Examining the Feasibility and Acceptability of a Fall Detection Device

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Abstract

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Falls are an incredibly complex problem in people over the age of 65 with a third of older adults falling at least once each year. This problem is ever increasing as the population of older adults continues to grow rapidly. Falls are dangerous in that they have the ability to damage the individual during the fall and also may leave them unable to get up from a fall independently. This “long lie” has been shown to be almost as damaging as the fall itself and has the ability to affect not only the fallen individual’s physical health but also their mental health. Current technology designed to detect these falls are often inappropriately designed for the older adult population and thus go unused or improperly used.

This dissertation includes 3 studies that cover various aspects of older adults’ use of fall detection technology. The first study is a systematic review which assesses the current state of

design and implementation of fall detection devices. A search of PubMed, CINAHL, and PsycINFO databases identified studies published up to 2013 involving a system with the purpose of detecting a fall in adults. A total of 125 articles were included in this systematic review providing a broad overview of the types of fall detection devices being researched and to what extent these devices have been tested in the real world with older adults

The second study seeks to more clearly understand older adults' perceptions of fall detection technology. This study is a qualitative analysis of 5 focus groups (n = 27) which centers on the opinions of older adults regarding fall detection devices. We identified 2 main themes of interest: 1) personal influences on the participants' desire to have a fall detection device and 2) participant recommendations regarding specific features and functionalities of these devices. Together, these themes suggest ways in which fall detection devices may be improved so that they are suitable for their intended population.

The third study is a feasibility study investigating the usability of a fall detection device that employs innovative GPS and automatic detection technologies. This device was deployed to older adults (n=18) to use on their own for a period of up to 4 months. Study procedures included 1) data collection from the device, 2) phone calls to or from participants at specific times during the study, and 3) individual interviews at baseline, midpoint and study completion. Eight participants completed the full trial while the other 10 left the study early. Over the course of the study participants experienced 84 false alarms and only 1 alarm that accurately identified a fall. This discrepancy suggests poor accuracy, sensitivity and specificity results from the device. Participant adherence was also measured as well as the participants' opinions on the device. In general, most participants had some complaints about the device while also suggesting some additional feature they thought was useful. This feedback points to a need for device customization based on the user as well as overall improvement in various aspects of the device.

Results from these three studies help to better understand the current research being conducted on these devices as well as the overall thoughts and usability concerns of older adults towards these devices. There are many challenges associated with these devices including usability issues, the lack of real world testing, and the lack of perceived need from older adults. It appears that fall detection technology needs to be improved greatly before achieving acceptance in the older adult community. Improvements could include less obtrusive technology, more accurate technology, technology developed to prevent a person from falling and a cultural change affecting how older adults perceive these devices.

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CHAPTER 1: Introduction

Significance of the Problem

By the year 2060 the U.S. population of older adults will double from 43.1 million to 92.0 million and 1 in every 5 people will be over the age 65 (U. S. Census Bureau, n.d.). Falls and fall related injuries represent a significant threat to the health and independence of older adults. Falls can be described as "unintentionally coming to ground, or some lower level not as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure" (Feder, Cryer, Donovan, & Carter, 2000). Adults 65 years of age or older experience higher rates of falling and are generally at a higher risk to fall (Hausdorff, Rios, & Edelberg, 2001; Lord, Sherrington, & Menz, 2001; Tinetti, 2003). It is estimated that 1 in every 3 persons over the age of 65 years falls at least once each year (Centers for Disease Control and Prevention, 2014; Hausdorff et al., 2001; Tinetti, 1994). One in every 2 persons, aged 80 or older, fall at least once a year (Campbell, Borrie, & Spears, 1989; Tinetti, Speechley, & Ginter, 1988). This number is higher for those in residential care with about two-thirds falling each year (Jensen, Lundin-Olsson, Nyberg, & Gustafson, 2002).

Falls can have severe consequences such as injury or death; in 2011 in the United States, 22,900 older adults died from fall related injuries, a number which has sharply increased over the last 10 years (Centers for Disease Control and Prevention, National Center for Injury Prevention and Control., n.d.). One in every 5 falls in the elderly requires medical care (Gillespie et al., 2009) and following a fall that requires hospitalization, it is estimated that 1 in 20 patients die during their hospital stay, while a little less than a quarter of the patients dying within a year (Fisher et al., 1991). Moderate to severe injuries such as head trauma, fractures and lacerations are experienced by around 20-30 percent of older people who fall and over 95% of hip fractures are the result of a fall (Hayes et al., 1993; Stevens, Corso, Finkelstein, & Miller, 2006). These injuries may trigger a rapid decline in health and greatly increase the risk of an early death (Sterling, O'Connor, & Bonadies, 2001). Even if a fall does not result in physical injury, it can often incur psychological damage. A fall may produce fear of falling resulting in a decrease in mobility, participation in activities, and independence (Ozcan, Donat, Gelecek, Ozdirenc, & Karadibak, 2005; Sattin et al., 1990). One of the greatest dangers in falling is the inability to get up after one has fallen, "the long lie", which can result in more trauma and injury (Mallinson & Green, 1985; Wilder-Smith & Thorp, 1981). Such an event can result in substantial damage to the individual's body and morale. Lying on the floor for an extended period of time can cause several medical complications such as dehydration, internal bleeding, sores or rhabdomyolysis (destruction of the skeletal muscle) or even death (Lord et al., 2001). In a more recent cohort study, a "long lie" was reported in 30% of the fallers (Fleming, Brayne, & collaboration, 2008). It has been shown that half of those who experience the "long lie" die within 6 months of the fall (Wild, Nayak, & Isaacs, 1981). While falls are dangerous, the "long lie" represents its own threat to the long term health of older adults. The faster a person is discovered after a fall has occurred, the better chance they have of survival and recovery (Gurley, Lum, Sande, Lo, & Katz, 1996; Wilder-Smith & Thorp, 1981)

Falls also have a substantial impact on the cost of healthcare. Direct medical costs of falls were measured to be 30 billion dollars in 2012, a number predicted to rise to around 43.8 billion by the year 2020. (Centers for Disease Control and Prevention, 2014; Stevens et al., 2006). Falls also have an international impact as in England and Wales the annual healthcare cost for treating falls in 2010 was greater than 15 million pounds(Ward, Fenton, & Maher, 2010). These costs naturally affect the individuals who have experienced a fall with one Medicare study showing that the total accumulated health costs per year was 29% higher in older adults who reported experiencing one fall that year and 79% higher in older adults reporting multiple falls when compared to non-fallers (Shumway-Cook et al., 2009). Another study showed that individuals experienced significantly greater direct medical costs attributable to falling in the year after suffering a fall (Bohl, Phelan, Fishman, & Harris, 2012).

There are many ways to prevent falls including regular strength and balance exercise, vitamin D supplementation, removing obstacles from one's home and having regular fall risk assessments(Campbell et al., 1997; Feder et al., 2000; Gillespie et al., 2009; Tinetti, 1994) Even with prevention techniques however, falls are still likely to occur and need to be quickly identified to prevent further damage to the fallen individual.

Systems to Detect Falls

Given the significance of timely fall detection, numerous approaches to detecting falls in older adults have been developed. One commercial solution for the detection of falls has been the use of Personal Emergency Response Systems or PERS. These systems provide a way for a fallen individual to contact an emergency center by pressing a button (Porter, 2005). While appropriate in some situations, the PERS system is rendered useless in the event that the person is unconscious or unable to reach the button. Even when the system is available and accessible, a recent cohort study found that around 80% of older adults wearing a PERS and unable to get up after a fall did not use their alarm system to call for help (Fleming et al., 2008). Thus, various passive monitoring solutions have been proposed to more accurately detect falls. As an alternative to PERS there are several automatic fall detection systems which have used anything from cameras to pressure sensors or even wearable devices (Auvinet, Multon, Saint-Arnaud, Rousseau, & Meunier, 2011; Hwang, Kang, Jang, & Kim, 2004; Lee & Mihailidis, 2005; Lindemann, Hock, Stuber, Keck, & Becker, 2005; Mathie, Basilakis, & Celler, 2001; Noury et al., 2003, 2007; Williams, Doughty, Cameron, & Bradley, 1998; Wu, 2000). While each type of system has its own advantages, camera systems have often been seen as too intrusive and restricted to a specific space. Pressure sensors also have these restrictions and cannot discriminate between multiple subjects. Thus, the most widely used solution involves placing a wearable device upon the body of an individual. Such small devices benefit from constantly being with the subject and having the ability to detect changes in velocity as well as register an impact shock when the person hits the ground. While these systems have worked well in experimental settings, their ability to distinguish falls in real world situations has been less reliable. False alarms and uncomfortable devices have led to rejection of these devices by the individuals (Noury et al., 2003, 2007). The need for accurate, reliable and non-obtrusive fall detection devices (FDDs) calls for real world testing to properly these product's ability to accurately detect falls and their acceptability amongst older adults.

Statement of the Study Purpose

There are three main objectives to this study:

Aim 1: Assess older adults' perceptions of wearable fall detection systems in general, and perceived advantages or concerns associated with their use. For this aim, we will conduct focus groups sessions with community dwelling older adults to assess participants' willingness to use a wearable fall detection system and discover any design or utility recommendations they may have.

Aim 2: Assess the feasibility, acceptability and conduct a preliminary examination of the accuracy of a wearable fall detection system which uses various parameters to monitor older adults including, accelerometry, magnetometry and GPS. For this aim, we will conduct a pilot study with ~15 community dwelling older adults who will be asked to wear the fall detection device for a period of 4-6 months. Specifically, we will:

- Assess the preliminary diagnostic accuracy (sensitivity, specificity) of the system in terms of fall detection and examine any potential sources of false positives.
- Assess acceptance and concerns pertaining to the device use by the subjects who participated in the study.

Aim 3: Propose design recommendations based on the feedback from our first two aims to maximize user experience and satisfaction as well as maximize efficiency in responding to falls.

Content of the Dissertation

This dissertation consists of 4 main chapters. In Chapter 2, I present findings from a systematic review of the literature focused on systems designed to detect when a person has fallen. This paper provides a broad overview of the current state of fall detection devices and also seeks to understand the context in which these devices are being tested as well as their use with older adults.

In Chapter 3, I present the findings from 5 focus groups conducted with older adults to examine their general perceptions of fall detection devices. This study provides insight into older adults' cultural attitudes towards these devices. More specifically I focus on two main themes: 1) personal influences on the participants' desire to have a fall detection device and 2) participant recommendations regarding specific features and functionalities of these devices. Together, these themes suggest ways in which fall detection devices may be improved so that they are suitable for their intended population.

Finally, in Chapter 4, I present findings from a long-term feasibility study in which participants were given the device to use for a period of 4 months. For this study I gathered data directly from the fall detection device to determine the accuracy of the device as well as understand the causes of false alarms. I also gathered participant feedback on the device to more clearly understand usability issues and the user needs for these devices.

Finally, in Chapter 5 I will summarize the findings from all studies. I will conclude by discussing the overall challenges involved with fall detection devices and suggest various opportunities for improving these devices specifically for older adults.

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CHAPTER 2: Fall Detection Devices and Their User with Older Adults: A Systematic Review[1]

Abstract:

Background:

Falls represent a significant threat to the health and independence of adults 65 years of age and older. As a wide variety and large amount of passive monitoring systems are currently and increasingly available to detect when an individual has fallen, there is a need to analyze and synthesize the evidence regarding their ability to accurately detect falls to determine which systems are most effective.

Objectives:

The purpose of this literature review is to systematically assess the current state of design and implementation of fall detection devices. This review also examines the extent to which these devices have been tested in the real world as well as the acceptability of these devices to older adults.

Data sources:

A systematic literature review was conducted in PubMed, CINAHL, EMBASE and PsycINFO from their respective inception dates to June 25, 2013.

Study Eligibility Criteria and Interventions:

Articles were included if they discussed a project or multiple projects involving a system with the purpose of detecting a fall in adults. It was not a requirement for inclusion in this review that the system targets persons over the age of 65. Articles were excluded if they were not written in English or if they looked at fall risk, fall detection in children, fall prevention or a Personal Emergency Response device.

Study appraisal and synthesis methods:

Studies were initially divided into those using sensitivity, specificity or accuracy in their evaluation methods, and those using other methods to evaluate their devices. Studies were further classified into wearable devices and non-wearable devices. Studies were appraised for inclusion of older adults in sample and if evaluation included real world settings.

Results:

This review identified 57 projects that used wearable systems and 35 projects using non-wearable systems, regardless of evaluation technique. Non-wearable systems included cameras, motion sensors, microphones and floor sensors. Of the projects examining wearable systems, only 7.1% reported monitoring older adults in a real world setting. There were no studies of non-wearable devices that used older adults as subjects in either a lab or a real world setting. In general, older adults appear to be interested in using such devices although they express concerns over privacy and understanding exactly what the device is doing at specific times.

Limitations:

This systematic review was limited to articles written in English and did not include gray literature. Manual paper screening and review processes may have been subject to interpretive bias.

Conclusions and implications of key findings:

There exists a large body of working describing various fall detection devices. The challenge in this area is to create highly accurate unobtrusive devices. From this review it appears that the technology is becoming more able to accomplish such a task. There is a need now for more real world tests as well as standardization of the evaluation of these devices.

Keywords: Falling, Elderly, Monitoring

[1]Reprinted, by permission, from the *Journal of Geriatric Physical Therapy.*

Introduction

Adults 65 years of age or older experience higher rates of falling and are generally at a higher risk for falls. [1-4] One in every 3 persons over the age of 65 years are estimated to fall 1 or more times each year. [5-7] Falls and fall related injuries represent a significant threat to the health and independence of adults 65 years of age and older. Falls can have severe consequences such as injury or death; in 2010 in the United States, 21,649 older adults died from fall related injuries. [8] Even if a fall does not result in a physical injury, they can often produce fear of falling resulting in a decrease in mobility, participation in activities, and independence. [9, 10] Fear of falling can be amplified in the presence of the "long lie", which is identified as involuntarily remaining on the ground for an hour or more following a fall. [1] Such an event can results in substantial damage to the individual's body and morale. Lying on the floor for an extended period of time often results in several medical complications such as dehydration, internal bleeding, pressure sores, rhabdomyolosis or even death. Half of those who experience the "long lie" die within 6 months of the fall. [11] A recent cohort study reported a "long lie" was seen in 30% of fallers; [12] therefore it represents a great threat to the long term health of older adults.

Evidence-based methods to prevent falls include regular exercise, vitamin D supplementation and having regular fall risk assessments. [2, 13-15] However, despite prevention efforts falls are still likely to occur as one ages, and they need to be quickly identified to prevent further injury to the fallen individual. Personal Emergency Response Systems or PERS represent one commercial solution to addressing this issue. These clinical alarm systems provide a way for individuals who fall to contact an emergency center by pressing a button. [16] While appropriate in many situations, the PERS system is rendered useless in the event that the person is unconscious or unable to reach the button. Even when the system is available, a recent cohort study found that around 80% of older adults wearing a PERS did not use their alarm system to call for help after experiencing a fall. [12]

Due to these challenges associated with PERS systems, passive monitoring solutions have been proposed to more accurately detect falls. Several solutions are currently available with most being wearable devices worn by a person (e.g. as a wristwatch or attached to clothing). Other solutions include technologies embedded in the residential setting such as cameras, microphones or pressure sensors installed underneath the flooring. Previous fall detection literature reviews have dealt with the principles of fall detection, the ethical issues associated with these systems or the practicality of such systems. [17-20] However, with the wide variety and sheer amount of available systems there is a need to synthesize the evidence of their ability to accurately detect falls.

Fall detection technologies enable rapid detection and intervention for individuals who have experienced a fall. This ability could reduce the physical and mental damage caused not only by the fall but time after a fall before discovery. These technologies will help to reassure those at a risk of falling as well as their caregivers and family. In the future, these devices can help physical therapists and other clinicians to clearly understand not only when the person experienced the fall , but also circumstances surrounding the fall, allowing for better treatment of the individual in question.

The primary aim of this paper is to review the evidence on fall detection devices and to analyze their level of success in automatically detecting falls. Secondary aims of this review are to examine older adults' usage and perceptions of these devices as well as the implementation of these devices in "real world" situations. "Real world," as we define it for the purposes of this review, is a certain period of time in which subjects use the device in their normal environment without any instructions given by the researcher. Simulating falls or activities of daily living (ADLs), as instructed by the researcher, in one's home would not be viewed as a "real world" situation for purposes of this review.

Methods

The systematic literature review was conducted in PubMed, CINAHL and EMBASE and PsycINFO from their respective inception dates to June 25, 2013. See Appendix A for detailed search strategy used for one of the databases.

We included articles in this review if they discussed a project or multiple projects involving a system with the purpose of detecting when an adult has fallen (including studies ultimately designed for use with adults but with laboratory tested "subjects" i.e. dummies simulations, actors). While we examined systems designed for adults it was not a requirement for inclusion in this review that the system specifically target adults over the age of 65. However, we did exclude systems that targeted children due to differences in fall patterns between children and adults. We excluded articles if they were literature reviews or if they looked at fall risk, fall detection in children, fall prevention or a PERS device.

The criteria for inclusion or exclusion were finalized by the team, and the primary search was carried out by the first author (S.C). Article selection was conducted by the first author who reviewed full texts of the relevant articles using a data extraction spreadsheet developed for this review. In order to ensure reliability of article selection, two of the authors (G.D., H.T.) blindly and independently assessed a subset of articles from the initial search for the appropriateness of inclusion in the final review. There was full agreement between all authors on articles selected for inclusion.

Quality scoring was conducted using the Statement on Reporting of Evaluation Studies in Health Informatics (STARE-HI) [21] In order to account for the variety of manuscripts, a condensed version of the STARE-HI was used which included 3 items deemed most important in the mini-STARE-HI[22, 23] as well as 3 additional criteria. 1) Description of how the system works, 2) Baseline demographic data/characteristics of participants, and 3) Basic outcome numbers (e.g., number of fall events , types of events, etc.). If the manuscript did address the criterion, they were given a score of 1, if they did not they were given a score of 0. Thus the possible range of quality score is 0-6 with a 6 indicating the paper addressed all of the STARE-HI quality criteria. In order to ensure reliability of quality scoring, one of the authors (H.T.) blindly and independently scored a random subset of articles. Differences in scoring were discussed and corrected before a final round of scoring was conducted.

The initial search yielded 617 results from which all abstracts were read to further determine eligibility for this review. Five hundred and sixteen papers found in the initial search did not focus on fall detection but instead focused on various topics from gait, balance and posture to seizures and medical instrumentation. These papers were eliminated leaving a total of 101 unique papers to be read in full. Scanning the reference lists of these papers allowed for the identification of 24 more papers that dealt primarily with fall detection, for a total of 125 papers. In reading the full texts, 12 dealt with children, fall risk, fall prevention or a PERS device and were excluded from this review. Of the remaining 113 papers, 31 did not attempt to evaluate their system based on accuracy, sensitivity or specificity of a detection device. Figure 1 fully diagrams the literature identification and screening process.

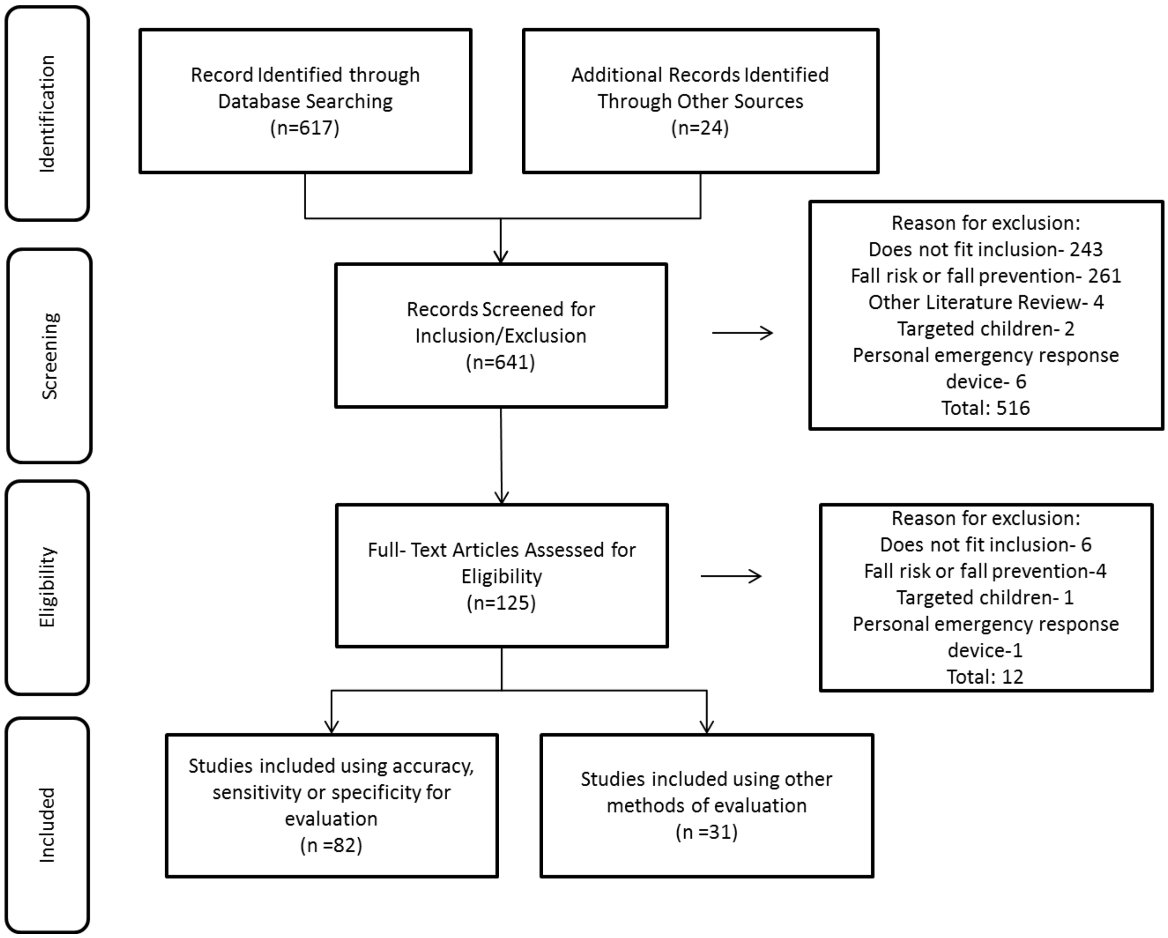

Figure 2.1 Flow Diagram of the literature review

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Results

The results section is divided into 3 parts. It first provides an overview of currently available systems and their classifications. Then, for ease of comparison, the next 2 sections are divided into projects which used measures of sensitivity, specificity or accuracy to evaluate their device and projects which used other methods to evaluate the device.

Current state of fall detection systems

The various existing detection devices can be divided into wearable and non-wearable systems. Wearable systems generally consist of placing an accelerometer upon the subject which can detect changes in acceleration, planes of motion or impact in order detect falls. [24-26] Non-wearable systems include cameras, [27-29] acoustic sensors [30, 31] and pressure sensors [32] that are placed in the subject's normal environment and use various measurements to determine if the subject has fallen. From this review, we identified 57 projects using wearable systems and 35 projects involving non-wearable systems (regardless of evaluation technique and not including projects using multiple systems).

Projects evaluating the device based on accuracy, sensitivity or specificity

Eighty-two papers described some method of device testing which included sensitivity, specificity or accuracy. These were further categorized by the different kind of sensors they were describing. Some papers described the results and procedures resulting from the same project. [24, 33-48] For the purpose of this analysis, we took their findings into account only once, resulting in 74 total projects.

Forty-two of these projects discussed the use of wearable sensors. Non-wearable devices included 16 projects using cameras or motion sensors, 4 projects using microphones, and 2 projects which used a floor sensor. There were also 10 projects which used multiple sensor systems to detect if a person had fallen. Multiple sensors, as we have defined them, can be any combination of 2 or more sensor types used to monitor a subject. Tables 1 through 3 list specific details about the various projects including how the researchers defined their subjects and their stated values for accuracy, sensitivity or specificity. Medians of accuracy, sensitivity and specificity are presented throughout the following sections. Some were difficult to determine as many projects either did not provide a value or provided a range of values depending on the amount of tests conducted for various types of falls (falling forwards, falling backward, etc.) The medians presented are taken only from papers that provided a single overall value for each element (i.e., papers using ranges or declaring multiple values for each fall types were not included in the calculation of a median). This does not account for many variables including year of the project or testing procedure and thus should not be used to compare the success of different device types and are meant only to provide a high level view of how each type of device performs.

By definition, most of the projects involving wearable devices placed their sensor onto their subject and tested them either in a simulated or real world environment (Table 1). Many papers attempted to identify a fall by impact, although there were also papers whose aim was to detect a fall pre-impact. When measuring impact, one has to measure the vibration of the impact through the body which could cause some inaccuracies. By measuring falls pre-impact, one is able to avoid this as well as any scenario where the device is damaged due to the fall. Also by measuring falls pre-impact it may be possible in the future to prevent falling injuries by using additional equipment such as airbags which would inflate right before the fall. Some of the wearable device projects compared the pre-impact fall detection capabilities of their system to that of a camera system. [36-38, 49] These projects were only using camera systems as a tool for comparison and thus were not listed under multiple sensors. Another example of such a project compared the accuracy of a cell phone to the accuracy of a device solely used for fall detection. [50]

About 19% of the wearable projects reported utilizing older adults to test their device in a controlled environment while only 7.1% reported monitoring older adults under real world settings. [25, 33, 34, 51, 52] The rest of the studies mostly used healthy young subjects who were volunteers, actors or participants in the study. Thirty-five of the projects used a single device while 4 projects used 2 separate devices and another 4 projects used 3 separate devices. The most common location for these devices was the trunk of the body (chest, waist, thorax, etc.). Other devices were placed near the head, arms, hands or feet of the subject. Systems with the device centering on the trunk had a median sensitivity of 97.5% (range 81-100) and a median specificity of 96.9% (range 77-100). Those involving multiple sensors had a median sensitivity of 93.4% (range 92.5-94.2) and a median specificity of 99.8% (range of 99.3-100). Finally the devices placed around the arm, hands, ears or feet had a lower median sensitivity and specificity [81.5% (range 70.4-100) and 83% (range 80-95.7) respectively] when compared to other sensors. Median accuracy was not available for all 3 categories of sensors and thus is not provided here.

[Table 2.1 about here]

Non-wearable devices were often set up in a room where the subjects would either walk around or live in for some amount of time (Table 2). While some real world applications of these projects exist, surprisingly there were no projects which explicitly stated using older adult subjects even in a controlled setting. The most common non-wearable systems involved cameras or motion detectors. These 2 device types are grouped together as it can be hard to differentiate them based on the descriptions given by the researcher. Usually a motion detector involved infrared sensors that identify motion, while cameras provided full images. Most of the projects used single cameras in their trials although 4 did specifically state that they used multiple camera networks. [86-88] Most of the cameras were stand-alone, however 1 study did require the subjects to wear reflective sensors on their body so that the camera could better identify them. [88] The median accuracy for cameras was 96.6% (range 77-100) while the median sensitivity and specificity were 93% (range 66.7-100) and 98.5% (range 87.5-100) respectively.

All 4 of the microphones systems used a robust array of microphone system, FADE, which was able to detect the 3-D sound source location. [30, 31, 89, 90] Of these 4 projects, a single project reported an accuracy of 100%, 2 reported sensitivities of 100% and 1 reported a specificity of 97%. The 2 floor sensors listed in this category have median sensitivities and specificities of 95.4% (range 90.7-100). [32, 91] However floor sensors were generally used in combination with other sensors.

[Table 2.2 about here]

Multiple sensor projects used various combinations of systems to detect a fall (Table 3). Papers which compared their systems to another system were not included in this category. Most of these projects were fairly recent and were implemented with the goal of more accurately measuring a fall by evaluating multiple signals. These projects had a surprisingly small number of human participants with some using computer generated falls or using anthropomorphic dummies for falls. However, 3 more recent projects have been tested with older adults in real world environments, a single study completed within their homes[100] and 2 in a clinic setting.[44, 52]

[Table 2.3 about here]

Table 4 provides a high level comparison between the different types of devices. The average number of subjects and the types of subjects involved were taken only from papers which clearly defined their samples and excluded any simulated data or fall dummies. As with earlier medians and ranges, these numbers should be interpreted cautiously as they do not account for many variables in the evaluation process including number of trials, number of subjects, types of falls etc.

Table 2.4 Summary of Project Sampling Characteristics and Fall Device Performance by Device Type

Device type (# of projects)	**Wearable devices (43)**	**Non-Wearable devices (22)**	**Multiple systems (any combination of two or more sensor types) (10)**
Range/average # of subjects (not including simulated subjects or dummies)	2-41 13.7	1-50 12.5	1-15 4.9
Projects without older adult subjects (young volunteers, simulations etc.) (%)	73.8	100	70
Projects where older adults were involved but only in laboratory settings (%)	19	0	0
Projects where older adults were involved and in real world settings (%)	7.1	0	30
Accuracy: range/ median (# of projects used in calculation)	90-100 96.0 (11)	77-100 97(7)	87.5-90.9 89.7 (4)
Sensitivity: range/ median (# of projects used in calculation)	70.4-100 97.5 (16)*	86.7-100 95.7(12)	62.5-100 95.7(4)
Specificity: range/ median (# of projects used in calculation)	77-100 96.7 (15)*	80-100 97 (11)	66.7-100 95.0(5)

*Lee added 2 values to this category for the phone and the fall-detection system

Projects evaluating their device in other ways

Thirty-one papers did not provide information on sensitivity, specificity or accuracy of the fall detection systems under study. These papers described either various design implementations of a system, or results from various focus groups, case studies, interviews or observational studies on a fall detection device. Twenty-two papers focused on the design of their devices describing in detail how the device works, how it is to be used and/or various methods for identifying falls. Of these designs, 11 devices were wearable with 1 even featuring a pre-emptive airbag. [107-117] Other devices involved wireless motion sensors or cameras [118-126] and phone applications. [127, 128]

Two papers used their fall detection devices in comparative studies. One compared the acceleration of simulated falls to that of real world falls. [129] They found many similarities between real life falls of older adults and experimental falls of middle aged subject although some characteristics from experimental falls were not detectable in real life falls. The other study compared residential communities with and without a fall detection system. Outcomes of interest were incident falls, hospitalizations, changes in needed level of care and resident attrition. [130] The authors found there were fewer falls per weeks, fewer weekly hospitalizations per week and a higher resident retention rate at the facility with the fall detection device.

The remaining 7 papers used various methodologies to elicit feedback from subjects on the feasibility of emerging or existing fall detection devices. Two studies used focus groups or questionnaires to help guide the development of a new fall detection device by suggesting various design specifications for their sensor systems. [131, 132] Another study used volunteers to gauge the feasibility of using a carpet sensor. [133] Other studies were more interested in the perceptions of older adults regarding fall detection devices. One study conducted a trial of an extended fall detection system vs. a standard pendant alarm and interviewed the subjects after the trial. [134] Older adults found that the use of telemonitoring gave them a greater sense of security and enabled them to remain at home. However, some found the device intrusive and did not feel they were in control of alerting the call center. Another study used structured interviews to look at older adults perceptions of having a video monitoring system in their home. [135] While they reported that 96% of their participants felt favorably towards the system, only 48% said they would actually use it. Another paper showed various groups of subjects videos of different types of falls. [136] They then proceeded to discuss the issues of falling and system designs with the subjects. Many of the subjects stated their desire for more passive fall detection systems and most wanted to have the ability to know exactly what the system was doing at all times. The final paper described the results of focus groups and a pilot study. [137] The focus groups discussed the potential for fall technologies with both adult users and health care providers, revealing neither group were all that receptive to the idea of fall detectors. The pilot study was used to gain insight into the effect of fall detectors on fear of falling. In this study they measure the participant's fear of falling using the Falls Efficacy Scale pre- and post-test. They found that the use of a detector did reduce the level of fear for 1 group but this reduction was not significant.

Discussion/Conclusion

An extensive body of work has been conducted in the area of fall detection using a variety of solutions. These devices can measure different aspects of the fall from velocity to impact and even the posture of the faller. Each type of device appears to have its own strengths coupled with certain weaknesses.

Wearable devices for example, if used properly are always with their subjects and can easily detect the acceleration or impact experienced by the subjects. However, these devices are reliant on the subject not only remembering to wear the device but also choosing to wear the device which can be especially difficult at nighttime. [17, 42, 87, 106, 107] These devices are also dependent on battery power and can suffer from false alarms due to impact or changes in acceleration not caused by falls. Non-wearable systems on the other hand do not rely on the subject to remember to use the system. Instead they are able to survey a certain area while hardly affecting the individual. However these systems are limited to a specific space and suffer from aspects of privacy concerns. [29, 87] Cameras, with their ability to take full photos or videos of their subjects, have been seen as too intrusive. These systems suffer from problems with occlusion (having the subject blocked by another object in the room) and being limited to indoor locations. [41] One solution to both these issues is using multiple sensors to account for the weaknesses in each device. For example, coupling a passive camera system with a wearable system would account for the subject leaving the space of the camera or the subject forgetting to wear the device at night. However, adding more and more devices could overwhelm the older adult causing them to reject such systems.

Studies have shown that older adults want to be able to live at home and are more or less willing to accept new technologies that support their independence. [137, 138] When dealing with fall detection technologies, many studies have shown that older adults are favorable to such systems and find that the use of these devices can give them a greater sense of security. [134-137] At the same time however, some older adults found such devices intrusive, were annoyed by false alarms and stated their desire for more passive systems along with an ability to know what the system was doing at all times. [25] The challenge in this area of work is to create highly accurate devices that are as unobtrusive as possible. From this literature review, it appears that the technology is becoming more available to accomplish such a task. What is needed now is further testing of such devices in real world settings.

As our review and previously published literature suggest, very few long-term real world tests of such devices have been documented. [25, 33, 34, 44, 100, 129, 139, 140] However, multiple commercial fall detection devices which are available to the public exist, whose accuracy is hard to identify. Real world tests can be difficult as they can often take a large amount of resources and time. It may also be difficult to recruit for such studies as older adults at risk of falling may also be more likely to be cognitively impaired or have a shorter life span. [141] Such difficulties were experienced in a recent study by Gietzelt et al. who noted of 3 subjects it was only possible to interview 1. [100] This was because of a death of a subject and the other subject developing a significantly impaired cognitive status which precluded interview.

One way to ease the challenge of real world testing may be to expand eligibility criteria allowing for healthier older adults to join the study. However, this reduction could also be a disadvantage as it may results in fewer fall events. Boyle et al. tried to use real time data with 15 adults over the course of 300 days and was only able to record 4 falls during that time. [59] Real world tests however, have been shown to be a more rigorous test of the device's accuracy than simulated testing. [52, 139, 140] Even with the aforementioned challenges, more real world tests are needed to prove the efficiency of these devices and to improve the health of the individuals these devices are made for. Suggestions for future research that may overcome these challenges include careful selection of subjects to include those at high risk for fall, and for whom these devices may most benefit. This includes community dwelling older adults with a fall in the previous year, or those with gait or balance disturbances that put them at high risk for fall.

Adding more real world testing may make it more difficult to standardize the evaluation process of such devices; however, it is difficult to compare the various measurements of accuracy between devices as there is as there is no common method for evaluating such devices. As has already been suggested, evaluating fall detection devices needs to become more standardized to be able to properly evaluate the strengths and weaknesses of the currently available devices. [17] One way to do this would be to have a subject live in a simulated environment for a certain period of time; this would allow for standardization across subjects while still providing real world data.

Limitations

This review was limited to articles written in English and indexed in PubMed, CINAHL, EMBASE or PsycINFO and as such may have omitted other relevant published studies. Also, as with any systematic literature review, manual paper screening and review processes may have been subject to interpretive bias.

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Table 2.1 Summary of Projects Involving Wearable Systems

Author	**Device Location**	**Subjects**	**Methods of Fall Assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
Albert et al. 2012 [53]	Phone	Fifteen healthy subjects, 8 females and 7 males (22-50 years of age)	Subjects performed a series of simulated falls onto pads in the lab. The subjects that performed simulated falls were instructed to perform 4 different classes of falls – slips, trips, left lateral, and right lateral falls. Subjects were instructed to perform each fall type 3 times for a total of 18 times per subject. Nine subjects also carried the accelerometers for 1 week to evaluate "fall-like" events.	6	Varied (95-98)	N/A	N/A

Author	**Device Location**	**Subjects**	**Methods of Fall Assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
Aziz & Robinovitch. 2011 [54]	Head, sternum, waist, ankles	Sixteen young adults, 12 men and 4 women (average age 25.6 ± 3.8)	In the experimental trials, participants fell onto a mat lined with foam, simulating various underlying causes of imbalance. Subjects were asked to watch videos of real life falls and mimic them. Participants were made to simulate, tripping slipping and falling using a combination of acting and various tools to help (i.e a rope or slippery floor) Overall they collected a total of 96 slips, 96 trips and 240 “other cause” falls	5	N/A	Varied (31-98)	Varied (68-100)

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Bianchi et al. 2010 [55]	Waist	Twelve males and 8 females (average age 23.7 ± 3 years). Two males and 3 females (average age 24 ± 3 years). Five males (average age 26.4 ±2.9 years)	Three different experimental protocols were conducted to investigate the implemented falls detection algorithm: Test A comprises of indoor simulated movements and falls; Test B comprises of outdoor simulated falls; and Test C comprises indoor and outdoor simulation of normal activities of daily living.	6	96.9	97.5	96.5
Bianchi et al. 2009 [56]	Waist	Nine males and 6 females (average age 23.7 ± 2.9 years)	All data collected in a controlled laboratory. A set of 16 different ambulatory and fall sequences were designed to test the performance of each algorithm. Falls were conducted onto a mattress. Each subject performed 1	6	97.1	97.8	96.7

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			instance of each sequence.				
Boissy et al. 2007 [57]	Front and side of the trunk	Ten young participants, 8 women and 2 men (average age 21.2 years)	Subjects performed simulated falls (9 conditions) on a protective mattress and non-fall events (6 conditions). The total data set comprised of 750 events (45 falls and 30 non falls per participant)	6	93	N/A	N/A
Bourke et al. 2008 [36-38]	Sternum	Five young healthy subjects (average age 25.6 ± 1.9 years)	Four different types of falls were completed from a platform onto crash mats. Following the fall subjects were asked to remain in a lying condition until recording had finished. ADL activities were also conducted including sitting on a chair, kneeling on the	6, 6, 6	N/A	100	100 (by design)

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			ground, coughing etc.				
Bourke et al. 2007 , Bourke & Lyons. 2008 [24, 35]	Trunk and thigh	Ten young healthy subjects (average age 23.7 ± 2.2 years). Eleven community dwelling older adults	Young subjects fells from a specially constructed platform. Each subject performed 8 different fall types 3 times each. The second part of the study involved elderly subjects performing ADLs in their own homes. Each ADL was performed 3 times by ever older person.	6, 6	N/A	100	100
Bourke et al. 2008 [25]	Vest	Ten older adults	Trials took place in a nursing home. Two teams of 5 elderly subjects wore the system in turn for 2	5	N/A	>90	>99

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			weeks each. Subjects wore the system over a course of 4 weeks for approximately 8 hours a day. In total 833 hours were recorded.				
Bourke et al. 2008 [58]	Vest	Eleven healthy young male subjects (average age 23.4 ± 4.6 years)	Subjects performed 8 different types of falls onto large foam crash-mats 3 times each. They also performed 5 normal ADLs using normal house hold furniture. The trials took place over the course of 5 days.	6	N/A	>90	>99
Bourke et al. 2010 [33, 34]	Waist	Ten healthy male volunteers (average age 27.2 ± 3.6 years). Ten older adult volunteers, 5 urban (2 women and 3 men), 5 rural (2 women and 3 men)	Young subjects fell from a specially constructed platform onto a large foam crash mat. Each subject performed 8 fall types and 4 different ADL types, 3 times each for a total of 240 falls and 120 ADLs. Older	6	N/A	Varied (94.6-100)	Varied (97.8-100)

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
		(average age 78.8 ± 5.1 years)	adults performed a series of scripted ADL and continuous unscripted and unsupervised ADL. The study took place in the volunteers own home.				
Boyle & Karunanithi. 2008 [59]	Belt	Fifteen older adults (average age 67 ± 18 years). One volunteer	Attempted real world studies with older adults in small hospital study for 309 patient monitored days. Only recorded 4 total falls. After lack of results, used healthy volunteer to perform 10 repetitions of each fall type.	4	N/A	Results difficult to interpret	Results difficult to interpret

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Campo & Grangereau. 2008 [60]	Waist	Unspecified Subject	The first test consists of the detection of a strong variation of the acceleration on the X axis going from acceleration to null when the person is lying on the ground. The second test is to detect from a brutal acceleration on the X axis, a lying position at the end of fall. This is entirely feasible, based on the acceleration due to gravity on Earth.	3	95	N/A	N/A
Chang et al. 2011 [61]	Waist and ankles	Four subjects	Each subject was tested for 5 sets of data for each motion state (running, walking etc.) which summed up to 100 sets of data.	4	Varied	N/A	N/A

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Chao et al. 2009 [62]	Chest and waist	Seven healthy male participants (average age 25 ± 1.5 years)	Participants simulated 8 types of falls and functional motions including posture transfers and dynamic activities. All falls were performed toward a thick mat designed for gymnastic and judo training.	6	N/A	Varied (3.6-100)	Varied (79-100)
de la Guia Solaz et al. 2010 [63]	Waist	Ten healthy young subjects (average age 23.7 ± 2.2 years). Ten community dwelling older adults, 3 females and 7 males (average age 77.2 ± 4.4 years)	In the first study young subjects performed simulated falls from a specially constructed platform onto a large crash mat. Each subject performed 8 different types of falls and each fall type was repeated 3 times. The second study involved elderly subjects performing ADLs in their own homes 3 times each.	5	100	N/A	N/A
Diaz et al. 2004 [64]	Waist	Eight volunteers	The volunteers performed several	6	N/A	N/A	N/A

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			physical activities wearing the prototype.				
Dinh et al. 2008 [65]	Thorax	Unspecified subject	One of the end devices was trapped on the thorax of an individual to test the system.	3	90	N/A	N/A
Estudillo-Valderrama et al. 2009 [66]	Watch or pendant	Thirty-one young and healthy subjects (average age 28 ± 4 years)	A total of 332 samples were developed on thin mats in laboratory facilities. Some experiments involved picking up objects from the floor or different knee fall patterns.	5	N/A	100	95.7
Godfrey et al. 2011 [67]	Chest	Ten healthy young subjects (average age 23.7 +/ 2 years). Ten healthy older adults (average age 77.2 ± 4.3 years)	In stage 1, the device was evaluated on the young healthy subjects all of whom performed 8 different activities of daily living 3 times each. In stage 2 the device was tested on older adults in their own homes.	6	N/A	Varied 86-92 for young, 83-89 for old	Varied 86-92 for young, 83-89 for old

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Huang et al.2010[68]	Head	Five young volunteers, 2 females (average age 24 ± 0 years) and 3 males (average age 26.7 ± 3.2 years)	Eight major types of falls, each with 1-3 kinds of directions. The falling directions including front fall, posterior fall and lateral fall at either left or right side were executed in the experiments. Also selected 7 types of daily movement with normal or fast speed.	4	100	N/A	N/A
Hwang et al. 2004 [69]	Chest	Three healthy adults (>26 years of age)	Subjects repeated 4 different fall experiments 10 times on a mattress. They also sat on a chair after walking about for 3 meters.	5	96.7	N/A	N/A
Kang et al. 2010 [70]	Waist	Ten healthy young subjects. Five healthy subjects (25.1 ± 0.6). One young healthy subject.	Experiments were performed on the 10 healthy subjects on activities such as falls (knee straight, knee flexed), walking, running, sit to stand, stand to sit, stand to lie etc. Each	4	96	N/A	N/A

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			movement was repeated 3 times. The five healthy subjects performed 9 movements 20 times. The 1 healthy subject performed ADLs for 3 hours.				
Kangas et al. 2007 [71]	Waist, wrist, and head	Two voluntary subjects (22-38 years of age)	Falls were performed towards an air filled bed or a combination of tatami and mattresses. ADL samples represented dynamic activities and posture transitions.	6	N/A	Varied up to 100	Varied up to 100
Kangas et al. 2008 [72]	Waist , wrist, and head	Five healthy volunteers, 2 females (38 years of age) and 3 males (42 , 48 and 22 years of age)	Falls were performed towards a mattress. Each subject performed 3 standardized types of falls in each of the 3 directions at least twice. A platform was used to simulate missing a step. ADL samples were	6	N/A	97-98	100

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			collected from 2 subjects				
Kangas et al. 2009 [26]	Waist	Twenty middle-aged test subjects, 6 males, 14 females (average age 48.4 ± 6.8 years). Twenty-one older adults, 11 males and 10 females (average age 82.8 ± 9.4 years)	Middle aged test subjects performed 6 different falls in a laboratory environment. Falls were performed from a podium or a bed onto a mattress. Each fall type was demonstrated once by a researcher and performed twice by each subject. Each subject also performed a sequential ADL protocol. Older adult subjects performed only ADLs	6	N/A	97.5	100
Karantonis et al. 2006 [73]	Waist	Six healthy subjects (5 of ages 22-23, and 1 of age 60)	Each subject performed a set of 12 different tasks. The fall and circuit tasks were repeated 3 times. For walking tasks subjects were asked to count their	5	95	N/A	N/A

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			number of steps. A mattress was used for falls.				
Lee & Carlisle. 2011 [50]	Waist, Phone	Eighteen healthy young adults, 12 males and 6 females (average age 29 ± 8.7 years)	The participants were requested to perform 3 repeats of several everyday activities: (sit-to-stand; stand-to-sit; walking on level ground and up and down stairs etc.) After the thresholds were preset, participants were requested to perform a series of simulated falls. All falls were performed under the close supervision of the researcher, and the participants were instructed to fall onto a large comfortable crash mat.	6	N/A	Phone: 81 Sensor: 82	Phone: 77 Sensor: 96

Author	**Device Location**	**Subjects**	**Methods of Fall Assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
Lindemann et al. 2005 [51]	Behind ear	One young volunteer. One healthy older adult (83 years of age)	Sensitivity was assessed by falls conducted by the volunteer several times on a mat. Specificity was assessed by investigation of activities of daily living (ADLs) for the volunteer. The older adults wore the sensor during the day.	5	N/A	100	N/A

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Naranjo-Hernandez et al. 2012 [74]	Unknown	Thirty-one healthy volunteers (average age ~28 years)	In the first phase, the optimization procedure for the impact detection algorithm was fed with a set of experiments that a cohort of 7 volunteers repeated to obtain the accelerometric data in different daily activities. In phase 2, the same impact and nonimpact activities previously described were performed by 4 new volunteers. Finally 2 sets of fall experiments were developed in laboratory facilities by 31 young and healthy males and females (11 of them were the same volunteers, and the rest were different volunteers)	5	N/A	100	95.7

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Nguyen et al. 2009 [75]	Waist	Unspecified Subject	Trials were conducted with ADLs. For each trial, after the system is turned on, subject should keep still for 30 seconds and then start doing activity. Before turning off our system, subjects should keep still for 30 seconds again. When subject stands still, the values of tri-axial acceleration are shown.	4	almost 100	N/A	N/A
Niazmand et al. 2010 [76]	Shirt	Ten healthy young volunteers (average age 21.8 ± 3 years)	Subjects were asked to fall 12 times each on a thick gymnastic mat for given scenarios. Every person also carried out 13 fall similar tasks of everyday life (fast walking, jumping etc.) Altogether subjects performed 250 tests	5	N/A	97.5	96.9

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			with falls and fall similar activities.				
Nocua et al. 2009 [77]	Palm	Seven adult subjects (average age 28 ± 7)	Each subject stood in standing position with their eyes closed, during one minute. After 1 minute, the subject was pushed in order to simulate a fall. The subject remained in the lying position during 1 minute. The subject's fall was cushioned by a thick mattress, ensuring their safety. For each subject the fall was simulated 6 times. In the second part, the subject did a normally standing to lying transition. The	5	N/A	70.4	80

Author	**Device Location**	**Subjects**	**Methods of Fall Assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
			event was repeated 3times				
Noury et al. 2003 [78]	Armpit	Ten healthy young subjects, 7 women, 3 men (20-24 years of age)	Fifteen falling situations each of which was played 5 times. Total of 750 falls on a mattress.	5	N/A	79	83
Nyan et al. 2006 [49]	Sternum, waist, and underarm	Ten young healthy volunteers, 5 males (average age 28 years) and 5 females (average age 26.4 years)	Subjects were first asked to perform a series of normal activities for an older adult. The subjects were then asked to carry out different fall activities 2 times each. In 1 activity the subject stood on a platform which moved from under them to simulate a slipping incident. The subjects were also told to stand on the mattress and simply relax themselves and fall to the sides. The	6	N/A	Varied up to 100	Varied up to 97.5

Author	**Device Location**	**Subjects**	**Methods of Fall Assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
			subjects did the fainting incidents on thick soft foam mattresses.				
Nyan et al. 2008 [79]	Torso and thigh	Twenty-one healthy young volunteers, 13 males (average age 23.4 years) and 8 females (average age 22.3 years)	In faint fall simulations, the subjects were told to stand on the floor beside a mattress and simply relax themselves and fall to the sides, back, and front. For ADLs, a chair, the mattress and 2 flights of stairs were used for sitting, sit–stand transitions, walking, stand–sit transitions, lying, ascending and descending stairs. Each activity was conducted twice.	6	N/A	95.2	100

Author	**Device Location**	**Subjects**	**Methods of Fall Assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
Quagliarella et al. 2008[45] [46]	Unknown	Ten young adults, 6 men and 4 women (average age 33.6 ± 1.2 years). Ten older adults, 5 men and 5 women (average age 75.8 ± 3.2 years)	The young adults performed 200 simulated "falls with loss of consciousness." Five different falls were performed by each participant onto a crash mat. Older adults performed 200 ADL-related tests 4 times each.	6	N/A	Varied	Varied (7-100)
Sim et al. 2011 [80]	Shoes	Three young subjects 2 males, 1 female (average age: 26 ± 2 years)	Falls performed in this study were forward fall, backward fall, and lateral fall. Every subject was required to mimic the elderly fall and repeat each fall type 3 times. Subjects also performed various ADLs.	5	N/A	81.5	N/A
Tamura et al. 2009 [81]	Vest (with an airbag)	Sixteen young healthy subjects (average age 22.2 ± 5.1 years).	Subjects mimicked different types of falls on double mattresses. Physiotherapists	6	93	N/A	N/A

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
		Nine physiotherapists (average age 31.2 ± 8.6 years). Four subjects (average age 23.0 ± 1.4 years)	performed various ADLs while wearing a belt meant to mimic the gait of an older adult. The 4 subjects performed simple backward falls to see if the airbag inflated.				
Tolkiehn et al. 2011 [82]	Waist	Twelve healthy subjects, 8 males and 4 females (average age 26.3 years)	Subjects wore the sensor and performed various falling and non-falling activities. Subjects simulated falls onto a thick mattress on the floor and were then asked to remain on the mattress for 15-25 seconds.	6	N/A	85.2	87.8
Wu G & Xue. 2008 [83]	Waist	Ten young adults (19-43 years of age). Fourteen older adults (72-91 years of age)	Subjects were instructed to perform a series of normal activities (walking, taking the elevator). Young subjects also performed near fall activities (swaying). Two subjects were	6	N/A	100	100

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			also asked to drive on local streets and on highways. All young subjects were then instructed to perform a series of simulated falls by being pushed by another person onto a thick foam pad.				
Yuwono et al. 2012 [84]	Waist	Eight healthy volunteers, 2 females and 6 males (19-28 years of age)	In group fall data was collected from 5 volunteers. Overall 293 fall signals were collected of which 153 were used for training and 140 were used for testing. Out group fall data was collected with 3 different male volunteers. The set included 85 signals which were not used as training data. Finally a total of 8 hours of ADL data was collected from 3 people with an	5	N/A	Varied 92.9-98.6	Varied 95.3-99.8

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			additional hour of gym exercise being collected from 2 people.				

Author	**Device Location**	**Subjects**	**Methods of Fall Assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
Zhang et al. 2006 [85]	Phone	Twelve older adult volunteers (60-80 years of age). Thirty-two young volunteers (20-39 years of age). A dummy was also used.	There were 6 categories of experiments: 1) ordinary daily activities 2) lower-risk fall down, the subjects fell down on the plane with soft cushion; 3) high-risk fall down, the subjects fell down on the hard plane, stairs and slope; 4) critical movement, the subjects did fleet movements that are some alike falling down 5) high-intensity daily activities 6) special movement, include holding the cellphone in hand and do some activities. Elderly volunteers only attended category 1 and 6 and young volunteers attended all categories except	5	Varied (84.4-100)	N/A	N/A

Author	Device Location	Subjects	Methods of Fall Assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			3. Category 2 was attended by a dummy				

Table 2.2 Summary of Projects Involving Non-Wearable Systems

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Alwan et al. 2006 [32]	Floor sensor	Dummies (Hybrid III, Rescue Randy)	Falls were simulated using anthropomorphic dummies similar to humans. The fall tests were conducted on concrete floors. A Hybrid-111® crash test dummy in the seated position and a Rescue Randy were used. The Hybrid-III dummy was used to emulate the scenario of a person falling when attempting to get out from a chair/ wheelchair and the Rescue Randy was used to emulate tripping and falling from an upright position. Experiments were repeated 3 times at each distance to ensure repeatability of the results.	6	N/A	100	100

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Auvinet et al. 2008 [87]	Camera/ Motion Sensors	One volunteer	They first created a dataset composed of video from 8 cameras placed around the room where falls were simulated by a neuropsychologist specialized in geriatrics. For testing purpose in some scenario, fake falls were present.	5	100	N/A	N/A
Auvinet et al. 2011 [86]	Camera/ Motion Sensors	Falls performed by authors	Designed scenarios were carried out by 1 of the authors who performed the falls in a laboratory with appropriate protection (mattress). Realism of the falling motion was not a key issue here as their approach focused on the post-fall phase. Overall there were 24 realistic scenarios showing 22 fall events and 24 confounding events	5	N/A	99.7	99.7

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Belshaw et al. 2011[27]	Camera/ Motion Sensor	Two healthy adult subjects	Two in home trials were conducted in 2 separate real living rooms. For each trial the subjects simulated falls and performed daily living behaviors for a continuous period of seven days. Participants for the second study were instructed to simulate falls and log such events. A total of 11 simulated falls were conducted during the seven days.	4	N/A	100	95
Belshaw et al. 2011[28]	Camera/ Motion Sensor	Training set, and able bodied participants	A training set that is per-frame annotated with fall or no-fall information was created. Training and testing data were collected from 3 office room settings. Over the course of 3 weeks, able-bodied participants were asked to perform several simulated fall	4	N/A	92	95

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			postures on the floor in all 3 rooms				
Chia-Wen & Zhi-Hong. 2007[92]	Camera/ Motion Sensors	Training set	In total, 78 sequences were created of which 48 were training sequences and 30 were test sequences. The training set contained 3 different motion types (16 for each). The 30 test sequences consist of 15 fall sequences and 15 walking sequences.	3	N/A	86.7	100
Foroughi et al. 2008 [93]	Camera/ Motion Sensors	Fifty participants (20-30 years of age)	The subjects repeated 10 kinds of activities 5 times in the experimental space. These activities were recorded to videos of which the algorithm was applied to.	5	97	92.8	97.6
Lee & Chung 2012 [94]	Camera/ Motion Sensors	Image sequences	A total of 175 video activities were capture in indoor environments using a Kinect sensor connected to a laptop computer.	4	97	94	98

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Lee & Lee 2008 [39, 40] Lee & Kim 2007	Camera/ Motion Sensors	Thirty healthy young subjects, 20 males and 10 females (average age 26.9 ± 3.6 years)	The monitoring system was installed in the experimental space. Each subject performed a forward fall, backward fall, side fall and sitting/standing 3 times each.	5,5	93.2	N/A	N/A
Lee & Mihailidis. 2005 [47, 48]	Camera/ Motion Sensors	Twenty-one subjects (20 to 40 years of age)	Trials were conducted in a mock bedroom setting. The mockup consisted of a bed, a chair and other typical bedroom furnishings. Subjects were asked to complete 5 scenarios 3 times each. These scenarios totaled 315 task with 126 fall simulated tasks and 189 non-fall simulated tasks.	5, 2	77	N/A	N/A
Leone et al. 2011 [95]	Camera/ Motion Sensor	Thirteen professional stuntmen (30-40 years of age)	A geriatrician gave instruction for the simulation of realistic falls which were performed using crash mats and knee/elbow	6	N/A	97.3	80

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			pad protectors. A total amount of 460 actions were simulated of which 260 were falls in all directions. Several ADLs were simulated other than falls in order to evaluate the ability of discriminating falls from ADLs				
Li et al. 2010 [30]	Microphone	Recorded training and test set	The training set was recorded in their lab and included 25 falls (on a mat) and 50 false alarms. The test set contained 30 falls and 120 false alarms.	5	N/A	100	Not reported
Li et al. 2012 [89]	Microphone	Three stunt actors, 2 females (32 and 46 years of age) and 1 male (30 years of age)	The experimental data consisted of falls and non-falls. The actors were trained by nursing collaborators to fall like an elderly. Dataset 1 was collected in a laboratory environment where the actors fell onto a mattress and generated a fall sound. Set 1 contains 120 files	6	N/A	100	97

Author	**Sensor type**	**Subjects**	**Methods of fall assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
			of falls and 120 files of non-falls. Dataset 2 was collected in a realistic living environment in 4 different apartments. Each actor performed 6 falls onto a mattress.				
Mirmahboub et al. 2013[96]	Camera/ Motion Sensors	One actor	The dataset contains 24 scenarios. In each scenario an actor plays a number of activities such as falling, sitting on a sofa, walking, pushing objects, etc. All actions are performed by 1 person with different garment colors.	5	95.2	Varied (95-100)	Varied (93.8-98.8)
Nyan et al. 2008 [88]	Camera/ Motion Sensors	Ten healthy young volunteers, 2 females and 8 males (19-24 years of age)	A total of 20 sets of data, 2 trials each per subject were recorded for. Subjects were told to relax their bodies in a limp manner allowing for free fall onto the mattress. Fall activities included, forward fall, backward fall, sideways	6	100	N/A	N/A

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			falls, fall to half-left, and fall to half-right. Subjects were instructed simulate typical daily normal activities.				
Popescu & Mahnot. 2009[90]	Microphone	Falls performed by authors	The training data consisted of 90 sound sequences, about 1s long that consisted of 30 falls and 60 non-falls. Non-falls sounds included dropping objects, knocking clapping and phone call related. The falls were performed by the authors on various surfaces such as carpet, soft-surface mat and hard-surface mat. The testing data consisted of an hour-long recording performed in our lab. In that time 72 non-fall sounds were produced (similar to the ones described in the training data) and 36 falls.	4	N/A	Results difficult to interpret	Results difficult to interpret

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Popescu et al. 2008 [31]	Microphone	One stunt actor	Five types of falls were performed with a nurse directing the actor during the fall session. They recorded 6 fall sessions with a total of 23 falls. A special 20 minute long session with 14 falls and noises was recorded and used for training.	4	100	N/A	N/A
Rimminen et al. 2010 [91]	Floor sensor	Ten volunteers	A test room was covered with a matrix of sensors. A group of 10 people with even gender distribution simulated falls in random locations using the test arrangement suggested by Noury et al.[17]	6	N/A	90.7	90.7
Rougier et al. 2006 [97]	Camera/ Motion Sensor	Image sequences	Fall detection has been tested on 19 image sequences of daily normal activities and simulated falls. Nine sequences show different falls like forward falls, backward	4	N/A	N/A	N/A

Author	**Sensor type**	**Subjects**	**Methods of fall assessment**	**STARE-HI Score (0-6)**	**Accuracy %**	**Sensitivity %**	**Specificity %**
			falls, falls when inappropriately sitting down, loss of balance. Ten sequences showed normal activities like sitting down, standing up, crouching down.				
Rougier et al. 2007 [98]	Camera/ Motion Sensor	Image sequences	The dataset is composed of video sequences representing 24 daily normal activities (walking, sitting down, standing up, crouching down) and 17 simulated falls (forward falls, backward falls, falls when inappropriately sitting down, loss of balance).	4	N/A	88	87.5

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Shieh & Huang 2012[99]	Camera/ Motion Sensors	Twenty young volunteers, 10 men and 10 women	Subjects are requested to perform different motions of non-falls and falls in above places. The non-fall motions include walking, running, sitting and standing. The fall motions include slipping, tripping, bending and fainting in any directions. In total 60 fall and 40 non fall motions are analyzed.	5	Varied (>90)	Varied (82-100)	Varied (90-100)
Sixsmith & Johnson. 2004 [29]	Camera/ Motion Sensors	One actor	A specialist actor performed 20 predefined fall and 10 predefined non-fall scenarios. They also conducted a field trial over a 2 month period in a single occupancy apartment. The detector was mounted close to a corner of the room and positioned to view as	4	Results difficult to interpret	Results difficult to interpret	Results difficult to interpret

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			much of the room as possible.				

Table 2.3 Summary of Projects Involving Multiple Devices

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Ariani et al. 2010 [101]	Motion, floor	Ten computer generated subjects, 5 females and 5 males (50-70 years of age)	A wireless sensor network (WSN) simulator generates movements of 10 elderly people. For each subject, 8 fall scenarios and 2 ADLs are simulated.	5	90.9	100	66.7
Ariani et al. 2012 [102]	Motion, floor	Computer generated subjects	A series of predefined simulated movements were generated to simulate an elderly person living alone, or cohabiting with either 1 or 2 family members. In particular, ADLs, a fall from bed after waking up, a fall after getting up from a chair, and a fall when walking or standing were simulated. For each falling event 3 types of post-fall scenarios are performed including successful recovery, remaining unconscious and being unable to stand. The simulator also produced a number of simple and complex scenarios involving 1 or more people walking.	6	89.3	100	77.1
Bloch et al. 2011[52]	Wearable, infrared	Ten older adults who presented with a risk of falling in a geriatric ward (average age 83.4 ± 7.4)	8 patients wore only the accelerometric sensors while the other two used the complete device. These patients were required to wear the sensor and were made to lie down in rooms equipped with infrared sensors. Average duration for wearing the device was 21 ± 19 days with a total of 168 for the group of eight and 28 for the group	6	N/A	62.5 (Wearable only)	99.5 (Wearable only)

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			of two. In the group of 8, 33 events were detected. In the group of 2, no events were detected.				
Bourenanne et al. 2013 [43] & Charlon et al. 2013[44]	Wearable, camera	Two older adult female patients in an Alzheimer care unit (84 and 88 years of age)	Motion sensors are deployed in the rooms of 2 patients and in the main living areas. A sensor is also placed as an adhesive patch on the back of the patient. Patients were autonomous in their movement but needed help in their daily grooming routine.	6, 5	87.5	N/A	N/A
Doukas & Maglogiannis. 2011 [103]	Wearable, camera, acoustic	Two male volunteers (28 years or age and 35 years of age)	Movement types included 1) simple walk; 2) simple walk and fall; and 3) simple walk and run. Each individual performed at least 2 experiments including all 3 motion types. The volunteers were directed to perform all movement types as realistically as possible. Individuals were also asked to walk within the experiment area and perform falls by simulating events like stumbling on furniture or falling down because of loss of consciousness.	5	~90	Varied (86-100)	Varied (80-100)
Gietzelt et al. 2012 [100]	Wearable, camera	One female, 2 males (average age 86 years)	The trials were carried out in the private homes of the individual subjects for a period of 60 days. Patients were asked to fill out a diary daily whether or not a fall had occurred. Overall 9 falls occurred during the study.	5	N/A	91.4 (Pre-study results)	95 (Pre-Study results)

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
Litvak et al. 2008 [42] and Zigel et al. 2009 [41]	Acoustic , floor	Rescue Randy, various objects (heavy bag, book, plastic box and a metal box.	The training and testing data sets for the algorithm were taken from experiments that have been performed on a typical concrete tile floor and a carpet using 4 “popular falling” objects and “Rescue Randy” a human mimicking doll. In total, the training set included 40 “human” drops and 26 drops of objects. The testing phase consisted of a total of 40 drops of Rescue Randy and 78 drops of objects.	6, 5	N/A	Varied 95-97.5	Varied 95-98.6
Srinivasan et al. 2007 [104]	Wearable, motion	Fifteen young subjects , 2 females and 13 males (24-37 years of age)	Each subject performed a varied sequence of sitting, standing, walking, hopping etc. The following categories of falls were also considered: falls in the sagittal plane and falls in the coronal plane. A total of 96 simulated falls and 1288 non-fall trials were collected.	5	Varied (94.7-100)	N/A	N/A
Tasoulis et al. 2013 [105]	Wearable, camera, acoustic	Unspecified subject	The first data set used in our experiments contains 6 synchronized data streams, taken from a person who is walking and then falls. The second dataset is taken for outdoor scenarios where	2	N/A	Varied	Varied

Author	Sensor type	Subjects	Methods of fall assessment	STARE-HI Score (0-6)	Accuracy %	Sensitivity %	Specificity %
			only the wearable device can be utilized. The person is initially walking and prior to the fall is running at random times.				
Zhang et al. 2011 [106]	Motion, floor	One healthy subject	The subject mimicked nighttime movements of an elderly individual living alone at home at night. Multiple scenarios were simulated including: fall with unconsciousness, fall with failure to recover, fall with successful recover, entering and leaving the room, out of bed and dressing, etc.	4	N/A	Varied (59.3-100)	100

CHAPTER 3: Older Adults' Perceptions of Fall Detection Devices[2]

Abstract

A third of adults over the age of 65 are estimated to fall at least once a year. Perhaps as dangerous as the fall itself is the time spent after a fall if the person is unable to move. While there are many devices available to detect when a person has fallen, little is known about the opinions of older adults regarding these fall detection devices. We conducted 5 focus groups with 27 older adults. Transcripts from sessions were coded to generate themes that captured participants' perceptions. Themes were identified that related to two topics of interest: 1) personal influences on the participants' desire to have a fall detection device and 2) participant recommendations regarding specific features and functionalities of these devices. Together, these themes suggest ways in which fall detection devices may be improved so that they are suitable for their intended population.

[2] This manuscript has been submitted for review in the *Journal of Applied Gerontology* and has been written to meet their publication guidelines.

Introduction

A third of older adults (OA)s are estimated to fall at least once annually (Centers for Disease Control and Prevention, 2014)]. Falls are the primary cause of fractures, loss of independence and injury-related death amongst older adults ("National Institute of Health"). The time spent after a fall can be especially dangerous if one is unable to stand or move. The "long lie" occurs when a person involuntarily remains on the ground for longer than an hour following a fall and can result in several medical complications or even death (Day, 2003; Mallinson & Green, 1985)]. Among those experiencing the long lie, half die within 6 months. It is essential to quickly identify and aid a person who has fallen to prevent further physical or emotional damage.

Current devices use various methods to detect when a person has fallen (Chaudhuri, Thompson, & Demiris, 2013; Noury et al., 2007; Ward, Holliday, Fielden, & Williams, 2012)]. Most commercial detectors involve a system where the fallen individual must manually push a button to call for help. More recent devices have the ability to trigger a call automatically ("Life Alert")]. Most academic research initiatives associated with fall detection devices (FDDs) use wearable automatic fall detectors in their studies (Bourke, O'Brien, & Lyons, 2007; Tamura, Yoshimura, Horiuchi, Higashi, & Fujimoto, 2000)]; however, environmental devices such as cameras or microphones have also been used (Auvinet, Multon, Saint-Arnaud, Rousseau, & Meunier, 2011; Belshaw, Taati, Giesbercht, & Mihailidis, 2011)]. The majority of research to date has focused on improving device accuracy. A much smaller literature has studied user perceptions of FDDs. In 1 study using interviews, OAs felt that FDDs might give them a greater sense of security; however, they also believed that the devices were intrusive and did not feel as though they were in control of triggering an alert (Horton, 2008)]. In another study also using interviews, while 96% of participants felt favorably towards the system, only 48% indicated they would use the device (Londei et al., 2009)].

While valuable, these studies are limited to exploring individual opinions of these devices and are unable to identify group norms and cultural values as is possible using focus groups. Focus groups also allow for the discussion of potentially sensitive topics and for participants to compare their experience leading to a collective brainstorming of new ideas ("Qualitative Research Guidelines Project,"). The one study that used focus groups to explore older adults opinions on fall detection devices, (Brownsell & Hawley, 2004) was published 10 years ago and only briefly touches on usability issues before focusing on a pilot study designed to see if these devices reduce fear of falling.

In order to add to the current knowledge in this area and more clearly understand users' perceptions of fall detection technology we conducted focus groups with OAs to more clearly understand their perceptions of current fall detection technologies and their willingness to use such devices. In this paper we present participants' perceptions of FDDs and specifically examine what factors affect their willingness to use these devices and what suggestions they have to improve this technology.

Methods

Setting/Recruitment

We recruited a convenience sample of subjects from independent and assisted living communities around the Puget Sound region. We conducted information sessions and posted fliers in the facilities to inform participants of the study. Focus groups continued until information saturation was reached. Inclusion criteria were: over age 60 and living in one of the targeted communities. Exclusion criteria included unwillingness to be audio-recorded, inability to provide informed consent or inability to speak English. The University of Washington's Institutional Review Board approved this research (Human Subject's application number 43841).

We conducted 5 focus groups at 3 independent and assisted living communities from July to October 2013. In total, there were 27 participants (22 female, 5 male). The communities were selected to provide range of settings from lower to middle-upper socioeconomic status. In order to better classify the participants we looked at cost of living for their respective facilities. Twenty-one participants were classified as higher socio economic (monthly housing cost $2,875-$4,785) while 6 of the participants were classified as lower socio economic (monthly housing cost $406-$607).

Focus Groups

Each focus group lasted approximately an hour and loosely followed a script (Appendix 1). They began with a brief presentation explaining the purpose of FDDs and showing examples of both wearable and environmental devices. A semi-structured interview guide was then used to generate discussion around the participants' thoughts on a theoretical device. Finally a tangible device was presented that participants could touch, test and discuss followed by open discussion.

Figure 3.1 Device A resting on a charger

The prototype device (henceforth termed Device A) was donated for the study by a third party company (Figure 1). It has the ability to automatically detect falls as well as GPS capabilities. It was used to facilitate a discussion of the pros and cons associated with this specific device and to clarify focus group participants' perceptions of an ideal fall detection device.

Coding

The focus group sessions were audio recorded and transcribed for thematic coding(Strauss & Corbin, 1998)]. Three researchers experienced with qualitative methods independently reviewed the transcripts and performed open coding to distinguish concepts related to the content. Coding was performed in Microsoft Word using the "comments" and "compare" features. Once coded, researchers met to reconcile codes and develop a master codebook which was then used to recode the transcripts separately, after which the researchers met again to reconcile the codes. This process was used to code relevant segments of the transcript into various themes.

Results

We have organized identified themes into two separate meta-themes. The first meta-theme describes personal influences on the participants' desire to have such a device. The second describes recommendations given for specific features of these devices. Additional quotes for each of these themes are located in Tables 1 and 2.

[Table 3.1 about here]

Personal influences

Perceived need.

Participants often told stories about past situations they had experienced, witnessed, or heard involving FDDs. These stories appeared to have a large influence on how the participants felt about such devices. Most stories involved either the failure of these devices to activate when needed, or cases where the devices activated unnecessarily.

Several participants also acknowledged personally experiencing a previous fall which appeared to provide some motivation to use FDDs in the future. One participant saw the benefit in having a device especially when isolated, *"I'm fortunate I wasn't injured very much, but you know, I could imagine…the last time I fell, I could have been there for quite a long time before anybody came along."*

Perceived isolation or helplessness during a previous or imagined fall event were often stated as important motivators to obtaining a fall detection device. Participants believed having an automated device would be especially useful in the event that the faller was unable to move or reach the button, *"Well, because, a lot of people can't press a button when they fall…if it's automatic it's much, much better."*

However, several participants across the groups expressed a lack of need or interest in such devices. Some participants did not feel they were the right population for this device instead suggesting it for some of their peers. Participants also cited needing some sort of proof they were in danger of falling before using such a device, *"I would probably have to have some kind of a fall related to balance; if it was related to carelessness then I still wouldn't think I needed one would because I would become more careful."*

Many participants expressed being near others or the availability of other options as reasons for not needing a fall detection system. For example, when asked if a participant was afraid of falling without a device she responded, "*No because I'm here with [participant's husband]. If I was on my own I would.*" In one of the larger focus group, all participants had access to a wearable manually activated fall detection system provided by their apartment community. However, when asked, no one acknowledged regularly using the device, prompting one participant to sum up her thoughts on how most people felt about these devices, "*...we all think it won't happen to me, until it does, and if people have a couple of falls then we will think about it. But until you do [fall] I don't think there's any way to persuade somebody.*"

Values.

Most participants valued their independence and autonomy wanting to avoid the stereotype of being old and a potentially stigmatizing device. Some participants agreed there was stigma associated with wearing the device, but didn't think the stigma would affect the use of a fall detection device, "*And the stigma too, probably of having something, 'oh you're wearing one of those'... "I don't think I'd be affected by stigma*." A common suggestion was to convince other people to wear the device to alleviate the stigma.

Stigma appeared to be closely related to independence, as many participants saw having a fall detection device as an indication of a loss of independence. One participant summed up the overall feeling of being asked to use such devices,

> *"We live in a world where it's, at our age wearing a hearing aid isn't the worst thing that ever happened to you. And of course a lot of people wear hearing aids and we don't even notice that they have them on. But anything that really goes beyond that kind of subtle thing, is very difficult unless you just had the living daylight scared out of you about your own wellbeing. Yeah, so the first time is the most important time and if you don't have that first time I think*

> *there's a lot of reluctance to use something, if its cane or you know…a cane or hearing aid, hearings aids are so easy. Walker, any of those things, it's really, really hard because it's telling you that, pardon the expression, you're an old poop."*

<u>Cost.</u>

Another barrier to the adoption of these devices was perceived initial and ongoing cost of a fall detection system. Many participants agreed that if the device were affordable they would own one.

Participants in multiple focus groups, regardless of economic status, suggested having an existing healthcare payer, such as Medicare, pay for the cost of a FDD. One participant in a higher-income focus group stated*, "Ideally I think everybody should have...access to such a device through social security say, or Medicare or, but that, if that's not realistic then I think health insurance plans in general should cover it."*

Feature assessment

[Table 3.2 about here]

<u>*Automation.*</u>

Participants saw benefits to having a device that automatically called for help. This feature was especially seen to benefit helpless subjects, *"because someone may be unconscious or in a position where they can't get at it [the device]."* Participants expressed concerns of false alarms caused by an automated response, and indicated needing the ability to turn off or cancel the device's call.

<u>*Call message, Volume, Usability, Battery life.*</u>

Feedback on FDDs focused on the basic functions associated with these devices i.e. volume, usability and messages. As an example many FDDs when triggered, first voice a message indicating its activity before placing a call. Along with desiring a shorter message, some participants complained about the volume of the message, *"I can hardly hear and plus you have instructions to what? Hold for 7 seconds, if you're destroyed, you're scared, you are panicking, your arm… I don't like it, sorry."* Some participants indicated it may be helpful to have a way to control the volume especially if they were expected to wear the device around their neck or near their waist.

Another issue with Device A, was the usability of the button. Participants in various sessions complained about the difficulty of pressing the button which appeared to be adequate for a healthy individual but was viewed as being potentially problematic for some of the participants' incapacitated friends or relatives.

Participants were undecided on Device A's battery life but were concerned with having to charge the device. One suggestion was to have two devices so that one could sit on the charger while the other was in use, *"… the customer has two of them. One is always here. The other is always on."* A participant in a different group had a similar suggestion but instead suggested having two interchangeable batteries that could be charged separately.

Wearable vs Environmental Devices.

Participants had several negative preconceptions of environmental devices. Several participant's described environmental devices as, *"too much like Big Brother,"* claiming them to be invasive. Participants were also concerned with the range of environmental devices, while others seemed to view them as an unnecessary nuisance that would take more time to install.

Wearable devices were preferred as they allowed for participants to be monitored at all times. This was especially appealing to participants who enjoyed walking or participating in activities outside the facility. However, participants disliked current wearable devices claiming them to be ugly, cumbersome or easy to forget.

Most participants agreed that having a wrist based FDD would be the best option, *"Because that's very convenient to touch, you don't have to grope for it and it's quite available."* Watches, while always on the body, were also seen as out of the way and thus more apt to be worn in bed. One participant indicated that a wristwatch could always be worn no matter the clothing of the participant as opposed to a device that needed to be clipped on to a belt.

Alternative functions.

Participants often suggested integrating FDD systems with alternative functionality to encourage their use. One of the suggestions involved having a FDD integrated within a cellphone, "*It would be much easier if it were in combination with say our cellphones. Because if you already carry your cellphone, it's gonna be kind of a pain to try to have make sure you've got two devices."* Other suggestions included a pedometer or an alarm to alert the individual of an appointment or to manage medications.

The most valued alternative function was a GPS function for tracking users during non-emergent situations. Participants wanted a device that they could use anywhere without restriction and stated the value of having the GPS ability in case you were to fall in an unknown area or were unable to communicate, *"I would be concerned about is, what if you are unconscious and you can't respond, how do they find you?"* Many participants found this feature to be especially useful for users prone to wandering. In general, there did not seem to be a concern for privacy when discussing GPS functionality. One participant discussed the expected tradeoff on having this capability, "*Seems to me, that …in exchange for support, one compromises privacy."*

Customization.

Many participants expressed a desire to be able to customize their FDD:

> *"..it would be nice to have a range of devices that fit your situation…Then it would [be] what I need, and not put on a lot of extra stuff that's gonna cost me more, cause you know I think it's essential to keep it within reasonable price range where you can afford it if you need. But if you don't need it you don't have to take it."*

Customization was discussed for several aspects of the device including deciding who the device would call in the event of a fall and GPS. When discussing GPS, participants wanted to choose exactly when the feature would be active seeing advantages to having a constantly active GPS for someone who tended to wander but also seeing value in having the GPS feature only activate in the event of a fall thus preserving battery life, and offering more privacy,

Participants also debated who the device should call in the event of a fall with possible contacts being a central call center, 911, or even a friend or family member. The preference of the notification was greatly influenced by the individual's personal life and previous experiences. In one group participants agreed that there might need to be a tiered cascade of calls made to different individuals/entities.

Fall detection vs. fall prevention.

Many participants were more interested in devices designed to prevent a fall. Some participants wanted a device that would warn you when you were about to fall instead of working only after a fall, *"And the thing I would like better than that is something that detected when I was going to fall that would say 'Balance up'."*

Discussion

Our focus group study enriches current understanding of OAs' perceptions of fall detection devices. From the focus group discussions we found that participants' desire for such a device were often related to the device's effect on participant independence as well as the cost associated with the device. We also found that most participants preferred a device that could automatically detect falls, keep track of their location and be worn on their wrist. In this section we make suggestions on how best to incorporate these devices into the lives of OAs and also provide a set of recommendations for characteristics of an idealized FDD as informed from our focus group discussions.

Personal considerations

In general, participants throughout the focus groups saw some benefit in having a FDD especially given the right situation. However many participants were unimpressed by current variations of FDDs. As an example, there were negative preconceptions focusing on environmental devices; people were concerned about the expense of these devices as well as the "Big Brother" aspect. Older adults' privacy concerns have been well documented in past studies which have shown that certain amount of intrusiveness is acceptable as long as the perceived need ameliorates privacy concerns (Demiris, Oliver, Giger, Skubic, & Rantz, 2009; Wild, Boise, Lundell, & Foucek, 2008). Along with providing some assurance of privacy, researchers in this area need to improve the utility of these devices to make them acceptable for OAs.

More generally several participants did not feel the need for such a device, believing they were targeted for some other person older than themselves (Aminzadeh & Edwards, 1998; Calhoun et al., 2011; Copolillo, Collins, Randall, & Cash, 2001). The great challenge in this arena will be to convince at risk individuals that FDDs will increase their independence and will be most useful before one ever experiences a fall. Confronting such a challenge will require a significant cultural shift in how these devices are introduced, advertised and sold to OAs. Rather than portraying the target of these devices as a feeble old woman who has fallen and is unable to get back up, it may be more beneficial to advertise OAs being able to enjoy their independence more with the safety and security of a fall detection device(Butler, 1989; Nelson, 2004)]. Additionally it could be more beneficial to first market individualized devices directly to OAs before attempting to sell them to their children or concerned relatives. Doing this will give the intended users of the device a greater sense of control over their own health, encouraging them to use the device more consistently and possibly increase their overall independence and well-being (Mallers, Claver, & Lares, 2014)].

Finally, the cost of these devices will need to be greatly reduced or covered by a form of health insurance. The U.S. spends around 20 billion dollars a year on medical care for OAs who have fallen, a number predicted to rise to around 43.8 billion by the year 2020 (Bohl, Phelan, Fishman, & Harris, 2012; Stevens, Corso, Finkelstein, & Miller, 2006)]. Investing in measures like FDDs that could prevent further injury would be a way to reduce these costs. Such changes will take time, but are necessary to convince OAs at risk of falling that wearing such a device is beneficial to their well-being.

Device recommendations

According to our analysis, the ideal FDD is a wearable device located on the wrist of the participant. This finding points to a gap in current FDD research, as to date, there have been few studies involving wrist-worn FDDs (Kangas, Konttila, Lindgren, Winblad, & Jämsä, 2008; Kangas, Konttila, Winblad, & Jämsä, 2007; Mathie, Coster, Lovell, & Celler, 2004; Nocua, Noury, Gehin, Dittmar, & McAdams, 2009)]. Admittedly, there are increased technical complications with making automatic wrist-worn FDDs due to the constant motion of the arm and the greater distance the wrist is from the person's center of mass. However, our participants felt that a wrist-worn device would ensure that the user could easily wear it, locate it during a fall event, and fit into daily social norms better than existing devices worn around the neck or on the waist.

The ideal device would have the ability to call for help both automatically and with the push of a button. While most participants found significant value in automatic detection during times when the individual is unable to press the button, most also wanted to preserve the manual function to increase accessibility of help. However, as discussed above, alerts must be able to be canceled easily to reduce the potential negative consequences of false alarms. While this system should be primarily designed to detect when a person falls, a system that also predicts falls before they happen would be ideal per participant comments.

The ideal device would have GPS capabilities and provide the user with the ability to customize when the GPS function was active. Similarly, this device would also allow the user to have a customized order of notifications in the event of a fall. This device would also have alternative functions aside from fall detection which could be added and removed on a case by case basis, including the ability to make phone calls or track the amount of steps the user had taken. One consideration that was mentioned in the focus groups, especially for the older adult population, is manufacturers will need to develop rules for allowing end-user customization.

This work was limited by selecting a convenience sample of participants residing in the Puget Sound area. Perceptions on FDDs may differ in other regions of the world. Demographic data were not collected directly from the participants. Additionally, focus group participants were only able to touch and test a single wearable FDD during the sessions which may have produced some bias; had there been different kinds of devices physically available to the participants their opinions might have varied. This concern was minimal as Device A was similar to many other off-the-shelf fall detection products.

Even with these limitations, this study's sample size was adequate to identify themes and involved participants of varying socio-economic status and varying living situations. Several findings echoed those of previous studies, which lends increased confidence in our new findings. Most of the subjects had either personally experienced a fall or were close to someone who had. Their thoughts and opinions provide meaningful direction that can greatly improve the usability and usefulness of FDDs.

Conclusion

Falls represent a significant threat to the health and independence of the elderly. Existing devices designed to detect when a person has fallen are often poorly designed for OAs and thus, under-utilized. In this study we used the results of focus groups with OAs to describe characteristics of an ideal FDD. These suggestion provide direction for the design of FDDs in the hopes of increasing appeal and thereby improving use of such devices in the future.

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Table 3.1 Personal factors that influences participants' desire for such a device

Perceived need	"I remember a news story about a man who accidentally set it off and then they sent the police and 911 people but he end up getting killed because he didn't even want them in there because he hadn't called them and he didn't even really at first understand why they were there ever there."
	"I always think back to [friend of the participant] when she fell a couple of years ago and she pounded on that button and nobody ever came."
	"she was in so much pain that she stood up but then she just collapsed on the floor and she barely could make her way to her door and there were protection devices one in the bathroom and one near the front door but, it was fine if you were standing… she couldn't reach it. Absolutely useless."
	"I fell on the stairs in this building. Oh a month or so ago… Was unable to get up. And I managed to, oh I was kicking on the door from the stairwell to the hallway and, fortunately someone heard me, and they came up."
	"…my opinion is such device is probably most applicable for someone who has an impairment, either mobility impairment or mental impairment."
	"I don't think, at the point I am now that I need one but, I'm still, not in really old age, but at some point I might."

	"I guess sometimes maybe I should be because I am not as steady as I used to be, but I usually use a cane and that takes care of…so, I don't feel that I'm in any jeopardy."
	"Well I have fallen…and broken an ankle in the process but it was on the sidewalk where there were lot of people passing by so I didn't need anything like that [points to device A]."
	"identify you as handicapped"
	"I don't see the stigma at all, I have never though it's a nuisance in remembering to put in on and, if you need it I think you'd wear it."
Values	"I think to them it would be a stigma 'cause they're not wearing it, 'cause they think they don't need it and they 'I don't need that…I am not that bad yet.' So that to me indicates being a stigma that I am helpless or I'm not strong as I was."
	"But I like, yeah the stereotype I mean, if sports enthusiasts are gonna be wearing it, you're not gonna feel like 'I'm old and I'm wearing it'."
	"I'd hate to have to wear one all the time…Just because I don't like being dependent, I like being independent."
	"And if we can't hold on to the youth we want to be as independent as we can be"

	"You know we've lived a long time we are sick and tired of doing what other people tell us what to do…And treating us like we are invisible and stupid cause we've got grey hair."
Cost	"..if it weren't so expensive, I mean you have to pay for the thing and then you have to pay a monthly fee, and its expensive. I would have one right this minute if I didn't if but the first one I checked into I went, 'Oh give me a break'."
	"I think it should be covered by your medical insurance… it's an important health device, I mean, they cover pacemakers."
	"Might be cheaper for Medicare to go into business and manufacture them and make 'em available, or the VA or somebody like that."

Table 3.2 Participant suggestions for device functionality and features

Automation	"Well there should be a device on this thing, that you could, a button you could press or something that says it was a false alarm…turn it off."
	"…we can't have perfection and there are some things where it would be humiliating to have this whole thing going on, when you were, and everybody's looking at you while you're waiting so you can do the cancel."
Call message, Volume, Usability, Battery life	"they can say all those words in about, a quarter of those number… too much information."
	"it doesn't need to say this is your answering service or whatever the heck it said in the first place. Yeah, I know! Who else is it gonna be! 'Hold it up to your mouth and talk', if that's what, that'd be fine."
	"I'm not sure I hear it well enough on my belt, that's my preferred location but I'm not sure I hear it well enough that far from my ears."
	Yeah I was trying, to think if uh, my husband could press that button. He has such bad Parkinson's."
	"This is taking, this is taking more, more strength to do. Course I guess you don't want it done accidentally. I mean I'm thinking about my mother who is 87 and was fumbling you know…"
	"I mean otherwise you're without it while it's being charged."
	"Well what's wrong with having a removable battery that could be on the charger."

Wearable vs Environmental Devices	"Oh I think cameras or microphones really produce a lot of false alarms"
	"And they're invasive besides"
	"…video or audio detection, I mean that's only good in the apartment"
	"If it is a multi-room apartment, you might need to install….in both rooms, or something or bathroom maybe, who knows. It seems the environmental device is potentially more difficult to implement and more expensive"
	if I wanted to rely on something I'd want it to be everywhere with me."
	"I would have a problem wearing it, 'cause it would be ugly and cumbersome,"
	"...it would be dangerous to sleep with a necklace."
	"I think if it was a wristband I would be more inclined to wear it."
	"I think the watch would be the most apt to be worn to bed."
	, "I can't see that I would wear this to bed [Device A]...This I might [points to his watch]."
	"I don't always wear garments where, uh I can put something on a waistband, so that seems more practical"

	, "…people wear health devices here at (facility) that only the range is only within the building. You know if you are two blocks away it's no help."
	"So, is this something that would work out of the country?"
Alternative functions	"I've fallen outside because terrible sidewalk, you know, tripped over bricks on the sidewalk or something like that. So for me, it's important it would be important to use it universally."
	"I'm not hiding any secrets I don't feel like it would matter if it was something I was thinking I need and would like help, I think it would be wonderful, but as far as being an intrusion that, that part of it wouldn't bother me,"
	"my mother moved here when she could no longer care for herself … she would go on the bus and she'd never been on those buses and I would just worry myself to death wondering if she would ever get home and if so if you had a little device thing that was following with her you could kinda track her down.."
Customization	"And that would be a good selling point, because you could say you know, this you know, you've heard of the fall detections this one also has the option for a wanderer and for non-wanderers, if you're using it solely for fall detection, then the GPS can be shut down until the fall event occurs and then turn it on, establish a location and transmit it."

Fall detection vs. fall prevention	"Has anybody tried to make a device that would warn you when you're losing your balance a little bit?... Yeah, because we want to prevent falls."
	"Well given what I said earlier that about my wobbles, I think it might be interesting I'm a member of [HMO] and it might be interesting if [HMO] had a device and a study that would collect data on my wobbling."
	"Yeah about behaviors, pre-fall behaviors. Do you follow me, like just unsteadiness?"
	"I think that's a very good idea to have something that would be more inclusive of your whole system … figures it out till it's, you know too late, and then you really got a problem."

Appendix 3.1. Focus group script

- Short multi-media presentation of device capabilities (10 minutes maximum, lay language only)
  - Goal is show what systems can do for their subjects and how they work
  - Brief overview of various devices (Wearable, Non-wearable, general goal)
- After overview discuss with group (15 minutes)
  - What are the benefits in having such a device?
  - If you had such a device would you use it? Would you recommend it for a friend?
  - What concerns do you have in using such devices?
  - What do you imagine such a device doing for your life? Does it improve it or is it a burden?
  - How much do you think a device like this should cost? Who should pay for the device? (you, your family, your insurance)
- After discussion show them the wearable device and how it works (<5 minutes)
  - Do a brief demonstration of where the device would be worn, and how calling could work
    - Allow for the subjects to look at, touch, and wear the device
    - Allow for questions about the device
    - Goal is to show exactly how the system works and what it can do for the subjects
- After showing the device discuss with group:
  - Look and feel of device (hand out the sheet)
    - What do you think of the device's:
      - Appearance (Shape, Size, Weight, Color)
      - Usability
      - Button size
      - Wearability (Clip or Lanyard)
      - Speaker phone location/audible cues
      - Alert notification
      - LED
  - Question the subjects on their perception and preferences for the device
    - Ease of use
      - Do you understand how the device works?
      - Would you find wearing this device easy?
      - Do you foresee any issues in wearing this device?
    - Usefulness
      - Would you use this sort of device? If yes: why? If no: what improvements would convince you to start using it?
      - Do you see any benefit in having such a device?
      - What do you imagine this device doing for your life? Does it improve it or is it a burden?
      - What do you think the device should do if you fall? What if you haven't actually fallen but the device registers a fall?
    - Intention to Use

        - Do you believe your friends or family would want you to use this system?
        - Would you see any problems in wearing this every day?
        - Do you see any problems about forgetting to wear this every day?
        - How much do you think the device should cost?
    - Other questions closing statements
        - Could you see such a device posing any threats to one's privacy?
        - What recommendations do you have for improving to the device?
        - Would you have concerns wearing this device? If yes, why?
        - What other functionalities would you like this device to have?
            - Ability to wirelessly upload biometric data, such as blood pressure or glucose levels, with a Bluetooth enabled home monitoring device
            - Activity monitoring (recording number of steps taken each day, overall activity level etc.)
            - Medication reminders (alerts to take medications at predetermined times of day)
            - Geo-fencing (alert when user travels outside of specified area, in particular for individuals with Alzheimer's or dementia)
        - If you were to design this, how would it be different?
        - What would be the best way to explain this to someone else?
    - Allow for any closing statements they have on the device

CHAPTER 4: Older Adults' Use of a Wearable Fall Detection System

Introduction

Falls are becoming an increasingly significant concern for people over the age of 65, a population which continues to grow as older adults live longer and the baby boomer generation transitions into this age group(1,2). Falls are the leading cause of injury deaths amongst older adults and around 30% of older adults fall at least once a year (3,4). In addition to falling, many older adults face the additional danger of being unable to get up independently following a fall. This "long lie" can result in additional physiological and psychological damage. It has been shown that older adults chance of survival increases the quicker they are discovered and treated following a fall (5,6).

Given this, there have been many commercial and academic efforts to develop systems that can identify a fallen individual and trigger a call for aid. (7–10). Most fall detection systems are designed to be worn upon the body and typically involve the user pressing a button to alert someone to the fact that they have fallen, although devices are starting to have the capability of automatically detecting when a person has fallen. While useful, the majority of these systems have only been evaluated in a laboratory setting using volunteers to test the accuracy of the device(7). Real world testing has been shown to be a more strenuous indicator of a device's accuracy, however these tests require more resources and are often hard to accomplish (11–13). As an example, a study by Boyle had 15 adults have a device for 300 days which only yielded 4 real world falls (14).

Just as there is limited real world testing of these devices there is also limited work done to evaluate and verify the usability of these devices for their intended populations (7). A few studies explore the use and feasibility of non-wearable systems such as cameras or carpet sensors

(15,16). One study on smart home use concluded that unfriendly and age-inappropriate design of the systems may be a deciding factor in not using the technology(17). Another study conducted a trial to compare a pendant alarm to a system using multiple sensors (18). In the trial, older adults found that such a system gave them a greater sense of security, however many felt the device invaded on their privacy and did not give them enough control to alert someone to the fact that they had fallen. Another longitudinal study had participants wear a device for several weeks to find that these devices had no significant effect on the participant's fear of falling (19). Other studies used focus groups to help design new detection devices and to better understand the participant's perception of these devices. (20–23)

The purpose of this pilot study was to thoroughly investigate the usability of a wearable fall detection device while also evaluating its performance in the real world by engaging older adults as end users. The study is meant to inform usability issues of a typical fall detection device, and provide suggestions on how to design these devices more appropriately for older adults.

Methods

Setting/Recruitment

Subjects were recruited from 3 independent and assisted living communities around the Puget Sound region. Participants were asked to wear and use a wearable fall detection device for a period of four months during which they were interviewed and monitored to better understand their actual use of and opinions of the device. The principal investigator recruited participants using information sessions and posting fliers in participating facilities. Possible subjects were initially screened for fall risk by using 2 questions: 1. Have you had two or more falls in the prior

12 months? 2. Are you interested in the study because of a recent fall? After a time these screening questions were found to be too stringent and were replaced by a new set of questions. The first asked if participants had experienced a fall in the past 12 months, and the second asked participants to complete the Short Fall Efficacy Scale (SFES)(24). Participants were eligible if they answered “Yes” to the first question OR scored a 14 or higher on the SFES. Participants were also required to score a 5 or higher in the Memory Impairment Screen (MIS) to ensure they were cognitively able to be a part of the study(25). Exclusion criteria included unwillingness to wear the device for 4 months, being under the age of 62 and the inability to speak English. The University of Washington’s Institutional Review Board approved this research.

The Device

Figure 4.1. Device A resting on a charger

A third party company manufactures the prototype device (henceforth termed Device A) and loaned 15 devices for use in this study (Figure 1). Device A has the ability to automatically detect falls and to track the location of the subjects via GPS. In the event of a detected or triggered alarm, this device facilitates two-way communication between the faller and a phone number of their choosing. If the person chooses to, they can cancel the call by pressing the button twice and holding for a certain period of time. For the purposes of this study we set up each device to call the front desk of the participant's respective community which were manned 24/7.

The device comes with a charging stand and the choice of either a clip or lanyard attachment, allowing the participant to choose how to wear the device. The device also has two sets of blinking lights that use colors to indicate battery life and signal strength. Finally, the device is supplemented by a secure online interface which provides various pieces of device data including changes in the device's charging state, changes in the device's location, and if the device had been used to place a call or if the device indicated a fall. The online interface also contains a map that shows participant's GPS location at given points in time. Due to privacy restrictions, only the primary researcher had access to view this map. In the event of a fall the front desk operators were instructed to contact the primary researcher if they needed to locate the fallen individual.

Participants were given verbal instructions on how the device works and how to use the device before their initial interview. Participants were also instructed to wear the device during their waking hours and to charge it at night.

Study procedures and analysis

Interviews were conducted in the participants' homes at baseline, 2 months, and 4 months and were recorded and transcribed. The baseline interview consisted mainly of yes/no questions to better understand the participant's demographic information, fall history and initial perceptions of the device. The midpoint and final interviews followed a semi-structured script that allowed participants to more freely discuss their experience with the devices. Participants were also encouraged to contact the primary researcher if they had any comments related to the device. These statements were recorded to create a fall/device log. Both the interviews and fall/device log were qualitatively coded by the primary author. These codes were used to create themes and general findings across the various participant experiences.

Device data were analyzed using a variety of methods. Over the course of the study, the primary researcher reviewed the participants' online log daily and recorded their use of the device. If the participant was seen to remove the device from the charger for at least 20 minutes the researcher would indicate that they had used the device that day. The researcher would also record any alarms and would contact the participant to confirm the veracity of the alarm and to understand what actions occurred before and after the alarm. Participants' explanations of device alarms were also categorized to understand the various causes for false alarms. Occasionally there were days in which no data were provided by the device. These days could either have indicated that the participant did not use the device, the device had powered off or the device could not properly relay a signal. For the purposes of this study these days were labelled as "Not Applicable" and were not included in our analyses. Participants were provided a fall calendar as well and were encouraged to mark it in the event of a fall or a false alarm.

Using these data, a binary classification analysis was conducted to evaluate the sensitivity, specificity, positive predictive value and negative predictive value of the device from our specific results. Days in which the participant's experienced no alarm and reported no falls were classified as true negatives. Similarly, days in which the device alarmed and the participant fell were classified as true positives. Days in which the participant experienced an alarm but reported not falling were classified as false positives. This daily analysis does not take into consideration multiple events in a given day.

Analyses were also conducted to look at trends in adherence which, for the purposes of this study, is a binary variable where any day in which the participant was seen to use the device for at least 20 minutes would be marked as “True”. The amount of time participants had the device was scaled to adjust for the variability allowing us to compare adherence between participants.

We conducted these analyses on all participants but also grouped participants into those who completed all 4 months of the study (Completers) and those who chose to exit the study early (Partial Completers). We compared these groups to see differences in baseline statistics, as well as the statistical measure mentioned above.

Results

In total 18 older adults participated in the study of whom 8 completed the full 4 month trial. Of the 10 partial completers, 9 voluntary chose to leave the study, while 1 was unable to complete the study after experiencing a fall. Those who chose to voluntarily leave the study gave a variety of reasons for doing so. One common reason was the volume of false alarms by the device. One participant described her experience with these alarms, *“It happened to me too often…I know it went off, let me see one night I took my daughter out to dinner. That was Monday night. And that’s when I decided I was going to give it up.”* Similarly, another participant complained that she was not in control of the device, *“I couldn't seem to control when it would go off, it would go off in the middle of the night or, strange or just strange times during the day.”* Another common reason given was the size or weight of the device with some participant's believing it to be too big, *"It is too heavy, to pinch and put on, the bra strap, which is where I would have put it"*

Other participants found the device to be too burdensome without any additional benefit, *"I didn't ever see, feel, or hear of anything that I could think of as an actual result and that made me think 'Why am I doing this'"* Some participants actually appreciated the device but had to leave for physical or personal reasons. One participant stopped using the device after the death of her daughter, and shortly after left the study. Another participant explained she was having trouble using the device, *"Well I have a lot of numbness in my hands and it's difficult for me to insert the device into its holder."*

Baseline demographics of the Completers and Partial Completers are available in Table 1. The study ran for a total of 211 days with participants having the device for an average of 80.7 days (range 8-124). The average participant had 29.8% of their data labelled "Not Applicable" (range 0-79.1%).

Table 4.1. Baseline Statistics

	Completers (n=8)	**Partial Completers (n=8)**	**Overall (n=18)**
Age (yrs.)			
Mean (SD)	83.1 (6.3)	89.1 (6.6)	86.4 (7.0)
Range	71-88	77-99	71-99
Gender			
Female, n (%)	5 (62.5)	9 (90)	14 (77)
Days on trial			
Mean (SD)	123.4 (1.1)	46.6 (30.9)	80.7 (45.26)
Living Situation			
Alone, n (%)	4 (50)	8 (80)	12 (67)
Pre-existing device			
Yes, n (%)	2 (25)	6 (60)	8 (44)
Initial wearing choice			
Clip, n (%)	8 (100)	4 (40)	12 (67)
Lanyard, n (%)	0	6 (60)	6 (33)

Device and fall data

A total of 84 alarms were recorded for all participants in which their respective device suspected the participant had fallen. Of these, 83 were reported as false alarms and are categorized in Table 2. When including multiple false alarms a day and not counting "Not Applicable" days, Completers had 58 false alarms over 812 days (7.1%) and Partial Completers had 25 false alarms over 263 total days (9.5%) (p=.31).

Table 4.2: Types of false alarms

Category, n (%)	Definition	Examples
Normal Activity 35 (42.2)	The participant was using the device as they normally would (i.e. sitting, cleaning, walking)	*"Sitting in my chair for a half hour, quietly, wasn't moving at all. Totally, didn't hit anything; it was spontaneous"*
		"Whenever I sit down at the dinner table I bump it, causing the false alarms"
Unknown 16 (19.3)	The participants did not recall an alarm or what set off the alarm.	Participant cannot remember any time when the device went off
Dropped Device 14 (16.9)	The participant reported dropping the device or the device falling.	The device was attached to her waist. When she stood up, it fell off, triggering an alarm
		"Darn thing won't stay on my belt, it is a pain in the neck"
Device Misuse 9 (10.8)	The participant reported using the device in an inappropriate way (i.e. not wearing the device as they should, or waving the device around)	Participant put the device on her walker
		Participant was showing it to her family and waving it, and it went off
Putting down device 9 (10.8)	The participant would place the device down themselves	Participant says one time she put it down on the table and it went off, *"I didn't even put it down very hard"*
		"The device has gone off when I place it on the bed, even without an abrupt motion. Could it be the change in position from being on my belt to lying horizontally?"

One true positive alarm occurred when a participant fell backwards and hit her head at a theater. While the device did place a call automatically, the participant was unconscious and unable to talk to the front desk representative. Three additional falls were reported by participants while wearing the device, although they were not identified as falls by the device. In one situation a participant reported *"a light fall into a person's lap"*. The other two falls occurred while the participants were sitting. In one, the chair broke under the participant as he was getting up, *"the leg broke on the chair and I went down with it, but by the time I got down, it was not one of those fast falls like the other one's had been where you're walking."* In the other, the person's clothing caused her to fall, *"my long bathrobe, got in my recliner and I fell when I stood up."* Neither participant chose to press the button as the first received aid immediately and the second was "*too busy trying to get up*". This participant also did not believe she needed help at the time, *"No 'cause I wasn't hurt. I probably could have used some help getting up and maybe I should have in retrospect thinking maybe I should have pressed the button."*

Finally, 8 falls were reported that occurred while participants were not wearing their devices. The majority (4) of these occurred with the device in the charger either while the participant was in bed or early in the morning. One fall occurred while the participant was dancing at a residential party*, "I was dancing backward I guess, and my heel went over the edge and I lost my balance backwards and fell into the band…"* The other fall caused one participant's family to withdraw her from the study. The participant reportedly fell at night and hit her head and was not found until morning when she walked out to the lobby with a bruise on her head. The final two falls were not described in detail.

Device and fall analyses

<u>*Binary classification*</u>

Table 3 shows the binary classification analysis for the overall group. Table 4 shows the same analyses between the Completers and the Partial Completers. Due to the lack of data in partially completed participants, the results do not have significant power.

*Table 4.3: Binary Classification Analysis for All Participants**

	Fall	No Fall
Device Alarm	1	64
Device No Alarm	3	734
Sensitivity	.25	
Specificity	.92	
Positive predictive value	0.02	
Negative predictive value	>.99	

**3 participants were excluded from this analysis for carrying their devices off their body*

*Table 4.4: Binary Classification Analysis Between groups**

Completers (n=7)			*Partial Completers (n=8)*		
	Fall	No Fall		Fall	No Fall
Device Alarm	1	53	Device Alarm	0	11
No Device Alarm	3	649	No Device Alarm	0	85
Sensitivity	0.25		Sensitivity	N/A	
Specificity	0.92		Specificity	0.89	
Positive predictive value	0.02		Positive predictive value	<0.01	
Negative predictive value	>0.99		Negative predictive value	>0.99	

*3 participants were excluded from this analysis for carrying their devices off their body

Adherence

Figure 1 illustrates the adherence of all participants throughout the study with dots representing the percentage of total participant adherence at each point in time. As an example, if all participants were seen to wear the device on day 1 of their respective trial, then the dot at the first time point would be at 100%.

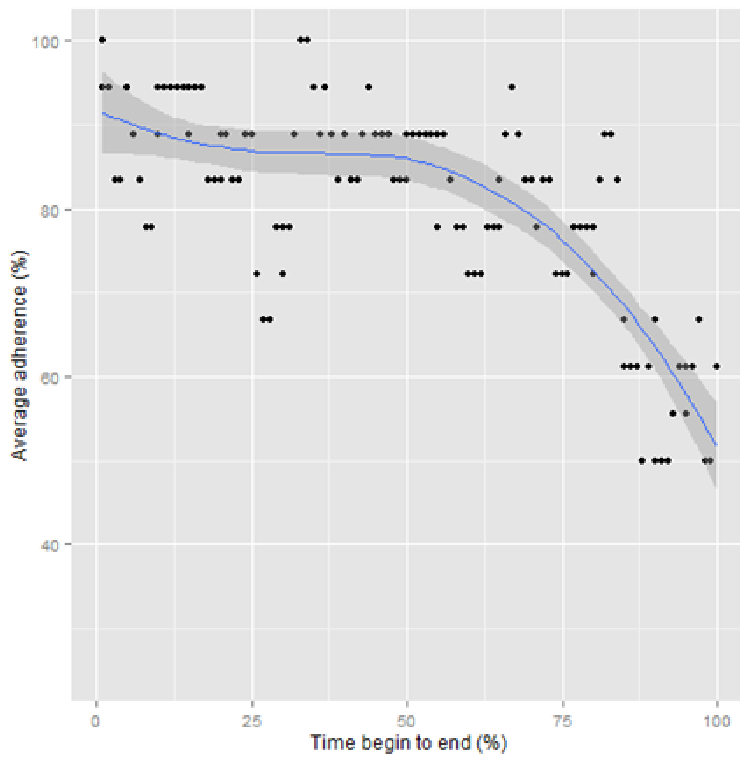

Figure 4.2. Percent adherence for all participants scaled to same timeline.

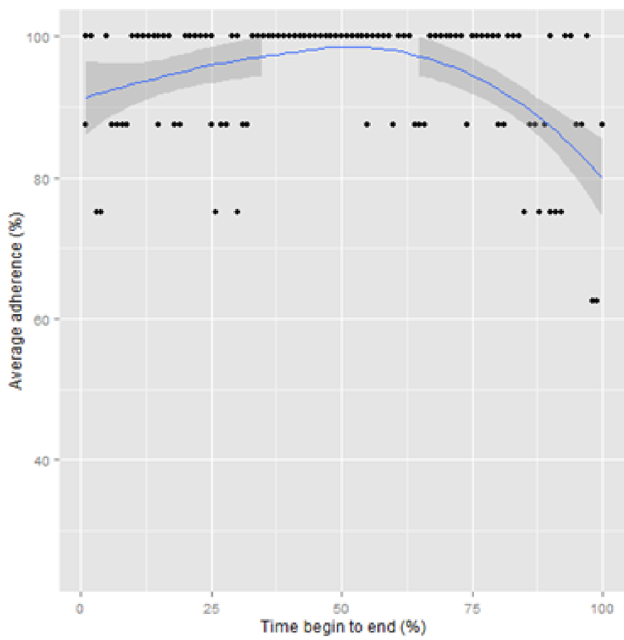

Figure 4.3. Percent adherence for all completers scaled to same

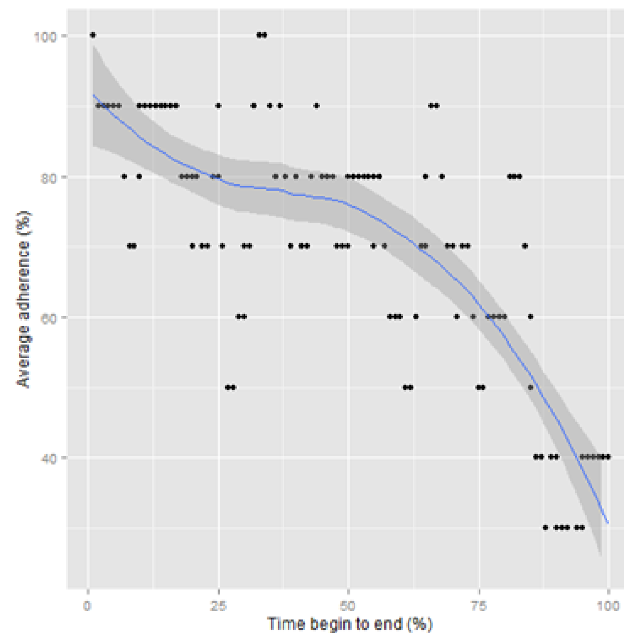

Figure 4.4. Percent adherence for all partial completers scaled to same timeline.

Once again, Completers and Partially Completers were separated in Figure 2 and 3. Participants who partially completed had significantly less adherence (p = 0.003) although completed participants also showed a drop in adherence around halfway through their trial (approximately 2 months).

In order to see influences on adherence a paired t-test was used to compare adherence 5 days prior and post a false alarm (p=0.67). We also compared use of the device 5 days prior and post a fall (p=0.63).

<u>*Comparisons*</u>

Outcomes of further analysis in patient behavior and characteristics are shown in Table 5. T-tests were performed on numeric values (highlighted in white), and Pearson Chi square tests were used to analyze binary data (highlighted in gray).

Table 4.5. Comparisons patient characteristics

	Completed	Partially Completed	p-value
Age, mean	83.1	89.1	0.07
Initial choice: clip, n(%)	8 (100)	4 (40)	0.048*
Female, n (%)	5 (62.5)	9 (90)	0.41
Living alone, n (%)	4 (50)	8 (80)	0.402
Pre-existing device, n (%)	2 (25)	6 (60)	0.314

Interviews and comment log

We conducted a total of 38 interviews (16 baseline, 7 midpoint and 15 final). Interviews with couples were conducted jointly. The researcher also logged a total of 78 device related comments made by participants during the course of the study.

<u>Baseline interviews</u>

All participants reported experiencing a fall before the study. Some falls were minor with participants explaining they, *"skinned their knee,"* or they had sat down on their walker without applying the brakes and it, *"went out from under me."* Other falls were more severe often causing serious injuries. One participant slipped on a wet shower liner explaining, *"turned suddenly and I crashed down… I had to hold my nose cause there was blood all over."* In another more public fall the participant explained she, *"fell in the beauty parlor… I hit the seat, with all the metal they said that I came out of it and looked like I was in a prize fight."* Some participants also reported having multiple previous falls and reported falling multiple times a year, *"about twice a year. I don't break bone, but skinned noses, skinned chins, hands."*

Just as interesting as the falls themselves was how participants handled the falls particularly in receiving aid. Some participants indicated helping themselves up and choosing to not go to the hospital, *"They said I should go to the nurse here. But I didn't. I just came home."* Others received aid either from close relationships or from people around them. One participant described falling on the sidewalk and talking to a passerby, *"Oh there was somebody walking on the sidewalk with a phone glued to her ear, 'Would you like me to call 911?'"* Another participant received direct aid from people passing by, *"And she helped me up and an old lady coming by did as well."* Finally 1 participant had multiple falls where she was unable to get up and had to find ways to be discovered. In 1 instance she states, "*...happened in the bathroom but somehow I managed to get to the hallway door and get it open and I was found lying on the floor of the hallway in my living room."* In another she didn't have to wait too long as one her nurses was already stopping by for a visit, *"I had a care person coming at that time and I was calling, hoping she was nearby, and she was within the couple of minutes."*

A few participants explained the roles their own fall detection device played in getting help. One participant was knocked unconscious after the fall but was able to press a fall button attached to the wall in her apartment. She described how quickly she believed aid came, *"Pretty quickly, you know they kept asking me if I had lost consciousness. I know I was conscious long enough to hit the button and I yet and I assured them I hadn't lost consciousness."* Another participant bypassed both her pendant and an emergency pull cord in her apartment to get help, *"instead of pressing that necklace I have, I somehow felt like I had to get to a telephone, and so I managed to get myself in to the telephone in the bedroom and call the desk."*

When asked what changes they had made to avoid falling many participants reported a change in their walking style, *"Well I tend to walk a little slower than I used to,"* or a change in where they walked to, *"Well I'm generally more careful of where I walk… the north side that sidewalk is really irregular, and that's where I did fall once."* Others reported relying more on mobility aids, *"I don't let loose of my walker, you know unless, I mean I make sure that its right there and I used to be a little careless about that,"* or an increased use in those same aids, *"Well*

I think I am using the cane more." Many participants reported going to exercise, yoga or balance classes. Some participants even reported going to classes that teach how to fall in addition to his exercise classes, *"So I figured those things are improving physical condition and learning to hold balance, and what to do if I lose that balance, and how to prevent loss of balance."*

Participants were also asked what they would do if they experienced a fall before receiving the experimental device. Some participants discussed first assessing their damage before trying to do anything, *"Oh I think what I do is try to make an assessment of whether I had any broken bones or not… so if I've got that determination then I would see fit if I could get up."* Other participants had pre-existing devices of their own or their apartment which they thought they might use, *"If I'm close to the wall I press that, and otherwise, I would press this [wrist device]."* One participant had a back-up plan *"Secondly if I realized that was not going to be possible I always carry my cellphone with me. So if I could get into my pocket if my arm wasn't broken or something, uh I'd use that secondarily."*

Figure 4.4. Wall sensors in 3 different communities. Two pull cords (left and middle) and a button (right)

Finally participants were asked for their initial opinions on the experimental device with many participants expressing enthusiasm for the device and its features. One participants was excited by the 2-way calling feature on the device, *"Well I think it sounds great. Especially that you can call somebody, get in touch with somebody."* Others saw benefit to the GPS feature:

"Well I like the fact that it is useable away from the building. Because I just have a feeling that things are pretty well covered here, but I am concerned that if I were away from the building if I could get some sort of aid."

However, participants did have several concerns in using the device. Some complained about the size of the device, *"It's pretty big to wear around your neck,"* and having to wear it at all times*, "I can see how I wouldn't want to wear it at times."* Others were worried they would not be able to remember to charge the device, *"I never charge anything because I don't, I gave up on the, you know the little porta- phone"* or remember to wear device, *"Just have to remember to put it on that's all…"* Some subjects felt that this device would add to their burden, *"You know, something else to wear, that's it more than anything else"* and effect their daily lives, *"Well right now I think of it more as a disruption…Turning it on and off, but once I get used to it probably won't make any difference anymore."*

Mid and final interviews

<u>*Limitations to device use*</u>

Most participants were able to use the device without any problems although there were a few device errors and unforeseen participant circumstances that occurred which prevented or stalled proper use of the device. As an example, one participant had trouble with her clip attachment falling out of her device. Her first solution was to rubber band it back on but she eventually needed help to properly attach the clip. Many participants initially had trouble finding an open electrical outlet close to where they intended to charge their device. One participant had several problems with the device receiving any sort of signal causing the device to drain battery rapidly. In order to solve this she wanted to charge the device near her window but could not find an appropriate electronic outlet to do so. A few participants had issues where the device would not charge at all and the researcher had to inspect and replace the device. Participants would also complain of occasional unexplainable noises or tunes from the device and were unsure of their meaning.

More common errors stemmed from participants' physical or mental limitations. One participant was unable to wear the device as a lanyard as she did not know what affect such a device might have on her pacemaker. Other participants had difficulty placing the device in the charger or on their person due to problems with their hands (Figure 5). One participant described this experience, "*Well I have a lot of numbness in my hands and it's difficult for me to insert the device into its holder.*" Many participants complained of not being able to hear the device. One participant with hearing aids described being able to hear the alarm but not knowing exactly what was being said, "*Well, hearing aids just don't work like 35 ears can. Everything is kind of muffled.*" Many participants also self-identified as having trouble with their memory and were worried about remembering to use the device. One participant came back to this concern during his trial, "*I'm just forgetting to put it on all the time.*" Another participant remembered to wear the device but did not remember to charge it and thus would wear the powered off device around without any awareness that it was not working. Finally many participants would forget about the device's abilities and were surprised when asked about them during the interview. One participant when asked about her experience after a fall questioned what the device was supposed to do, "*Well if that one went accidentally, who, would somebody call me… Like I say my memory is not the best. I may have not realized that*." Finally, some participants experienced varying life events including, injuries, falls, strokes or the death of a family member which would prevent them from using the device.

Figure 4.5. Participant demonstrating needing two hands to put the device in the charger

Device Benefits

Many of the features described as beneficial before using the device, were still perceived as such by participants after they had the device for up to 4 months. One participant discussed the value of having both the GPS and 2-way calling features, *"This is wonderful especially GPS. When I walk up to the library and I fall, I can call someone and talk to someone who knows me."* Participant's also appreciated the device's ability to automatically detect falls, *"I like the GPS function, and I like the being alone function, and I like the not having to press the button function. I think those, those are the three big items."*

In addition to appreciating these device features, participants also stated feeling more secure with such a device, *"one of the advantages for me is the security knowing that if I did have a fall and I was out walking around the park or Northgate or something it's there to use."* This feeling of security was amplified as they received calls from the primary researcher asking about recent alarms. One participant described how these calls affected his view of these devices, *"I was always gratified by your calls…I realized is that it was being picked up somewhere else* *as well as at the reception desk. And that was encouraging."* Some participants also claimed these devices even made them more aware of the danger of falling, *"Yes, it has made me more conscious of the tendency to fall in in situations and I can take more conscious steps to avert it."*

<u>Device Limitations</u>

Participants expressed several concerns with the device most of which focused on the device's alarms. One type of alarm was associated with the device's battery which often caused participants to complain about the device's ability to maintain a charge, *"Like I'll put it on early in the morning and then by noon or something it tells me I need to recharge it again."* Similarly participants complained about the inconsistency of the battery and never knowing when they needed to charge it again, *"it didn't seem to have any correlation to how long it was charged at night…some days it would be 6 o'clock in the evening some days it would be 10 in the morning."* This problem was amplified by the fact that these alarms often occurred at inopportune times. One participant described the device interrupting one of her meetings,

> *"I was sitting at a meeting when the device told me that it needed charging so I quickly pulled it out…Then I settled back in quiet, and in a lapse in which I thought all was well, It went off. I tried to cancel, but it was too late. I was somewhat excused for the commotion, when someone said 'It's not a cell phone'"*

Many other participants described public times when the device would alarm. One participant expressed her desire for less notifications, *"I wish there were a more subtle way of, it telling me that needs to be recharged."*

False alarms were often blamed on poor button design. One participant described this flaw in greater detail, "*Another design problem: it has a protruding rather than recessed call button. I've been carrying it in a fanny pack so it won't keep slipping of my belt, but if it bumps up against something it sends a signal."* A few other participants experienced a similar problem with their devices which they wore as lanyard and had to adjust how they wore the device to prevent it from bumping into too many things.

Only a few participants reported cancelling the call while most participants forgot exactly how to cancel the alarm. One participant described her experience with cancelling, "*I think I just got flustered, I didn't know what to do, and if I maybe gone through it one or two times and done what I was supposed to do then maybe I could have turned if off.*" Another participant complained that the cancelling procedure was too slow compared to the front desk picking up the phone, "*How do I cancel it in time. I can cancel by talking to the front desk, but I want to be able to cancel before it even gets down there…How do they pick up so fast.*"

How participant's chose to wear the device

Participants were allowed to choose between a lanyard attachment which is typically worn around their neck and a clip attachment which is typically worn on their belt or pants. However, some participants came up with non-traditional methods to wear the device that best fit their needs. As an example, one participant did not want to wear the device at all and instead placed the device on her walker whenever she would go out. Another participant already had a device which she wore around her neck, and chose to clip Device A to the lanyard attachment of her existing device. Similarly another participant initially chose to wear the device on his belt, but after having the device fall off too many times he then began to place it in his fanny pack.

The choice between clip and lanyard was usually based on personal preference and comfort. One participant desired to wear the device around her neck, but not knowing what affect it might have on her pacemaker, she instead chose to wear it on belt. More participants initially chose the lanyard attachment with some participant's believing it to be more secure, *"The lanyard is, very secure, even though it kind of gets in the way more"*. Some participant's experienced problems with the length of the necklace which caused the device to hang around their waist area causing the device to be unintentionally bumped too often. These subjects chose to use bobby pins to shorten the lanyard connection as well as wear the device so that the button faced towards their chest, *"Yeah, so the lights were toward the body. That certainly cut down on the number of error calls, however, it's an awkward way to wear it and it makes you look heavier than you are."* The more common problem with the lanyard attachment was the often displeasing aesthetic of the device especially when wearing certain kinds of tight fitting or shear clothing. One participant described not wanting to wear the device with one of her shirts, ""*"Oh because, what I was wearing was shear, and would show this light which, everybody is curious about, and, it just didn't look good with, I didn't want to wear it."* Another male participant describes the change in his outfit he was wearing to a veteran's function, "*"I had on my shirt and everything, ribbons, whatnot, and it bulges, or if I'd put on a dress suit, there would be a bulge in my shirt."*

The clip was commonly used to place the device on the participant's pants or on their bras. While there were fewer complaints about the look of the device when using the clip, there were more concerns about the device staying on their body. Wearing the device on pants was particularly problematic as the device was constantly bumped or fell which at times caused the device to be lost. One specifically complained about wearing the device on her waist when going to the restroom, *"I thought I would clip it to my waistband, but I go to the bathroom 8 times a day, and after the first two or three times it fell off when I pulled my pants down, so that didn't* *work"*

Figure 4.6. A participant who clipped the device to her gold chain

Figure 4.7. A participant labelling his device to keep from losing it

This same participant attached the clip of her device to one of her gold chains so as to be able to wear the device around her neck (Figure 6). Two participant's lost their devices with clip attachments but were lucky to have them returned to them. After losing the device these participant's printed their name and phone number to their device in case they lost them again (Figure 7). During the study 5 participants asked to change the attachment on their device with 4 of the 5 switching from a clip attachment to a lanyard attachment.

When participant's chose to wear the device

Another point of interest was the times of day participants chose to wear the device. As they were instructed to charge the device at night, most participant's put the device on in the morning when they get dressed and removed it before they went to bed. Exactly when they put on the device would usually depend on their morning activities and what they were planning to do during the day,

> *"I don't always put it on first thing, I run around in my night gown. And I water the flowers and I get breakfast and I brush my teeth then, then when I get dressed to go out then I take it out of its charger and put it on."*

While most participants would wear their device at all times, some participants chose to only wear the device outside as that is where they felt they were most at risk, *"I used it when I went on walks."*

Along with safety, participants gave a variety of reasons for not wearing the device. Participants would often forget to put on the device in the morning, but there were several instances in which they chose to not wear the device. Due to the already stated issue of false alarms many participant's would take off the device when they would go to public meetings or church, "*went to a meeting and I didn't want it to go off in a meeting so I just left it here*." Participants would also travel or go on vacation and did not want to take the device with them because it would not be useful for them to contact their communities' front desk, and because they did not want to lose the device. One participant specifically took off her device the day she was going in to the get an MRI saying, *"Well, because I couldn't take it into the MRI I had to take off everything."*

Participants expressed concerned about being unprotected at night when the device was in the charger. One participant explained that her husband would often go to the bathroom at night and was worried she might not hear him fall, *"Is there some design a person could have where they could wear it 24 hours a day… Because I'm thinking of people who get up during the night."* Other participants however were not as concerned, *"I guess you could fall out of bed but it didn't ever seem to be a problem to me."*

Many participants also did not use the device in the shower even though the device was stated to be water resistant. Although many participant's stated not knowing it could be used in the shower, several also asked where they would place the device with the clip attachment.

Participants would often place the device near them when they showered, *“I have a little place I have it outside the shower.”*

<u>Perceived need and alternatives to wearing the device</u>

Several participants were not concerned about falling without the device as they relied on other methods to prevent a fall. Participants used various assistive devices including canes, walkers grabbers and handrails to complete everyday task safely. Many participants specifically mentioned grab bars in the shower as being useful and reassuring. One participant describes these bars as a fail-safe, “*there are grab bars anyway if I had been anxious about it.*” Participant’s also mentioned taking a variety of exercise, strength and balance classes claiming these improved their muscles and ensured they would not fall. One participant mentioned his own method for strengthening his muscles so as to prevent a fall, *“But I found a way of really getting a lot more strength back in my legs. I stand up and watch television now… Made a tremendous difference in my, particularly in my hip strength.”* Other personal changes participants made to avoid falls included walking with a close acquaintance or just being more careful in general. Some participants had their own fall detection devices that included lanyards, wrist devices, wall buttons or pull cords. With their own devices many participant’s complained about not being able to use it outside the building or it not being able to detect if they had fallen. However more participant’s seems to enjoy wearing the wrist-worn device, and never having to charge their own device.

Many participants also did not believe they were in danger of falling and thus saw no immediate need for the device. One participant, who experienced at least 4 falls during the course of the trial, explained what attribute was necessary to have this device, “*Oh being a frequent faller.”* He continued by saying, “*I don't consider myself a faller*.” Other participants felt that these devices were for older more physically unable people with one participant saying, *"You know if I were a high risk, high fall risk, it might be...but at the moment I don't consider that. When I get old maybe."* Participants also claimed this device did not fit their particular needs with some wanting a device that was more for fall prevention and others believing their cellphone could do everything the device could.

However, there were some participants that expressed a need for such a device. One participant explained the differences in perceived need between him and his wife, "*Since my health isn't quite as good as hers, I think I'm I would probably want to keep it."* He continued by saying, "*It's annoying and it's a nuisance but I know I'll probably be better protected if I have it*." Another participant who had many complaints about the device also realized some of the value, "*Sometimes I am in an area where there aren't people around for a little ways. It might accelerate someone reaching me by a few minutes, so it would be of some value for that*."

<u>Stigma and embarrassment</u>

Many participants were embarrassed by the device when it would alarm in public. One participant was especially worried when those around him would pretend not to notice the alarm, *"It's when they don't say anything you wonder kinda what their thinking looking at that, cause they do take notice of it."* Participants did not like the attention this device brought them and found different ways to handle the embarrassment by saying they were in a study or, as one participant describes, by simply pretending they did not know where the sound was coming from "*You know what you do is you start looking at other people like, 'Was that you?'"*

Aside from the alarm, some participants were also worried about others being able to see the device. One participant described an experience in which the device cause a visible bump in his shirt, "*people probably wonder you know, we sort of perceive it as some people wouldn't say anything at all, we kinda wonder, what, you gotta a big growth there or what is that?*" Several participants, however, did not experience these problems as their clothing would either hide their device or muffle the alarm. One participant in particular described not worrying about what other people believed, *"If I need it, I wear it. I don't look what other people because we all have different needs…"*

Suggestions for improvement

Participants had varying suggestions to improve the device with 1 common suggestion being to make the device smaller or less obtrusive. Another suggestion involved enabling the device so that it could be worn at all times. One participant explained this,

> *"I supposed if you are really wearing something to warn you about falling, uh, maybe you should wear one all the time, I mean even at night you can get up and people tell me that all the time, they'll get up and turn on their light, and fall."*

Other suggestions involved fixing the design flaws of the device including the protruding button or its ability to stay attached to a belt. Participants also asked to reduce the false alarms produced by the device and requested a device which they did not have to charge.

Privacy/GPS/Monitoring

There was no need to use the GPS feature to locate a fallen subject during this trial. However, when looking at the GPS data for the 1 true detected fall, the location of the subject was remarkably inaccurate with the device identifying the participant as being in a large body of water instead of the downtown theater where she identified falling. The GPS signal would also have been largely ineffective if any participant had fallen indoors as it only identified the building in which the participant was in. With many participants living on multi-floor, multiapartment communities, this signal would not help locate the participant if they were to fall anywhere but their stated apartment.

Participants varied in their feelings when shown their map data with some being concerned about their privacy and other's being indifferent to it. Many participants did not mind being monitored as they believed they had nothing to hide. One participant described this, *"at this stage of the game, who cares, who would care where I go."* Other participants, however, were more concerned about their privacy, especially who would be able to see such data. One participant was particularly concerned about the government being able to track her while another participant had more of a concern over insurance companies, *"If they knew you had 20 falls a month, they might reconsider whether or not they would insure you."* Some participants accepted the invasion of the privacy as they felt the benefit of the device outweighed the disadvantage of being tracked, "*I'm not happy about being tracked all the time but if it's to be worthwhile, you need it. Don't you?"*

Discussion

The variety and range of responses seen in these results lead to an even more complex discussion. While it is clear that there is no single solution to fix fall detection devices, there are several pieces of information that can be learned from this study and applied to future fall detection technology.

Adherence measurements from our study are interesting in that while there was a significant difference between the completers and partial completers there was also a similar decrease in adherence seen around the halfway point of the trial in both groups. This might indicate that participants either grew weary of using the device or began to forget to use the device as the study continued, regardless of their opinion of the device. And while it is interesting that 100% of the completers initially chose to use the clip attachment (a significant difference to the 40% of partial completers), it is difficult to explain this choice having any effect on their willingness to stay in the study given that many participants who initially chose a clip also asked to switch to a lanyard at some point in the study. Another point of interest was how close to significant the difference in age was between the 2 groups. A larger, or more equal, sample may be able to show significantly greater adherence and acceptance of this technology amongst younger older adults (26).

In terms of the accuracy of automatic fall detection our findings suggest that Device A is fairly inaccurate with subjects experiencing numerous false alarms and having 3 reported falls go undetected. In contrast, Device A's company trained their device using 59 volunteers performing prescribed falls, ADLs, and near falls (stumbles). The system was tested on an independent data set of subjects that were not included in the training set, and yielded results of sensitivity ranging from 94.1% to 94.4% and specificity ranging from 92.1% to 94.6%. The specificity results were validated on a real life database of approximately 10000 events. While their specificity matches ours fairly closely and it is difficult to compare the 2 studies given the difference in sample size and fall data, such a comparison would appear to match previous evidence suggesting that real world falls are more difficult to accurately detect (11–13). Regardless of the necessary improvements to the accuracy of this and other devices, developers need to better ensure that alarms only occur when necessary and create easier ways for older adults to be able to silence alarms both before and after an alarm has sounded. Reducing the rate of alarms and further empowering participants with the ability to better control their device will prevent participant embarrassment and allow participant's to wear these devices at all times (18,27).

In terms of wearability, advances in miniaturization and sensor technology will allow developers to make smaller, less obtrusive devices that will be more acceptable to older adults (28,29). Increases in battery life will also help to ensure participants no longer have to remember to charge these devices and can wear them uninterrupted for longer periods of time. However, there are several age-related issues with these devices that need to be addressed. Engineers must work to better develop this technology so that it is accessible to people with hearing loss, limited dexterity and low vision(30) Affordances also need to be more clear and visible to allow people with memory problems to be able to remember not only what the device is meant to do, but how to use it in their time of need. Utilizing age appropriate design techniques will help make these devices more user friendly. Finally, while it is important to give older adult's several options for how to wear the device, device builders should expect this population to be extremely varied in their wearing habits and should plan for this device to work no matter how it is worn.

Additional existing device features, such as GPS and 2-way calling are already encouraging more participants to use the device. However just as with the detection of falls, the accuracy of the GPS needs to be more refined to be of value. Furthermore there is a great need for these devices to be able to locate a participant if they fall indoors especially on a multi-level multi-room building. Finally although GPS was seen as a great advantage to many participants, developers need to find ways to keep their data secure in order to ensure the participant's privacy.

Unfortunately, even with further functional improvements, it is difficult to imagine automatic fall detection devices becoming a popular technology amongst older adults in the near future (31). Although there were a few subjects who expressed needing or liking these devices, the majority off our participants were unhappy having to use such a device. Along with the stigma associated with these devices, many participants seem to already have a large variety of methods to ensure they are safe in case of a fall without such a device. In short, these devices do not appear to provide enough additional benefit for the amount of agitation they add to the subjects (29). Further work and innovation is necessary to develop devices that not only detect that a person has fallen, but also have the ability to prevent a fall and reduce participant injury (32). Increased usage of these devices amongst older adults may also require a larger cultural change reducing the stigma of these devices and educating participant's to the importance of preparing for fall.

This work was limited by selecting a convenience sample of participants residing in the Puget Sound area. Use of and opinions on fall detection devices may vary in other parts of the world. In addition we were limited by only testing 1 wearable fall detection device. This concern was minimal as Device A is similar to many other off-the-shelf fall detection products. In the future, however, a comparison of multiple devices and multiple types of devices may lead to more innovative conclusions. Future studies should also recruit larger samples to wear the device for longer periods of time to be able to better validate the statistical accuracy of these devices.

Despite these limitations, this pilot study adequately investigated the usability of a wearable fall detection device in the real world using an appropriate sample of older adults. Although preliminary, this study informs on usability issues of fall detection devices and provides suggestions for designing these devices for older adults.

Conclusion

Falls and the time spent after a fall continues to represent a great danger to the wellness and independence of older adults. For this study we explored the usability and real world accuracy of a particular fall detection device by having older adults wear the device for up to 4 months and conducting interviews with them. We provide design recommendations to help future device designers make these devices more appropriate for older adults.

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Appendix: Additional Participant Quotes

Device errors	
Charging	*Device was not charging when I went in to have him re-consent. Didn't know if it was off or on; wants to switch to a lanyard as he keeps losing the device; the clip doesn't stay on well enough, and if he swings his hands he can knock it off his belt. Clip is not that solid. Device would not charge again switched his device;*
	Believed her device had turned off; didn't know how to check; device is no longer charging. Will need to go in and fix
	also has a lot of trouble getting the device out of the charger and finding a place to place the charger near a window.
Signals	*Her device has been giving weird signals lately. Asked company and they don't know why, have sent something to reset the device. Talking to P02 she forgot to put the device in the charger last night. She also complained that the charge needs to last longer, it still tells me in the middle of the afternoon to charge; if an all night charge could last longer it would b enice. She says she really likes the device, and she really likes that I can keep track of her. She doesnt want the government to keep track of her but it makes her feel safe to know someone is looking out for her.*
Limitations to device use	
Dexterity	*Has a hard time putting it in the charger hands aren't nimble enough;*
	It is too heavy, to pinch and put on, the bra strap, which is where I would have put it, um. I can reach it, but I can't pinch it at the same time and have it stick
Hearing	*Oh, quite a few, um, because at first it didn't seem to be doing that, and it took me, because my hearing is bad, it took me awhile to figure out that this voice that was coming from somewhere was coming from that device.*
	And I would say that it might be good to go over it would somebody like me who has hearing problem about how, what, how to react to it if it goes off accidentally.
	ou know my hearing loss is a problem too. Cause that's not loud, those messages, they are, I guess that's another thing I could say that could be improved. Just not loud enough to hear, even with my hearing aids.

	I could tell somebody is saying something, but I couldn't always tell what it is. So no I, you know, I wouldn't use it.. But they they go back to the drawing board and make some improvements..
	I can't hear it from the fanny pack because I have hearing loss. By the time I get it out so I can hear it then [
Memory	*at my age, remembering about it and then putting it on and then, getting it secure so it's not going to slip off and fall*
	It's one more thing for, me, now maybe that might not be important to other people but for me with my memory going, it's one more thing I have to remember. I already have so much to remember you have no idea.
Device Benefits	
GPS	*"Except that I could wear it away from the building, that was, that was what I thought was the really neat thing."*
	"I like the idea that, I could wear it away from the building. That was very nice"
	"If you want something, you want something that will work away from home as well as at home."
	Well it was good that it certainly proved that it works, that it works just as well as thing I'm wearing, at the moment. Now I know it works better because it works outside the house.
	But, er, it's possible that sometimes when I walk from here up to the mall, I am in an area where there aren't people around for a little ways. It might accelerated someone reaching me by a few minutes, so it would be of some value for that.
2 way calling	*"2 way communication is valuable. They can talk to me and I can talk to them"*
	"Very, very comforting to have a two way conversation, I really appreciate that"
	"It's very sensitive, its uh wonderful to be able to hear a voice at the other end which the one I used to wear didn't have a two way conversation, didn't have a one way conversation"
Automatic detection	*"Yes, I think it's impressive and at times lifesaving"*

	"…one of their dear friends had fallen and was unconscious and he wasn't found for two or three days and he felt if he had been found, they could have, they could have saved his life. So they lost a friend that they felt they wouldn't have had to if he had had this kind of thing, where you didn't have to really press it yourself consciously, for help."
	Well the two or three times, or more, maybe that uh I, there, didn't fall, um I was surprised that it set it off, whatever I did wasn't much but I certainly didn't fall. But it's fairly easy to, when the phone is answered and I can say, "Oh, it's a false alarm, I'm ok."
Security	*"Well it uh, gave me a kind of a security assurance that if I did have a bad fall, broken bone or something like, then it would be really valuable except that in motion all those decisions that have to be made about where to go and all that. So it was a, kinda like a security blanket"*
	"Oh, uh, there's certainly the um, knowledge that they have a procedure to follow in case of a fall."
	"I will miss it on the outside, uh, I've felt, I've always felt more comfortable with it walking outside"
	I you know usually pretty regular in putting it on and um, relied on it when I was out just in case I did fall, and I had good faith in it.
Device Limitations	
Size	*"Well, make it little smaller, so it's not quite so heavy."*
	"The only thing I would think would be nice if it were smaller... it's a little, it's a little obtrusive."
	Belt clip was a little, sizeable, so it, makes it a little too big to do that
	Well, make it little smaller, so it's not quite so heavy.
False alarms	*"Button is too sensitive; 4 false alarms in first two days. Can't keep it in my pocket can't keep it in my belt*
	"I'm not technically astute but I would think it's too sensitive.
	Button needs to be more concave. When I put it on my belt and sit down it turns it on; So I turned it inside out and put it in my pocket; Then it won't

	accidentally turn it off. He has had to cancel it a few times. Decided to switch to a lanyard.
	But these other false alarms and design, what I consider to be design problems, and I guess that's about it. Were not a nuisance but they were a bit annoying, cause we'd have, I thought it would be better than that in a sense.
	Well, because false alarms, there's no good way for me to carry it, no easy way for me to carry it.
	P12. That's true it did go off a couple of times at Saturday university... *P13. Lectures down at the Asian Art Museum.* *SC. Really, OK. You two just sort of just kept looking straight ahead?* *P12. We looked innocent.*
	And then I got a little careless, um, and then I got irritated with it, because it was going off, and my son was staying here, and he didn't know what was going on... voices in the middle of the night.
	Except that like I said, when it started going off at irrational times, um then it affected my daily life.
	t had, gone off like it just did now and said I needed to recharge it, and I was sitting with several other women at a table and of course they wanted to know what it was and I told them about the trial period I was doing, and took it off to show them, and then just laid it down. And then it went off once, and uh, and one of the other ladies that had used it before finally got it to go off, but then she handed it back to me and I just laid it down again and it went off again.
	Is it charged or am I going to get it out into a lecture or something and the lady comes on and says, "Get that home and charge it."
	No I, there were times when I'd be out in a, like a large meeting group where she would say something and I wasn't sure what she'd said but I always had to press the button. So I assumed it was not the power off it was just a false alarm.
	And I got confusing messages from the lady on the tape.
	No I, there were times when I'd be out in a, like a large meeting group where she would say something and I wasn't sure what she'd said but I always had to

	press the button. So I assumed it was not the power off it was just a false alarm.
	P17: Well I think I know what happened. First it said it needed to be charged. So I, probably because I was in a meeting probably I abruptly tried to hide it or something. And maybe that's what it is and then a few moments later, you know it let me know that the fall had been detected. And I guess I probably in a hurry tried to cancel it. Not soon enough because reception had already answered. And then in the meeting, she kept you know, and it went all over the room you know. So, "This is Charo.. This is Charo.." [chuckle]. I should have just gotten up and left quietly, but I was just… somebody.. the leader of the meeting came over to me and he said "Open it up". And I said "Open it up?, you know. He thought it was a cell phone. And so, you know, I just, I should have just gotten up.
Charging	*And that is my complaint is that I want the charge to last until I go to bed again instead of going off at 3:30 or 4 every afternoon which is annoying because other people don't know what that voice is*
	It seems that even with a long night's charging it needs to be recharged at that hour
	The devices, because they have to be charged, that was confusing. We never knew whether they were completely charged or not
	quite early in being told to power up um, recharge it, um, I learned to just ignore it.
	The other thing I would say is, that battery doesn't last too long, uh, you know I tend to charge it overnight but by say 5, 5 or 6 in the evening I'm getting a message to recharge the battery. That's a definite shortcoming. They need a longer life battery
	No, except that they say that coming on that I need to charge it, in a meeting after I've been charging it all night. And I think I had it on the charger correctly you know you have to get that just right with those contacts. I watched the thing and it lights up. So, uh, I would like the…but I mean I charged it all night, I guess I was perplexed about why I had to charge it again during the day.
	And I'm embarrassed when I'm out anyplace with people around and it tells me it's time to recharge your battery... It is because people sort of look around at me.
	ell I remember the last time you'd said you'd gotten two alarms, I finally figured out what that was about, uh, it had, gone off like it just did now and said I

	needed to recharge it, and I was sitting with several other women at a table and of course they wanted to know what it was and I told them about the trial period I was doing, and took it off to show them, and then just laid it down. And then it went off once, and uh, and one of the other ladies that had used it before finally got it to go off, but then she handed it back to me and I just laid it down again and it went off again.
How participants chose to wear their devices.	
Clip	*I was afraid to use it on my belt because it kept coming off I didn't want to lose it, so I thought it I was going to use it safely*
	"The device slips off my belt whenever I do anything in the vicinity (yesterday I was wrapping a jacket around my waster and later removed it and it fell off"
	"Doesn't sit on the belt very well, it came off the other day and was lost"
	Yeah, anything around my waist was, I didn't like.
	Lost it twice belt clip is not very secure
	When I put it on the, elastic of my slacks, either on the right or the left side, uh, when I got up from being seated, it fell twice, as I got up.
Lanyard	*Wants to switch to wearing it using the clip; she has too many things on her neck (other pendant, necklace, new pendant*
	The fact that I can't put it over my head, can't wear it. That's my problem.
	That it did alter how I dressed myself because I didn't like to have something like that dangling.
	I don't really want something around my neck. You know if I were a high risk, high fall risk, it might be. But at the moment I don't consider that.
Wearability	*I found it heavy to wear around my neck, um, little uncomfortable, and um, wondering you know whether there was something lighter that would be used instead of that would still accomplish what you wanted to. .*
	I felt it, I mean its bulky but, uh more the fear that it was going to fall off.
	And and, it fell off too many times when I got up

	Well no, I figured that you wanted to know what a normal life was like so what I would do would be to hook it into the middle of my bra in the morning and then take it off at night.
Aesthetics	*It was very obvious unless I had a voluminous scarf or something (laughter) but um, if I had a serious health problem at the time I think it would be a very good idea to do that… wear something such as that.*
	If I wore it under my shirt it kind of makes a bulge which I didn't care for
	With the summer coming and the low cut necklines, um, I find it, too difficult to wear the rope, one, which is the the alternate to the, putting it on your shoulder.
	No, but it just doesn't look pretty, especially now. People are wearing 4 sets of beads, you know that's the new style now, it's just not a rope of pearls now, they put, different colors and pearls and stuff like that, and therefore I don't think that uh, you know a grey lanyard (chuckles) would be attractive.
	Well sometimes, during the summer you wear necks that are low you know and sometimes there's were gap open if you bend over or something, so then I put it on my pants.
When they wore the device	*Well I put it on in the morning when I got dressed*
	I would do would be to hook it into the middle of my bra in the morning and then take it off at night.
	I mean I kept in until sometimes it was 11 o'clock, 12 o'clock at night. I take it off and then charge it.
	Well, I just get up and most of the time I put it on either before breakfast or after breakfast depending on whether or not I'm dress."
	Once I put it on, I wear it [laughs]. All day [laughs]. I try to put it on in the morning before I leave my room and take it off when I go to bed [laughs].
Where they wore the device	*once I put it on, I keep it on whether I'm here or elsewhere until it's time to put it back in the charger*
	would have certainly put it on when we go outside, because that's where the danger usually is, we never really fell in here very much, although we've had a fair amount of residents in the building who have fallen in their.

	I didn't really use it that much. Just use it when I went out. Didn't use it around the apartment very often.
	If I were to have a stroke or something, I've got the pull chain right there by the bed. So, and there's one in the bathroom. So, I, if I'm here, in the apartment well I'm pretty well protected. Although people think that I could easily fall like over there, there's no pull cord over there
Reasons not to wear the device	*Oh yeah, I never take it off except for the shower.*
	No, because I was afraid, what if I lose it there? What if I leave it on the plane?
	one morning I forgot it wasn't until almost noon that I remembered that I hadn't put it on, if I get distracted if the phone rings or something happens
	Grandson, is just a, you know this is a new place for him so he just gets into everything, opens drawers, and you know, he's investigating everything so I did put it up along with everything else.
	I think there were a couple of times when I forgot and usually it would be you know maybe, hmm, 11 o'clock in the morning before I would really put it on but um
	I'm just forgetting to put it on all the time.
Unprotected times	*So far I haven't fallen, but I believe I am more likely to fall in the shower in the morning or the bathroom at night when I won't be wearing the thing.*
	No, I did not wear it to bed because I don't wear a bra to bed so I didn't have anything to put it on. And besides that's when I recharge it.
	Oh, I take my shower before I put it on.
	Yeah, which is terrible. Now, I, did not wear it in the shower, so I don't know, does it work in the shower?
	I didn't know it was waterproof.
	As a matter of fact what would I attach it to? There's only one thing and it won't fit that.
	Just because I didn't want to get it wet. I really didn't think about it and again that's in a sense a danger time and you really should have it on and uh, but, I did have the wrist one that um they issue here and it took that

	off when I showered too so, uh, same problem. I don't know.
	Is there some design a person could have where they could wear it 24 hours a day, except if you want to take it off for shopping or something like that... Because he gets up during the night and I don't always, but he could fall, if he couldn't call me or press a button we have a lot of buttons around here to call for help, but if he was unconscious, I probably wouldn't know unless I really heard him, but if I'm in a deep sleep I don't think I'd hear the fall.
	If you have to charge it at night, um, the time when you probably need it the most, then you're not wearing it, which I thought was not good
	I did, we did go away overnight or two overnights and different times, for 1 night, and we didn't take our chargers along so we just didn't wear it, because we wanted to make sure we didn't leave anything accidentally. And that was fine, and then I took another day, partial day, because I was wearing sort of a form fitting outfit, and I didn't want the bulge.
Alternatives to having a device	
Assistive devices	*No, no, there are bars everywhere. That is a very well equipped shower. And I do hang on to the bars*
	Always, if there's a handrail I always make sure to hold on to it. Because I have fallen, in the past, but not really to hurt myself.
	If I have to reach something overhead, I have a little gadget to reach with
	Well I have lots of things to hold onto, shower bars and things like that, so.
	And, I carry the cane, and that's a good sign because before I had to literally put it down and use it, now I carry it in case I'm ready to go down.
Exercise classes	*I was taking balance classes and they were $70 dollars an hour,*
	I had a seminar in the past on how to fall, and I'm fallen over by catching an inch of the rug for instance, falling forward, and just getting up and going on. For other people, they break their rib or something like that. So I have that and uh, periodic seminar, I think we have one next week on how to fall.
	Because uh, that's one of the exercises that we do in our two exercise classes is we have to get up and

	down from a chair and I have no problem I see some people have a lot of problems.
Personal Changes	*I life my foot a little higher now than I did, and I don't get caught in those cracks in the sidewalks, things like that.*
	I've been walking with someone in the last 3 months at least, which is unusual, which is different than what I had been doing before.
	And like going in and out of our van our big bus, the step is kind of narrow. And so I go down sideways so that my foot, the whole foot is on the step. And they all want to help me and I said, "No, thank you but I've got, I need to hold on to something solid not somebody's hand."
	I'm very careful not to make any move in the shower without having my hand on something, one hand or the other, or both on uh, the metal piping that's around. So
Alternate fall detection devices	*We do have a cellphone so when we go out and walk, we take the cellphone and we can call the front desk, we can call our children, we can call 911.*
	I did have the wrist one that um they issue here and it took that off when I showered too so, uh, same problem.
	No they re, they recharge it. You know, and um, they uh, one time I guess I must have hit it against something because they came to the door, and I had like with the other kind I had a neck thing and I think I told you about that last where I had leaned over to get something and pressed it and the machine, "Emergency, emergency," you know they start yelling.
	had it on a necklace around and I was sitting at my kitchen table and I was talking to someone on the phone and she was asking me something and I needed to reach over there and I didn't realize that it pressed it, and the next thing I know, "Emergency! Emergency!" You know, they're calling because I had box that was on the shelf and uh, so I was real surprised.
Did not believe they would fall	*I'm pretty confident. Everybody thinks they are never going to fall, and I think I'm not going to fall.*
	I didn't see any necessity for wearing it in the building… Because I'm very cautious, and I wasn't about to fall
Devices for older people than them	*Oh, oh, I feel, uh, kind of glad because I don't have to pin it up and worry about how much the bulge is*

	going to be, but if I were in less good physical condition, I am sure I would consider something like that.
	And the device would be maybe a couple of 100, one or more hundreds…Yes, yes, if the person felt they really needed it, yes.
	"Oh just because I guess that makes me feel old, incapable, and at this point, I don't really get lost. But with my problem, I could, you know in the future."
Device doesn't fit their needs	*Well originally I guess we thought it might be something that would help you prevent falls and I don't think it does that and we do have a cellphone so when we go out and walk, we take the cellphone and we can call the front desk, we can call our children, we can call 911.*
	It was just too much bother with no more benefit than what we already have with our cellphone.
	It just didn't really seem to be doing anything for me.
Stigma	
Embarrassing alarms	*"I was sitting at a meeting when the device told me that it needed charging (at 3:30, so I quickly pulled it out.. Then I settled back in quiet, and in a lapse in which I thought all was well, It went off. I tried to cancel, but it was too late. The volume of the receptionist at the front desk seemed high!! I was somewhat excused for the commotion, when someone said"" It's not a cell phone"" "*
	And I was sitting with several other women at a table and of course they wanted to know what it was and I told them about the trial period I was doing, and took it off to show them, and then just laid it down. And then it went off once, and uh, and one of the other ladies that had used it before finally got it to go off, but then she handed it back to me and I just laid it down again and it went off again.
	I know one time at dinner it started talking to me and everybody was, "Oh, what's that" (laughter)
	I was in a meeting and it went off and that was kind of embarrassing I think I told you about that.
Other people's reaction	*It is because people sort of look around at me.*
	Except when it goes off (laughter). I have to explain it to people (laughter).
	I don't know, just because it, goes off in strange places and when I haven't fallen or anything and it's I

	keep having to explain to people what this thing is that is talking, or whatever (laughter)
	The weight factor again, I know that sounds terribly vain, but uh, I think both of us, we're fairly used to, not necessarily tight fitting clothes, but it really kinda pooches things up there and people probably wonder you know, we sort of perceive it as some people wouldn't say anything at all, we kinda wonder, what, you gotta a big growth there or what is that?
	Oh that was fine, that was fine except that it was just um, you know I just, um, you know that I was just, didn't want to interrupt them too much but you know it was a minor thing
	Well they don't talk about it, if they do. Once when, well when I first started using it, a long time ago, it started talking to me when I was out in the activity room, something about 'your device needs to be recharged' [laughs] you know, and everyone looked at me sort of funny and I'm 'Oh, I'm doing this survey' [laughs] and that was all that ever happened with that.
	I mean I picked it up and somebody offers to pick it up for you, but that's not what you really want you know, and so that's the only thing,
No problem	*It wasn't a problem with the voice going off when we were sitting in like the dining room or in a lecture and so forth, because the way we were wearing it with the lanyard, with a shirt over it or a blouse over it. We could hear but I think a lot of people around us just sort of looked around for a second and just kinda wondered what that was.*
	That wouldn't have bothered me at all. If somebody would have said to me what's that bulge, "Oh that's my fall detection device", you know, and then I'd have explained it.
	We couldn't turn it off if we wanted, but it never caused us any embarrassment although I did see people around me on 4 or 5 different occasions kind look around and go, "Where's that coming from?". And so it was never an embarrassment
	I've worn it to church and various places never had problems.
	No, nobody really knows whether I have it on or not. Because nobody sees it
Reason for leaving the study	

Lack of benefit	*It was not quite as definitive as I had hoped it might be because, I am trying to remember, it slipped off a few times and it was very non obtrusive except that it did alter how I dressed myself because I didn't like to have something like that dangling. It actually just felt like an extra little nuisance that I was using…Yeah. I think it just didn't do for me what I had expected it to.*
	Well I expected it to be some way of, well, for instance if I had tripped over the door step or something. No, it was very benign.
	It was just too much bother with no more benefit than what we already have with our cellphone.
	Well originally I guess we thought it might be something that would help you prevent falls and I don't think it does that and we do have a cellphone so when we go out and walk
False alarms	*That's it, I found many problems. It would go off. I suppose the thing's charged. I've kept it in my walker and it would go off. I'd have to call in. Ten minutes later, go off again.*
	And if you get this straightened out about going off, I'd like to know about it. And I would say that it might be good to go over it would somebody like me who has hearing problem about how, what, how to react to it if it goes off accidentally.
Device size	*And they were a little bulky too for me. If I wore it under my shirt it kind of makes a bulge which I didn't care for. So it just seemed like something we didn't want to handle.*
	Maybe it's a little bit big,
	It is too heavy, to pinch and put on, the bra strap, which is where I would have put it, um. I can reach it, but I can't pinch it at the same time and have it stick. With the summer coming and the low cut necklines, um, I find it, too difficult to wear the rope, one, which is the alternate to the, putting it on your shoulder.
	I found it and heavy to wear around my neck, um, little uncomfortable, and um, wondering you know whether there was something lighter that would be used instead of that would still accomplish what you wanted to.
Other	*Well I have a lot of numbness in my hands and it's difficult for me to insert to insert the device into its*

	holder. That's the main problem. And also to be wearing the two devices together on my neck.
	P07. Oh I liked it, I liked it very much. But I got used to it and um, I like the idea that, I could wear it away from the building. That was very nice. What I didn't like was that And because my hearing is bad, uh, I didn't know where it was coming from and um so I just decided it wasn't for me right now.
	P14: Um, aside from that my other question was, if you have to charge it at night, um, the time when you probably need it the most, then you're not wearing it, which I thought was not good. Now I don't know whether that just because it's the prototype or whether that would be the way it works later on.
Suggestions for improvement	
Ability to wear device at unprotected times	*No. If I had a device though I would get one of the watches or whatever you can wear to press because..*
	Needs to wear the device through the night, cant while its charging; needs to have two devices
	I supposed if you are really wearing something to warn you about falling, uh, maybe you should wear one all the time, I mean even at night you can get up and..and people tell me that all the time, they'll get up and turn on their light, and fall
	Is there some design a person could have where they could wear it 24 hours a day, except if you want to take it off for shopping or something like that. Because I'm thinking of people who get up during the night.
	Well, I would think, well at least have it very close by, or wear it at night because that's I think a time when it might be most applicable or something like that.
Physical Device Design	*Button needs to be more concave. When I put it on my belt and sit down it turns it on; So I turned it inside out and put it in my pocket; Then it won't accidentally turn it off. He has had to cancel it a few times. Decided to switch to a lanyard.*
	The only thing I would think would be nice if it were smaller.
	Don't know whether you could have a lighter weight button or something that's a little less intrusive on your person

	Well it's OK, um, it would nicer if it were smaller and lighter weight. I think that would be a good idea but uh, it's not a bad idea of course I don't know if it would duplicate this.
	They can adjust some things, get a better battery, and recess that button so you can't bump it. Fix the doggone belt connection. That would make it more applicable.
Alerts and Charging	*I wish there were a more subtle way of, it telling me that needs to be recharged*
	It would be nice if I didn't have to be concerned about charging it.
	If it was in a form where it didn't have to be charged all the time, course maybe that's the nature of the beast.
	Just get that straightened out so it doesn't go off.
Ease of use	*SC. And you were talking about a button to be able to turn it off? Maybe like a snooze button?* *P15. Oh yes, that kind of thing.*
	Um, we did come to the realization when you are sitting in a movie or a lecture and it flashes up on the screen that you should turn off your cellphone. We never turned this one off obviously, we didn't take it off, take it out. *P12. No, we didn't know how to turn it off for one thing but we didn't, but it wasn't a cellphone so we thought, "no".*
	Well uh, I think a little, maybe I haven't checked into this enough yet, having a kinda user friendly list of steps one needs to take to use this instrument properly. It's all in the manual there if you read the manual, make our own checklist, but for us lazy old coots, we gotta have things kinda listed and it would be nice to have a checklist. Is there list in there, maybe there's..
	And less things that we have to do to facilitate
Preventing a fall	*originally I guess we thought it might be something that would help you prevent falls*
	Yeah, so when you stop to think about preventing that sort of thing, that's uh, it's different than just, you really don't want to fall. That's a big incentive, it isn't just letting someone know that you fell, maybe you know that might just help, be a little more careful...

GPS	
No privacy concerns	*She says she really likes the device, and she really likes that I can keep track of her. She doesn't want the government to keep track of her but it makes her feel safe to know someone is looking out for her.*
	But how do you feel about me knowing where you are? *P01: Oh that doesn't bother me.*
	Not as long as I had agreed to do it in the first place.
	I don't care because I don't do anything that I'm ashamed of…
	I don't know, it doesn't bother me I don't think. Um, I can't think, I can see why some people might not like that, but it doesn't bother me. Of course, you wouldn't share that with anybody would you?
	P12. Indifferent. *P13. Yeah, totally indifferent, we are not strong HIPAA people.*
	Oh, I don't care. You know I'm not carrying on an affair or anything, I'm not uh, I'm not consulting with an ISIS cell or anything, so, it's fine, I don't care if you know where I go. No, no, it's fine, everybody may not have the attitude, but, at this stage of the game, who cares, who would care where I go?
Privacy concerns	*one lady already had a device felt like it was a chain that they were using to keep track of her all the time*
	Well that would well be helpful. On the other hand I think that there is always a fear when you're going to do something like this, of going overboard and being intrusive. Beyond being helpful. Well I think if there were very close description of places and length of time and so forth. I think it would be too minute in detail..
	Well I can't say that I like the idea. Because I know it is impinging on my privacy.
	That would bother me to know somebody knows can follow me and knows what I'm doing
	I mean if, in an emergency, that is the way they would find me. So, I can't have it both ways. And I think I would rather they have the data than that they didn't.

	Big brother is watching.
Specific monitoring concerns	*She doesnt want the government to keep track of her but it makes her feel safe to know someone is looking out for her.*
	P13. No, the only one's I could think of might be the insurance companies cause it might affect premium, things of that sort. *SC. Oh that's really interesting.* *P13. Yeah but um, even there…* *P12. But we're not doing anything dangerous, like zip cording or anything zip lining (laughter)* *P13. No but if they knew you had 20 falls a month, they might reconsider whether or not they would insure you.*
	Uh, if it's just you, but I don't want this shared.
GPS Benefits	*Well that's OK, I mean that's what it's for. Another thing that might help would be helpful, if you lost something and you couldn't remember where you'd been and you could, that would tell you where'd you'd been.*
	want somebody who can help me know exactly where I am, not lost in the basement here. See that happened to a lady that was in the laundry room and they took 15 minutes finding her. And in 15 minutes you could be really dead if you had some kind of a TIA? Or something, it's just bad news. So, what good is that [mumble

CHAPTER 5: Conclusion

Summary

The threat of falling, especially while alone, represents a great danger to the ever expanding population of older adults. While there have been several efforts to accurately detect when a person has fallen, systems designed for this purpose have yet to gain significant traction in the older adult community. The aim of this dissertation is to explore how older adults use these devices and better understand how they can be improved to encourage greater use. The papers presented in this dissertation address the gaps in research concerning these devices, the perceived usability of these devices, and the actual usability and accuracy of a wearable device in the real-world.

The first paper is a systematic literature review which provides a comprehensive summary of the current state of research focused on fall detection devices. In this paper, I categorized the various types of devices available and the relative accuracies of these devices. I also looked at methods used to test these devices in order to better understand how these devices were tested with older adults. This review points to various gaps in the literature including the lack of real-world and usability testing of these systems as well as the lack of work conducted to evaluate the overall acceptance of these devices by older adults.

The second and third paper aim to address these gaps, with the second paper looking at older adults' opinions of these devices. In this study, I conducted focus groups with 27 participants to better understand the cultural perception and feelings surrounding these devices. From the focus group discussions I identified 2 major themes relating to participant's interest in fall detection systems. The first theme involves personal influences that affect a participant's desire to have a fall detection device including independence, privacy and cost. The second theme involves participant recommendations on specific features and functionalities of these devices including the ability to be worn on the wrist and possibly prevent a fall from occurring. Combined, these themes provide various recommendations to increase the appeal and usability of future systems specifically for older adults.

The third paper examines the actual usability and real world accuracy of a wearable fall detection device designed for older adults. In this study I gave 18 older adults a specific fall detection device to use for a period of up to 4 months. Results from this study relate to the accuracy of the device, participants' adherence to the device and the participants' observations on the usability of the device. Although the results are limited by the sample size, this study points to the device being inaccurate in a real world setting. Participant adherence was significantly different between those who completed the study and those who chose to leave early, but both groups experienced a drop in adherence shortly after the midpoint of the study. Finally, participants gave their thoughts on how they chose to wear the device as well as the benefits and limitations of the device. This paper provides insight into the usability and real world accuracy of a wearable fall detection device.

Together, these papers provide several recommendations which could be used to improve the overall design of fall detection systems for older adults. Although these studies are limited to research conducted in the Pacific Northwest which test a single wearable device with a relatively small sample size, this dissertation strongly represents older adults' opinions and suggestions to improve a typical fall detection device.

Design Recommendations

Design recommendations from this dissertation will help to improve fall detection devices so that they are more ubiquitously used by those in danger of falling. Ensuring full compliance to these devices will be paramount for ensuring their success. Recent research on hip protectors showed that although the devices were successful in reducing injury during a fall, ultimately these devices failed to reduce injury rates due to lack of participant compliance(Combes & Price, 2014). Manufacturers need to identify methods to generate greater adherence to their devices before considering additional features(Hill, Bird, & Johnson, 2001; McAuley, Courneya, Rudolph, & Lox, 1994). Reducing the size and weight of these devices will cause them to be less obtrusive and easier to wear(Espay et al., 2010; Gövercin et al., 2010; Toh, 2014). Reducing the visibility of these devices may also work to reduce stigma allowing more participants to use these devices discreetly. While many older adults suggested creating a wrist-worn device in our focus group study, observations from our pilot study suggest designing for this specific wearing position may not be essential as many participants were seen to customize how they wore their own device. What is important is to ensure that older adults have a variety of options for wearing the device and that these options provide ways in which older adults can wear the device at all times while still maintaining accuracy in detecting a fall. Device manufacturers should work to reduce the amount of time older adults are without the device by ensuring they can wear the device to bed or in the shower.

Features such as GPS and automatic fall detection will also encourage older adults to use the device, however both features need improvements in accuracy. Devices with GPS need to be able to accurately identify participants both inside and outside of buildings regardless of where they live. Similarly devices intended to automatically detect falls need to ensure that they are able to do so correctly. Accuracy, sensitivity and specificity of fall detection systems are widely discussed in previous studies, however given the variety of methods used to test these systems, it is difficult to compare devices and identify a gold standard (Chaudhuri, Thompson, & Demiris, 2013). Device testing needs to be standardized and conducted more frequently in real world settings to truly understand how these devices will react to fall. Such testing will hopefully prevent false readings and ensure that devices correctly and quickly identify a person that has fallen. While it is obviously important for the health of the person to detect when a person has fallen, it is almost as important to understand when a person has not fallen. False alarms were shown to be a primary deterrent to using these devices during our focus groups and were seen to frequently cause agitation and embarrassment amongst participants in our pilot study. Even with highly accurate devices, designers should provide some way for the user to activate and cancel an alarm quickly and discreetly.

Fall detection on its own, however, does not appear to have enough value to convince older adults to use the device. Participants from both the focus groups and pilot study questioned the value of a device that only worked to detect a person that has already fallen and is most likely injured. Instead developers need to work on methods to prevent a person from falling or suffering an injury during a fall. While deploying airbags around a falling person has been conceived, developers need to work out methods for making these airbags as small an unobtrusive as possible (Tamura, Yoshimura, & Sekine, 2007; Tamura, Yoshimura, Sekine, Uchida, & Tanaka, 2009). One possible existing method involves an airbag that looks like a scarf when deflated but adequately protects the head when inflated("Swedes Develop Invisible Bike Helmet," n.d.). Preventing falls themselves will be more difficult with some possible methods being a device that warns a person they are off balance or even a device that can track changes in participant over time to predict when they may fall (Gabel, Renshaw, Schuster, & Gilad-Bachrach, 2012). Being able to predict when a fall might occur would allow health care providers or family members to better protect the at-risk individual and possibly enroll them in a program to improve their balance. Such a change will help to change the overall image that these devices are meant solely for people who have trouble with falls to being meant for people who are interested in maintaining their independence and health. This sort of cultural shift will be necessary not just when designing these devices but also when advertising and selling these devices. Fall detection devices need to be advertised as tools that help empower individuals. When possible these systems should be sold directly to older adults and should allow for the older adults to be able to customize the device features and the services offered (Acampora, Cook, Rashidi, & Vasilakos, 2013).

Implications for practice and policy

Changes in the design and advertising of these tools will encourage more participants to use them. Other stakeholders can also have an impact on the overall use of these devices. Government agencies such as the U.S Food and Drug administration (FDA) are generally responsible for approving fall detection devices given the possible health risk these devices pose if they were to inaccurately determine a fall. However the FDA mostly allows manufacturers to classify their own devices (Allen & Pierce, 2015). Even in our study, the third party company providing the device avoided classifying their device in such a way that the FDA would have to review their product. Such external classification could lead to inaccurate or unsafe devices being placed in the hands of users. The FDA and other agencies should work to properly classify fall detection devices and then set and enforce standards for testing these devices to ensure their accuracy before they are used by consumers.

Such classifications could also work to improve the perceived importance of these devices which should affect how health insurance providers treat these devices. In order to encourage more participants to use these devices it is paramount that health insurance providers, specifically Medicare, provide older adults with these devices for free or at a reduced cost. This will not only ensure that more older adults have these devices but also ensure socioeconomic equality amongst those who have the device.

Another set of stakeholder that could be vital in encouraging the use of such devices would be health care providers (HCP), especially those who often see patient at risk of falling. As seen in this dissertation, many older adults do not see the need or use of such devices, believing they are meant for someone older than they are. HCPs could be a good source for information to determine a person's fall risk and to determine an appropriate time for the person to start using these devices. If HCPs were to offer these devices in association with a fall prevention program it may also encourage older adults to view these devices as tools for health promotion rather than a source of dependency. These devices could also benefit many HCPs as it has been shown that less than half of fallers talk to their healthcare providers about it. (Stevens et al., 2012) Increased usage of these devices may help HCPs to be more informed of the falling habits of their patients.

Finally family members will also be responsible for encouraging older adults to use these devices. If the family member begins to notice changes in gait or stability in the older adults they should ensure that the individual is assessed for fall risk. Family members can also assist in choosing a fall detector that would work best for the individual and continue to encourage them to use such devices.

Implications for future research

There is still a need to conduct more research on these devices to ensure their improvement. Future research on these devices should involve trials that contain wider variety of older adults and larger sample sizes to more accurately gauge overall opinions on future devices. As an example, the research in this dissertation was conducted with participants who lived in communities where there was a good chance of being discovered if they were to fall. As the accuracy of these devices improve, it will be necessary to test these device with participants who may be in more danger after experiencing a fall to understand the perceived usability and need of these devices for this specific population. Additionally any further real world testing of these devices should be conducted for a longer period of time to counteract the possibility of having limited fall events during the study. Randomized controlled trials (RCTs) may be useful in determining differences in time until discovery after a fall or fear of falling. If these devices were to have additional fall prevention capabilities as suggested above, then RCTs would be even more valuable in testing the effect such devices have on preventing falls in older adults.

Conclusions

This dissertation provides an insightful look into how fall detection devices are perceived and used by older adults. Results and observations from these studies provide meaningful and actionable recommendations for the design of future fall detection devices. Falling remains a great danger to the health and independence of older adults. Improving these devices and encouraging the use of these devices will help to mitigate this danger and allow more older adults to live a life with a reduced fear of falling.

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