging among older adults. Since the older adult population is growing rapidly worldwide, it is estimated that the number of older adults with mobility limitation will increase substantially. Considerable efforts have been sought to accurately assess, monitor, and manage mobility for older adults; one of such efforts is adopting home-based sensor technologies to monitor an older adult's level of activities and mobility with less intrusion on their daily lives. Despite the increasing interest, these technologies are rarely used as a means for health monitoring and promotion among Asian American older adults including Koreans, even though it may greatly extend the access to healthcare and sustainability of healthy behaviors. Also, there is lack of studies examining what perceptions and concerns they have toward home-based sensor technologies. The work presented in this dissertation is but the beginning of what can be learned from the feasibility testing of home-based sensor technology and exploration of sensor technology acceptance among ethnic minority older adults.

The studies in this dissertation have addressed key issues surrounding the measurement of mobility limitation among community-dwelling older adults, cultural factors affecting the acceptability of home-based monitoring technologies among Korean older adults and Korean American older adults, and the use of home-based sensors as a tool to monitor mobility and activity levels among Korean American older adults.

In the first paper, instruments to assess mobility were reviewed with a focus on older adults living in the community. The primary contribution of this part of the dissertation study was provide a comprehensive picture of mobility measurement tools for community-dwelling

older adults, either self-report or performance-based instruments. Studies were identified based on their definitions of mobility limitation; constructs of mobility included in those studies were analyzed and categorized according to the Nagi model of the pathway from disease to disability. Thus, this review assists with better understanding of elements included in mobility measurement. More importantly, this part of the dissertation provides evidence to support that the current state of instruments to measure mobility lacks consistency in terms of definition of mobility limitation, empirical constructs, types of instruments and administration methods. The lack of consistency suggests a need for developing a comprehensive theoretical framework of mobility for community-dwelling older adults. It will then be possible to accurately identify older adults at risk of mobility limitation.

The second part of the dissertation is an exploration of sensor technology acceptance among older adults living in Korea and immigrant Korean elderly in the US. This qualitative study is focused on examining cultural and contextual factors influencing technology acceptance. Both groups reported perceived usefulness of home-based monitoring technologies especially if their health condition was deteriorated. Several cultural factors affecting perceived usefulness and the acceptability were identified; weakened filial piety and immigration resulting in the elderly living alone were a major factor for sensor technology acceptance. Participants discussed their willingness to adopt an innovative sensor technology in a relation to the quality of health care system and the government's efforts to increase access to technologies. This study suggested a need for examining the role of culture when investigating an end user's perceptions and decisions regarding the adoption of innovative technologies. Also, findings from this study addressed the importance of tailoring diffusion strategies while reducing barriers to needed technologies according to cultural characteristics.

The final study was an exploratory case study conducted to determine the feasibility of a multi-sensor monitoring platform to assess mobility and daily activity patterns among Korean American older adults. The sensor system was deployed for 2-3 months in four homes of Korean American older adults (N = 6) living in the community. This case study demonstrated successful implementation of a home-based sensor system, by continuously monitoring multiple parameters of in-home activity and mobility patterns, such as 24-hour pattern of activity or changes in long-term mobility trends. The analysis of sensor data showed that no one experienced a decline in their activity levels and that natural variations were found in older adults' daily activities and mobility over time. Also, individual variation in activity patterns was observed for study participants. Despite some privacy concerns related to the bathroom sensor, sensor technologies were acceptable to Korean American older adults. This study suggested that innovative technology solutions could be successfully performed for health purposes in the minority population of older adults.

To my knowledge, this dissertation is a first published study to examine Korean and Korean American older adults' perceptions of using sensor-based monitoring at home and apply sensor technologies to residences of Korean American older adults. These studies gave us valuable information on what features and types of home monitoring technologies are acceptable to older adults according to their cultural backgrounds. Based on the findings from these studies, these technologies could be designed appropriately for different types of people in various ethnic groups with an aim of achieving aging in place. That way, we can ensure the optimal use of innovative technology solutions in the home environment.

Implications for Future Research

With an increasing number of older adults, there is a need for technologies that monitor

health or deliver care in a real-time, accessible, cost-effective, and minimally intrusive way. Based on this work, a field study involving various types of home-based sensor technologies (motion sensor, pressure sensor, or temperature/smoke detection sensor) or wearable sensors (GPS-based pedometer, accelerometer, etc.) could be designed for activity pattern recognition over time, targeting community-dwelling older adults from minority ethnic groups in an extended period of time. Despite the small sample size, this dissertation study gave us an opportunity to examine Korean American older adults' activity levels with a focus on mobility based on continuous sensor-based monitoring, which has not been explored yet. The mobility data generated from this study, for example, can be a component of intervention programs for preventing mobility limitation or enhancing physical activity among older adults. Sensor data then can be used to send positive reinforcement via message or prompts to older adults as a means to promote behavior change. Given that different cultural backgrounds affect perceptions and acceptability of technology differently among people, culturally competent approaches would be needed to design field research when reaching out to older people from diverse socioeconomic or racial/ethnic groups. The findings of the dissertation will serve as basic components for a new theoretical framework of technology adoption, which can explain the growing phenomenon of technology-mediated health promotion intervention for older adults from various cultural groups.

It is also necessary to provide evidence of the efficacy of sensor-based interventions in changing lifestyle behaviors for improving mobility and overall activity levels among community-dwelling older adults. If it is proven to be effective, we can improve the reach of health promotion in diverse minority communities. However, community partnerships and the availability of recruiters capable of establishing and sustaining therapeutic rapport would be

necessary in order to ensure its success. Ethical issues or other challenges related to technology adoption, such as privacy, data gathering and sharing, and informed decision making, should be considered prior to the intervention and discussed with multiple stakeholders in communities.

APPENDIX:

Complete References of All Selected Articles for the Systematic Review (Chapter 2)

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