

Abstract

Background: Falls are the leading cause of injury related death in older adults. Due to various constraints, objective fall risk screening is seldom performed in clinical settings. Smartphones offer high potential to provide fall risk screening for older adults in home settings. However, there is limited understanding of whether smartphone technology for falls screening is usable by older adults who present age-related changes in perceptual, cognitive, and motor capabilities.

Objective: The aims of this study were to develop a fall risk mobile health application (app) and to determine the usability of the fall risk app in healthy, older adults.

Methods: A fall risk app was developed that consists of health history questionnaires and five mobility tasks to measure individual fall risk. An iterative design-evaluation process of semi-structured interviews were performed to determine the usability of the app on a smartphone and tablet. Participants also completed a Systematic Usability Scale (SUS). Six older adults participated in the first round of interviews, and five older adults participated in the second round. Interviews were videotaped and transcribed, and the data was coded to create themes. Average SUS scores were calculated for the smartphone and tablet.

Results: Two themes were identified from the first round of interviews related to perceived ease of use and perceived usefulness. While instructions for balance tasks were difficult to understand, participants found it beneficial to learn about their risk for falls, found the app easy to follow, and reported confidence in using the app on their own. Modifications were made to the app, and following a second round of interviews, participants reported high ease of use and usefulness in learning about their risk of falling. Little differences were reported between using a smartphone or tablet. Average SUS scores ranged from 79 to 84.

Conclusions: Our fall risk app was found to be highly usable by older adults as reported from interviews and high scores on the SUS. When designing a mobile health app for older adults, developers should include clear and simple instructions and preventative strategies to improve health. Furthermore, if the design accommodates for age-related sensory changes, smartphones can be as effective as tablets. A mobile app to assess fall risk has potential to be used in home settings by older adults.

Introduction

One in four adults 65 years or older fall per year [1]. Falls are also the leading cause of injury related death in older adults [2]. The CDC recommends annual falls screening for all older adults. However, objective fall screening is rarely assessed in clinical settings in part because it requires expensive equipment, clinicians have time constraints, or they may not have the training or relevant expertise [3].

Mobile technology such as smartphones offer a potential solution for measuring fall risk objectively, inexpensively, and with minimal training required. Unlike gold standard technology for fall risk assessment (i.e., force plates, stand-alone accelerometers, high-speed motion capture cameras), smartphones are commercially available and cost efficient [4]. While smartphone technology may be useful, older adults tend to be slow to adopt new technologies [5]. However, having high perceived usefulness, the belief that using a system enhances performance, and high perceived ease of use, the belief that a system is free of effort, are foundational determinants of technology acceptance [6].

High perceived usefulness and perceived ease of use may explain why older adults are the fastest growing population of smartphone users [7]. As of 2017, 42% of adults 65 years and older own a smartphone [8]. Moreover, 74% of adults aged 50-64 own smartphones [8]. Therefore, adoption of smartphone apps for older adults should be designed for high perceived ease of use and perceived usefulness.

There is growing evidence of validity of smartphone usage for fall risk screening. Two recent systematic reviews have indicated that smartphone accelerometers and smartphone applications (apps) have potential to measure fall risk through quantifying gait and balance [9, 10]. For instance, Ozinga and Alberts [11] found high correlations in root mean square

acceleration and 95% volume of acceleration between an iPad and 3D-motion capture during static balance conditions. The growing body of evidence for smartphone use to measure fall risk brings strong potential for falls screening in the home setting. This provides opportunity for older adults to assess their own individual fall risk, a necessary step in determining the type of fall prevention treatment needed.

Establishing the validity and the reliability of smartphones for assessing balance and fall risk is the first step. However, the critical next step is to ensure usability by the target users. Our review of the literature indicated that the usability aspect is typically not part of the reported evaluations [11-13]. A smartphone can effectively address the issue of inadequate fall risk screening, but only if older adults are able to use the app. A usable app must be designed to accommodate age-related changes in perceptual, cognitive, and motor capabilities [14].

Designing for accommodation of age-related changes is necessary but not sufficient for ensuring usability by older adults [15]. Usability testing with members of the target user group is needed to identify additional usability challenges. Therefore, the purpose of this study was to develop a fall risk app and test the usability of the app in healthy, older adults. A smartphone app that is usable by our target population will improve falls screening and help identify those in need of fall prevention resources.

Methods

Application Design and Development

The fall risk application, Steady™, was developed in Android Studio version 3.1.2 for smartphone and tablet devices. Steady™ consists of two components. The first is a 13-item questionnaire of health history (i.e., age, gender, number of falls in the last year, perceived balance confidence [16]) (Figure 1A). These questions were chosen because are predictive of

falls and recurrent falls in community-dwelling older adults [17]. The second component is a progressive postural stability test (Figure 1B) wherein the device guides participants through 5 progressively difficult tasks. These include 4 30-second balance tasks (eyes open, eyes closed, tandem, single leg), plus a 30-second sit to stand test. These tasks were chosen because they have shown to discriminate between high and low risk of falling in older adults [4, 18]. Instructions prior to each balance task is provided through text, and users are asked to hold the phone against their chest for the duration of each test. On completion of each task, users report whether they attempted the task. If so, they then report whether they were able to complete the task (Figure C). These data, alongside data from the health history questionnaire, are entered into a weighted algorithm to produce a score ranging from 0-100 and classified into very low, low, moderate, high, and very high risk of falling (Figure 1D). Higher scores represent a greater risk for falls.

[Insert Figure 1 About Here]

The first iteration of the app was developed with consideration for age-related changes that might influence usability. With respect to sensory changes we ensured that font size was at least size 14 and sans serif, the recommended font size and type for older adults [19]. All text is black text on a white background to maximize contrast. The app also utilizes an audio component for the balance tasks. To begin each balance task, five identical beeps are presented and the 30-second posture task begins at a unique (i.e., higher) sixth beep. We ensured the audio is loud enough for older adults to hear, and we added vibrations during each auditory tone for those hard of hearing. We minimized the cognitive demands by listing one set of instructions or task per screen. In doing so we aimed to reduce working memory overload. In total, there are 10 screens to navigate before receiving a final fall risk score. Lastly, we accommodated motor capabilities of older adults by incorporating large buttons when entering information.

Usability Testing

Participant Characteristics

A total of 11 healthy, older adults participated in usability testing. Our approach was to have older adults interact with the app, identify usability issues, improve the design, and then have another group of older adults interact with the app. This iterative approach is ideal for identifying use challenges. Nielson [20] has argued that small numbers of participants (~5) are sufficient for identifying usability problems. Consequently, we included 6 older adults in our first iteration and 5 in our second. Inclusion criteria included being over 70 years of age, self-reported ability to swipe on a touchscreen device, and able to stand with or without aide. Demographic information of all participants is included in Table 1. All procedures were approved by the University of Illinois at Urbana-Champaign Institutional Review Board, and all participants completed written informed consent prior to participation.

Table 1. Demographic information of all participants. Age is represented in mean \pm standard deviation. Falls in the previous year is represented in range (median).

	Iteration 1 (n=6)	Iteration 2 (n=5)
Age (years)	78.3 \pm 7.3	81 \pm 3.7
Gender	1 male; 5 females	1 male; 4 females
Education	3 Phds; 2 Master's; 1 Bachelors	2 Master's; 3 High School Diploma
Smartphone Usage	5 users	4 users
Tablet Usage	3 users	3 users
Falls in Last Year	0-5 (2)	0-2 (0)

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Procedures

An iterative design-evaluation process of semi-structured, videotaped interviews was used to determine the optimal usability of Steady™ [21]. Participants were presented with a smartphone (Samsung Galaxy S6) and tablet (Samsung Galaxy Tab S3) and asked to pick their choice of device to use first. After selecting a device, participants were asked to open the app and follow all instructions while thinking aloud and narrating their thoughts. In addition, a series of open-ended questions related to ease of use, recommendations for modifications, and feasibility were asked after completing the healthy history questionnaires, after completing the balance tasks, and after receiving their final fall risk score. These questions are included in Appendix A. After completion, participants repeated testing measures with the alternate device and were asked to report differences in using the smartphone and tablet. Participants then completed the Systematic Usability Scale (SUS) [22] for both the smartphone and tablet. The SUS is widely used to quantify the usability of user-machine interfaces, consisting of ten standard questions on a five-point Likert scale with higher scores indicating greater usability [22].

After the first iterative cycle, changes were made to the app based on identified issues from the interviews. A second iterative cycle was conducted on five older adults, following the same format as the first cycle. No new usability challenge themes emerged after the second cycle.

Data and Statistical Analysis

All videotapes and field notes taken during the interview were transcribed verbatim. Qualitative data from transcripts and field notes were reviewed by KH to develop a coding

system. Based on their content, data were assigned with codes, and codes with similar content were grouped into thematic categories.

Following a mixed-methods approach, SUS data were used to complement the qualitative results. SUS scores were averaged for each participant and transformed into a usability score out of 100, where the average score is a 68 [23].

Results

Iteration 1

Usability Testing Interviews

Transcript analysis and coding revealed two distinct usability themes: 1) Perceived Ease of Use, and 2) Perceived Usefulness. Main issues, sample quotes, and solutions to each issue are described in Table 2.

Perceived Ease of Use

Overall, participants found the app easy to follow and free of clutter. Some participants found difficulties swiping between screens and answering the balance confidence questions in the health history questionnaire. In the first iteration, a slide bar was used to indicate a percentage for 0 through 100 (Figure 2A). However, four participants were unable to drag the side bar or needed multiple attempts. Therefore, the slide bar was replaced with a key-in entry (Figure 2B), and “forward” and “back” arrows were added to each screen.

[Insert Figure 2 About Here]

Participants reported confusion following the instructions to begin and end each balance task. The first five beeps prior to starting each balance task was programmed to allow time for

participants set-up for each task. Four of the six participants, however, were confused on when to start or stop each task. Participants thought the task ended at the sixth beep instead of starting at the sixth beep. As a potential solution, instructions were added prior to each balance task explaining when each task begins and ends within the second iteration of the app (Figure 3).

[Insert Figure 3 About Here]

Additionally, participants completed the health history questionnaire and balance tasks in the incorrect order. In the first iteration, participants' fall risk would be displayed following completion of the balance tasks, regardless of whether the health history questionnaire was completed. This resulted in an inaccurate initial score. This resulted because the button to initiate the balance tasks was displayed above the button for the health history, and participants often completed the balance tasks first. To address this issue in the second iteration, only the questionnaire button is displayed until the questionnaires are complete (Figure 4).

[Insert Figure 4 About Here]

In comparing using the smartphone and the tablet, there were few differences reported in using the two devices. Three participants reported no differences between the two devices. One participant preferred holding the tablet for the balance tasks, and two participants preferred holding the phone for the balance tasks.

Perceived Usefulness

Participants enjoyed learning their risk of falling from the app. Four of the six participants reported concerns and fear of falling, indicating that this app may address their concerns. For example, one participant mentioned that it helped her think about her balance and falls.

I think this [the app] would be helpful for me because I wasn't too steady. This helps me think about balance exercises when I go to the gym. [Female, 74 years old]

It appeared that the greatest benefit for participants was to receive their fall risk and be more aware of falls. Half of the participants reported this benefit. Moreover, all participants who received a high risk of falls wanted to receive fall prevention strategies to lower their fall risk.

Participants also reported confidence and acceptance in using the app on their own if it were downloaded on their own device. Four participants explained that the app is easy to follow on their own. One participant indicated that she may need assistance to start the app, but could finish on her own. While a care-giver may not be needed, some participants mentioned they would want to be near a sturdy object in case they lose their balance. This was further included in the safety instructions provided at the start of each in-app testing session.

I am comfortable using [the app] by myself. [Female, 77 years old]

Table 2. Main issues with sample quotes identified from the first round of usability testing, with solutions implemented in the second iteration of the app.

Domain	Issue	Sample Quotes	Solution
Perceived Ease of Use	Instructions for beginning each balance task	<i>The instructions should be in the beginning and say the first five beeps do the purpose to adjust the device. Then the sixth beep is when you start the test and you do it until a final beep after 30 seconds.</i>	Instructions were added prior to each balance task explaining when each task begins and ends within the second iteration of the app.
	Inaccurate fall risk score	<i>What do I do next?</i>	Only the questionnaire button is displayed until the questionnaires are

		<i>Do I go to Full Test?</i>	complete. The Full Test button appears after the questionnaires are complete.
	Dragging a slide bar	<i>How do I change the number?</i> <i>My fingers can't move the bar.</i>	The slide bar was replaced with a key-in entry.
	Swiping between screens	<i>You should indicate if I need to swipe left to right or up to down.</i>	“Forward” and “Back” arrows were added to each screen.
Perceived Usefulness	Fall prevention strategies	<i>It was very beneficial to get your prediction for falling. I would, at the very end, provide a link to demonstrate preventative measures to reduce the risk of falling.</i>	

Usability Testing Questionnaire

The average score on the SUS for the smartphone was 79.17, and the average score on the SUS for the tablet was 77.92 (Figure 5). These scores represent good usability for both devices[23].

[Insert Figure 5 About Here]

Iteration 2

Usability Testing Interviews

Transcript analysis and codes in the second round of interviews revealed two distinct themes: 1) Perceived Ease of Use, and 2) Perceived Usefulness

Perceived Ease of Use

In the second round of interviews, participants reported little to no difficulty in navigating through the app and understanding instructions. Participants in the second round preferred the smartphone over the tablet. Three participants preferred the smartphone more because it was easier to hold against their chest. One participant preferred the tablet because it was easier to read, while one reported no differences. No other errors related to ease of use were identified during the second round of interviews.

Perceived Usefulness

Similar to responses from the first interviews, four participants reported a benefit of learning about their risk of falling. Participants also reported that Steady™ would be useful for them and other older adults, especially for those who do not have access to fall risk screening.

In this place [retirement community] we have a lot of exercises and programs and balance tests, but I think there are a lot of people who are at home and who don't have access to all that, and I think it could be very helpful to them. [Female, 83 years old]

After receiving their fall risk score, four participants also wanted to understand fall prevention strategies they could adopt. Participants suggested the app displaying simple exercises that they could practice at home.

Furthermore, not only did participants find Steady™ to be useful, but they reported that they would be able to use it on their own. Four of five participants reported that they could

complete the app on their own. Because the tests are short, the instructions are clear, and app is easy to follow, participants reported that they would be able to use Steady™ in their own homes. One participant indicated they would want a caregiver's help to assist in spotting during the balance tasks.

The instructions were clear and I could download this on my own phone and use it on my own. [Male, 85 years old].

Usability Testing Questionnaire

The average score for the SUS on the smartphone was 84, and the average score for the SUS on the tablet was 80 (Figure 5).

Discussion

Principal Results

The iterative development and testing of a fall risk mobile application resulted in a usable device for older adults to measure their risk of falling. Through two rounds of usability testing, Steady™ accommodates for age-related perceptual, cognitive, and motor changes to promote use in older adults. Participants reported positive ease of use and perceived usefulness. High SUS scores also indicated high usability of the fall risk app for both the phone and tablet, although older adults appeared to prefer using the phone for the balance activities.

This study suggests potential for mobile technology to offer fall risk screening to older adults. The two themes generated from the interviews were perceived ease of use and perceived usefulness. Both perceived ease of use and perceived usefulness are factors that predict technology acceptance among older adults [5]. This suggests that older adults may have high

acceptance of a fall risk app. Furthermore, a fall risk app that older adults find both usable and useful has high potential to provide falls screening to older adults outside a clinical setting. Along with previous studies that have found smartphones to provide valid balance and fall risk screening, mobile technology may offer a solution to identify high fall risk older adults to seek fall prevention treatment.

Through iterative usability testing, we identified key lessons to use when developing a mobile health application for older adults. First, instructions should be as clear and simple as possible. This became prevalent when the 30-second balance task instructions were confusing for our participants. Rewording the instructions and maintaining consistency of these instructions drastically improved performance. Second, measuring fall risk is a necessary step to prevent falls, but older adults also wanted to learn how to lower their fall risk. While participants reported high usefulness, there is potential to increase usefulness by adding prevention strategies. When developing a health app, both measurement and prevention strategies should be taken into consideration. Third, a smartphone can be just as effective as a tablet if the app has high perceived ease of use. We found that by incorporating large font sizes, keeping text consistent, and using contrasting colors, participants found no differences in reading or entering information in the phone or tablet. Because Steady™ involves holding the device to the chest, the smartphone was found to be the more feasible device. Following these lessons may help develop a highly usable mobile health app for older adults.

Limitations

One limitation in the design of Steady™ is that the balance tasks are constrained to individuals who can stand with or without aide. This limits older adults with significant mobility impairments (i.e. wheelchair users) from using the app. Wheelchair users have shown to have an

elevated fall risk [24], and future iterations of Steady™ should develop and test fall risk for wheelchair users. Steady™ also uses visual text to guide users through the app, which is a limitation for older adults with significant vision impairment or who are blind. Future iterations of Steady™ should also include an auditory instruction to guide users through the app.

In addition, our sample of older adults is well-educated. Almost all participants had a college degree or higher. Those with higher education levels may also have greater technology experience, and they may perceive different issues with usability than older adults with lower education levels.

While the accelerometer embedded in the smartphone captured data during the balance tasks, the acceleration results were not incorporated into the final fall risk score. In the next iteration, the fall risk score will include both balance performance from acceleration data and health history questionnaire data. This will enhance classification of low, moderate, and high risk fallers. Furthermore, the next iteration will also include fall prevention strategies, as this was a common request among participants.

Comparison with Prior Work

To the authors' knowledge, this is the first study to test the usability of an app that measures fall risk in older adults. Because fall risk screening is underutilized in clinical settings, this study suggests that a smartphone app can not only offer fall risk screening but can also be used by older adults. Compared to previous studies, Steady™ provides a quick and understandable fall risk output. A previous study used a smartphone worn at the hip to monitor fall risk during a dancing game [24]. Another study tested the usability of mobile technology to detect falls in older adults [25]. While both studies found high usability, neither the game nor the

fall detection app provided a fall risk score for users. Providing fall risk knowledge to older adults is the first step to seeking treatments to lower their risk of falling.

Conclusions

In conclusion, through a mixed-methods, iterative design, we developed and tested an app on a smartphone and tablet to measure older adults' risk of falling. After one round of usability testing, confusion with task instructions and visual and tactile errors were corrected. After a second round of testing, older adults found the app useful and easy to use. High SUS scores for both the smartphone and tablet also indicated high usability, but participants preferred holding the smartphone over the tablet. A fall risk app has potential to be used by older adults to measure their individual risk of falling.