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Original Paper

Tablet-Based Well-Being Check for the Elderly: Development and Evaluation of Usability and Acceptability

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Abstract

Background: Many elderly people prefer to live at home independently. One of the major concerns raised by the family members is the safety and well-being of their elderly family members when living independently in a home environment. To address this issue, assistive technology solutions have been available in the market. Despite their availability and proliferation, these types of solutions are not popular with the elderly due to their intrusive nature, privacy-related issues, social stigma, and fear of losing human interaction. This study shares the experience in the development of a digital photo frame system that helps family members to check the well-being of the elderly, exploiting their desire to remain socially connected.

Objectives: The aim of this study was to iteratively design, implement, and assess the usability, user friendliness, and acceptability of a tablet-based system to check the well-being of the elderly.

Methods: Our study methodology comprises three separate stages: initial system development, contextual assessment, and comparative case study evaluation.

Results: In the first stage, requirements were elicited from the elderly to design a well-being check prototype. In the second stage, areas for improvements (eg, privacy features) were identified. Also, additional features (such as medication prompts or food reminders) were suggested to help aged and health care service providers with effective but subtle monitoring of the elderly. These would lower their operating cost by reducing visits by care providers to the homes of the elderly. In the third stage, the results highlighted the difference (between users in India and Australia) in the levels of familiarity of the elderly with this technology. Some elderly participants at the Kalyani Institute for Study, Planning and Action for Rural Change, India latched onto this technology quickly while a few refused to use the system. However, in all cases, the support of family members was crucial for their willingness to use the technology.

Conclusions: This project has three major outcomes. First, a picture frame prototype was tested with the elderly to leverage the benefits of social communication. Second, the project helped us test and implement the “Silvercare” model for supporting the elderly through young retired people residing in the area. Finally, the project helped formalize the agile three-stage design methodology to develop information technology solutions for the elderly. Also, the project contributed to an ongoing European Union Project called Victoryahome, which involves more than 50 sites across 5 countries (Norway, Sweden, Netherlands, Portugal, and Australia) to assess the use of telepresence robots, wearable fall detectors, and medication dispensers for the elderly living independently.

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KEYWORDS

agile methodology; elderly people; information and communications technology application; silvercare model; tablet-based well-being system

Introduction

Background

Between 2000 and 2050, the population aged above 65 years will double from the current 8%-16% in the world [1]. In Australia, the number of senior citizens aged over 65 years is projected to nearly double its population from 13.5% of a population in 2010 to 22.7% by 2050 [2].

In 2006, 2.74 million people in Australia were aged 65 and over and around 29% of them (0.78 million) were living alone and independently [3]. However, there have been risks associated with greater numbers of the elderly living alone at home, such as a higher risk of falls [4]. In this case, the extended family members are often worried about the well-being of elderly family members [5].

There is a growing demand for well-being monitoring technologies such as fall detection, remote health monitoring, smart home solutions, and video surveillance, which would provide the elderly with a sense of security and independence [6]. Researchers believe that these well-being technologies have their potential to reduce the number of visits to clinics and hospitals [7].

Existing technological solutions for aged care are often designed from a technical perspective and do not appropriately address the needs and/or preferences of the elderly [8]. Hence there is a need to involve the elderly in the development process of the well-being technology [9]. Also, a closer look at the gerontology literature and research is required to understand the values and attitudes of the elderly toward technology.

Some studies have revealed that the elderly mostly adopt and use technology with an element of human interaction [9-11].

A recent study concluded that there were significant changes in the elderly's attitude toward information and communications technology (ICT) [12-14]. Most participants admitted that the Internet helped them to maintain constant communication with family members and friends [12]. The Internet has also been used by the elderly to pay bills, access Web-based banking services, and search for information on their health conditions [12,14]. In keeping with the trend, technology vendors are developing ICT systems that can bridge and enhance social interactions between the elderly and their family members [15].

One of the examples is an interactive, digital photo frame that enables both the elderly and their family to share pictures, memorable moments, and their activities [5]. The solution is Web-based and runs on a wide range of devices like iPad and Android tablets. It can enhance social interaction and check the well-being of the elderly. Its development adopted an agile methodology and involved multiple end users and stakeholders.

This paper is organized as follows. The paper starts with a literature review of the existing well-being technologies for the elderly. This is followed by a discussion of the needs for a

methodology to develop information technology solutions for the elderly, incorporating participatory design involving the elderly at several stages. This is followed by a description of our three-stage methodology for the design and assessment of a tablet-based well-being system for the elderly. The paper concludes with a short discussion.

The Existing Well-Being Technologies for the Elderly

Most technology products available for the elderly in the market are designed to enhance the functional abilities of the elderly, such as assistive robots [16,17], digital photo frames [18,19], telehealth [20,21], smart homes [22,23], video games [24,25], and video surveillance for fall detection [26,27]. During their design and development, there has been minimal or no involvement of the elderly to understand their needs and requirements [28]. Some research findings have demonstrated the importance of addressing human factors in designing ICT products to attain the positive impact on the elderly's well-being [29,30]. The following review below discusses the existing well-being technology solutions and main issues in their adoption.

There are a growing number of studies on animal robots to provide emotional support and treatment to the elderly [31,32]. Two of the most prominent examples are a baby seal robot called "Paro" [15] and a robotic dog called "AIBO" [32,33]. Some studies found that the availability of "Paro" could have a beneficial effect on the quality of the elderly's life (both physiologically and socially) [32,33]. In a study by Kidd et al [33], it was found that the elderly formed a special attachment to Paro. As therapy aids, AIBO facilitated effective communication between the elderly, their family, and nursing homes, and improved the quality of the elderly's life [34].

Some of these assistive robots were designed to establish engagement with and provide enjoyable experience to the users; nevertheless, a deeper emotional bond may cause unwanted situations [35]. Findings from Tapus et al [36] showed that the elderly with Alzheimer disease felt emptiness and loss when the robot was removed from their side.

A study conducted by Mynatt et al [5] has revealed that digital family portraits with a qualitative visualization of the family members' life allow them to remain emotionally connected. This study has also found that that sharing day events by sending photos and drawings on display screens would be greatly appreciated to support communication between the elderly and their geographically distant family members [5].

Telehealth can be used to monitor the health status of people with chronic diseases (such as cardiovascular diseases, diabetes, and obesity) [37]. For example, Holter monitors and automatic blood pressure (BP) cuffs are routinely used to measure heart rhythm/rate and BP, respectively [37]. Some studies have suggested that the elderly may object and refuse to adopt wearable sensors due to a number of reasons such as the

wearable sensor being uncomfortable to wear and being viewed as a stigmatizing symbol of their frailty or age [21,38].

Wireless sensor monitoring is a rapidly emerging area that supports the elderly living independently [22]. It is currently being developed to help elderly people achieve greater levels of safety and independence [22]. Care systems such as smart homes are being equipped with multiple sensors that can interact with other sensors worn by the elderly [23].

A study by Zhang et al [39] used ambient sensors (motion infrared detectors and pressure mat sensors) to detect a fall at the night time in a one-person household. The limitation of using ambient sensors is that it can only monitor 1 person during the night time and it is not suitable for multiple occupancy households (ie, residential aged care or nursing home facilities).

Recently, a number of studies have been conducted to investigate therapeutic effects of video games for the elderly [24,25]. A study by Lee and Shin [24] used video games (ie, PlayStation 2, Sony, Tokyo, Japan) to improve their balance, gait, falls efficacy, and strength.

In general, two common causes of problems during gaming sessions are aged-related physical and mental changes and lack of familiarity with video games [25]. Ijsselstein et al [40] have accordingly made recommendations for the design of video games for the inexperienced elderly: (1) the first-level games, which ensure that the elderly are already able to master the basic skills needed before continuing with the next levels of games, and (2) a feature that provides continual performance feedback at each level of the games.

In a study by Fleck and Straßer [26], multiple cameras were placed around a health facility to determine the occurrence of a fall, and Google Earth was used to display the floor plan of the health care facility [27]. In the case of a fall, the system would immediately send an emergency alert and automatically share the world-coordinate location of the faller [26].

Video surveillance has been chosen over other sensor technologies due to a number of reasons. The price of video cameras is decreasing rapidly [41]; the system is able to detect multiple events simultaneously; and the user is not required to wear any devices all the time [42]. Since the surveillance system records all activities inside the house, security and privacy-related issues are extremely crucial to be considered [43,44].

Although there have been attempts to design and evaluate the above types of technologies for the elderly, there is no integrated, systematic methodology for the design and evaluation of information technology solutions for the elderly. We now discuss the field from such a methodology perspective.

Methods

Study Design

The main barriers to the deployment of assistive health technologies are the lack of research in innovation translation, issues with interoperability and usability of assistive health

technologies, and the lack of comparative studies across sites and systems [45].

Approximately, 33% of off-the-shelf assistive technologies have been abandoned after being used for 12 months [46]. According to a report by Plaza et al [47], one significant inhibitor for the elderly's adoption of mobile apps is the ill-designed user interface. As they age, they inevitably experience physical and cognitive capabilities decline. This requires an even more user-friendly interface to encourage their willingness and usage of a technology product.

In order to obtain higher acceptance of technology among the elderly, and thus achieve its potential benefits, it is important to conduct a series of studies or consulting sessions to understand their needs, preferences, and desires for a product [48]. The elderly's involvement should not be limited to the requirements elicitation stage but all other stages as well (eg, product design, development, and testing).

Some studies have recommended the use of iterative design methods for the designing of mobile apps [49,50]. The iterative design can be defined as a product design process in which the test and evaluation of the deployed product are performed in every stage of design to remove major usability flaws before the product is launched [51].

This study employed the iterative approach to design and develop a digital photo frame-based well-being monitoring system. The approach included three stages: a prototype development, a contextual assessment, and a case study evaluation (across India and Australia). It assured a solid and continuous engagement between the researchers and various stakeholders (the elderly, family members, caregivers, and health care professionals).

The next section presents the three-stage iterative methodology for the design and implementation of a tablet-based well-being check system that uses the "Silvercare" model for its deployment. The study was backed up by ethics approvals in Swinburne University of Technology (Phase 1), the University of New South Wales -Australia (Phases 2 and 3), and the University of Sunshine Coast (Phase 3).

Phase 1: Initial System Development

A cooperative (consulting with elderly users and service providers) development model was adopted, using an agile (iterative) methodology as shown in Figure 1 [51]. The analysis and design were carried out by a multidisciplinary team (with specializations in public health, aged care, and ICT). The testing was done with elderly users and also with aged care service providers at each stage.

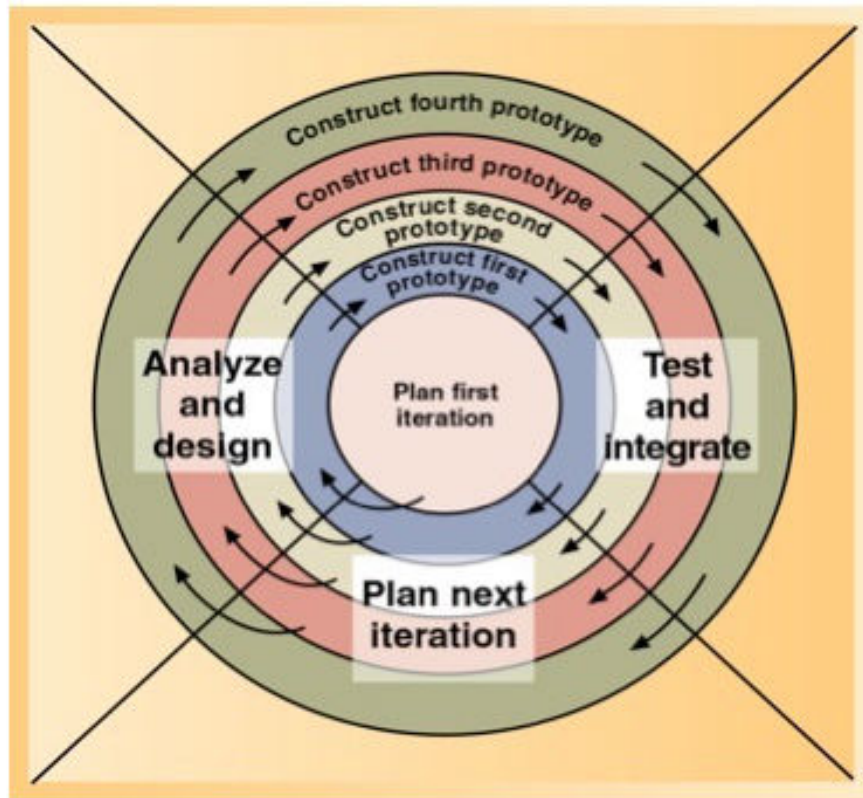
Initial requirements came from some existing elderly alert systems, such as the Mount Eliza Personalised Alert Control System in Victoria, Australia. There were two common features in these systems: (1) a notification of emergency situation (eg, the elderly was able to activate an emergency alert by pressing a button on the pendant) and (2) a well-being check. On a daily basis, the elderly notified their health condition to their trusted service providers by clicking a button in the application window. If no "well-being notification" is sent within a certain period

of time, the service provider would contact the elderly to ensure their safety and well-being [52].

Many users of these systems were reluctant to use them. They felt uncomfortable with the integration of new technologies into

their daily routine activities. If they did not wear a pendant during, for example, an emergency, they could not receive immediate support from others as required. The findings of this stage have been published in [53].

Figure 1. The spiral development model based on agile methodology [51].



Problems With the Current System

Researchers from Swinburne University of Technology conducted an ethnographic study to identify a design solution for an emergency system based on psychological needs of the end users. In this study, 3 groups of 4 people each (a total of 12) were recruited: (1) a group of senior citizens aged between 85 and 91 years, who had an emergency response system in place; (2) a group of family members whose relatives had experience with the personal alarm system; and (3) a group of senior citizens aged between 66 and 79 years, who had never used the personal alarm system before [54].

The elderly reported that the use of a personal alarm system was not part of their daily routine and its inclusion had an impact on their activities in an unwanted manner, such as follow-up calls from service providers every time when they forgot to press the well-being check button. They believed that there was no social context involved when pressing the well-being check button and the system failed to send the notifications to their family. This led to the need for designing and deploying a new system since the existing personal alarm systems had failed to fulfill the emotional needs of their users [54].

The Development of a Well-Being Monitoring Prototype

To address the issues mentioned above, the Smart Services CRC, a software development organization, developed a digital photo frame-based well-being monitoring prototype. Instead of sending a one-way signal or a notification, the prototype allowed the elderly to stay in touch with their family by sharing photos or informing their current health condition through a two-way message exchange. The prototype had two different applications: a mobile app for researchers and a digital photo frame for the elderly. The digital photo frame worked in any Web browsers of computers or tablets (such as iPad).

The mobile app for researchers had several menus, including alert, event, and installation (as shown in Figure 2). They appeared on the left side of the browser window. The installation menu enabled the researchers to add new users into the system. The events menu displayed all recent activities from all users. When the list of events was updated with the latest activity of a particular user, the previous events from other users were placed in chronological order based on the date and time of the latest activity. The alerts menu allowed researchers to monitor any alerts sent by users. There were two types of alerts: investigation and investigation cancel. The “investigation” alert would be triggered if the user had not checked in for a period of time. The “investigation cancel” alert would be triggered if

the user had pressed the OK button during the investigation period. Whenever an alarm was triggered, researchers had the responsibility to contact the users directly or to notify their family and/or service providers.

At the user side, the digital photo frame would display images and messages sent by their family (as shown in Figure 3). Every image had a caption explaining the content of the picture and displayed the alias or sender's email address. A swipe able carousel-like gallery was also available for displaying multiple images.

Figure 2. Administrator's section – alert, event and installation menus.

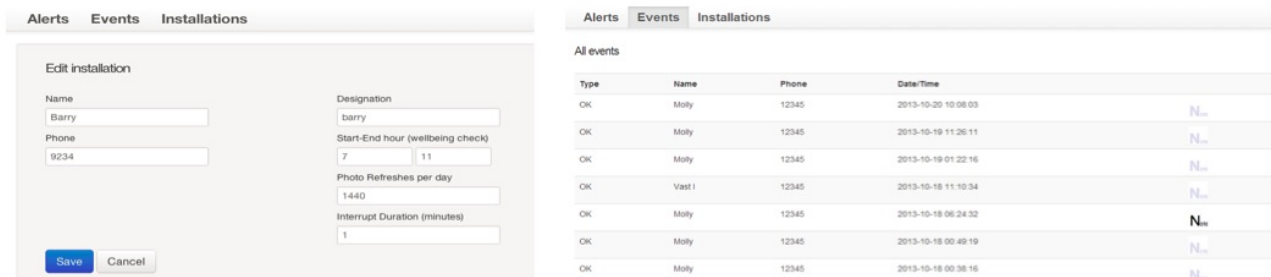
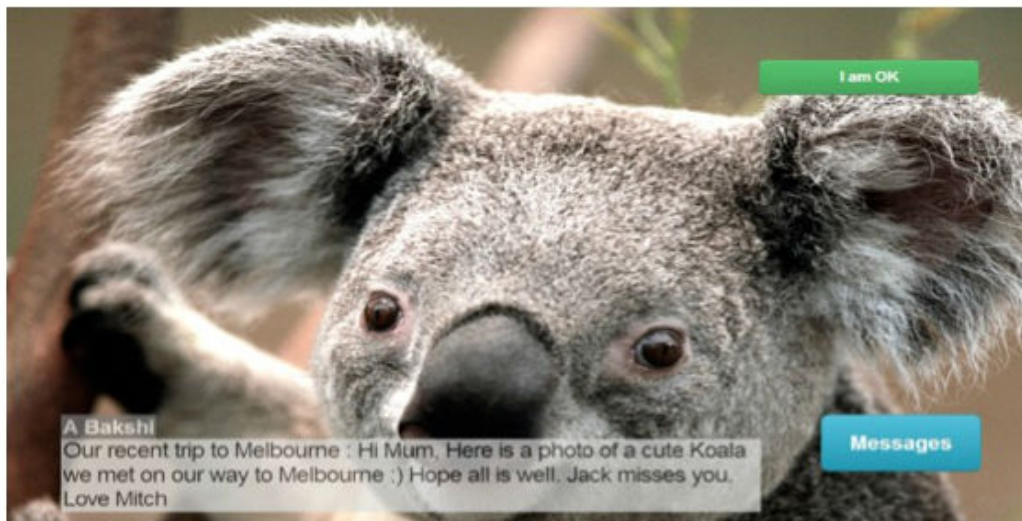


Figure 3. Photo frame user interface.



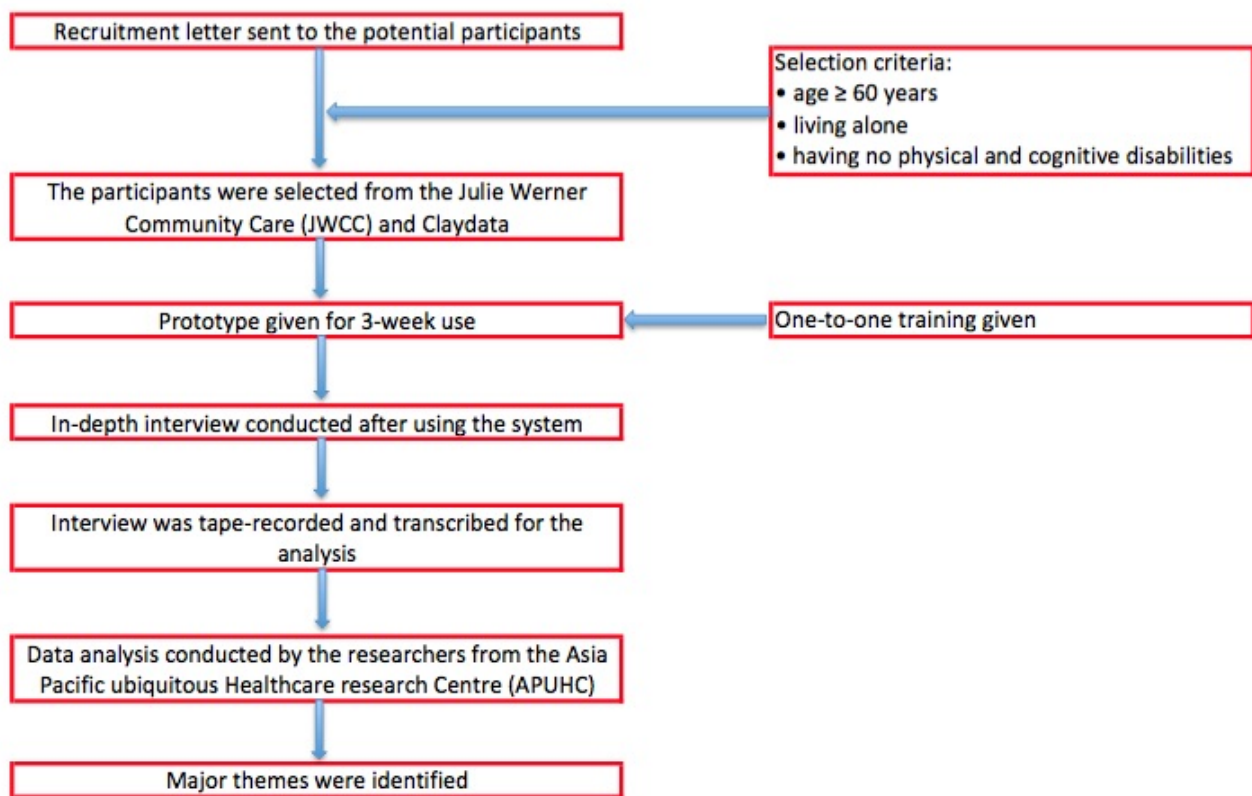
Testing

The testing was conducted between September and October 2013. It was done with 12 elderly participants aged between 69 and 92 years and residing in Melbourne, Victoria. The results showed that the elderly preferred a more indirect method (eg, to use the digital photo frame) instead of existing emergency alert systems. The elderly agreed that this prototype could be seamlessly integrated with their daily routine and enabled them to maintain social contact with their family [54]. Also, the prototype was demonstrated to a large aged care service provider in Australia. They deemed that the system was not suitable for trial and deployment due to the absence of many required

features from their perspective (eg, lack of basic security, lack of voice interface for the elderly, and small fonts)

Phase 2: Contextual Assessment

On the basis of the collected feedback, the technical team modified the system between November and December 2013. The system added voice-based interfaces and access control, and also enlarged the font size. The users' perception of the system's usability was evaluated in December 2013. The evaluation process was performed from a health/aged care service provider's perspective and the elderly's perspective (Figure 4).

Figure 4. Steps undertaken in a field trial.

Stage 1: Assessment From Service Providers' Perspectives

A total of 4 participants were selected from residential and community care services. Inclusion criteria included: (1) those directly involved in providing aged care services to the elderly and (2) those who had been working part-time or full-time at the organization for more than one year. The participants had various professional backgrounds, such as business, ICT, and nursing.

Video tutorials on how to use the system were initially provided to the participants. On the completion of the training, they were given access to the prototype and were allowed to try it out for 3 weeks. Subsequently, interviews with open-ended questions were conducted to investigate their perception on the usability and acceptance of the prototype.

The participants appreciated the idea of using photos and two-way messages to socially engage with the elderly and keep their well-being checked. For the ease of use, they were positive. During the discussion, they also suggested the areas with potential for improvement. All suggestions are discussed below.

Functional Requirements

Additional functional requirements were collected for possible future development: (1) to allow the elderly to send messages to their service provider if they feel unwell or require immediate help or assistance, (2) to enable service providers to monitor the frequency of communication between the elderly and their family, (3) to send the elderly reminders for medication or meals, and (4) to add an entertainment feature (like games and

videos) that would help engage with the user and also improve their cognitive level.

Security

At the time of data collection, the app was previewed in a Web browser and had open access to the database, which might lead to a massive loophole for privacy invasion. One suggestion was that the user must enter their username and password to regain access to the system.

Ease of Use

In addition to technical issues, one felt that it would be difficult to use for elderly people living with chronic diseases (eg, dementia or visual impairment).

Maintainability

It was observed that ongoing support would be costly. For the elderly, on-site support instead of remote support would always be required due to their low level of computer literacy. It was deemed to be critical to design and implement a robust and sustainable support strategy.

Stage 2: Assessment From Elderly Users' Perspectives

A total of 8 elderly people were selected from one community care organization (Table 1). Inclusion criteria included: (1) those aged 60 years and above, (2) those living alone, and (3) those eligible for the low level of care, as per Aged Care Assessment Team assessment. Of the total, 1 participant withdrew from the trial due to health problem. After using the prototype for 3 weeks, the participants were invited for in-depth interviews to examine their perceptions on its usability and acceptance.

Attitude

All participants had a positive attitude toward the system and they would like to continue using this system in the future.

Design of Interface

Some elders might have forgotten to press “I am OK” due to age-related memory loss and dementia. It would be useful to have another option to automatically generate an “OK” message when the user touches any part of the tablet screen. This feature would enable the service provider to continuously monitor the elderly’s current condition.

Another comment was that pop-up reminders for reminding were too small. One recommendation was to provide a sound alert feature that would notify the elderly when a new message was received or when the medication needed to be taken.

A few who received many photos from their family had difficulties in identifying new photos from old ones. Difficulties were always found in searching for particular photos since the system was set to automatically scroll down the photos. Some recommendations included the use of timestamp when displaying frames, the Trash Can feature for deleting old photos or multiple duplicate photos, and a scroll feature that enables the user to manually scroll through the photos.

Ease of Learning

All participants used this system regularly, except one, because of her sickness. They were able to independently operate basic functions like pressing green or red buttons on the screen. However, they were struggling to send messages or to play Web-based games.

The researchers also noticed that most elderly people preferred face-to-face learning environment to the user manual. This might be caused by their low technology skills and unfamiliarity with built-in help functions.

Language barriers had a profound impact on the elderly’s learning process. For those with English as a second language, their children attended all training sessions. Participants were more comfortable with training given in their mother tongue.

Ease of Use

In this trial, 5 participants used an iPad and the other 2 used an Android tablet. The latter faced more technical difficulties and were less happy with the size of the screen in comparison with the former. The Android tablet had a shorter battery life and a more sensitive touch screen, which caused more incidents of websites closing accidentally. In addition, because of their unfamiliarity with touch screen devices, the elderly were anxious in using all features of the system at the beginning of the trial.

All participants found it difficult to open the prototype page when they accidentally closed the Web browser. Even after training, they were not able to open their account page on the screen by themselves. Each requested easier ways to navigate through their account. A shortcut could be created to the home screen to avoid multiple steps or a pop-up alert like “Are you sure you want to close this program—Yes or No” when a Web browser was about to be closed. However, the number of incidents was reduced after 1 week, as the elderly became more familiar with the system.

Perception of Usefulness

Participants agreed that their social connections with their family were significantly improved by using this system. It was also revealed that the ongoing involvement and motivation of the family positively affected their willingness to use such a system.

In addition to personalized communication, many participants found pop-up messages for medication reminders useful. One service provider suggested its integration with medication management systems so that care workers would not always be required for the administration of medication to the elderly.

A few participants questioned the usability of the system in the monitoring of well-being. They were looking for a system with an emergency alert feature. For instance, for fall incidents, immediate medical intervention might be required. It is important to mention that this well-being check system has been designed to support the elderly’s independent living and not for an emergency alert.

Table 1. The demographic profile of elderly participants in phase 2.

Demography	Number of participants (N=7)
Age (in years)	
60-70	4
71-80	2
Above 80	1
Gender	
Male	1
Female	6
Level of education	
Primary school	1
Secondary school	3
Tertiary school	3

Overall, digital photo frames have a greater chance of being accepted by the elderly living in residential settings [55]. The digital photo frame is generally easier to obtain and this technology merged with a familiar object, only software modifications are needed when upgrading the system and the process is much simpler when compared with other technologies that required hardware modifications [55].

Phase 3: Case Study Evaluation

The third stage was to examine users' experiences in using the "well-being communication" system and their attitudes toward the technology in different economic and cultural settings. The comparative case studies were conducted in 2 countries, India and Australia, between September and December 2015. The Indian trial was conducted by the Kalyani Institute for Study, Planning and Action for Rural Change (KINSPARC, a nongovernmental organization that provides aged care services to Indian community) and the Australian trial was conducted by the University of Sunshine Coast and members of the University of the Third Age, located in Sunshine Coast.

The Australian study recruited 30 participants, 27 users and 3 peer tutors. In India, there were 20 participants. The average age of participants was 70.8 years. There were 31 females (66%, 31/47) and 16 males (34%, 16/47). Of the 20 participants in India, 8 had never had any experience of using an electronic table, computer, or mobile phone.

Inclusion criteria for the elderly included: (1) those aged 65 years and over, (2) those living alone, and (3) those who had no record of cognitive impairments and blindness. Inclusion

criteria for the care coordinator staff included: (1) those who had the time and would be willing to help the elderly in their area by physically visiting them at least once in a week, (2) those who were comfortable with the use of mobile phones, and (3) those supported by pension (did not need any financial support from this project). The demographic profile of participants in phase 3 is summarized in Table 2. There were 27 participants from Australia (Sunshine Coast) and 20 from India (Kalyani).

In order to overcome the problem of deployment and maintainability, this comparative study adopted the concept of "Silvercare," which involves young retired people as coordinators who support about ten elderly people in their geographical vicinity [56].

In these comparative studies, Dropbox had been selected for sharing and storing photographs safely, while Skype for video conference calls. The user acceptance of the "well-being communication" system was evaluated with 7 variables (anxiety, attitude, facilitating condition, intention to use the system, self-efficacy, social influence, and usefulness).

The effect of potential moderators (like age, gender, and experience) on the independent variable was also investigated in this study. After using the "well-being communication" system for 2 months, each participant was asked to fill out 2 surveys. They were developed based on the unified theory of acceptance and use of technology model to collect quantitative data [57]. The interview guide used at Stage 2 was reused to collect qualitative data. This phase of the evaluation has been reported in detail in [58].

Table 2. The demographic profile of elderly participants in a comparative evaluation [58].

Demography	Total (n=47), n (%)	Australia (n=27), n (%)	India (n=20), n (%)
Age (in years)			
60-70	23 (49)	11 (41)	12 (60)
71-80	17 (36)	12 (44)	5 (25)
Above 80	7 (15)	4 (15)	3 (15)
Gender			
Male	16 (34)	9 (33)	7 (35)
Female	31 (66)	18 (67)	13 (65)
Level of education			
High school/GED	8 (17)	5 (19)	3 (15)
Diploma course	6 (13)	6 (22)	0 (0)
Bachelor's degree	20 (43)	8 (30)	12 (60)
Master's degree	9 (19)	5 (18)	4 (20)
Doctoral degree	1 (2)	0 (0)	1 (5)
Vocational/ technical	3 (6)	3 (11)	0 (0)
Previous technological experience			
Used an electronic tablet, mobile phone or computer before	39 (83)	27 (100)	12 (60)

Anxiety: Most participants confirmed that they had not been anxious when using those applications (Australia=85.2%, India=60.0%). Some felt intimidated (Australia=3.7%, India=20.0%) and even feared of making mistakes (Australia=11.1%, India=25.0%).

Attitude: All participants had a positive attitude toward the applications. The obtained results accorded well with findings from previous study [59]. For example, the Australian participants believed that the applications were good ideas (Skype Australia=88.9%, Dropbox Australia=85.2%), easy to operate on the tablet (Skype Australia=62.9%, Dropbox Australia=59.2%), enjoyable (Skype Australia=66.6%, Dropbox Australia=66.6%), and enabled active communication (Skype Australia=74.2%, Dropbox Australia=62.9%).

Facilitating condition: From the observation, the participants who had experience with computers or mobile phones were able to use those applications without any difficulties (Australia=74.1%, India=80.0%). They also agreed that those applications were well fitted in their current lifestyle (Australia=66.6%, India=80.0%).

Intention to use the system: A majority of users agreed or strongly agreed that the applications were useful (Skype Australia=62.9%, Dropbox Australia=37.0%, India=95.0%) and indicated that using them improved their communication (Skype Australia=55.9%, Dropbox Australia=51.8%, India=80.0%). Some admitted that these applications were able to increase the frequency of communication with their family.

Self-efficacy: Despite the fact that most participants were able to use those applications (Skype Australia=70.4%, Dropbox Australia=66.7%, India=45.0%), they preferred to seek help from professional sources (Skype Australia=81.5%, Dropbox Australia=70.0%, India=55.0%) or the Web (Skype Australia=44.4%, India=65.0%).

Social influence: It was shown that the family's ongoing involvement and motivation positively affected their willingness to use such applications (Skype Australia=59.2%, Dropbox Australia=55.5%, India=95.0%).

Usefulness: Findings also revealed that those applications were easy to use (Skype Australia=74.2%, Dropbox Australia=62.9%, India=80.0%) and that it did not take much time to learn (Skype Australia=66.6%, Dropbox Australia=62.9%, India=75.0%).

Overall, the use of mobile apps on tablets has been quite useful in both India and Australia, though a small number of participants have not accepted the technology. It was heartening to see some of the elderly people latching onto this communication mechanism wholeheartedly. The detailed explanation of this stage has been published in [58]. The results cannot be generalized for a population in a large country with diverse population as in India in view of the small sample size and study conducted in one place. However, the project has successfully tested the iterative methodology for the design of IT systems for the care of the elderly.

Discussion

This paper presented the experience of this multiphase project on the development of tablet-based well-being check for the elderly. The paper presented a new three-phase iterative methodology for the cooperative system design and implementation. The three phases involved were:

Phase 1: The development of a prototype for a tablet-based well-being check using an agile design methodology. It allows the elderly to, for example, share photos or inform their current health condition through a two-way message exchange.

Phase 2: A contextual assessment of this technology of the elderly users in collaboration with aged care providers and family members of the elderly. The areas (eg, privacy features) for improvement were identified.

Phase 3: A case study evaluation of the tablet-based well-being check in the homes of the elderly across India and Australia. Between participants from the two countries, the results highlighted their different levels of familiarity with technology. In all cases, their family support was crucial to their willingness to use the technology.

As stated in the Methods section, there were changes made in the system after every phase based on the feedback of users (elderly, family members, and aged care providers) on functionality, security, usability, and maintainability. The same methodology can be used for the development of various IT systems and services for the elderly.

We now summarize below the lessons learned from this project based on the three main contributions:

First, development and testing of digital photo frames to facilitate communication between the elderly, family members, and the carers. The seniors said that the system had become a part of their daily routine. They were looking for the digital frame when they woke up in the morning and also used it occasionally during the day. On the other side, the community service provider agreed on the potential benefits of the system, especially for monitoring of well-being of the elderly. They are now demanding more sophisticated forms of user interface and also security management applications.

Second, this research illustrated a new iterative design methodology (three phases) to design, test, and evaluate the tablet-based well-being check system for the elderly. This methodology evolved while we were executing the project. We initially started the design based on traditional system development models. However, it became clear while carrying out the field study that multiple phases would be required.

Third, implementation and testing of the pragmatic "Silvercare" model. We had to use this innovative model to effectively educate, train, and support the elderly in the use of the tablet-based system. That way we were able to incorporate the peculiar support needs (different from those for younger users) for IT systems for the elderly. However, this "Silvercare" model is generic enough to be used for a range of aged care services in different parts of the world.

We hope this paper will lead to more research in the three areas of our contribution and possibly more new research on this important subject in view of the aging population all over the world.

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Conflicts of Interest

None declared.

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Abbreviations

ICT: information and communications technology

IT: information technology

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Original Paper

Personal Communication Device Use by Nurses Providing In-Patient Care: Survey of Prevalence, Patterns, and Distraction Potential

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Abstract

Background: Coincident with the proliferation of employer-provided mobile communication devices, personal communication devices, including basic and enhanced mobile phones (smartphones) and tablet computers that are owned by the user, have become ubiquitous among registered nurses working in hospitals. While there are numerous benefits of personal communication device use by nurses at work, little is known about the impact of these devices on in-patient care.

Objective: Our aim was to examine how hospital-registered nurses use their personal communication devices while doing both work-related and non work-related activities and to assess the impact of these devices on in-patient care.

Methods: A previously validated survey was emailed to 14,797 members of two national nursing organizations. Participants were asked about personal communication device use and their opinions about the impact of these devices on their own and their colleagues' work.

Results: Of the 1268 respondents (8.57% response rate), only 5.65% (70/1237) never used their personal communication device at work (excluding lunch and breaks). Respondents self-reported using their personal communication devices at work for work-related activities including checking or sending text messages or emails to health care team members (29.02%, 363/1251), as a calculator (25.34%, 316/1247), and to access work-related medical information (20.13%, 251/1247). Fewer nurses reported using their devices for non work-related activities including checking or sending text messages or emails to friends and family (18.75%, 235/1253), shopping (5.14%, 64/1244), or playing games (2.73%, 34/1249). A minority of respondents believe that their personal device use at work had a positive effect on their work including reducing stress (29.88%, 369/1235), benefiting patient care (28.74%, 357/1242), improving coordination of patient care among the health care team (25.34%, 315/1243), or increasing unit teamwork (17.70%, 220/1243). A majority (69.06%, 848/1228) of respondents believe that on average personal communication devices have a more negative than positive impact on patient care and 39.07% (481/1231) reported that personal communication devices were always or often a distraction while working. Respondents acknowledged their own device use negatively affected their work performance (7.56%, 94/1243), or caused them to miss important clinical information (3.83%, 47/1225) or make a medical error (0.90%, 11/1218). Respondents reported witnessing another nurse's use of devices negatively affect their work performance (69.41%, 860/1239), or cause them to miss important clinical information (30.61%, 378/1235) or make a medical error (12.51%, 155/1239). Younger respondents reported greater device use while at work than older respondents and generally had more positive opinions about the impact of personal communication devices on their work.

Conclusions: The majority of registered nurses believe that the use of personal communication devices on hospital units raises significant safety issues. The high rate of respondents who saw colleagues distracted by their devices compared to the rate who acknowledged their own distraction may be an indication that nurses are unaware of their own attention deficits while using their devices. There were clear generational differences in personal communication device use at work and opinions about the impact

of these devices on patient care. Professional codes of conduct for personal communication device use by hospital nurses need to be developed that maximize the benefits of personal communication device use, while reducing the potential for distraction and adverse outcomes.

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KEYWORDS

distraction; mobile devices; nurses

Introduction

Personal communication devices (PCDs) such as basic and enhanced mobile phones (smartphones) and tablet computers that are owned by the user offer unprecedented convenience in our daily lives. Immediate social interaction and information retrieval have made PCDs indispensable for many individuals. Excluding employer-provided mobile communication devices, previous research has demonstrated that registered nurses who work in hospitals use their PCDs to access medical information, including drug and treatment information, as clinical decision tools, and to identify other clinical information that supports their ability to care for patients [1-3]. In addition to work-related PCD use, there is an ever-increasing number and diversity of recreational sites available to working nurses including video games, TV/movies, music, and social networking sites. Previous research reported that non work-related Internet use during working hours was increasingly common and that a majority of workers, regardless of age or occupational status, reported using PCDs to engage in non work-related activities while at work [4-6]. Notwithstanding the many advantages for clinicians and patients, little is known about the impact of PCDs on the work of clinicians. Katz-Sidlow et al [7] reported that 37% of medical residents and 12% of faculty self-reported using their smartphones to read or respond to personal emails or texts during in-patient attending rounds and that 15% of residents admitting using their smartphones to engage in other non-patient care uses during rounds. In addition, 19% of residents and 12% of attending physicians acknowledged missing important clinical information because of smartphone distraction during rounds and 34% of residents and 20% of attending physicians reported observing another team member miss important clinical information because of smartphone distraction during in-patient round attendance. Smith et al [8] surveyed surgical technicians about their use of their mobile phones while operating a heart-lung machine. He found that 55.6% self-reported using their mobile phone while working, 49.2% acknowledged sending text messages, 21% accessed personal email, 15.1% browsed the Internet, and 3.1% checked or posted on social networking sites. Although 92.7% of the respondents in Smith's study reported that they had never been distracted by or had their performance at work negatively affected by their mobile phones and 98% reported that they had never made a medical error at work that could be attributed to their mobile phone use, 34.5% reported seeing another surgical technician distracted by their mobile phone during surgery. Safety concerns were reported by 78.3% of respondents who believed that mobile phones introduced a potentially significant safety risk to patients while working. These results suggest that while many clinicians were aware of the potential dangers of using PCDs while working,

they may not be aware of their own decreased performance resulting from their PCD use.

Our study examined how registered nurses working on in-patient units used their PCDs at work (excluding lunch and breaks) and their opinions about how PCD use impacted their work and the work of their colleagues.

Methods

In April 2014, 14,797 recruitment emails containing the link to a previously validated anonymous Web-based survey concerning personal communication device use at work were sent to members of the Academy of Medical Surgical Nurses (10,978 members) and the Society of Pediatric Nurses (3819 members). Two weeks after the initial email, a reminder email containing the survey link was sent to the membership. A total of 1268 respondents to the two emails met the inclusion criteria of having been employed as a registered nurse who averaged more than 20 hours a week of patient contact on an in-patient unit at some point within the last 5 years. These two national nursing organizations were selected because nurses often specialize in either adult or pediatric specialties and it was anticipated that there would be little overlap between the memberships of these two organizations.

The survey instrument was piloted in 2013 [9]. It consisted of four parts: (1) demographics, (2) PCD use at work, (3) opinions about PCD effects on registered nurses' work, and (4) hospital policies concerning PCDs ([Multimedia Appendix 1](#)). Respondents were asked to rank statements concerning PCD use on a 5-point Likert scale to indicate their agreement. This scale was chosen because the piloted version demonstrated that it allowed for adequate response dispersion and meaningful PCD use identification among nurses. The survey pilot version was tested on hospital nurses for face validity, redundancy, and ease of use. Nurses were asked about their own PCD use, as well as their observations of other nurses' use while working (excluding lunch and breaks). The statistical approach of this paper was to (1) describe the frequency of PCD use by nurses at work, (2) identify concerns and opinions among nurses regarding PCD use at work, and (3) compare the response of different demographic groups with regards to their use of PCDs and its effect on their work and the work of their colleagues. A chi-square test was conducted to examine whether the whole group of respondents preferred certain answer options to others and whether different groups of respondents present different opinions in the survey questions. A two-tailed Z test was used to examine the equality of proportions between each pair of respondent groups. For study purposes, a PCD was broadly defined as any basic mobile phone, enhanced mobile phone

(smartphones), or tablet computer that was owned and paid for by the user. The definition of PCD excluded employer-provided mobile communication devices that were used for electronic medical information documentation or clinical communication among providers of any Health Insurance Portability and Accountability Act (HIPPA) protected patient information. Exempt status approval from the Institutional Research Board of the University of Hawai'i Human Subjects Committee was received on January 2, 2014 (CHS# 21816).

Results

We received 1268 responses out of 14,797 potential participants (8.57%). Of the 14,797 potential participants, 58 were excluded because they did not have an email contact and 125 were excluded because they did not meet the inclusion criteria, primarily because they did not average more than 20 hours of patient contact per week on an in-patient unit. The average age of the respondents was 47.82 years, with 94.47% (1198/1268) of the respondents being female and 5.52% male (70/1268).

Employment Characteristics

The majority of respondents were staff nurses (54.69%, 688/1258), while 14.39% (181/1258) were charge nurses, 10.65% (134/1258) nurse managers, 5.88% (74/1258) advanced practice nurses, 5.17% (65/1258) nurse faculty, 2.70% (34/1258) nurse executives, and 5.96% (75/1258) had other unidentified nursing-related positions.

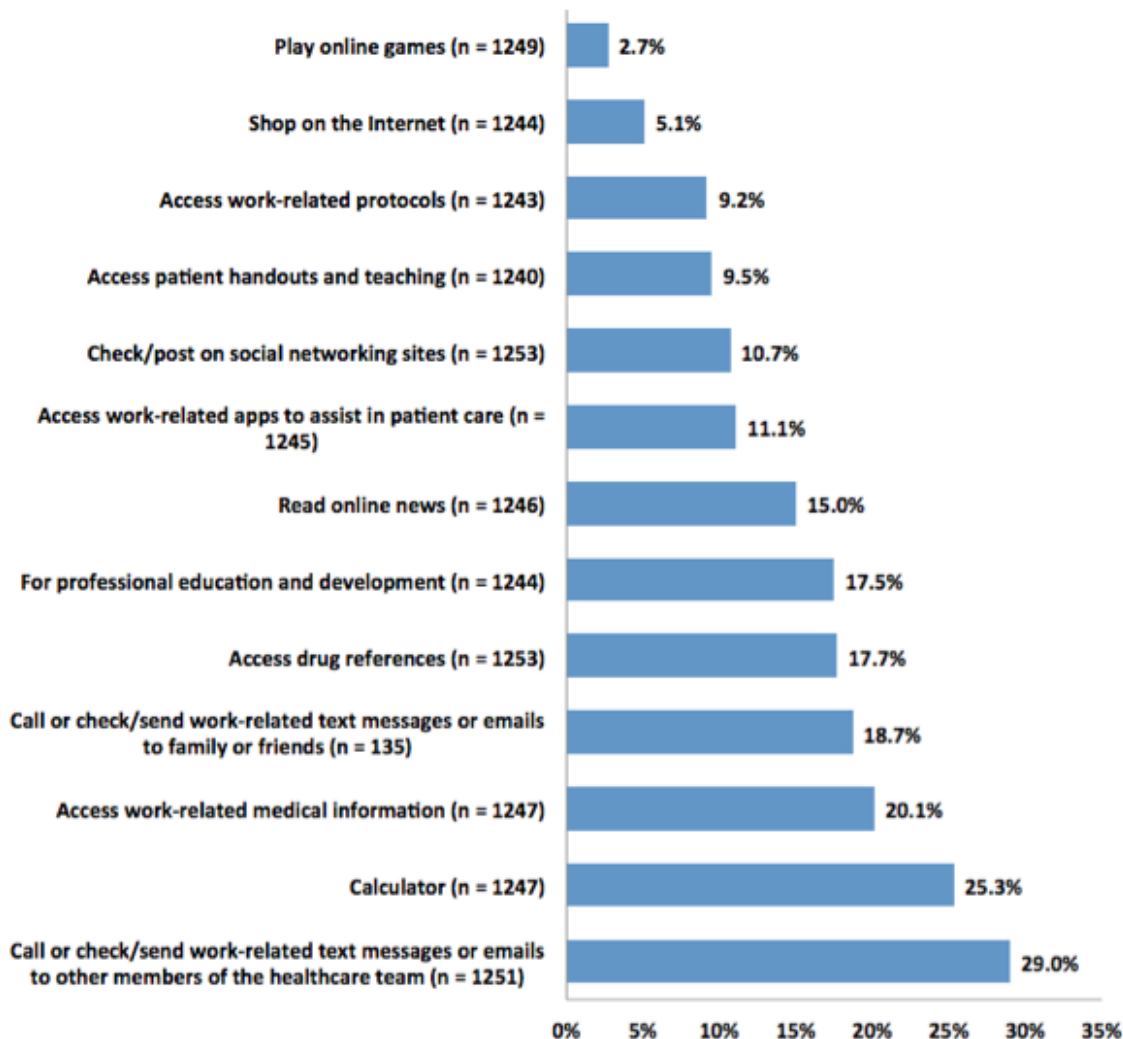
Respondents' Use of Personal Communication Devices

Personal communication devices are pervasive in hospitals. Among respondents 98.67% (1142/1212) owned a PCD and 64.94% (804/1238) self-reported using their PCD often or always while at work (excluding lunch and breaks), 17.45% (216/1238) used their PCD sometimes while at work, and 17.61% (218/1238) rarely or never used their PCD while at

work. Only 5.65% (70/1237) of respondents indicated that they never used a PCD while working. A chi-square test was conducted to examine whether these percentages statistically differ from the situation where respondents chose the answer options by chance alone (ie, one third for each option). The results showed significant difference, indicating that the distribution of use of PCD is not uniform ($\chi^2=556.66, P<.001$).

Although it might be assumed that nurses would use their personal devices at work for only non work-related activities, respondents indicated that they frequently used their PCDs at work for activities that supported their work caring for patients. Both work-related and non work-related use of PCDs at work (excluding lunch and breaks) were assessed using 13 activities that were determined to be significant in the pilot study [9]. Work-related activities included checking or sending text messages or emails to other health care team members (29.02%, 363/1251), as a calculator (25.34%, 316/1247), accessing work-related medical information (20.16%, 251/1247), accessing drug references (17.48%, 219/1253), for professional education and development (17.52%, 218/1244), accessing work-related apps to assist in patient care (11.08%, 138/1245), accessing patient handouts and teaching material (9.52%, 118/1240), and accessing work-related protocols (9.17%, 114/1243). Non work-related activities included calling, checking or sending text messages or emails to family or friends (18.75%, 235/1253), reading online news (15.00%, 187/1246), checking or posting on social networking sites (6.98%, 87/1246), shopping (5.14%, 64/1244), and playing online games (2.72%, 34/1249). A *t* test was performed to compare work-related and non work-related activities. Work-related activities were found to be statistically significantly more likely than non work-related activities at the 5% significance level ($t_2=2.67, P<.001$). This analysis showed that nurses were much more likely to use their PCDs at work for activities that supported their work caring for patients than for non work-related activities (Figure 1).

Figure 1. PCD use at work (excluding lunch or breaks). Although this figure is primarily descriptive, we performed t tests of each combination. Most of the variables are statistically significantly different from each other at the 5% level, and specifically only 6/78 combinations were not significant at the 5% level. These exceptions were access to drug references and professional education and development, access to patient handouts and access to work-related protocols, access to patient handouts and access to work-related apps, personal emails and access to drug references, personal emails and nursing or work-related information, personal emails and professional education and development.

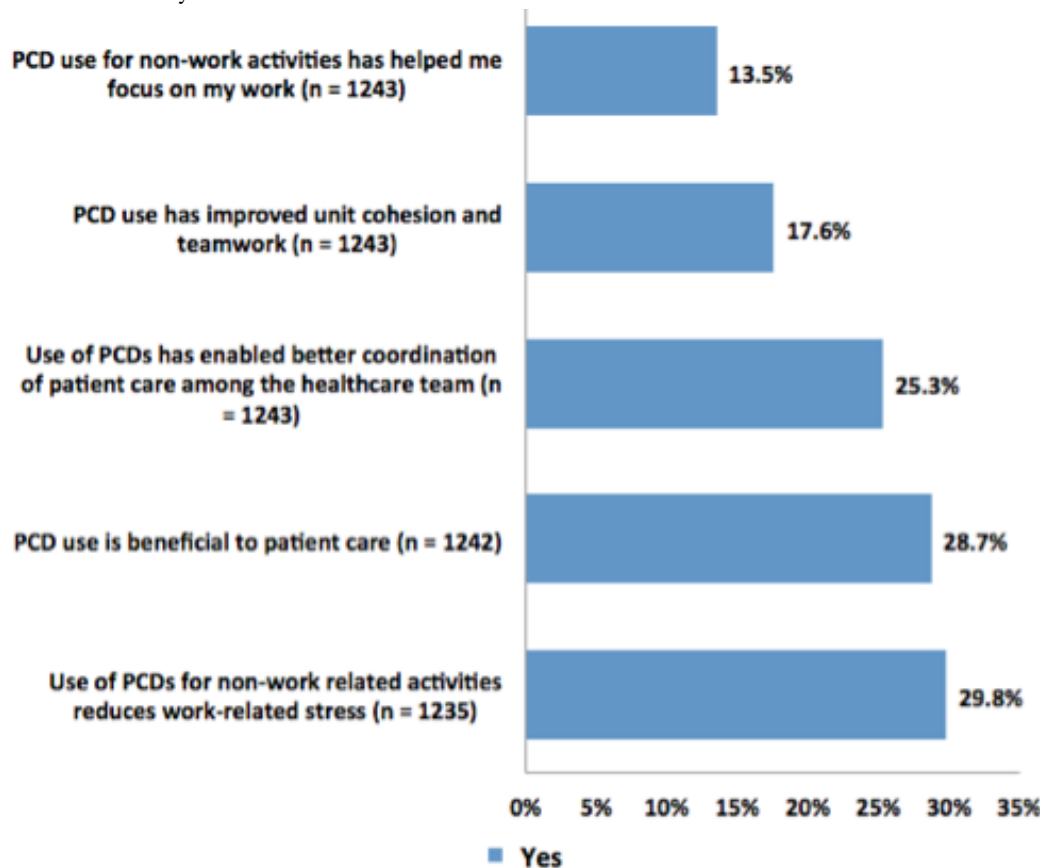


Positive Impact on Work Performance

Both positive and negative impacts of PCD use by hospital nurses were assessed using ten statements previously determined to be significant in the pilot study [9]. A minority of respondents agreed or strongly agreed that PCD use at work (excluding breaks and lunch) positively impacted their work including reduced stress (29.88%, 369/1235), was beneficial to patient care (28.74%, 357/1242), enabled better patient care coordination among the health care team (25.34%, 315/1243), improved patient safety (18.47%, 229/1240), improved unit

cohesion and teamwork (17.70%, 220/1243), or improved one’s ability to focus on work (13.52%, 168/1243) (Figure 2). Although it seems intuitive that non work-related PCD use at work would negatively affect productivity and performance by taking away time from work-related activities, these results indicate that some nurses believe that use of PCDs at work has benefits both for the individual and for the organization as a whole. An unanswered question involves whether these reported benefits could potentially violate HIPPA laws related to the transmission of protected patient information on unsecured networks.

Figure 2. Experiences with PCD use positively affecting work performance. Although this figure is primarily descriptive, we performed t tests of each combination. All the means are statistically significantly different from each other at the 5% level of significance with the single exception of the mean for PCD use being beneficial to patient care and use of PCDs for non-work-related activities reduces work-related stress. The means of these two variables are not statistically different from each other.



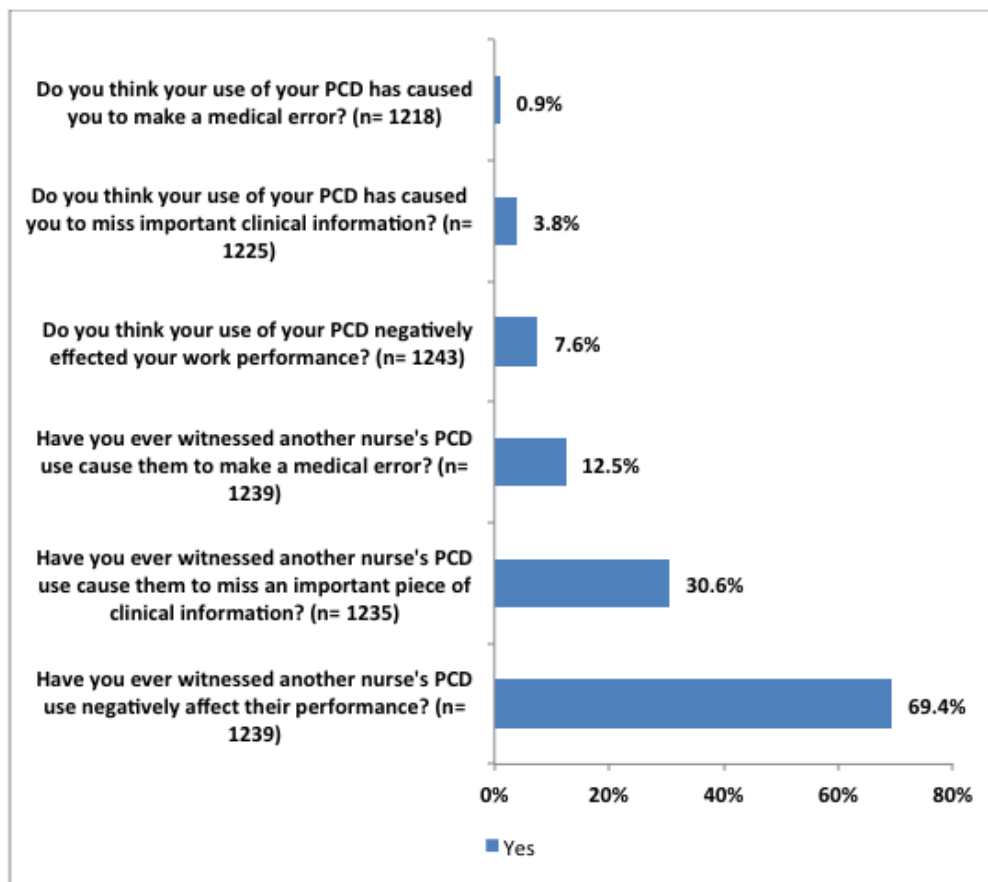
Negative Impact on Work Performance

Three survey questions assessed self-reported and witnessed performance decrements associated with PCD use in the following areas: (1) negative performance, (2) medical errors, and (3) missed clinical information (Figure 3). For the purposes of this survey, a medical error was defined as an adverse effect on care, including a near miss or sentinel event.

Figure 3 presents three pairs of survey question results, with each pair involving the experiences with PCD use negatively affecting respondents' own work performance as well as their observations of PCD use negatively affecting other nurses' work performance. While presenting each pair of results, we also conducted Z tests on the equality of proportions and present the results in parentheses. Respondents were more likely to report that PCD use had negatively affected another nurse's work performance than their own ($Z=31.67$, $P<.001$). A majority

(69.41%, 860/1239) of respondents had witnessed other nurses' PCD use negatively affect their work performance. In contrast, few respondents (7.56%, 94/1243) acknowledged that their own PCD use had negatively affected their work performance.

In addition, less than one percent (0.90%, 11/1218) of respondents reported having made a medical error because of PCD distraction while 12.5% (155/1239) reported having witnessed a colleague make a medical error because of their PCD use ($Z=-11.46$, $P<.001$). Similarly, 3.84% (47/1225) reported having missed an important piece of clinical information because of PCD distraction, compared to 30.6% (378/1235) who reported witnessing a colleague miss important clinical information because of their PCD use ($Z=-17.56$, $P<.001$). The significant results indicate that respondents were ten times more likely to report witnessing PCDs negatively affecting the work of their colleagues than to report PCD use negatively affecting their own work.

Figure 3. Experiences with PCD use negatively affecting work performance.

Overall Effects of Personal Communication Device Use While Working

Over two-thirds (69.06%, 848/1228) of respondents believed that PCD use by nurses in hospitals had more negative than positive effects on patient care, whereas less than a third (30.94%, 380/1228) of respondents believed that PCD use had more positive than negative effects on patient care. Chi-square test results indicated that significantly more respondents considered PCD use as having more negative than positive effects on patient care ($X^2_2=178.36, P<.001$).

In addition, 39.07% (481/1231) of respondents reported that PCDs were always or often a distraction while working, 51.02% (628/1231) reported that PCDs were sometimes a distraction, and 9.91% (122/1231) felt that PCDs were rarely or never a distraction (Figure 4).

Age and Personal Communication Device Use While at Work

The chi-square test was used to determine how age affected the frequency of use of PCDs at work. When comparing opinions across different respondent segments, the clearest trend and biggest differences existed across the youngest and oldest age groups. Younger respondents reported greater PCD use while

at work than older respondents, and chi-square test results indicated that such a difference was statistically significant ($X^2_2=17.85, P<.001$). Three quarters (74.1%, 157/212) of respondents younger than 35 years old reported using a PCD often or always while at work. This percentage diminished across older age groups until, among those 55 or older, 58.0% (244/421) reported using a PCD often or always while at work (Figure 5).

Younger respondents were more likely to use their PCD for work-related activities than older respondents (Table 1). Specifically, 37.9% (80/211) of respondents under age 35, compared to 15.7% (67/428) of those over age 54 reported using their PCD as a calculator often or always ($Z=6.29, P<.001$). Similar differences existed for using a PCD to access drug references in younger nurses (25.9%, 55/212) versus older (15.1%, 65/430) ($Z=3.31, P<.001$).

Younger respondents reported believing that PCD use was beneficial to patient care at higher rates than older respondents (Table 2). For example, just over half of respondents under 35 years of age (51.9%, 110/212) agreed or strongly agreed that PCD use reduced stress, compared to a fifth of respondents older than 54 years of age (21.2%, 90/424) who agreed or strongly agreed that this was true ($Z=7.85, P<.001$).

Figure 4. Belief about whether PCDs are a serious distraction at work.

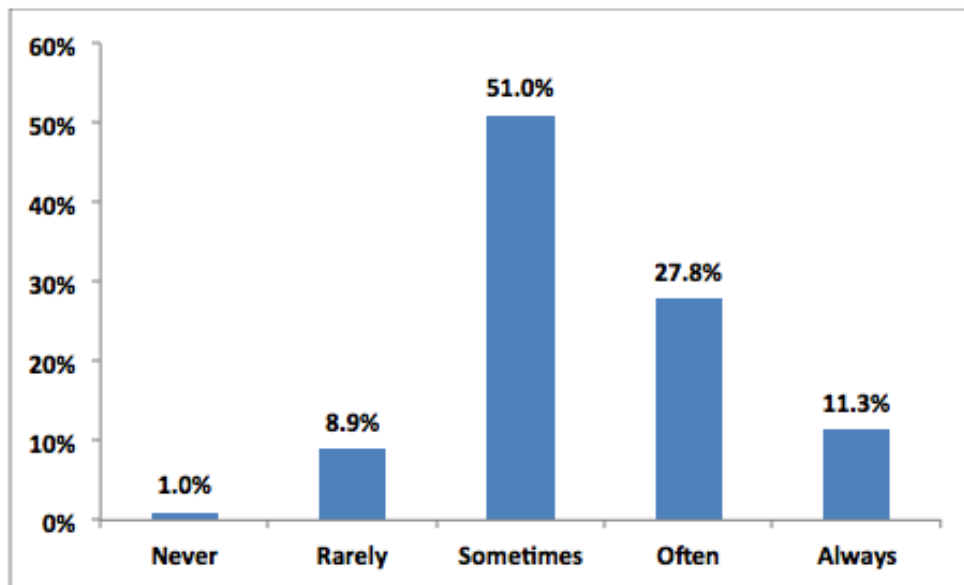


Figure 5. PCD use at work by age.

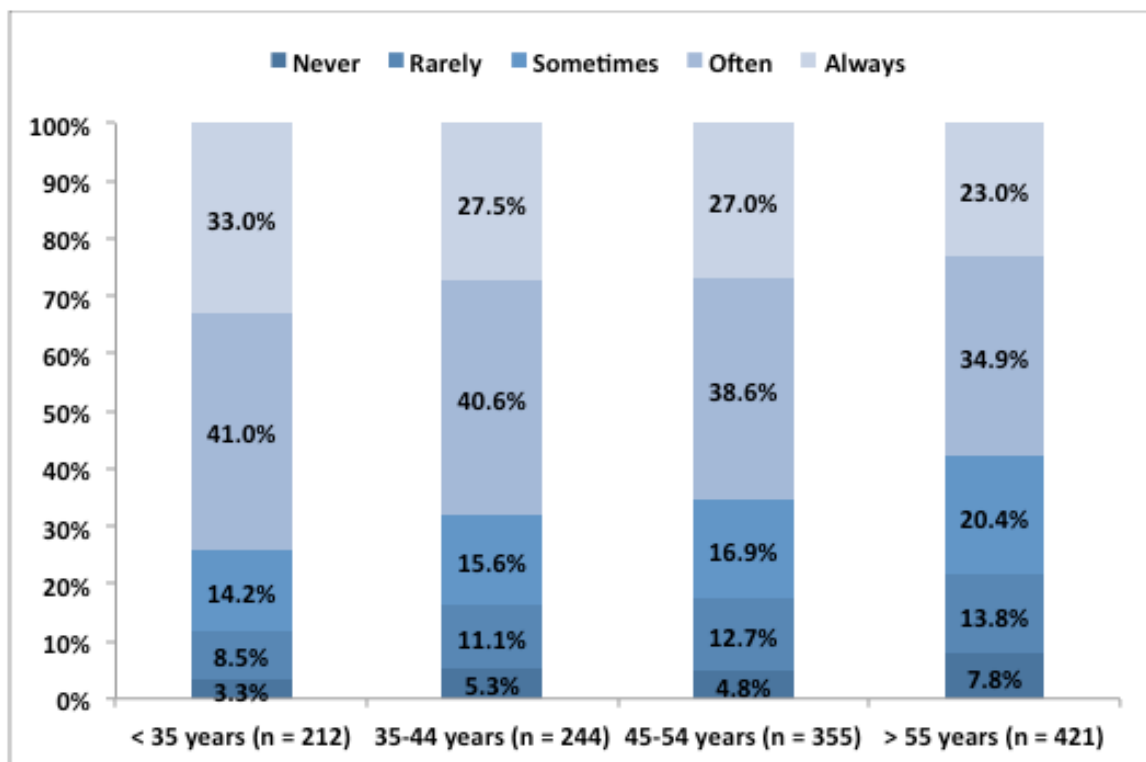


Table 1. PCD activities at work by age^a.

PCD activities	<35 years (N=211-212) n (%)	35-44 years (N=242-246) n (%)	45-54 years (N=354-360) n (%)	>54 years (N=424-431) n (%)
Call or check/send work-related text messages or emails to other members of the health care team	67 (31.8)	76 (30.9)	101 (28.2)	117 (27.2)
Calculator	80 (37.9) ^{c,d}	78 (32.2) ^{c,d}	88 (24.4) ^d	67 (15.7)
Access work-related medical information	54 (25.6)	44 (18)	68 (18.9)	84 (19.7)
Call or check/send text messages or emails to family or friends	50 (23.7) ^{c,d}	63 (25.6) ^{c,d}	56 (15.6)	65 (15.1)
Access drug references	55 (25.9) ^{b,c,d}	45 (18.3)	58 (16.2)	65 (15.1)
For professional education and development	33 (15.6)	43 (17.6)	62 (17.3)	77 (18.1)
Read online news	33 (15.6)	44 (18.1)	50 (14)	60 (14)
Access work-related apps to assist in patient care	32 (15.2) ^c	29 (11.9)	34 (9.5)	44 (10.3)
Access patient handouts and teaching	20 (9.4)	20 (8.2)	35 (9.9)	44 (10.4)
Access work-related protocols	15 (7.1)	25 (10.2)	32 (9)	43 (10.1)
Check/post on social networking sites	27 (12.7) ^{c,d}	22 (9.1) ^d	25 (7) ^d	13 (3)
Shop on the Internet	12 (5.7)	16 (6.6)	19 (5.3)	17 (4)
Play online games	9 (4.2)	5 (2)	11 (3.1)	9 (2.1)

^aWe conducted equality of proportion tests to examine whether each pair of age groups are significantly different in the percentages reporting the activities above often or always. The significant differences based on the statistical test results are also presented in this table. The cells with superscripts indicate that the corresponding group has a significantly larger proportion of respondents reporting the corresponding activity often or always compared to each group in the superscript at 5% level of significance.

^b35-44 years group.

^c45-54 years group.

^d>54 years group.

Table 2. Agreement level with statements about PCD work use by age^a.

Statements about PCD use	<35 years (N=210-212) n (%)	35-44 years (N=240-244) n (%)	45-54 years (N=353-356) n (%)	>54 years (N=424-429) n (%)
Use of PCDs at work reduces stress.	110 (51.9) ^{b,c,d}	83 (34.6) ^{c,d}	84 (23.8)	90 (21.2)
PCD use is beneficial to patient care.	76 (36.2) ^{c,d}	76 (31.1)	90 (25.4)	114 (26.6)
Use of PCDs has enabled better coordination of patient care among the health care team.	73 (34.6) ^{b,c,d}	58 (23.8)	85 (24.1)	99 (23.1)
PCD use has improved unit cohesion and teamwork.	52 (24.5) ^{b,c,d}	41 (16.9)	53 (14.9)	74 (17.4)
PCD use helps me focus on my work.	30 (14.3)	36 (14.8)	57 (16) ^c	44 (10.3)

^aWe conducted equality of proportion tests to examine whether each pair of age groups are significantly different in the percentages (strongly) agreeing with the statements above. The significant differences based on the statistical test results are also presented in this table. The cells with superscripts indicate that the corresponding group has a significantly larger proportion of respondents (strongly) agreeing with the corresponding statement compared to each group in the superscript at 5% level of significance.

^b35-44 years group.

^c45-54 years group.

^d>54 years group.

Respondents under age 25 were the only age group in which more than half (56%, 10/18) believed PCD use had a more positive than negative effect on patient care, though such proportion might be due to chance as the chi-square test is not statistically significant ($X^2=0.22$, $P=.637$). For all other age

groups, more than half reported that PCD use had a more negative than positive effect on patient care. This percentage increased across age groups, up to the age of 65 years or older where over three-quarters (77%, 23/30) believed that PCDs had

a more negative than positive effect on patient care ($X^2_2=8.53$, $P=.003$).

Older respondents were more likely than younger respondents to believe PCD use was a distraction at work. Over half of respondents over age 65 (57%, 17/30) believed PCD use was always or often a serious distraction at work, compared to just over a quarter of respondents between age 25 and 34 years (27.6%, 53/192). Equality of proportion test results indicate that such a difference is statistically significant ($Z=3.19$, $P=.001$).

Discussion

Principal Findings

Nurses and their patients benefit from the many capabilities of personal communication devices on in-patient units. PCDs contain medical references, facilitate communication transfer, and assist in patient care coordination on in-patient units. However, despite their significant advantages, PCDs introduce another source of distraction into the hospital environment. While some interruptions can be beneficial, others, even those that are self-initiated, can be distracting and detrimental to patient care. Studies from psychology and education have reported on the negative consequences of distraction on task performance. Mobile phone use while operating a motor vehicle can be hazardous. Lesch and Hancock [10] reported on the awareness of motor vehicle drivers of their reduced driving ability while operating a mobile phone. They found that drivers were oblivious to their reduced driving ability caused by concurrent mobile phone use and that there was a great discrepancy between driver perceptions and actual driving performance. Strayer et al [11] found that drivers described other drivers using their mobile phones as driving poorly but reported that their own driving during mobile phone use remained normal, even when the results of driving performance tests showed otherwise. These results concur with this study's results: that there is an apparent disconnect between self-reported and observed performance among respondents about PCD use. Although respondents self-reported low levels of performance decrements, the significantly higher level of reported witnessed performance decrements should be cause for concern because it raises the possibility of patient safety issues.

Although PCD use at work differs from other types of potentially nonsanctioned behaviors, some insight may be gained by looking at research into another form of rule breaking, academic cheating. Jordan [12] reported that student cheaters differed from noncheaters in a number of different ways including their perceptions of social norms regarding cheating, their knowledge of institutional policy regarding cheating, and their attitudes toward cheating. According to Jordan, lack of knowledge of institutional policy was the best predictor of student cheating, followed by positive attitudes about social norms about cheating. A 2014 survey of US hospitals [13] found that 88% of US hospitals reported having a policy on PCD use by nurses at work. The lack of knowledge of a PCD policy at work and perceptions of peer comparisons and social acceptability of PCD use at work (eg, "Everyone else is doing it"), which may or may not be accurate, influence attitudes and

behaviors at work. Complex interactions of many variables likely contribute to the risks of continuing PCD use in the face of performance decrements by nurses.

Unlike nurse demographics—which offer little guidance to institutions for curbing misuse of PCDs—attitudes, knowledge of PCD policies, and social comparison factors are potentially open to manipulation. For example, persuasive ethical arguments for restricted use of PCDs on nursing units may be addressed in workforce training, including during hospital orientation and unit training programs. This training could contain information about institutional policies and address issues of professionalism and peer accountability. These types of programs may reinforce and increase the attitudes towards responsible PCD use that many nurses hold and may dissuade them from engaging in high-risk PCD use.

Limitations

Several limitations of this study should be acknowledged. Self-selection bias affects any survey that allows respondents to decide whether to participate. To mitigate this potential problem, the characteristics of the respondents in our study were compared with those of California-based registered nurses. The respondents were not systematically different from those of the state's average registered nurse in terms of gender, age, race/ethnicity, job title, and experience with PCDs.

Another weakness of the study was the low response rate. Because measuring the relation between nonresponse and the accuracy of a survey statistic is complex and expensive, few rigorously designed studies provide empirical evidence to document the consequences of lower response rates. However, Holbrook et al [13] examined the results of 81 national surveys with response rates varying from 5% to 54%. They found that surveys with much lower response rates were only minimally less accurate than those with higher response rates. Nevertheless, the low response rate did increase the statistical error in the analysis and prevent extensive subanalyses. Further testing with a higher response rate would be necessary to overcome this limitation.

The self-reported nature of the data increases the risk of response bias as respondents may overreport or underreport their use of PCDs at work in order to present themselves in a socially desirable manner. Previous research has shown that study participants demonstrate lower social desirability when they respond to an online survey compared to a paper questionnaire [14]. This survey focuses on making medical errors and missing important clinical information, which could reflect badly on study participants. Therefore, we used an online survey to ensure that the impact of social desirability was kept to a minimum and anonymity was protected. As a result of these issues, data comparisons should be interpreted with caution.

Conclusion

A majority of nurses in our study agreed that PCD use can be a significant distraction while providing in-patient care. Although many hospitals have policies outlining appropriate PCD use by clinicians at work, frequently hospitals allow workers to decide on their own how and when to use their devices. This presumes that workers can accurately assess the

risks associated with PCD use and can appropriately modify their behavior. The results of this study suggest that nurses expressed a disproportionately high confidence in their ability to manage the risk associated with PCD use at work and may not be able to accurately assess when it is appropriate to use their PCDs or to modify their behavior accordingly. The

development and implementation of professional codes of conduct for PCD use on in-patient units are important for patient safety. Guidelines on PCD use should be developed that maximize the benefits of PCD use in the hospital environment, while reducing the potential for distraction and adverse outcomes.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Nurses' use of personal communication devices questionnaire.

[[PDF File \(Adobe PDF File\), 46KB - humanfactors_v4i2e10_app1.pdf](#)]

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Abbreviations

HIPPA: Health Insurance Portability and Accountability Act

PCD: personal communication device

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Original Paper

Toward a More Usable Home-Based Video Telemedicine System: A Heuristic Evaluation of the Clinician User Interfaces of Home-Based Video Telemedicine Systems

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Abstract

Background: Telemedicine is the use of technology to provide and support health care when distance separates the clinical service and the patient. Home-based telemedicine systems involve the use of such technology for medical support and care connecting the patient from the comfort of their homes with the clinician. In order for such a system to be used extensively, it is necessary to understand not only the issues faced by the patients in using them but also the clinician.

Objectives: The aim of this study was to conduct a heuristic evaluation of 4 telemedicine software platforms—Doxy.me, Polycom, Vidyo, and VSee—to assess possible problems and limitations that could affect the usability of the system from the clinician's perspective.

Methods: It was found that 5 experts individually evaluated all four systems using Nielsen's list of heuristics, classifying the issues based on a severity rating scale.

Results: A total of 46 unique problems were identified by the experts. The heuristics most frequently violated were *visibility of system status* and *Error prevention* amounting to 24% (11/46 issues) each. *Esthetic and minimalist design* was second contributing to 13% (6/46 issues) of the total errors.

Conclusions: Heuristic evaluation coupled with a severity rating scale was found to be an effective method for identifying problems with the systems. Prioritization of these problems based on the rating provides a good starting point for resolving the issues affecting these platforms. There is a need for better transparency and a more streamlined approach for how physicians use telemedicine systems. Visibility of the system status and speaking the users' language are keys for achieving this.

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KEYWORDS

telemedicine; heuristics, Internet, user-computer interface, cognition

Introduction

Health Care System

The health care system in the United States is currently undergoing extensive changes. Possible causes for such challenges faced by its delivery system are increased demand for health care due to an increased number and changing lifestyle leading to an increase in chronic diseases, the demand for increased accessibility of care outside hospitals, moving health services into the patient's own homes, the need for increased efficiency, individualization and equity of quality-oriented health care with limited financial resources, the difficulties of recruiting and retaining personnel in health care services in general, and in home and elderly care in particular [1,2]. Telehealth, the use of electronic information and telecommunication technologies to support long-distance clinical health care, patient and professional health-related education, public health and health administration [1,3], has the potential to address these issues. One subsection, telemedicine, the use of technology to provide and support health care when distance separates the clinical service and the patient, appears to be particularly attractive [4].

Although playing an important role in addressing the health issues of patients living in underserved and rural areas, telemedicine is now attracting attention beyond these limited regions. It offers mechanisms for centralizing specialists, reducing costs for specialty care, and supporting primary care clinician needs in the urban and suburban areas these typically serve [5-9]. The possible benefits of using these systems have resulted in an increased interest in telemedicine. For example, they help patients with chronic illness and those with limited mobility to connect with a health care facility from the comfort of their homes [1], and it is important because it reduces the stress for patients who otherwise would have to travel long distances for their appointments [10]. Currently, this remote care is extensively used for clinical visits that do not require physical presence such as behavioral health [11,12], counseling [13-15], follow-up [8,16], and patient education [17], with studies finding telemedicine an appealing solution for the real-time remote monitoring of patients. It has also shown promise for improving patient knowledge of health care, thus helping them better manage their diseases or illnesses. With the expanding technical capabilities and the decreasing costs of telemedicine software solutions, home-based telemedicine is becoming more widely used, evidenced by a recent workshop conducted by the National Academies that discussed the potential of scaling such delivery of care for a growing number of patients [2,18].

Telemedicine System

Unlike face-to-face encounters, in which clinicians and patients are both located in the same setting, telemedicine participants usually use the teleconferencing systems at their respective locations. Thus, for a telemedicine system to become widely accepted, it should not only be functional but also user-friendly [19-23]. The Institute of Medicine (IOM) recently emphasized the role of usability in telemedicine systems, given its potential

to replace regular clinical visits which are both time-consuming and resource-demanding [2,8,23].

However, limited research has been conducted evaluating the perceived usefulness and usability of such tools from a home-based video telemedicine system perspective [24,25]. The evaluation of a user interface can be carried out by 4 ways; *formally* using analytical tools, *automatically* using computer technology, *empirically*, that is, testing with users, and *heuristically* [25-27]. Heuristic evaluation is the process of usability testing wherein evaluators are provided with an interface and asked to comment on it based on a set of heuristics [27,28]. The efficiency of this system of evaluation allows for an iterative design process of user interfaces [18]. Studies have found that this type of evaluation can reveal both major and minor usability issues, including problems that lead to errors and user dissatisfaction content [29-31]. Furthermore, it has been extensively used to ascertain usability issues in the medical field ranging from websites to medical devices [25,32-34] to health information technology applications [35-40]. In light of these advantages of a heuristic evaluation, this study aimed to understand the issues of the clinician's interfaces of 4 telemedicine platforms. The issues uncovered through this heuristic evaluation could serve as a basis to improve the clinician's interface in telemedicine platforms.

Methods

Telemedicine Systems

The criteria for a telemedicine system to be included in this heuristic evaluation were as follows: (1) the system is primarily used to deliver video-based telemedicine at home; (2) the system does not require specialized or proprietary equipment for home use; (3) the system runs on an Internet-connected computer with audio and video capabilities; and (4) the system is Health Insurance Portability and Accountability Act (HIPAA) compliant, which aims at protecting the health rights and privacy of patients [41]. Initially, the telemedicine systems used by the medical staff at the Medical University of South Carolina (MUSC) Center for Telehealth and South Carolina (SC) Telehealth Alliance were reviewed. Subsequently, 8 software applications, Adobe Connect, Cisco WebEx, Cisco Jabber, Doxy.me, Polycom, Skype, Vidyo, and VSee, were identified as potential candidates based on this preliminary review. Next, a detailed analysis of the features of each and its primary use were conducted. A total of 5 key stakeholders including the physicians and directors associated with MUSC Center for Telehealth and SC Telehealth Alliance were consulted. It was understood that Adobe Connect, Skype, Cisco WebEx, and Cisco Jabber could be used to deliver video-based telemedicine, but they were not currently used extensively for doing so. On the basis of this feedback, the telemedicine tools selected for this research were (1) Doxy.me, (2) Vidyo, (3) VSee, and (4) Polycom.

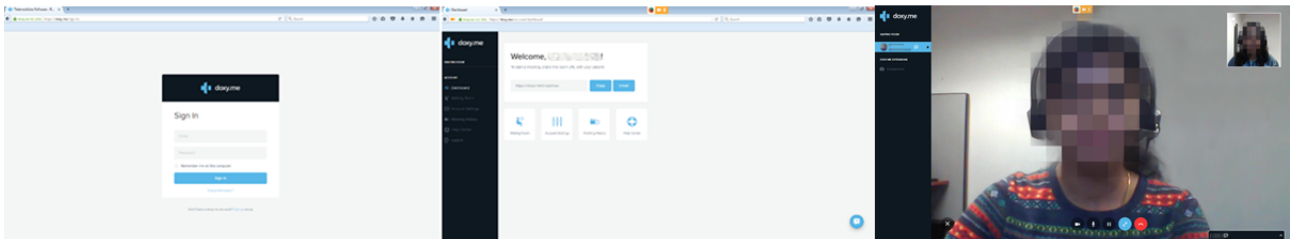
Doxy.me

Doxy.me is a free Web-based system (as opposed to downloaded desktop application) specifically designed for telemedicine purposes. Clinicians create an account and a personalized waiting room where they communicate with their patients, either

copying and emailing or directly emailing the address of their waiting room. By clicking on this link, patient is directed to the clinician's waiting room. There is a self-view box at the top right and a chat box at the bottom right of the screen. Volume

and video control buttons are located below the patient's video. In addition to these features, the clinician can edit the waiting room and change the account settings. [Figure 1](#) below shows the Doxy.me log-in screen, waiting room, and clinician's view.

Figure 1. Doxy.me log-in screen, waiting room, and clinician's view.

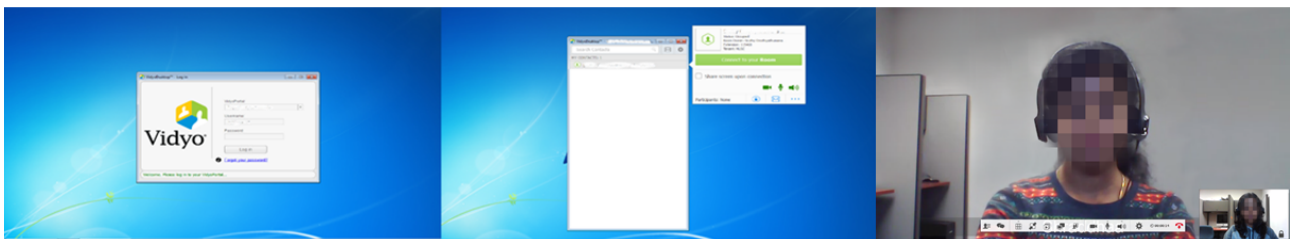


Vidyo

Vidyo is one of the leading telemedicine videoconferencing desktop-based application solutions. After creating an account, the clinician receives an email with log-in credentials and a Vidyo portal. The Vidyo desktop application is downloaded by clicking the portal. The clinician sends a Vidyo meeting

invitation after logging into this application. He or she can change the video quality and other settings by clicking on the configuration button. In addition, this task bar includes the volume and video control buttons, group chat option, self-view option, screen layout option, and end call option. [Figure 2](#) shows the Vidyo desktop application from the clinician's perspective.

Figure 2. Vidyo log-in screen, contact list, and clinician's view.

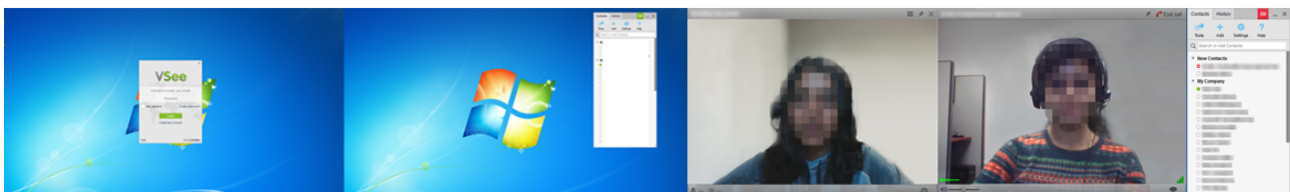


VSee

VSee is a telemedicine system which requires the clinician to create an account and install a desktop application. After logging into the account, the clinician invites patients by entering their email ids or copying and emailing them an invitation link. This

system includes an option for text chatting with the patient as well as separate windows for self-view, clinician's video, chat box, and contacts, with the microphone and camera settings being found on the self-view window. [Figure 3](#) shows the VSee log-in screen, application screen, and clinician's view.

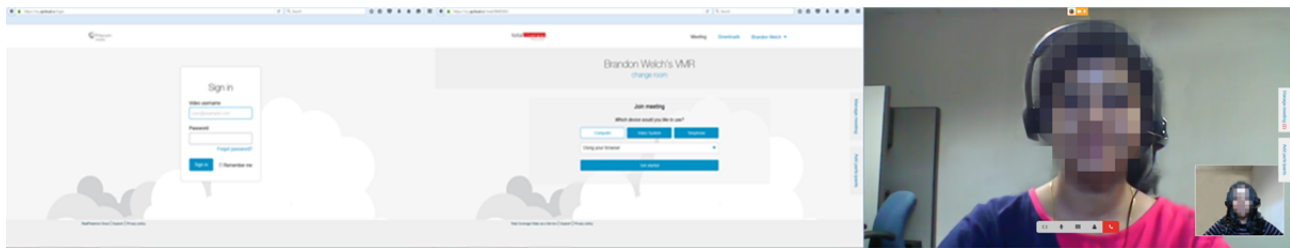
Figure 3. VSee log-in screen, application screen, and clinician's view.



Polycom

Polycom, a licensed Web-based application that can be purchased from the Polycom website, provides telemedicine and video services for remote conferencing and collaboration. Although this company provides a hardware-based telemedicine solution, this study used a lightweight product for home-based care. The clinician receives an email with log-in credentials and a link for accessing the account. After logging into the account,

the clinician selects the devices or system, which includes an option for adding participants and managing meetings. The clinician invites patients by emailing them the address of his or her chat room; after clicking this link, the patient is then directed to the meeting. There is a self-view option on the left side of the screen, the participant list on the right, and the patient's video in the middle. The control buttons are located below the patient's video. [Figure 4](#) shows the Polycom log-in screen, welcome room, and clinician's view.

Figure 4. Polycom log-in screen, welcome screen, and clinician's view.

Study Personnel

The investigation reported here was based on the experts' heuristic evaluations and the severity of the problems based on a severity rating scale. A heuristic evaluation is a discounted usability method in which the evaluation of an interface is done based on established usability principles. Five human factors engineers—three PhD students, one assistant professor, and one master's degree student, all with prior training in conducting heuristic evaluations—were recruited to serve as the subject matter experts for this study. All received verbal information about the purpose and the goal of the study, and a detailed

written task flow to guide the evaluation of the 4 telemedicine platforms using a modified heuristic evaluation procedure. They were compensated with a US \$20 Amazon gift card for their time.

Study Design and Procedure

The method of evaluation used in the study was a heuristic evaluation, a discounted usability evaluation method, combined with a severity rating scale [27,42]. Specifically, Nielsen's heuristics were used because of their widespread use and acceptability [27,43-45]. The heuristics, which are listed in Table 1, were used to highlight possible usability issues.

Table 1. Usability heuristics used for evaluating the telemedicine interfaces (adapted from Nielsen's heuristics [27,28]).

Heuristic	Description
Visibility of system status	The system should always keep users informed about what is going on, through appropriate feedback within a reasonable amount of time.
Match between system and the real world	The system should speak the users' language, using familiar words, phrases, and concepts rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
User control and freedom	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialog. Support undo and redo.
Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
Error prevention	Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
Recognition rather than recall	Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialog to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
Flexibility and efficiency of use	Accelerators—unseen by the novice user—may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
Esthetic and minimalist design	Dialogs should not contain information that is irrelevant or rarely needed. Every extra unit of information in a dialog competes with the relevant units of information and diminishes their relative visibility.
Help users recognize, diagnose, and recover from errors	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
Help and documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

A heuristic evaluation, typically conducted with 5 experts, detects up to 80% of the problems [18]. For this study, the experts individually conducted the assessment in a closed lab setting to avoid bystander bias. A 5-point severity scale was applied to each of the usability issues to indicate the level of concern [27]. The scale ranged from issues which may not

impact the usability of the system to issues that could potentially lead to its failure. The 5-point scale is as follows [46]:

0—May not be a problem: other observers do not agree that this is a usability problem

1—Cosmetic problem only: it need not be fixed unless extra time is available

2—Minor usability problem: fixing it should be given low priority

3—Major usability problem: it is important to fix it, should be given high priority

4—Usability catastrophe: imperative that it is fixed before product can be released

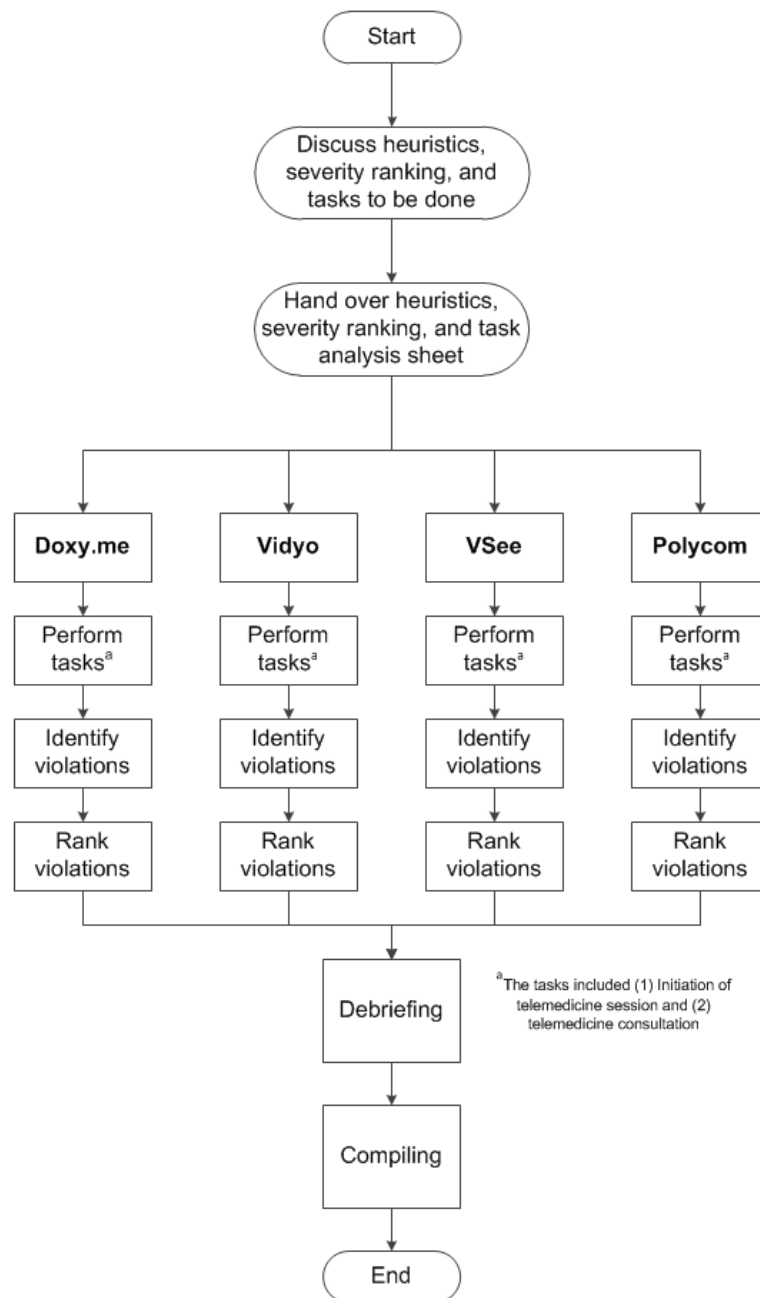
Understanding the source of errors in a task begins with an in-depth understanding of the task flow [33]. This study, thus, began with a detailed task analysis for each of the 4 telemedicine systems to help understand the feedback they provide and the potential problems the user could face. This task analysis also included determining the knowledge the user must have in order to perform the task successfully. Before actual evaluation, the researcher discussed the detailed task analysis, heuristics, and severity ranking scale with the experts. As the experts were from the field of human factors and familiar with heuristic evaluation studies, only context-specific instructions were provided to evaluate the telemedicine platforms. A separate sheet containing the list of the heuristics and the severity rating

chart was also given to the experts for their reference. The experts then evaluated the systems from the clinician's perspective with the help of a hypothetical patient with whom no communication was carried out. After which, they listed the heuristic violations individually. The tasks to be completed by the evaluators were as follows:

Initiation: Create an account, log into the portal or desktop application, send an email invitation for the telemedicine session, call the patient.

Consultation: Toggle microphone and video, enter full screen mode, enter data into a chat box (where applicable), and end video call.

On completing individual evaluations, experts discussed their findings with others in a postevaluation debriefing session. In the case of extreme inconsistencies, the evaluators discussed and came to a consensus about the appropriate rating. Individual lists were subsequently compiled for data analysis. [Figure 5](#) outlines the experimental procedure followed in this study which lasted approximately 1 h.

Figure 5. Experimental procedure followed.

Data Analysis

For the evaluation, each expert recorded the heuristic violations for the respective tasks, including grading the severity of the issues. The individual ratings from the evaluators were averaged to obtain a single value of the severity. These data were then compiled to understand which heuristics were most violated and the severity was analyzed to prioritize the problems. The number of heuristics violated was graphed for the telemedicine session initiation and consultation.

Results

Heuristic Violations

The heuristic evaluations of the experts for the clinician's interface revealed a total of 46 unique issues: 11 for Doxy.me, 10 for Vidyo, 12 for VSee, and 13 for Polycom. Of these, 22% (10/46) concerns were recognized by all the experts. [Tables 2-4](#) list the important usability issues and the heuristics they violated for initiating, conducting, and concluding a telemedicine session, respectively. [Figures 6-8](#) are graphical representations of heuristic violations for initiating, conducting, and concluding a telemedicine session, respectively. As these figures show,

60.9% (28 issues) of the issues was identified in the initiation phase, 33% (15/46 issues) in the telemedicine session phase, and 7% (3/46 issues) in the conclusion phase. Sharing or setting up microphone and camera was one of the specific issues observed in the initiation phase (Figure 9). Using default email

client (Microsoft Outlook) to invite patients was one of the issues identified during the telemedicine session. During conclusion, difficulty to find the log-out button was pointed out as an important issue (Figure 10).

Table 2. Heuristic violations identified in the telemedicine initiation session.

Task	Problem description	Solution recommendation	Heuristic violated	Severity rating
Doxy.me				
Entering room name (Doxy.me)	User may not comprehend the meaning of "room name" in a Web-based system setting	Provide explanation or rename as "clinician's name"	Match between system and the real world	2.5
Select check boxes	The check boxes are not noticeable	Make the check box more noticeable	Error prevention	4
Sharing camera and microphone	Instruction says "allow" camera and microphone, but popup says "share"	Keep the instruction consistent with the website features	Consistency and standards	3
An email verification is sent to the user	Email is very lengthy and has too many links	Email could consist of a body with just the essential links	Esthetic and minimalistic design	3.5
Vidyo				
Click on the link in the welcome email sent by the company	Clicking on the link does not lead to log-in page. Instead, it downloads the application	Reword the link description or the link must lead to the log-in page	Consistency and standards	0
Click on email icon on top right corner of the application	Not all users may recognize the icon of an envelope as symbolizing email	There could be a label below the icon	Error prevention	3
Click log-in	Log-in button remains inactive if the portal is entered after entering username and password	Application should show an error message	Help users recognize, diagnose, and recover from errors	3
VSee				
Downloading .exe file	Does not prompt to confirm if download should be initiated. Download starts automatically	Notify user before downloading. Provide a prompt asking the users if they want to download the application at that moment or later	Visibility of system status	3.5
Enter email address in "Enter your email" tab	Email id is mandatory and cannot proceed to free video sign up option	Email entry could be on top with the sign-up for free tab below it instead of beside it	Error prevention	3
Polycom				
Click on the your account URL in the welcome email	Email contains a link for online account and another link for downloading. User might get confused and download application	Provide sufficient information about each link	Error prevention. Help and documentation	4
Selecting check in devices and software	There is multiple check in options which may confuse users	Provide sufficient information about each device and software	Error prevention. Help and documentation	3
Set camera, microphone, and speaker	There is no option to go back and redo these actions if they are missed	Provide an option to do these checks when necessary	Help users recognize, diagnose, and recover from errors	2

Table 3. Heuristic violations identified during the telemedicine session.

Task	Problem description	Solution recommendation	Heuristic violated	Severity rating
Doxy.me				
Click on email tab on the right side of the link	Not enough information provided about copy and email tabs. Directly going to default mail client	Popup boxes explaining meaning or function. Users need to choose the email client	User control and freedom	3.3
Enter data in chat box provided at the bottom right corner of the screen	The notification for an incoming message is not salient. Only the chat box symbol turns red	Make the chat box header turn another color	Visibility of system status	4
Vidyo				
Click on email icon on top right corner of the application	Clicking on the icon directly leads to default mail client	Application needs to allow user to choose preferred email client	User control and freedom	4
Click on your name	Room owner's name is shown under "my contacts." Tab or option to the chat room is not obvious	Popup with "connect your room" button needs to pop up when the user hovers the mouse over the name	Visibility of system status	3.3
Patient comes online	No popup when the patient comes online	Popup and audio notification to indicate that the patient is online	Visibility of system status	3
VSee				
Inviting patient	Direct email invitation and copy option are next to each other. This may confuse the user about whether both actions must be completed or only one	A simple "or" in between the two tabs	Esthetic and minimalist design	3
Disabling video and audio	Video and audio toggling icons are not salient	Icon could be presented in a brighter color	Recognition rather than recall	3
Enlarging the screen	Application does not have a full screen button. User has to drag to enlarge the screen	Provide a full screen button	Consistency and standards	4
Polycom				
Compose email in default email client	The invitation to the patient has to be sent from the default email client	Application must provide the option to the user regarding preferred email client	User control and freedom	4
Compose invitation email to patient	Application always redirects to default mailer	An option to enter patient's email id could be provided with an example invitation email	User control and freedom	4
Compose email in default email client	Directly goes to default mail client	Allow user to choose preferred email client	User control and freedom	4
Enter full screen by clicking on full screen icon at the bottom of the page	System says "my rplcloud.vc" is full screen when the view is changed to full screen mode	Use terms which user can easily understand	Match between system and the real world	1

The heuristics most frequently seen violated were *visibility of system status* and *error prevention*, each with 11 violations (24%, 11/46), with *esthetic and minimalist design* being second with 6 out of 46 violations (13%, 6/46). Violations were not observed for the heuristics *user control and freedom* and *flexibility and efficiency of use*. It was found that (1) 4 out of 46 (9%, 4/46) violations were recorded for each of *consistency and standards*, *recognition rather than recall*, *help users recognize, diagnose, and recover from errors* and *help and*

documentation heuristics, and (2) 2 out of 46 (4%, 2/46) violations were observed for *match between system and real world* heuristic. Specific issues related to *visibility of system status* included lack of feedback while downloading setup (.exe), lack of saliency of notifications on receiving a message or when a patient enters a Web-based waiting room, and the absence of salient call end and log-out icons. Inconspicuous check boxes, inadequate labeling of icons, and failure to exit full screen on completion of a session were identified under *error prevention*.

Table 4. Heuristic violations identified while concluding the telemedicine session.

Task	Problem description	Solution recommendation	Heuristic violated	Severity rating
Doxy.me				
Click on red phone icon at the bottom of the page to end session	Remains in full screen even after ending the call	A dialog box saying press escape or automatically escape from full screen	Error prevention	1
Vidyo				
Log-out of the application	No obvious log-out button	Provide conspicuous log-out button	Visibility of system status	4
VSee				
Click on log-out	Log-out button is not easily seen	Provide conspicuous log-out button	Visibility of system status	3
Polycom				
No issues were identified				

Figure 6. Heuristics violated during the telemedicine initiation session.

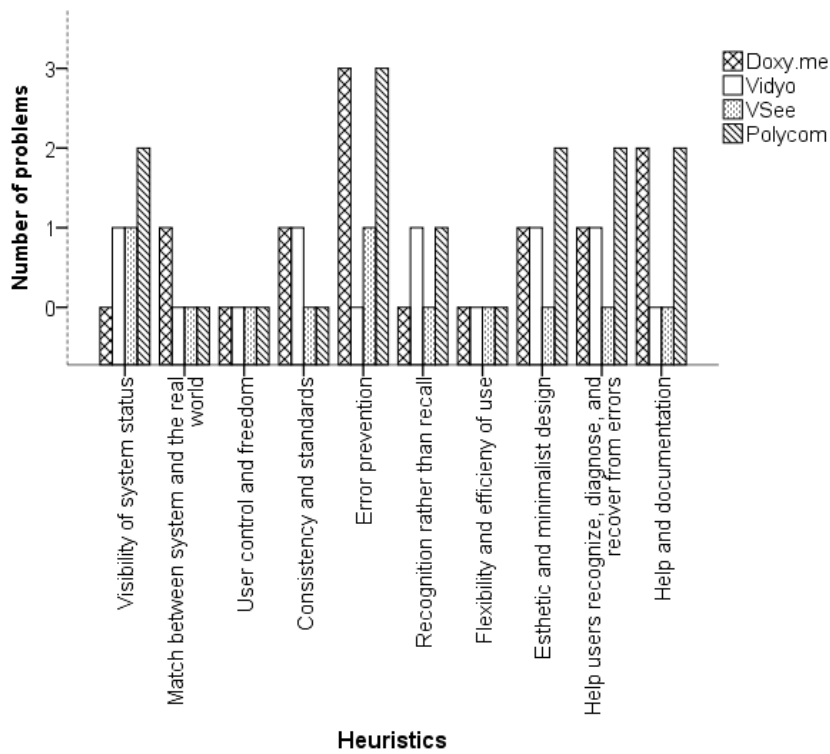


Figure 7. Heuristics violated during the telemedicine consultation.

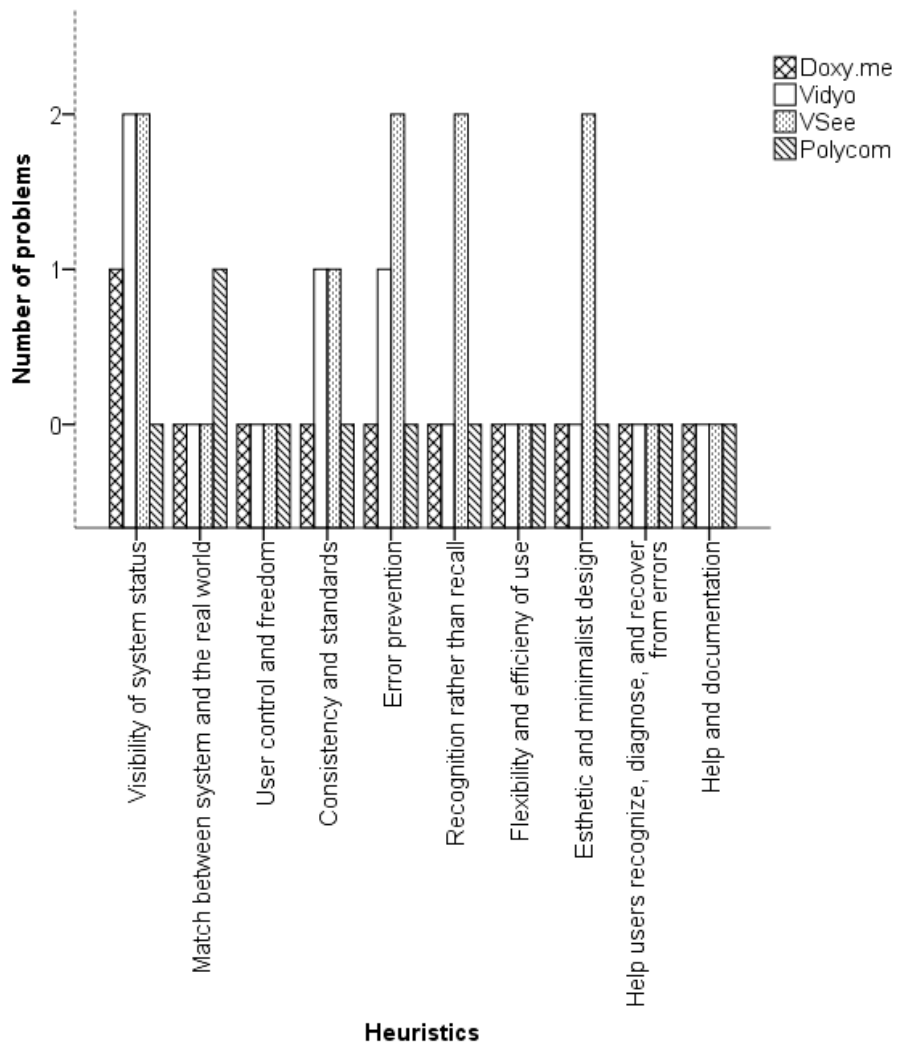


Figure 8. Heuristics violated during the telemedicine session conclusion.

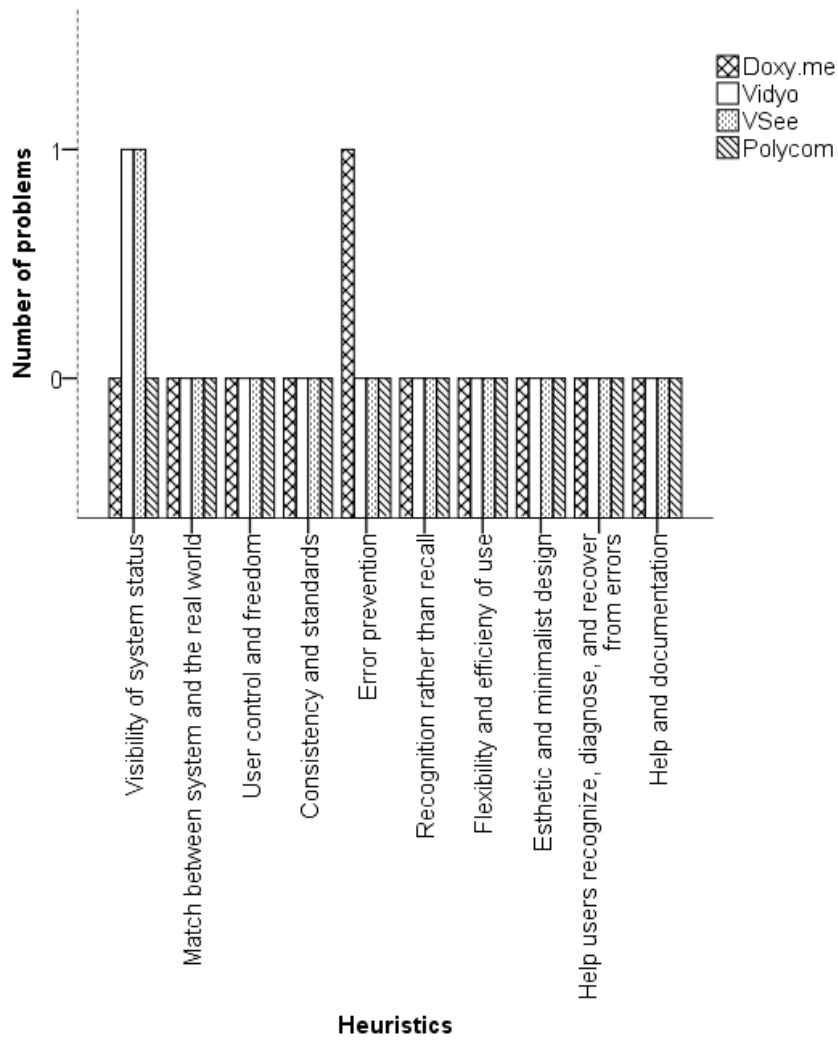


Figure 9. Microphone and camera sharing option.

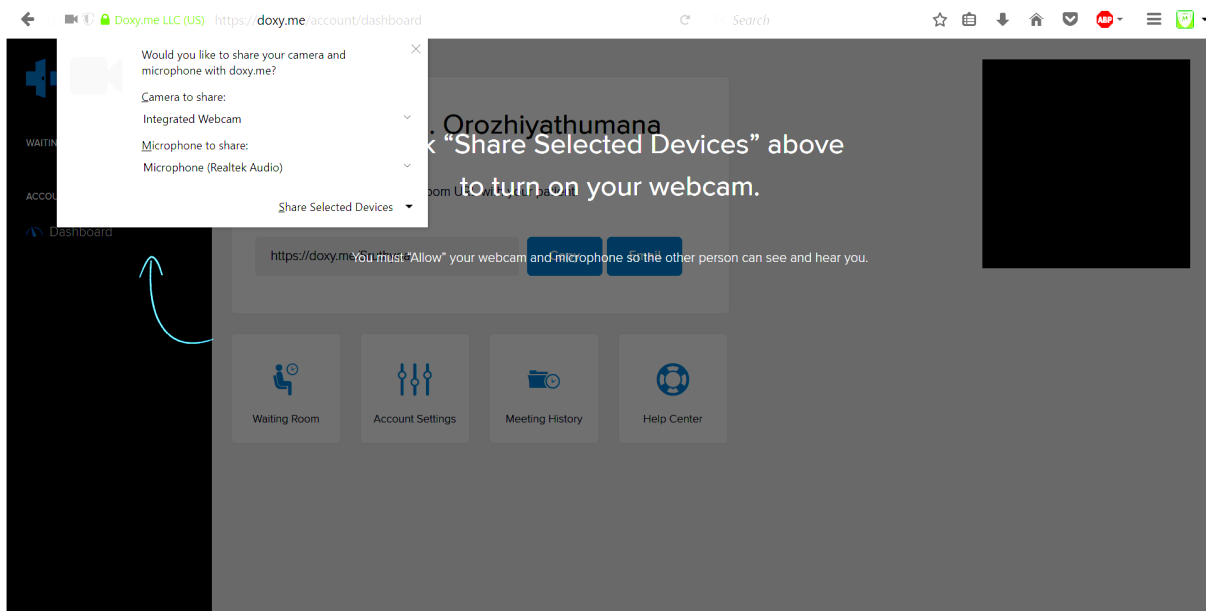
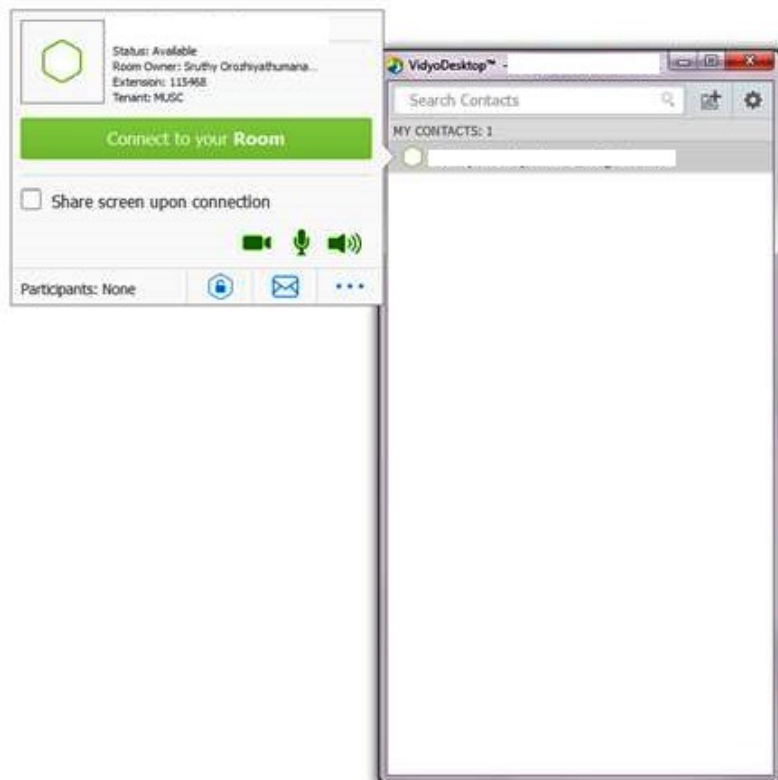


Figure 10. Absence of log-out option.



Issues Requiring Immediate Attention

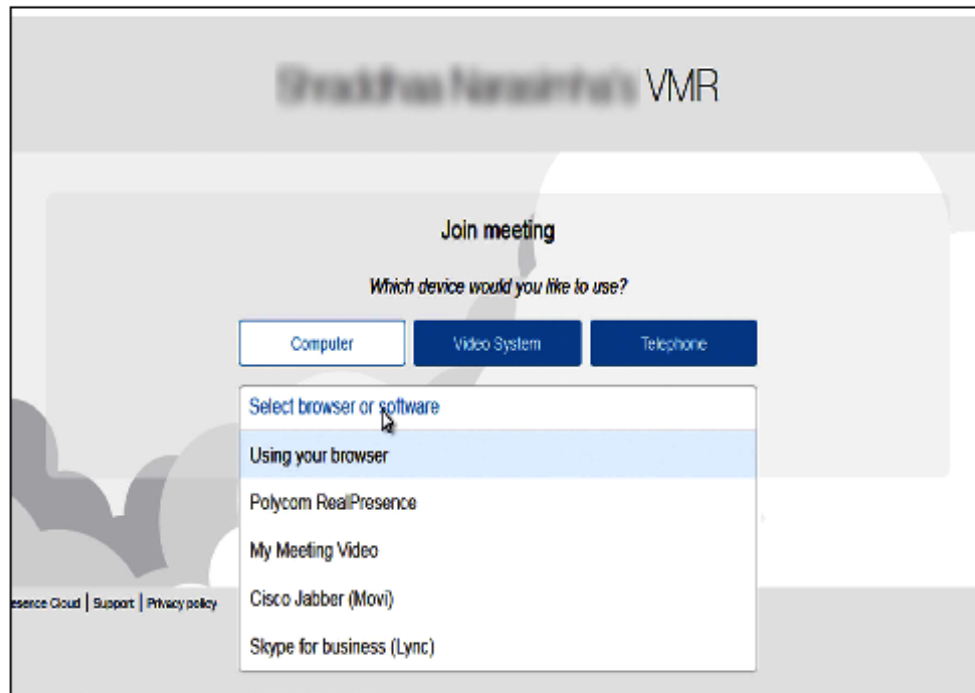
The experts rated two issues as requiring immediate action. The multiple check-in options available in the welcome screen of Polycom was one, with the experts finding that the availability of multiple options confused the user, and that the welcome screen did not contain sufficient information to choose the appropriate device (Figure 11). The second problem highlighted

by the experts was the use of a default email client to email invitations to the patients. Three (Doxy.me, Vidydo, and Polycom) of the four conditions redirect the user to the default email client to send email invitations to the patients. It may be more effective to give the user the choice of using the email client of his or her choice.

During the debriefing, experts discussed their most and least favorite aspects of each of the platforms. Experts indicated that they preferred interfaces that were not cluttered with too many options, language that they could relate to that in the real world, and systems that provided adequate and timely feedback for

their actions. The least enjoyable aspects were welcome emails from the telemedicine platforms with multiple links, the use of a default email client to invite patients, and the failure of many options to respond the way expected.

Figure 11. Multiple log-in options in Polycom.



Discussion

Principal Findings

The heuristic evaluation was conducted using a structured table containing the task flow and a column for experts to input the problems they found for each task, the respective heuristic violated, the severity of the violation, and possible solutions. Several issues were identified during the course of this evaluation. Visibility, error prevention, and minimalistic design issues were frequently violated. The effect of such issues on the ability of a user to process information can be explained using the information processing model [47]. A detailed description of the different aspects of the information processing model that are affected due to these issues would result in developing better solutions.

The information processing model [47] can be used to understand the impact of these issues on the user's ability to understand and make decisions (Figure 12). This model illustrates the procedure of the human cognition process. The sensory register includes our sense organs that help a person take cues from our surroundings, which then leads to understanding or perceiving these cues. The working memory refers to the understanding and retention of information only for the span of completing a task. However, the long-term memory involves the retention of information for longer period of time such as a few weeks, months, or years. Using the

information in the working memory and the long-term memory, the process of thinking and decision-making occurs to make a decision about the cues obtained from the environment. Once thoughts about the cues have been formed, an appropriate response to the cue is developed and based on this, an action is executed in response to the cue obtained. The execution of the response is again taken in by the sensory register and stored in the long-term memory for future situations. Throughout this process, there is also a constant requirement of attentional resources which help the user to focus on the necessary information and eliminate the rest.

On the basis of the issues specified, the lack of feedback would have a direct effect on the perception of the process. As a result, the user would have difficulty in deciding the subsequent process to be carried out in the procedure. It was also indicated that the popup for the chat box was not salient. This would directly affect the sensory register as the popup would not be visible and hence the user would fail to understand (perception) that a message has been received. The icon size and design would again affect sensory register and perception. The content of the email invitation, which was reported to require immediate attention, will prove to be an important issue affecting the working memory. The working memory, responsible for understanding and retaining information until the completion of a task, would be affected due to the large amount of information or the lack of information in the email invitation.

Another problem reported as requiring immediate attention was the use of default email client to send email invitations to patients. This could potentially require the retrieval of passwords to log into the system which affects the long-term memory.

Although of lesser importance, there exist some other issues which must be studied with respect to their impact on a user's decision-making. One such issue is the need to enter large amount of data for registration. This could affect the working memory limits of a person as they would be required to read and retain multiple data to enter. In three of the four platforms analyzed—Doxy.me, Polycom, and Vidyo—it was seen that the clinician was required to send an email invitation for every meeting. This would add to the working memory limits to

process immediately available information and the long-term memory to remember patient name and email address to send the emails. The popups used to share the microphone and camera was indicated to be inconspicuous resulting in additional load on the sensory register due to lack of visibility.

On the basis of the understanding of the different areas of the information processing model affected by the issues and the issues highlighted by the experts, certain design recommendations were developed for telemedicine systems. Some of the key findings for improving the interaction of physician with the interface to enhance the usability of telemedicine platforms are given in [Textbox 1](#).

Textbox 1. Key findings for improving the physician-interface interaction.

Telemedicine initiation

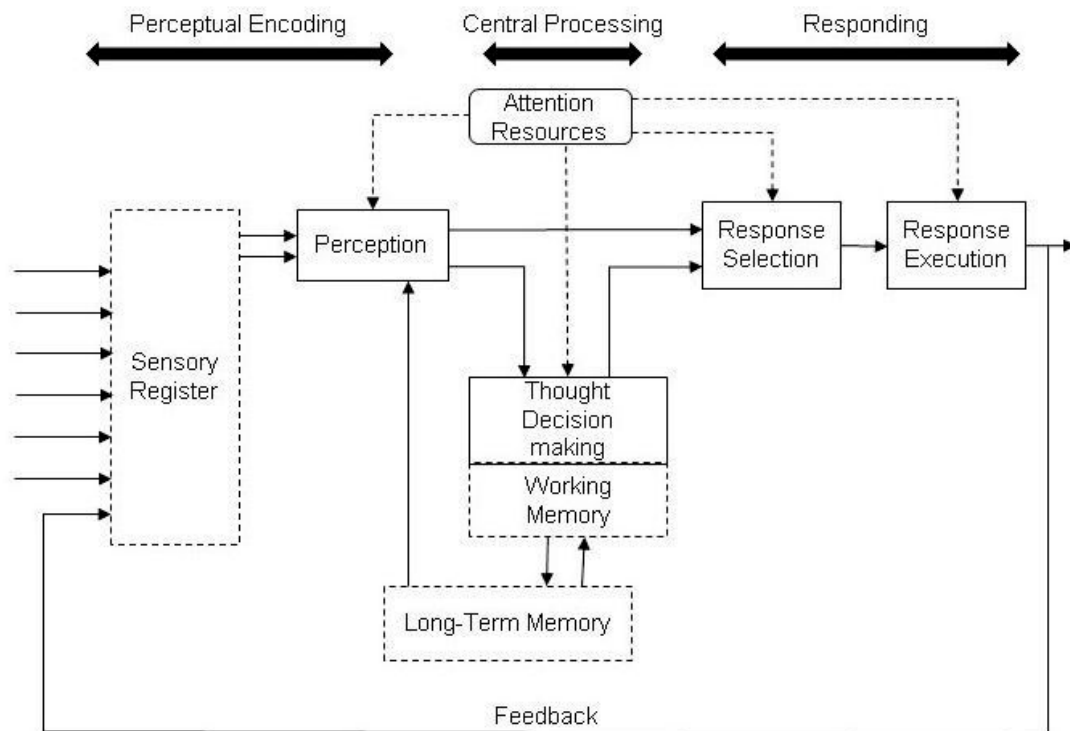
- Provide browser-based applications rather than desktop applications. VSee and Vidyo require their respective applications to be installed on the user's device. A browser-based application avoids the installation process
- Highlight required field in the registration process and provide clear error message when the users fail to fill it
- Ask for only limited information for creating an account and provide an option to update user profile later
- Send an easy-to-comprehend and simple welcome email to the users upon account creation. The link which connects to the telemedicine platform needs to be highlighted as a hyperlink or a button
- Include an introductory tutorial to help users understand the different options the platform offers. Only VSee provides a tutorial tour upon logging into the application for the first time. Most of the tutorial tours do not appear as soon as the users log into the platform for the first time. They need to find the option (hidden in most cases) to watch the tour
- Give users the freedom to choose their email client without connecting it to the system's default. Vidyo directly links to the default email client. If the clinician does not have an account with it, he/ or she cannot send an invitation. Polycom and Doxy.me allow users to choose among a number of email clients. Doxy.me and VSee allow users to log in to their email externally and send an invitation to a patient by copying and pasting the URL
- Have an option to save added contacts so that the user can contact patients again without having to go through the process of inviting them. Currently, only 1 of the 4 telemedicine platforms, VSee, has this feature

Telemedicine consultation

- Provide options for users to check their microphone and speaker connectivity before every conversation. Polycom has a foolproof system that allows users to join the conversation only if the connections are working. VSee allows the user to set up audio and video during the first log-in attempt. For the other two platforms, the clinician does not realize issues with the connectivity until he begins the conversation. Doxy.me instructs the user to click "allow" to share devices. However, the popup that appears does not have an allow button
- Provide adequate and clear feedback when major tasks like adding a patient, accepting a patient, and ending call are performed. When patients accept the invitation on Vidyo, it gives auditory notification; however, there is no popup notification of their status. For Polycom, only the number 1 appears on the side of screen; however, that number does not signify anything to the clinician. Doxy.me sounds a chime, and the patient's name appear on the side; however, it is hard to notice because it usually blends into the page
- Provide conspicuous icons with popup feedback. VSee and Vidyo do not have salient log-out buttons, making the log-out process difficult
- Make the interface simple. Most frequently used icons can be made static, labeled, and grouped together. Cluttered interface with multiple windows and scattered icons may confuse users

or Apart from providing recommendations for improvement based on the information processing model, this study also demonstrates the practicality and ease of applying heuristic evaluation in usability studies. The entire process of conducting

the study and analyzing the results took a week's time and did not involve the use of any software applications. The efficiency of this method makes it well-suited for use during the early development stages [18].

Figure 12. Information processing model.

Limitations

This study is not without its limitations. In this study, we evaluated the telemedicine systems on a Windows 7 computer with Mozilla Firefox browser only. These systems need to be tested on multiple operating systems and Web browsers. Also, the evaluators for this study were not medically trained professionals. Future studies have to be conducted with actual clinicians to find usability issues from their perspective. Furthermore, as indicated by Nielsen and Molich [27], this heuristic evaluation like all others, only helps to identify the usability issues without providing solutions to address them.

Conclusions

Multiple studies have been carried out explaining the effectiveness of telemedicine in providing medical care with little research focusing on the ease and usability of these systems [24]. In this study, we used a heuristic evaluation and severity rating method to assess the usability of 4 telemedicine software platforms with a focus on understanding the interface issues faced by the clinician. Furthermore, the information processing model was used as the baseline to explain the impact of these issues on the user's capability in making decisions. The heuristic evaluation and severity rating method was found to be effective in uncovering issues in the interface as 46 unique issues were uncovered across 4 different platforms. Prominent issues among

these, whose impact was explained using the information processing model, is an indication of the need for further human factors concept-based studies of the interfaces of telemedicine systems.

With a focus on the clinician's interface design, this heuristic evaluation was found to be an effective method for uncovering violations. This heuristic evaluation identified only potential usability problems in an existing interface; usability studies involving physicians could further indicate aspects of the system that work well and identify the most appropriate functionalities. However, with limited resources available, heuristic evaluation is a practical, affordable, and efficient method for revealing usability problems. Experts liked systems that had a straightforward and simple interface and that did not require installation. In addition, they preferred systems that sent simple welcome emails. From a telemedicine point of view, this is important as clinicians and technicians do not have the time to spend navigating and comprehending complex platforms.

Heuristic evaluation is a discounted usability evaluation method with limited generalizability. Future studies need to focus on detailed usability evaluation with actual clinicians and patients. Conducting retrospective interviews with the users help the designers understand their needs and in turn design or modify the system appropriately.

Conflicts of Interest

None declared.

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Abbreviations

HIPAA: Health Insurance Portability and Accountability Act

IOM: Institute of Medicine

MUSC: Medical University of South Carolina

SC: South Carolina

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Original Paper

A Web-Based Graphical Food Frequency Assessment System: Design, Development and Usability Metrics

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Abstract

Background: Food frequency questionnaires (FFQs) are well established in the nutrition field, but there remain important questions around how to develop online tools in a way that can facilitate wider uptake. Also, FFQ user acceptance and evaluation have not been investigated extensively.

Objective: This paper presents a Web-based graphical food frequency assessment system that addresses challenges of reproducibility, scalability, mobile friendliness, security, and usability and also presents the utilization metrics and user feedback from a deployment study.

Methods: The application design employs a single-page application Web architecture with back-end services (database, authentication, and authorization) provided by Google Firebase's free plan. Its design and responsiveness take advantage of the Bootstrap framework. The FFQ was deployed in Kuwait as part of the EatWellQ8 study during 2016. The EatWellQ8 FFQ contains 146 food items (including drinks). Participants were recruited in Kuwait without financial incentive. Completion time was based on browser timestamps and usability was measured using the System Usability Scale (SUS), scoring between 0 and 100. Products with a SUS higher than 70 are considered to be good.

Results: A total of 235 participants created accounts in the system, and 163 completed the FFQ. Of those 163 participants, 142 reported their gender (93 female, 49 male) and 144 reported their date of birth (mean age of 35 years, range from 18-65 years). The mean completion time for all FFQs (n=163), excluding periods of interruption, was 14.2 minutes (95% CI 13.3-15.1 minutes). Female participants (n=93) completed in 14.1 minutes (95% CI 12.9-15.3 minutes) and male participants (n=49) completed in 14.3 minutes (95% CI 12.6-15.9 minutes). Participants using laptops or desktops (n=69) completed the FFQ in an average of 13.9 minutes (95% CI 12.6-15.1 minutes) and participants using smartphones or tablets (n=91) completed in an average of 14.5 minutes (95% CI 13.2-15.8 minutes). The median SUS score (n=141) was 75.0 (interquartile range [IQR] 12.5), and 84% of the participants who completed the SUS classified the system either "good" (n=50) or "excellent" (n=69). Considering only participants using smartphones or tablets (n=80), the median score was 72.5 (IQR 12.5), slightly below the SUS median for desktops and laptops (n=58), which was 75.0 (IQR 12.5). No significant differences were found between genders or age groups (below and above the median) for the SUS or completion time.

Conclusions: Taking into account all the requirements, the deployment used professional cloud computing at no cost, and the resulting system had good user acceptance. The results for smartphones/tablets were comparable with desktops/laptops. This work has potential to promote wider uptake of online tools that can assess dietary intake at scale.

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KEYWORDS

nutrition assessment; FFQ; food frequency questionnaire; personalized nutrition; nutrition informatics; dietary intake; usability; SUS

Introduction

Food frequency questionnaires (FFQs) are a commonly used tool for dietary assessment, and paper-based FFQs have been used for decades in the field of human nutrition [1-2]. An FFQ consists of a list of food and drink items, and for each item, an individual indicates their typical consumption frequency and portion size, based on their dietary intake for a given reference period (eg, the past month). The list of foods is based on the most frequent foods in the region and typically has around 100 items. Consumption frequencies are normally indicated using categories described in text (eg, 1 per day). Portion sizes can be indicated by selecting text-based categories (eg, small, medium, or large) or by selecting the closest match from a selection of portion-size photographs of actual foods [3]. There have been studies published on the validity of FFQs in different countries, in both paper-based and digital versions [4-13]. FFQs are frequently used in epidemiological (ie, population) studies as they are inexpensive to process, can be self-administered, and are relatively quick for participants to complete [14-15]. However, they are also prone to reporting bias; the consumption of healthy foods has been overestimated using this method [16-17].

FFQs have traditionally been delivered using a pen-and-paper format, but there is a burden associated with this format for study participants, health professionals, and investigators. The digitalization of nutrition assessment methods has excellent potential to save time and resources, is preferred by participants [18], and is more suitable for large-scale studies. Other online dietary assessment methods such as the 24-hour recall [19-21] claim better accuracy than FFQs. However, the motivations for investigating online FFQs include that they are easier to replicate technically than these other methods, which often require a much larger food database and more complex technologies such as text search functionality; FFQs may also be more suitable for certain applications including online personalized nutrition interventions [22]. Although some Web-based FFQs have been developed in recent years, they have not been used widely in this format as yet, and there are few published results in terms of user acceptability of online FFQs.

In order to facilitate the dissemination of online FFQs, it is important that the scientific and public health communities have open and free access, not only to the final results of validation studies but also to the design, architecture, development, and deployment of scalable, replicable, and secure tools. Furthermore, interdisciplinary collaboration and shared understanding between the health and technical communities is important for furthering research in this field, and as such, it is appropriate that studies also report their work from the perspectives of multiple disciplines. Therefore, this paper presents both the technical design of a Web-based graphical food frequency assessment system and results from user testing, with an aim of making a contribution to the wider uptake of digital FFQs.

The online FFQ described in this paper was designed and developed for the Eat Well Kuwait project (EatWellQ8, www.eatwellq8.org), which aims ultimately to investigate whether Web-based personalized nutrition (based on dietary intake and anthropometrics) is as effective as face-to-face communication of personalized nutrition in Kuwait. The project is a collaboration between the University of Reading and the Dasman Diabetes Institute in Kuwait City [23]. The first stage of this project focused on the design and development of the Web-based FFQ, and a validation study is currently under way to compare the online FFQ with the current paper version of a Kuwaiti FFQ and a 4-day weighed food record.

Objectives

Overview

This paper aims to make a contribution to the wider uptake of digital FFQs by describing the rationale, design, implementation, administration, and user feedback of a Web-based graphical food frequency assessment system. Online FFQs are not yet being used widely, and this is due in part to a variety of technical challenges. This section summarizes some of the technical considerations relevant to facilitating wide deployment of online FFQs.

Reproducibility

With a view to decreasing completion time and thereby increasing user acceptability, the list of food items in an FFQ normally includes only the most common foods in a region, divided into food groups (fruits, vegetables, etc). As these food lists and their related portion size images vary by location, it is useful to have either a customizable central system or an easily replicable system to help ensure that locally applicable FFQs for different regions can be created easily. Ideally, this system should be inexpensive in order to mitigate financial constraints that could block deployment. Furthermore, any need for technological expertise in customization and administration could hinder reproducibility, so it is important to design these aspects with ease-of-use in mind.

Scalability

One of the drivers for developing online dietary assessment methods is the potential to support population-level studies. When operating at this large scale, there is a potential to see high peaks in the system traffic, which are not easily handled. This is an important requirement to be considered in the system architecture.

Mobile Friendly

The need to consider deployment on mobile devices and tablets is more and more relevant, considering an increase in the market share of smartphones and tablets as compared with desktops and laptops [24]. The delivery of an FFQ via tablets and smartphones presents particular challenges. For example, due to screen size constraints, it is difficult to present all the portion sizes (usually between 3 and 7 images) on the screen

simultaneously. The layout and interaction design has the potential to influence participant responses or increase the task completion time and requires careful consideration.

Security

Population studies often store sensitive data, since they usually collect medical information together with personal details. In this scenario, it is important to provide authentication and authorization features, protect the database from unauthorized access, and communicate with the database using a secure protocol.

Usability

Empirical data on system usability is important for enabling evidence-based decisions in the design and improvement of further systems. The system should build in the ability to collect metrics such as completion time and usability surveys.

Methods

Technical Design

Overview

The design of the EatWellQ8 food frequency questionnaire considered the main requirements described in the previous section and assessed and compared these with the main advantages and disadvantages of the currently most-used Web architectures and technologies.

The requirements showed that the system was not intense computationally, pointing to the possibility of using a modern Web architecture called single-page application (SPA) [25]. In this paradigm, all the necessary code (HTML, Cascading Style Sheets, and JavaScript) is retrieved in a single load, and the updates in the view are managed by the code running in the browser. The JavaScript framework for creating SPA proposed by Google is called AngularJS, which is entirely client-side (ie, browser only) [26].

An SPA architecture creates the possibility of using static hosting for delivering the code and media files (eg, food images in this project), which is much cheaper than dynamic hosting (ie, servers) and removes any need for server maintenance.

Beside the static hosting, there were three basic requirements that needed to be fulfilled: user authentication, user authorization, and a secure database. After analyzing several major cloud-computing providers (ie, Amazon Web Services, Google, IBM, and Microsoft), it was clear that the typical Web app architecture could be delivered by any of them. One particular service that stood out during this comparison was Google Firebase for its particular focus in providing the most essential features for developing Web and mobile apps in a very affordable way, which has attracted more than 400,000 developers worldwide. Its main features are a real-time database, user authentication, and static hosting [27].

Reproducibility

Since data collection and retention standards are different around the world, a customizable central system may face some practical difficulties for implementation. This was one of the

main reasons for choosing to create an easily replicable system using cloud-computing services, which are accessible worldwide.

Data is stored in a JavaScript Object Notation (JSON) document in the Firebase database. In order to facilitate food list modification by nontechnical administrators, the original food table was created as an Excel spreadsheet (Microsoft Corp). The cells were then concatenated (using Excel's concatenate function) into comma-separated values text, which was then converted to JSON (using an online converter such as convertcsv.com). The JSON was then imported to Firebase. The following object shows a food item structured in JSON, illustrating its human-readable format:

```
"foods" : [ { "arabic" : "Broccoli in arabic", "english" : "Broccoli", "id" : 0 }, ... ]
```

Scalability

Using an SPA approach combined with a Firebase database, all the processing is transferred to the client (browser), which can easily handle simple interactions and functions for rendering the pages. The Firebase Spark Plan (free) can support 100 simultaneous connections with the database (this increases to unlimited simultaneous connections with the Flame Plan which, at the time of writing, costs US \$25/month) using a secure https protocol and deliver the pages and images via its global Content Delivery Network [27].

Mobile Friendly

In order to design a Web app that can be used readily on mobile devices, the design was based on Bootstrap, a highly popular responsive Web framework. It is open source and has built up a big developer community since its launch in 2011 [28].

The Bootstrap functionalities that played important roles in our implementation were the responsive navigation bar and the modal component; the former creates an adjustable navigation bar that converts into a hamburger icon on small devices, and the latter displays a pop-up window on top of a current page (this was used to be able to display food portion images using the entire screen).

Security

Firebase provides a complete authentication feature. Among the possible authentication providers (Facebook, Google account, etc), the email and password combination was enough for this project, although others could also be provided as alternatives. Firebase enables the use of AngularJS combined with its product via the AngularFire library. It provides a 3-way binding between the HTML, the JavaScript, and the database. This means that any modification in one of these parts can be propagated to the other two. For example, a modification of one value in the database triggers an update in the website. This feature becomes even more powerful when different systems are connected to the same real-time database, enabling users to switch between a website and a mobile app, for example, with their data synchronized between the two. Best practices in terms of authentication and page routing are provided by Firebase in the AngularFire Seed, a small open-source project that contains

the implementation of the basic features (log in, password reset, data binding, etc) that were used in this project.

Besides the authentication feature, Firebase provides Security Rules for defining authorization. Every time a user authenticates, an internal variable (*auth*) is populated with user information (eg, user unique ID). Using a simple JavaScript-like syntax, authorization was defined in order to prevent unexpected access. The following rules exemplify how to block access (read/write) to new objects and only allow authenticated users to access their own FFQ results:

```
{“rules”: {“read”: false, “write”: false,
“ffq”: {“$user”: {“read”: “auth.uid ===
$user”, “write”: “auth.uid === $user” }}}
```

Another important security aspect is communication between the browser and the database. Firebase uses https, which requires encryption in the communication between the browser and Firebase. If a custom domain is desired for the deployment (eg, <https://eatwellq8.org>), it will be necessary to configure the Domain Name Server according to the records provided by Firebase.

EatWellQ8 Food Frequency Questionnaire

The EatWellQ8 FFQ contains 146 food items (including drinks), adapted from the European Prospective Investigation into Cancer Study [29] and Food4Me FFQs [4] to reflect a Kuwaiti diet. The food names are shown in both English and Arabic. For each item, users indicate consumption frequency during the last month by selecting from 1 of 8 options: “never or less than 1 per month,” “1 to 3 per month,” “2 to 4 per week,” “5 to 6 per week,” “1 per day,” “2 to 3 per day,” “4 to 6 per day” and “more than 6 per day” [4]. Due to the number of options, the selection was implemented via a select element (drop-down list), which is expanded on mobile devices. In order to speed up the completion time, the default choice was set to the first option (“never or less than 1 per month”), so that participants could simply skip an item if they did not consume that specific food item (Figure 1).

Users indicated portion size by selecting from 1 of 3 photographs of actual food portion sizes (Figure 2). Other studies have investigated various options to enable users to specify food portion sizes from photographs, including selecting from 1 of 8 portion size photographs [30] and a combination of having 3 portion size photographs to select from combined with 4 radio buttons to indicate portion sizes that were bigger/smaller than those depicted in the photos [31]. For the current system, the decision to present 3 portion size photos was based partly on prior (unpublished, from the FFQ described elsewhere [31]) user data indicating that photos are far more frequently selected than radio button options without an associated photograph and an aim of presenting all the photos to users in an efficient manner even on small screen sizes. Portion size photographs are sometimes labeled using descriptive labels of the portion sizes: for example, small, medium, or large. In our study, the photographs are presented without any labels to avoid potentially biasing the users in their choices. Each time a user selects a food frequency, the appropriate portion images are automatically

presented to the user; this is implemented in a pop-up window using the modal component described earlier. After the portion size has been selected, the users’ selections are presented as “Size A,” “Size B,” or “Size C” (see Figure 1).

Although participants are encouraged to complete the FFQ in one sitting/session, it is important to offer the possibility to save the FFQ, in case the user is interrupted or loses Internet connection temporarily. Hence, each food selection is saved individually (after the portion size selection), and the user has the option to retrieve the FFQ of a particular day when returning to the system. A timestamp (format yyyy-mm-dd) is saved together with each FFQ entry in the database, after formatting the JavaScript Date Object, in order to check the existence of an entry for that specific day.

Usability Metrics

To enable collection of data on system usability and use, the system included a usability survey and also logged usage data. The usability survey was presented after completion of the food frequency questionnaire. A modified version of the System Usability Scale (SUS) [32], originally defined by Brooke [33], was used to assess the user acceptance of the online FFQ. The SUS consists of 10 questions alternating between positive and negative statements, with 5 possible responses from “strongly disagree” to “strongly agree.” The statements relate to a range of aspects of system use, such as complexity, ease-of-use, and learnability. Each participant’s responses are then scored, providing an overall SUS score between 0 and 100. After this stage, the overall usability of the system is evaluated via a general question, “Overall, I would rate the user-friendliness of this system as,” with the following options: “worst imaginable,” “awful,” “poor,” “fair,” “good,” “excellent,” and “best imaginable.” An additional question (“Have you found difficulties in some part of the system?”) was also presented. In the case of a positive answer, a textual description of the difficulties was requested.

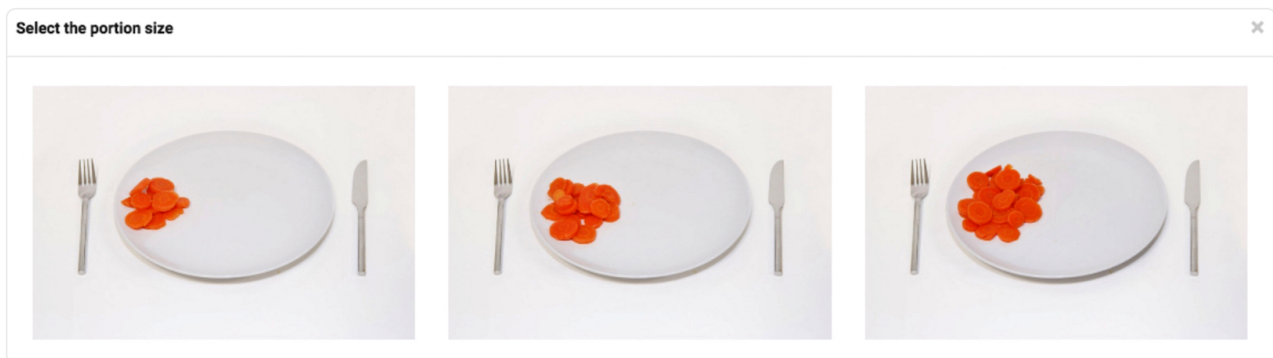
Collecting usage data involved storing browser information and logging user interactions with the system. Details of the browser were collected via the JavaScript Navigator Object. This object is not intrusive, is supported by all major browsers, and contains information such as browser name, platform, version, and language.

In terms of logging user interactions, the system logged timestamps on actions completed during the completion of the FFQ (eg, opening and closing of the portion size selection screen) using the JavaScript Date Object, which contains the time in milliseconds since the beginning of the year 1970 [34]. The timestamps were analyzed for the total time spent completing the FFQ, calculated based on the first and last click interaction with the FFQ. As the system allowed users to stop partway through the FFQ and to return to it within the same day, in order to measure only the periods in which the volunteers were actively engaged in using the system, time intervals greater than 60 seconds without any click interactions were considered interruptions (ie, period of inactivity) and subtracted from the total completion time.

Figure 1. Food items and frequencies presented by the system.

Food name	Select Frequency	Portion Size
Broccoli, green leafy vegetables القربيط	1-3 per month	Size B
Cabbage ملفوف	1-3 per month	Size A
Carrot جزر	<ul style="list-style-type: none"> ✓ never or less than 1 per month 1-3 per month 1 per week 2-4 per week 5-6 per week 1 per day 2-3 per day 4-6 per day 6 per day 	
Cauliflower زهرة		
Beetroot شمندر		
Cucumber خيار	never or less than 1 per month	
Garlic ثوم	never or less than 1 per month	

Figure 2. Portion sizes presented by the system.

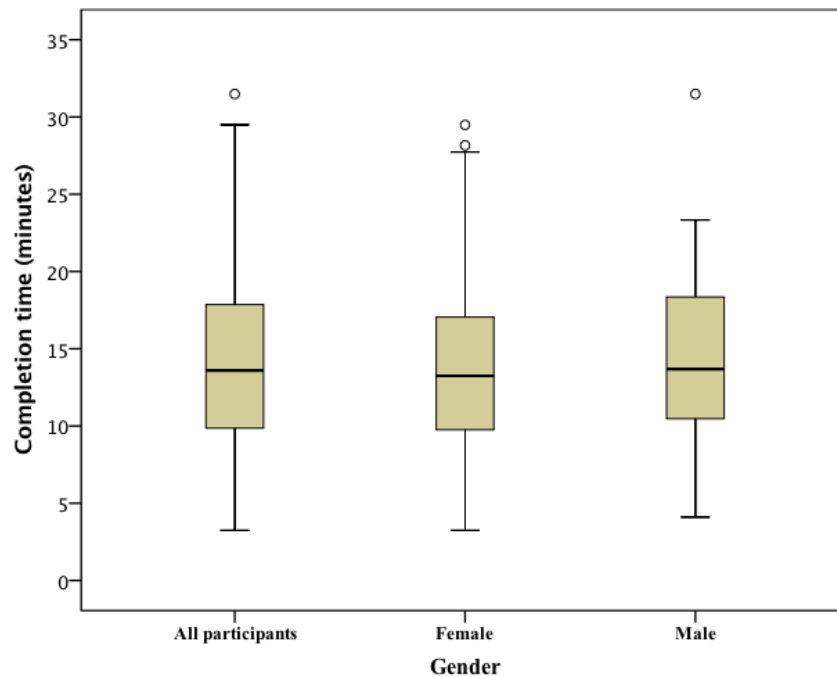


The EatWellQ8 Web-based food frequency questionnaire was deployed in January 2016 as part of a validation study comparing the online FFQ against a preexisting paper version of a Kuwaiti FFQ and a 4-day weighed food record. The study was subject to ethical review according to the procedures specified by the University of Reading Research Ethics Committee (UREC 15/50) and by the Diabetes Institute’s International Scientific Advisory Board and Ethics Review Committee (RA-2015-018) and was given favorable ethical opinions for conduct.

Because the usability study was being performed in parallel with the EatWellQ8 validation study, participant recruitment and eligibility criteria were set by the requirements of the wider study. Participants were recruited in Kuwait as part of the EatWellQ8 study without financial incentive. Recruitment was conducted via the Internet, posters, and social media or word of mouth, mainly from the higher education institutions in Kuwait, during 2016. Volunteers were requested to create an online account on the study website and to complete a screening questionnaire to determine their eligibility to participate in the study. Participants with chronic diseases (eg, diabetes), food

allergies or food intolerances, or not within the age range (18-65 years) were not eligible to participate in the study.

Figure 3. Food frequency questionnaire completion time for all participants (n=163) and by gender (93 female, 49 male).



Results

A total of 235 participants created accounts in the system, of which 163 completed the FFQ. Of those 163 participants, 142 reported their gender (93 female, 49 male) and 144 reported their date of birth (mean age of 35 years, range from 18-65 years).

Regarding the devices participants used to complete the FFQ, 69 participants used a laptop/desktop computer, 87 used a smartphone, 4 used a tablet, and 3 devices/browsers did not return their JavaScript Navigator Object correctly and hence the device information is not available.

The mean completion time for all FFQs (n=163), excluding periods of interruption, was 14.2 minutes (95% CI 13.3-15.1 minutes). Female participants (n=93) completed in 14.1 minutes (95% CI 12.9-15.3 minutes) and male participants (n=49) completed in 14.3 minutes (95% CI 12.6-15.9 minutes) (Figure 3). Participants using laptops or desktops (n=69) completed the FFQ in an average of 13.9 minutes (95% CI 12.6-15.1 minutes) and participants using smartphones or tablets (n=91) completed in an average of 14.5 minutes (95% CI 13.2-15.8 minutes) (Figure 4). Out of the 163 FFQs, 71 were completed without any interruptions (ie, there was no gap of more than 60 seconds without any interaction). Considering the 146 food items, the volunteers spent on average 5.84 seconds per food item. As the system collects timestamps just before the portion image presentation (ie, after the frequency selection) and when they are selected (ie, click on the portion image), it was possible to calculate the mean time spent in the portion size selection (4.18 seconds per food item) and by subtraction the rest of the time (1.66 seconds per food item) was considered spent on the

frequency selection component of the task. For items where the frequency was “never,” no explicit selection was required.

Regarding the portion size selection, we did not have the timestamp required to separate the time required for image loading from the time required by participants to decide on and select a photo due to the fact that this information cannot be captured by the Web app. However, informal testing with a good Internet connection showed that the pop-up is rendered with the 3 images (around 150 KB in total) in less than 1 second.

For all participants, the usability survey was presented after completion of the FFQ. Of the 141 who elected to complete the usability survey, 125 reported their gender (80 female, 45 male) and 124 reported their date of birth (mean age of 36 years, range from 18-65 years). The median SUS score (n=141) was 75.0 (interquartile range [IQR] 12.5) for all the participants, and of the 125 who reported their gender, the results were 72.5 (IQR 12.5) for female (n=80) and 75 (IQR 11.25) for male (n=45) (Figure 5). Products with a SUS score higher than 70 are considered to be good [35-36]; this is discussed further in the Discussion section. No significant differences were found between genders or age groups (below and above the median) for SUS or completion time. Considering only participants using smartphones or tablets (n=80), the median was 72.5 (IQR 12.5), slightly below the SUS median for desktops and laptops (n=58), which was 75.0 (IQR 12.5). Users’ ratings on the overall user-friendliness of the system (based on the question “Overall, I would rate the user-friendliness of this system as”) were predominantly “good” and “excellent” (Figure 6).

In the final question (“Have you found difficulties in some part of the system?”), 126 volunteers answered “no” and 15 answered “yes.” Further examination of the participants who provided comments (n=13) showed that their responses were more related

to the process (eg, “too long and detailed,” “repeated questions,” “gets boring,” and “time consuming”) rather than fundamental problems with the system. Only 3 participants reported fundamental problems and they were related to the portion size pop-up in smartphones. Selected comments related to the usability of the system follow:

The portion size pop-up aspect of the FFQ became a bit tedious. I think it might be slightly more

user-friendly if the portion pictures are posted on the website rather than in pop-up form.

The pictures were great and really were on spot with the amounts difference.

It was not clear for me when choosing the portion/size if there was more than a, b, and c. By using mobile it was not easy at all to scroll down the size option.

Figure 4. Food frequency questionnaire completion time for all devices (n=163) and by device (69 laptops/desktops, 91 smartphones/tablets).

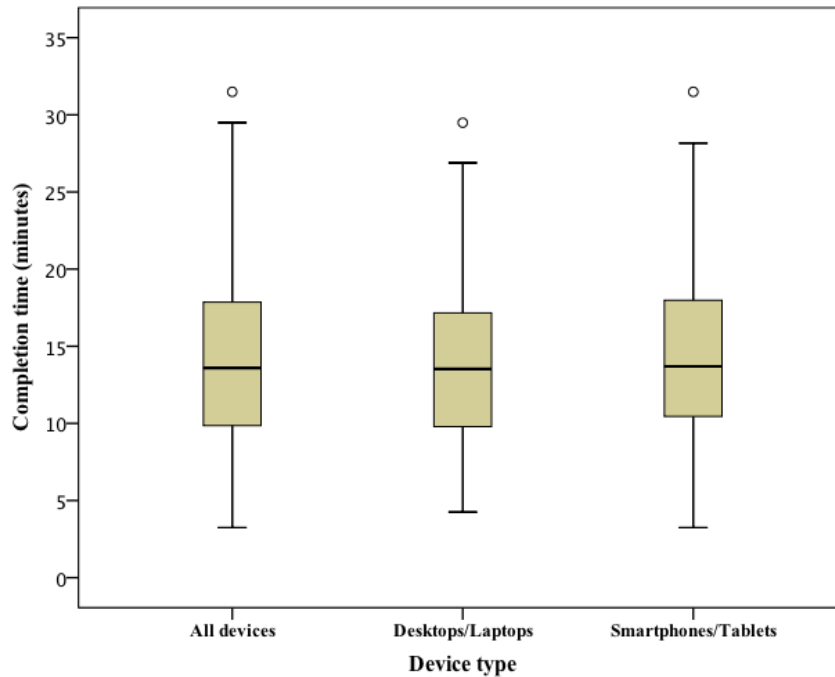


Figure 5. System Usability Scale of the food frequency assessment system by the study participants (n=141) and presented by female (n=80) and male (n=45) for those who reported gender (n=125).

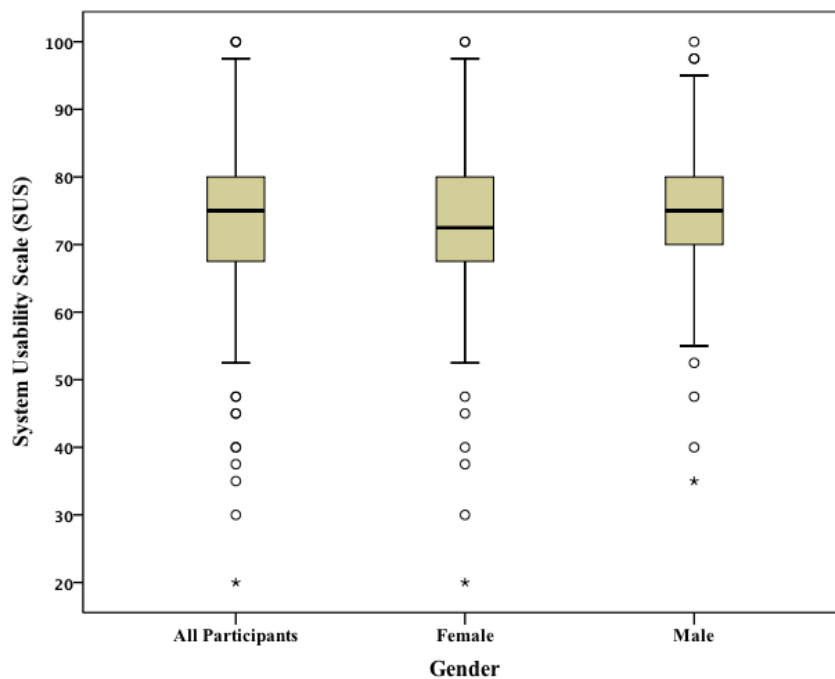
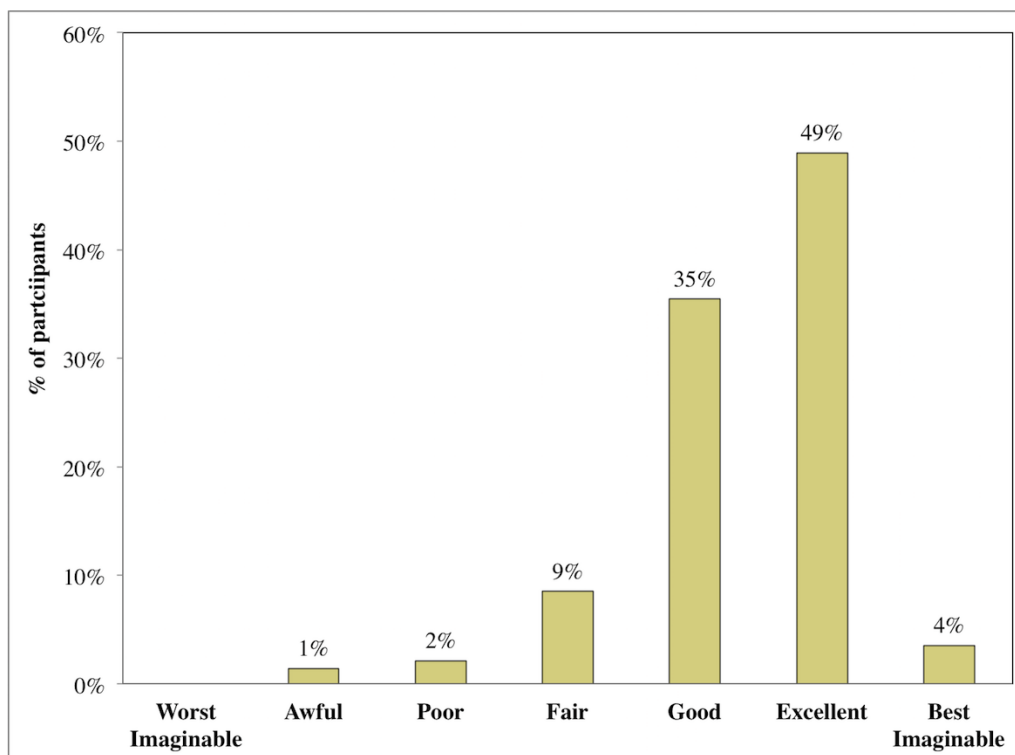


Figure 6. Overall user evaluation of the food frequency assessment system by the study participants (n=141).

Discussion

Principal Findings

Participants gave the EatWellQ8 system a median SUS score of 75.0 (IQR 12.5). Kurtom and Bangor measured popular services and products and reported a SUS average of 70.14, including Microsoft Excel (54.4), Amazon (79.0), and an automated teller machine (80.5) [35-36]. Products with a SUS score higher than 70 are considered to be good [35]. When using this scale, it is useful to compare results within the same category. A very recent study published the SUS results of an online 24-hour recall system designed and developed during the project myfood24 [37]. For an adult population, it resulted in a SUS median of 68 (IQR 40) for the beta version, and a SUS median of 80 (IQR 25) for the live version. No similar results have been published for online FFQs, but the SUS median from this study indicates good design and user acceptability. We acknowledge potential for selection bias, which could not be quantified. This is further supported by participants' positive responses relating to the overall quality of the system (Figure 6). We observed similar completion times and SUS medians for completing the FFQ on smartphones/tablets when compared with laptops/desktops, which indicates a good responsive design.

Although retrospective dietary assessment methods such as the FFQ and 24-hour recall require less effort from users than prospective methods using similar technologies (eg, Web-based food diaries), completion times of around 14 minutes for completing the FFQ in full can still be a barrier if participants

are not engaged with the study objectives. The challenge of engaging participants to complete data collection could potentially be addressed by providing personalized online feedback, acting as a reward to incentivize participants to complete the FFQ. A newer version of the EatWellQ8 system is currently under development with the ability to provide personalized feedback, which may further improve user satisfaction and interest for investing this amount of time to complete the FFQ.

Conclusions

We have designed and deployed an online FFQ in a way that encourages reproducibility and is available to be used in other studies, using the same cloud services, for free. In this way, we hope to make a contribution to the wider uptake of digital FFQs and to make more widely accessible their benefits in terms of time and resource savings and suitability to support large-scale studies.

The FFQ we have developed is a responsive website that has been tested on smartphones and tablets using two major mobile operating systems (iOS and Android). It addresses security requirements using features provided by Google Firebase, a cloud-based real-time database service. The user rating of this version from 141 participants was good (75 out of 100, using the SUS), and the completion time calculated from 163 FFQs (14.2 minutes) seems to be acceptable but with room for improvement. This paper is an important landmark in encouraging the research community to publish technical designs and usability information of online dietary assessment methods.

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Authors' Contributions

All authors contributed to the study conceptualization and design. BAA was responsible for the EatWellQ8 ethical approval and recruitment. RZF was responsible for system design, development and data analysis, and article draft. RF, JAL, and FH were responsible for the final writing, critical revision, and approval of the paper. The research data from this study can be accessed by contacting the corresponding author.

Conflicts of Interest

None declared.

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Abbreviations

- EatWellQ8:** Eat Well Kuwait
- FFQ:** food frequency questionnaire
- IQR:** interquartile range
- JSON:** JavaScript Object Notation
- SPA:** single-page application

SUS: System Usability Scale

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Original Paper

Fall Prevention Self-Assessments Via Mobile 3D Visualization Technologies: Community Dwelling Older Adults' Perceptions of Opportunities and Challenges

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Abstract

Background: In the field of occupational therapy, the assistive equipment provision process (AEPP) is a prominent preventive strategy used to promote independent living and to identify and alleviate fall risk factors via the provision of assistive equipment within the home environment. Current practice involves the use of paper-based forms that include 2D measurement guidance diagrams that aim to communicate the precise points and dimensions that must be measured in order to make AEPP assessments. There are, however, issues such as “poor fit” of equipment due to inaccurate measurements taken and recorded, resulting in more than 50% of equipment installed within the home being abandoned by patients. This paper presents a novel 3D measurement aid prototype (3D-MAP) that provides enhanced measurement and assessment guidance to patients via the use of 3D visualization technologies.

Objective: The purpose of this study was to explore the perceptions of older adults with regard to the barriers and opportunities of using the 3D-MAP application as a tool that enables patient self-delivery of the AEPP.

Methods: Thirty-three community-dwelling older adults participated in interactive sessions with a bespoke 3D-MAP application utilizing the retrospective think-aloud protocol and semistructured focus group discussions. The system usability scale (SUS) questionnaire was used to evaluate the application's usability. Thematic template analysis was carried out on the SUS item discussions, think-aloud, and semistructured focus group data.

Results: The quantitative SUS results revealed that the application may be described as having “marginal-high” and “good” levels of usability, along with strong agreement with items relating to the usability ($P=.004$) and learnability ($P<.001$) of the application. Four high-level themes emerged from think-aloud and focus groups discussions: (1) perceived usefulness (PU), (2) perceived ease of use (PEOU), (3) application use (AU) and (4) self-assessment (SA). The application was seen as a useful tool to enhance visualization of measurement guidance and also to promote independent living, ownership of care, and potentially reduce waiting times. Several design and functionality recommendations emerged from the study, such as a need to manipulate the view and position of the 3D furniture models, and a need for clearer visual prompts and alternative keyboard interface for measurement entry.

Conclusions: Participants perceived the 3D-MAP application as a useful tool that has the potential to make significant improvements to the AEPP, not only in terms of accuracy of measurement, but also by potentially enabling older adult patients to carry out the data collection element of the AEPP themselves. Further research is needed to further adapt the 3D-MAP application in line with the study outcomes and to establish its clinical utility with regards to effectiveness, efficiency, accuracy, and reliability of measurements that are recorded using the application and to compare it with 2D measurement guidance leaflets.

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KEYWORDS

health informatics; falls; occupational therapy; assistive equipment provision process; self-assessment; measurement guidance; extrinsic risk factors; 3D visualization; technology-based systems

Introduction

Fall Prevention Technologies and Patient Involvement

Due to an ageing world population, the number of fall-related injuries has risen in recent years, hence, posing a significant global health challenge [1]. Approximately 30% of older adults over 65 years and 50% of adults over 80 years who live independently fall each year [2]. Falls result in injuries that can precipitate early hospital and long-term care admissions, and, in some cases, can be the cause of death. The result is an ever increasing demand for health and social care services and resources [3,4]. In the United Kingdom, the cost of falls to the National Health Service (NHS) is estimated at over £2.3 billion per year. Government and health authorities see new and innovative applications of information and communication technologies (ICTs) within the falls prevention domain as having the potential to reduce health care costs while also addressing the increased burden that an ageing population places on health and social care services [5]. In particular, ICTs deployed within the health sector are seen as having the potential to enable patients to self-assess, self-manage, and provide self-care, thus reducing the demand for clinicians in the delivery of a range of health interventions [6,7]. Additional anticipated benefits of technology-assisted interventions include a potential rise in levels of patient engagement and adherence, which may in turn result in higher levels of overall patient satisfaction and quality of life [5]. Already, there appears to be a shift away from the traditional paternalistic models of health care where the patient is a passive recipient toward more patient-centered models where the patient is given more responsibility for providing their own care such as carrying out self-assessments and management of their own conditions [8]. Part of this change is related to the emergence of the notion of the “expert patient,” one who is expected to be able to access relevant information, utilize self-testing and manage medical devices and applications effectively, and make independent decisions about their own care [9,10].

In the field of occupational therapy, the assistive equipment provision process (AEPP) is widely used as a prevention strategy to promote independent living, and to identify and mitigate falls risk factors via the provision of assistive equipment (also referred to as assistive technology) where appropriate. AEPP involves occupational therapists (OTs) working, often with older adult patients, to identify intrinsic and extrinsic falls risk factors that impact patients’ ability to carry out activities of daily living (ADL). Intrinsic risk factors include functional ability deficits and cognitive and balance impairments. Extrinsic risk factors include poor lighting, slippery surfaces, and obstacle and trip hazards as well as inappropriate or “poor fit” of assistive equipment and lack of stair handrails and bathroom grab rails [11]. Existing research literature indicates that much effort has been focused on developing technology-based systems and software applications that attempt to mitigate intrinsic fall risks [12,13], however, comparatively little effort has been invested

into developing technology-based systems that address and overcome extrinsic risk factors.

Assistive Equipment Provision and Patient-Led Self-Assessment

The aim of the AEPP is to reduce barriers that impact patients’ ability to perform day-to-day living tasks and reduce fall risk factors. This is typically achieved by recommending adaptations to the home and the installation of assistive equipment such as bath boards, shower chairs, toilet raisers, chair raisers, bed raisers, and grab rails to help with transfers when bathing or climbing stairs [14]. Adaptation of the home and installation of such equipment is carried out to accommodate functional changes, assist with ageing-in-place, and reduce fall risk factors [15]. A key strategy to mitigate the adverse impact of functional decline is to identify and accurately prescribe assistive equipment that will sustain independent living and quality of life [15-18]. Therefore, clinicians undertake home visits to assess functional abilities and take measurements from the patient, fittings, and key items of furniture that form the basis upon which assistive equipment and home adaptations are prescribed. Recorded measurements inform the precise type, size, and nature of the assistive equipment that is prescribed, and therefore, play a vital role in ensuring the successful fit between the assistive device and the person using it [19,20].

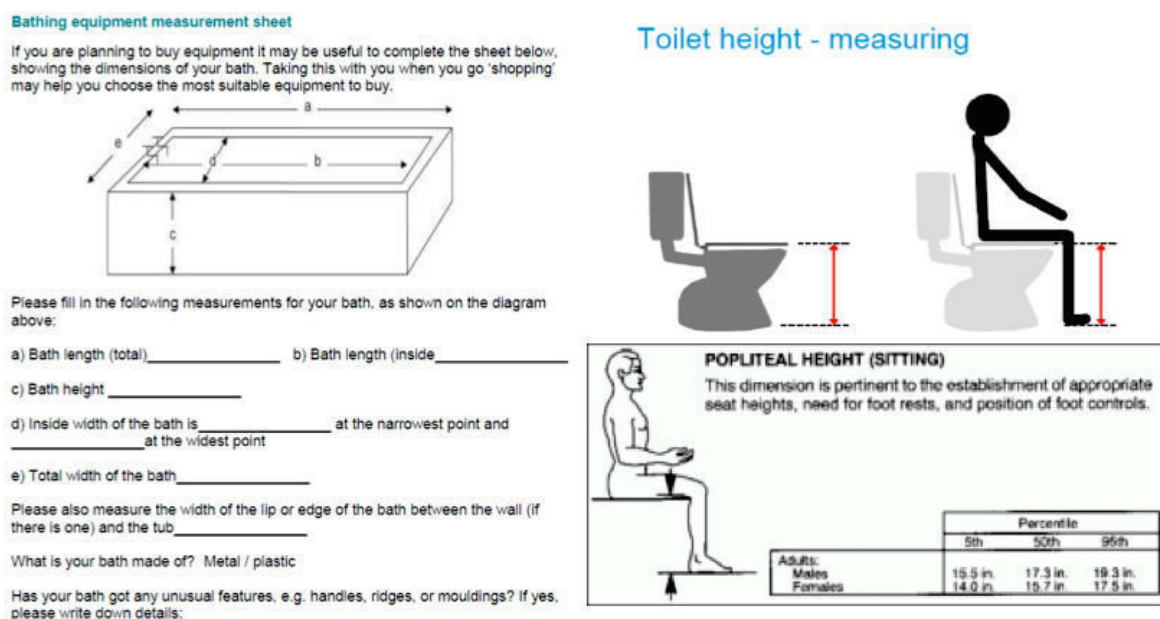
Currently, paper-based forms are used in the AEPP to record measurements and associated patient data. These forms include measurement guidance that is presented in the form of 2D illustrations of information that must be collected from key items of home furniture, fittings, and the patient. The paper-based 2D illustrations are typically annotated with measurement arrows that serve as prompts to indicate the precise points in 3D space that must be accurately identified and measured by the clinician in order to gather the necessary data to formulate an assessment; the data is subsequently used to prescribe the necessary home adaptations and assistive equipment [21]. Figure 1 shows some examples of paper-based forms and the 2D illustrations that are currently used as part of the AEPP [22,23].

Despite the importance of accurate measurement and the prominent use of 2D paper-based measurement guidance, approximately 50% of assistive equipment that is prescribed as a result of the AEPP is abandoned by service users [24]. One of the principal reasons of equipment abandonment is due to “poor fit” between the equipment and the individual using it, despite the fact that trained OTs carry out the measurement tasks [24,25]. The impact of this “poor fit” issue is significant and wide-spread and negatively impacts patient health outcomes, accelerates functional decline, increases overall exposure to fall risks in the home, and more generally, unnecessarily depletes already scarce and valuable health care resources [26,27]. To compound this issue, it is anticipated that due to time and OT resource limitations, the responsibility of taking and recording of measurements will soon become that of the service users or

their family members or carers [28]. Given the issues of “poor fit” that already arise as a result of trained OTs carrying out these tasks, it is likely that “poor fit” will remain a significant issue if patients and carers will be given the responsibility for carrying out these skilled tasks [29]. Indeed, patients taking their own measurements and carrying out self-assessment has already become part of practice in some NHS trusts in the United Kingdom [28]. However, little is known with regards to the tools that patients use to facilitate taking and recording accurate measurements as part self-assessing for equipment to ensure

successful or correct fit of equipment [30], particularly given the patients desire to being involved in self-assessing for the provision of equipment. If patients, family members, and carers are to be able to carry out the AEPP effectively, there is a need to be supported via the provision of appropriate information, training, and new and innovative tools that provide clear and effective guidance, support, and facilitate the necessary gathering of reliable and accurate information. Currently, there appears to be no such tool or guidance designed specifically for use by patients to carry out the AEPP.

Figure 1. 2D paper-based measurement guidance form used within the AEPP in practice. AEPP: assistive equipment provision process.



3D Visualization Technologies for Guiding Assistive Equipment Provision Process (AEPP) Self-Assessment

The term 3D visualization refers to computer graphics software applications that capitalize upon natural aspects of human perception by visually simulating 3 spatial dimensions in 2D space, hence enabling the user to visualize, interact with, and control a given object within a 3D space. The value of 3D visualization technologies in the falls prevention research domain has already been demonstrated in a number of existing studies that focus on the areas of exercise intervention. Some examples include Uzor et al [31] and Doyle et al [32] who aim to improve uptake and adherence to home-based falls prevention exercise programs by replacing traditional paper-based 2D illustrated exercises with equivalent interactive 3D visualization of these programs. One existing study explores the potential of exploiting 3D visualization technologies to assist clinicians in identifying extrinsic fall hazards. Du et al [33] developed a robotic system to automatically model patients' home environments in 3D space. A 3D visualization of the environment is constructed, with the help of the robot, to assist clinicians in identifying the precise location and nature of extrinsic fall hazards. Examples in other areas of health care include the work of Spyridonis et al [34] who found that

enabling patients to carry out self-assessments by reporting the type and precise location of back pain by using a 3D visualization of the human body was more accurate and intuitive than the traditional paper-based 2D model of the human body typically used in practice. Other studies have found similar benefits in utilizing 3D visualizations to communicate other forms of pain to clinicians. For example, Jang et al [35] enable patients to express and communicate their symptoms of pain to clinicians by annotating specific regions on an on-screen 3D representation of the human body using free-hand drawing. De Heras Ciecchowski et al [36] propose a preoperative surgical 3D visualization system for breast augmentation using 2D digital photographs of the patient's torso and reconstructing these into 3D models. This system helps clinicians to perform virtual clinical analysis without the patient being present and visualizes the required measurements on the modeled body in order to facilitate accurate measurements for the treatment.

The research literature to date indicates that the use of 3D visualizations have shown promise in providing opportunities to overcome the challenges of existing 2D clinical tools to sufficiently provide the visual quality necessary to conceptualize visual cues as part of a particular treatment and assessment [37,38]. In light of the equipment abandonment issues faced by the current AEPP process, discussed previously, there is a need

to explore the potential value of 3D visualization applications developed specifically for use by service users that serve as an aid in the process of carrying out the key measurement tasks that form part of the AEPP.

Patient Perceptions and Acceptance of Technology

The effective design of health technologies that are usable and deliver functionality aligned with the needs and preferences of the patient is as important as the innovation itself [39], since this is likely to realize higher levels of engagement and adoption of a given technological innovation [40-42]. Consequently, it is vital that patient experiences and perceptions are sought and explored if new tools and technologies are to be viable, accepted, and usable in clinical practice [43]. Involving end users in the development of technology in a formalized manner ensures that user needs, design considerations, and crucial aspects of clinical interventions are appropriated within the design and development process. A number of formal user-centered methods [39] and technology adoption theories are available to gain valuable insights into user needs and perceptions of technology, and they can be factored into the design of that technology [44,45]. For example, the technology acceptance model (TAM) has been increasingly seen within the health care field as an appropriate theory used to better understand factors that predict actual system use, adoption, and acceptance [46,47]. Recent research has explored both clinicians and patients' responses using TAM within a quantitative context [48]; however, the use of TAM in qualitative work has become increasingly recognized [46]. More specifically, to use the predefined high-level TAM constructs such as perceived usefulness (PU) and perceived ease of use (PEOU) as a deductive framework by means of which user perceptions of emerging technologies may be interpreted and made sense of [49]. In turn, the perceptions of users may be used to inform the iterative design and development of proposed technological innovations within a health care context.

This study presents a novel mobile 3D visualization application prototype designed to provide measurement guidance to users as part of the AEPP. The aim of this study was to investigate the perceptions of community dwelling older adults regarding the feasibility, benefits, and challenges of using a 3D visualization technology application to facilitate carrying out AEPP self-assessment tasks in practice. The next section describes the initial design phase activities and provides a detailed walkthrough of the application prototype and system architecture. Next, the main study is presented along with the methods used to explore the experiences and views of community-dwelling older adults after using the 3D visualization application for carrying out AEPP measurement tasks. The results of the main study are then presented followed by a discussion of the findings and implications and recommendations for use of the 3D visualization application in practice. Conclusions are then drawn, along with details of future research directions.

Concept Design Phase and Application Walkthrough

This section provides details of the initial concept design phase and a walkthrough of the prototype application developed for use in the main study.

Initial Concept Design of the Prototype Application

In order to significantly improve user experience, usability evaluations should be performed continuously through the early stages of low and high fidelity prototype development [50]. Therefore, an initial concept design phase was undertaken to inform the overall design and development of the 3D measurement aid prototype (3D-MAP). User-centered design methods and design guidelines were employed and adhered to in this phase to ensure the application was aligned with the needs of the intended users [51,52]. Figure 2 presents an overview of the protocol followed during this phase.

A total of 3 interaction designers, 5 community-dwelling older adults, and 8 OTs took part in the concept design phase. The objectives of the session were to identify high-level requirements specific to the application and to reflect on existing evidence-based practice and explore ways in which the application could be designed to support current practice. An overview of existing AEPP practice was presented to participants at the start of the session. In addition, samples of existing 2D paper-based measurement guidance leaflets were provided as a point of reference to encourage older adults to design their sketches in accordance with the provided materials. Participants were also shown examples of existing clinical visualization applications, which demonstrated how 2D illustrations may be presented using 3D visualization technologies on mobile phones, tablets, and laptops.

Participants were asked to explore the idea of utilizing a software application to enable AEPP self-assessment tasks and to suggest key design features and functionality that not only matched but enhanced the conventional 2D leaflets if the application were to replace them. As a result, participants were encouraged to sketch out rough ideas, and with help from interaction designers, fine-tune these ideas into more complete annotated concept sketches of a potential application interfaces and associated functionality. Figure 3 presents an example of a concept sketch produced during the initial concept design session.

Once all participatory design sessions were completed, notes and recordings of the sessions along with the annotated concept sketches were perused and used to inform the design and development of the 3D-MAP application. A total of 8 user requirements (UR1-UR8) were identified as a result of this concept design phase.

OTs believed that measurements should be recorded electronically to remove the need to keep paper records of measurements (UR1). They envisaged the application would allow them to annotate 3D representations of the item by adding measurements directly to the item being modeled by the application. UR2 reflects the fact that OTs stated they required a clean looking interface that includes only necessary information or functionality to enable them to carry out the task at hand. Enabling the user to rotate and zoom the position and the view perspective of the 3D model to improve interpretation of clinically significant landmarks was also seen as crucially important (UR3). Participants suggested that arrows (as often used in 2D paper-based guidance) would serve as a useful prompt to provide guidance but could also serve as a feature

for inputting measurements when clicked (UR4). Automatic generation of assessment reports, as much of what the application provides, was seen as a potential feature (UR5). OTs also saw potential for integrating data collected automatically into patient records (UR6). Given the nature of carrying out home visit assessments often in patient’s homes,

it was more fitting for the application to be deployed on a mobile platform, given the reported increase of use of mobile devices within OTs professional roles (UR7). Clinicians felt that audio instructions that guide the user while using the application would be useful for them but also for patients if they were ever expected to use such an application (UR8).

Figure 2. Overview of the procedure for the initial concept design phase.

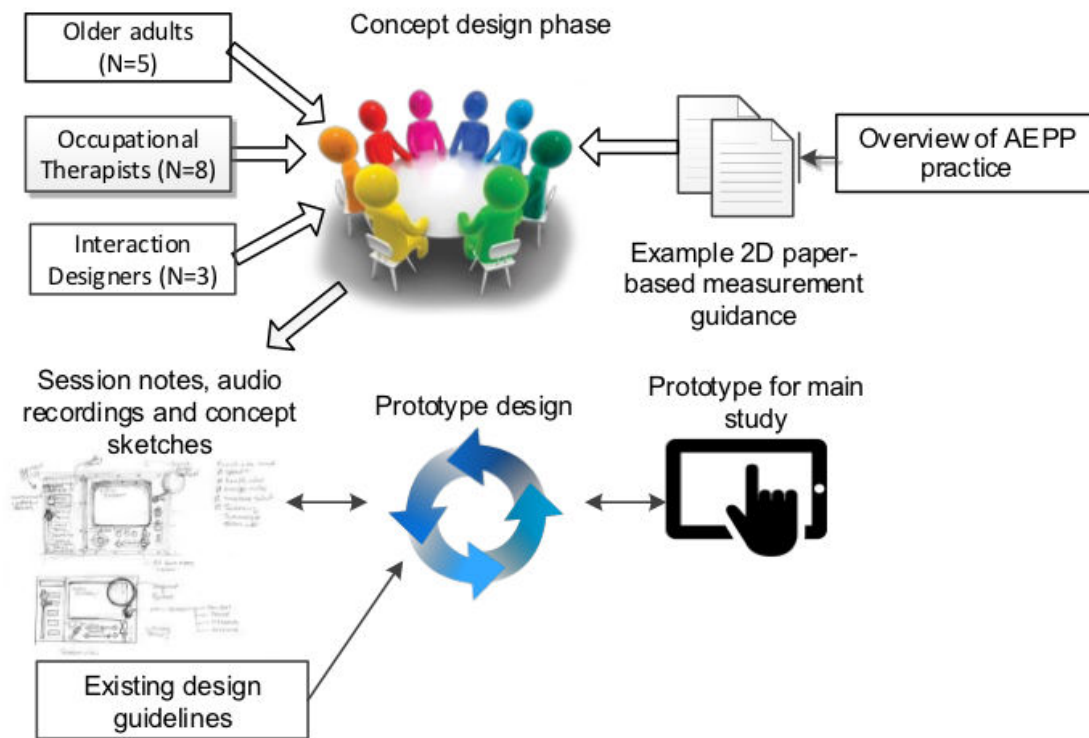
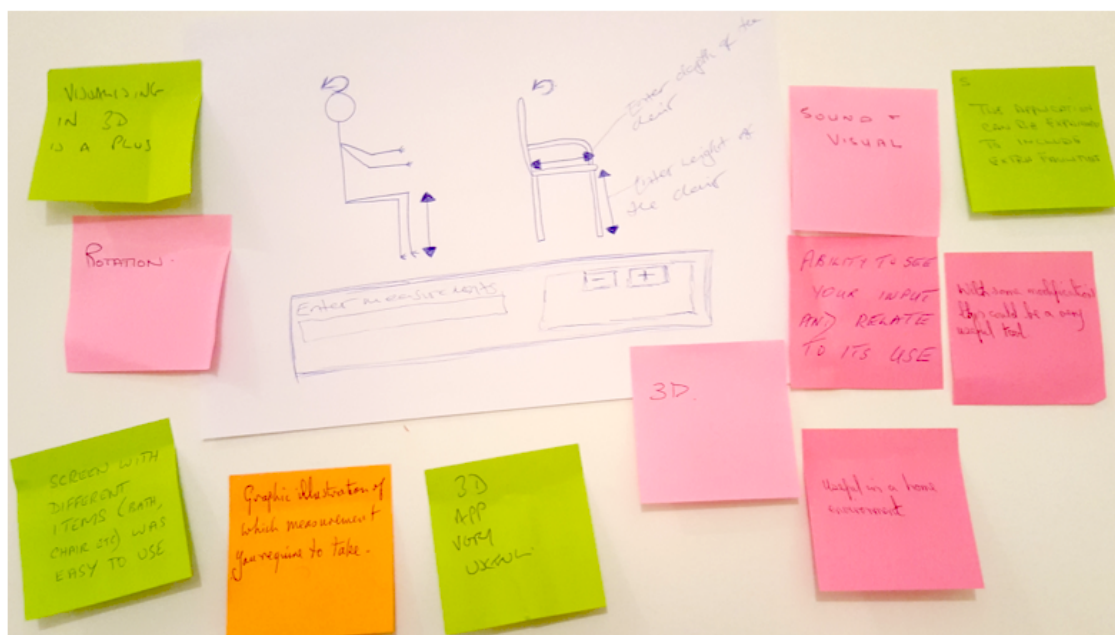


Figure 3. Concept sketches of a self-assessment tool designed by older adults during the participatory design sessions.



Overview of the 3D Measurement Aid Prototype (3D-MAP) Prototype

The 3D-MAP application, which is an interactive and functional application (high fidelity prototype) utilizing 3D visualization technology, has been developed according to the user requirements and concept sketches that emerged from the initial concept design phase, and it is consistent with existing 3D visualization guidelines presented in the existing research literature [53-56]. The system design and architecture of 3D-MAP is now presented along with an application walkthrough.

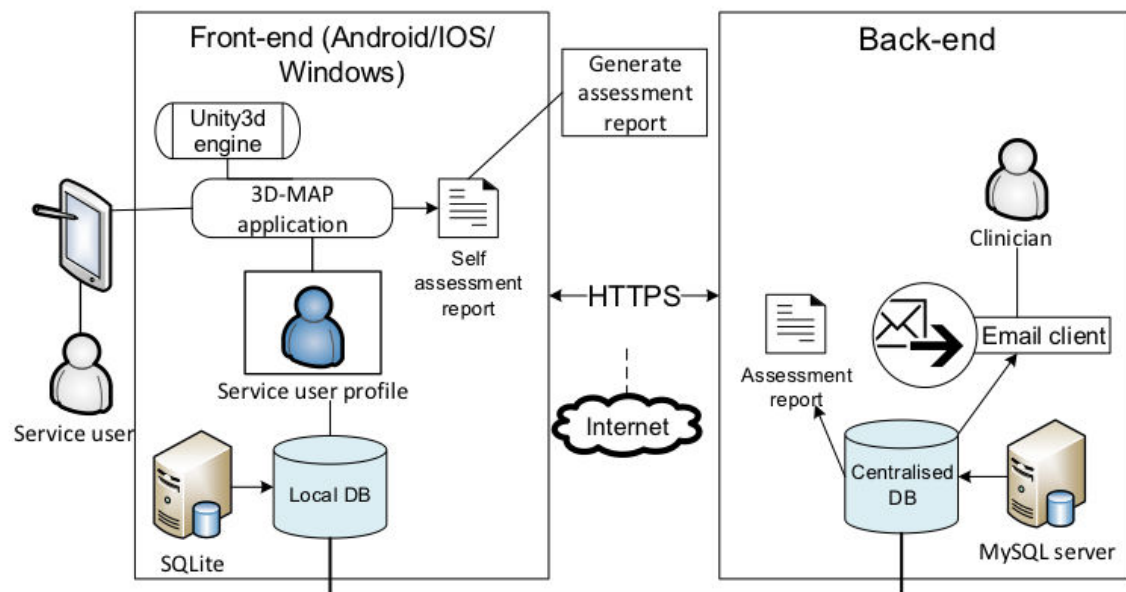
System Architecture

The deployment platform for the 3D-MAP prototype was the Android operating system (OS), which is an open-source platform that is freely available for both personal and commercial use. In the anticipation of the prototype being used on multiple platforms, the prototype was developed using the Unity3D game engine that allows applications to be deployed on multiple platforms including Android, iOS, and Windows (UR7). Unity3D (Unity Technologies, San Francisco, United states) is a tool chosen for its capabilities of rendering 3D models

and deploying applications on mobile devices seamlessly. Considering the user requirements that emerged from the initial concept design phase, Figure 4 shows the underlying system architecture of the 3D-MAP prototype.

The user has the ability to input measurements by using the device's touchscreen. Measurements are stored in a local database located on the device. The stored data is then transmitted through hypertext transfer protocol secure (HTTPS) to a centralized MySQL database in encrypted format and is only accessible by authorized clinical users. All relevant application data stored locally is encrypted and is deleted from the device subsequent to sending the data to the centralized database. The users have the option of generating a self-assessment report (UR5). Once the necessary data is collected, the user can email the assessment report to their appointed clinician. Data collected are both stored locally and remotely to a service user profile. This offers a workable electronic record for each patient that has received assessments from clinicians and for those who have self-assessed; this application also offers capabilities of sharing patient records to other clinicians.

Figure 4. 3D measurement aid prototype (3D-MAP) system architecture.



Application Walkthrough

A crucial feature of the application is the audio prompt and visualization of the measurement guidance. The application displays 3D models of the 5 home furniture items (bed, bath, toilet, chair, and stairs), that are most commonly associated with extrinsic falls within the home environment [24] and are therefore typically measured as part of the AEPP. Arrows are used as prompts to indicate discrete points on the home furniture to be measured (UR4). The 3D models and measurement arrows were developed using Blender (Stichting Blender Foundation, Amsterdam), which is an open-source software package for designing 3D graphics and animation [57]. The models were

then converted into an “.obj” file format and imported into Unity3D. More specifically, the measurement guidance was presented using two prompt features: arrows and audio prompt (UR8). Measurement guidance is available for each respective furniture item from the main menu as shown in Figure 5 (UR2).

The user is presented with the home furniture item interface and with the necessary measurement prompts, using indicative arrows superimposed onto each respective 3D model within 3D space. These measurement prompts were positioned as indicated by existing 2D paper-based guides, the positions of which were verified via careful consultation with clinicians who specialize in the AEPP measurement training. An example of the toilet scene, including a measurement prompt is given in Figure 6.

Figure 5. 3D measurement aid prototype (3D-MAP) application (main menu).

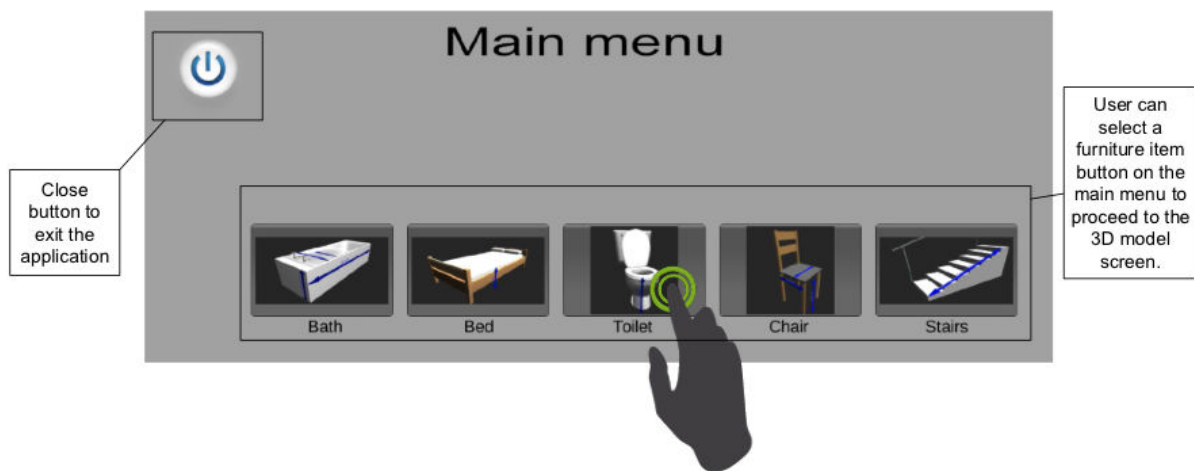
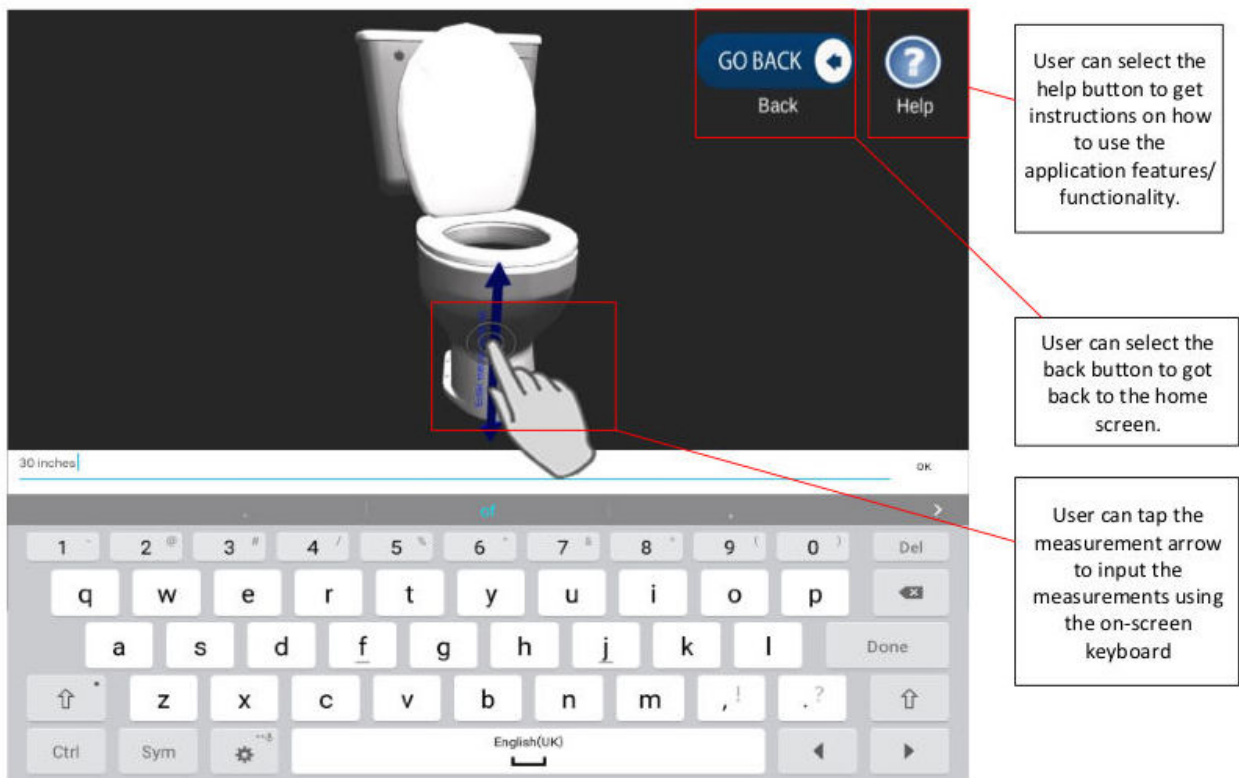


Figure 6. 3D toilet model screen.



The 3D models of the items of furniture and prompts (arrows) were developed using Blender [57], converted into an “.obj” file format and imported into Unity3D. The measurement guidance is presented using two prompt features: 3D arrow lines and audio instructions that guide the user to provide the necessary measurements. In line with the requirements gathered from the initial concept stage, written instructions from the paper-based forms were taken and translated into audio files. Audio cues (UR8) are activated when the arrows are touched

providing instruction on how and where to accurately measure specific parts of home furniture (UR4).

Users have the ability to rotate the 3D furniture models to view discreet areas of interest in detail (UR3). In order to do so, the figure swipe gesture input was employed, which enabled the handling of rotating the models. Figure 7 presents an example of rotating one of the models clockwise, by the user swiping their finger horizontally to the left in order for the model to follow suit, similarly, a horizontal swipe to the right rotates the model anticlockwise.

Figure 7. Rotation feature to manipulate 3D models to facilitate gaining a better understanding of the clinical guidance.

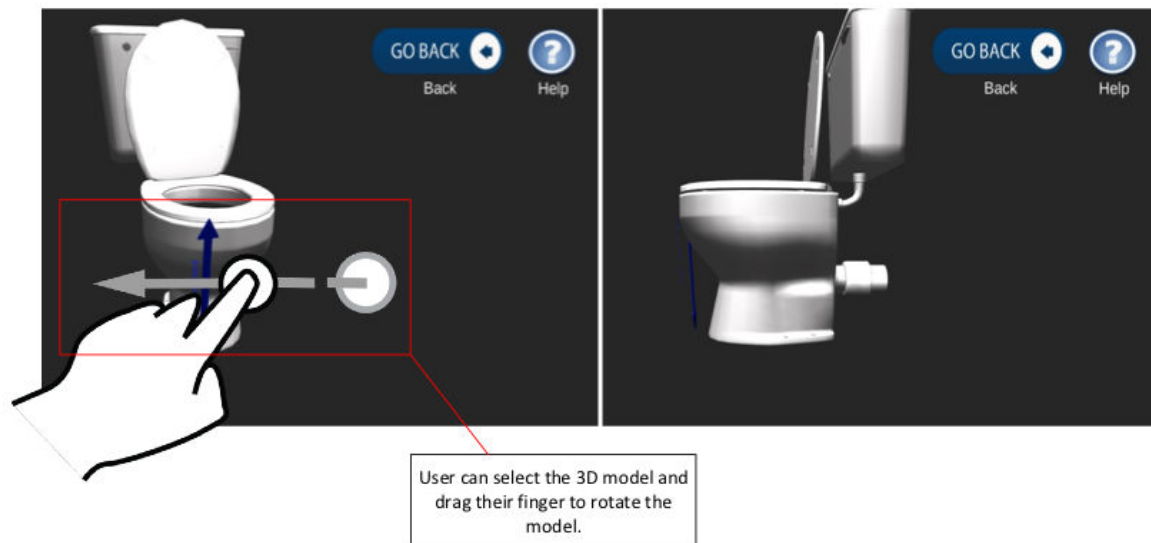
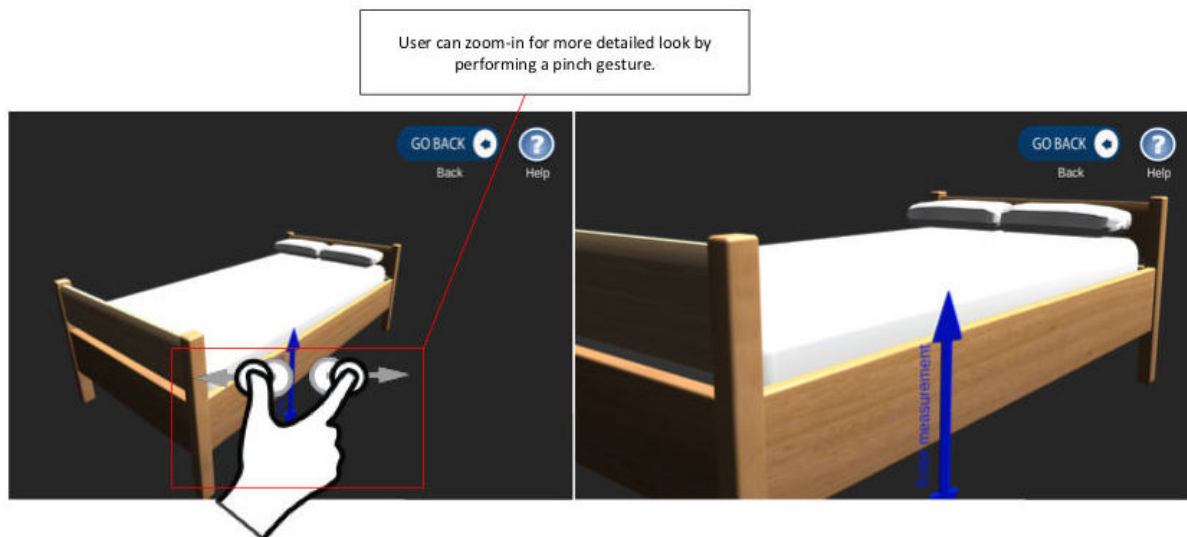


Figure 8. Zoom in/out feature to manipulate 3D models to facilitate gaining a better understanding of the clinical guidance.



Another key component of the design is the zoom-in and zoom-out feature (UR3), which changes the viewpoint and perspective for a more detailed look at the 3D furniture models by using the pinch gesture to achieve this (as shown in [Figure 8](#)).

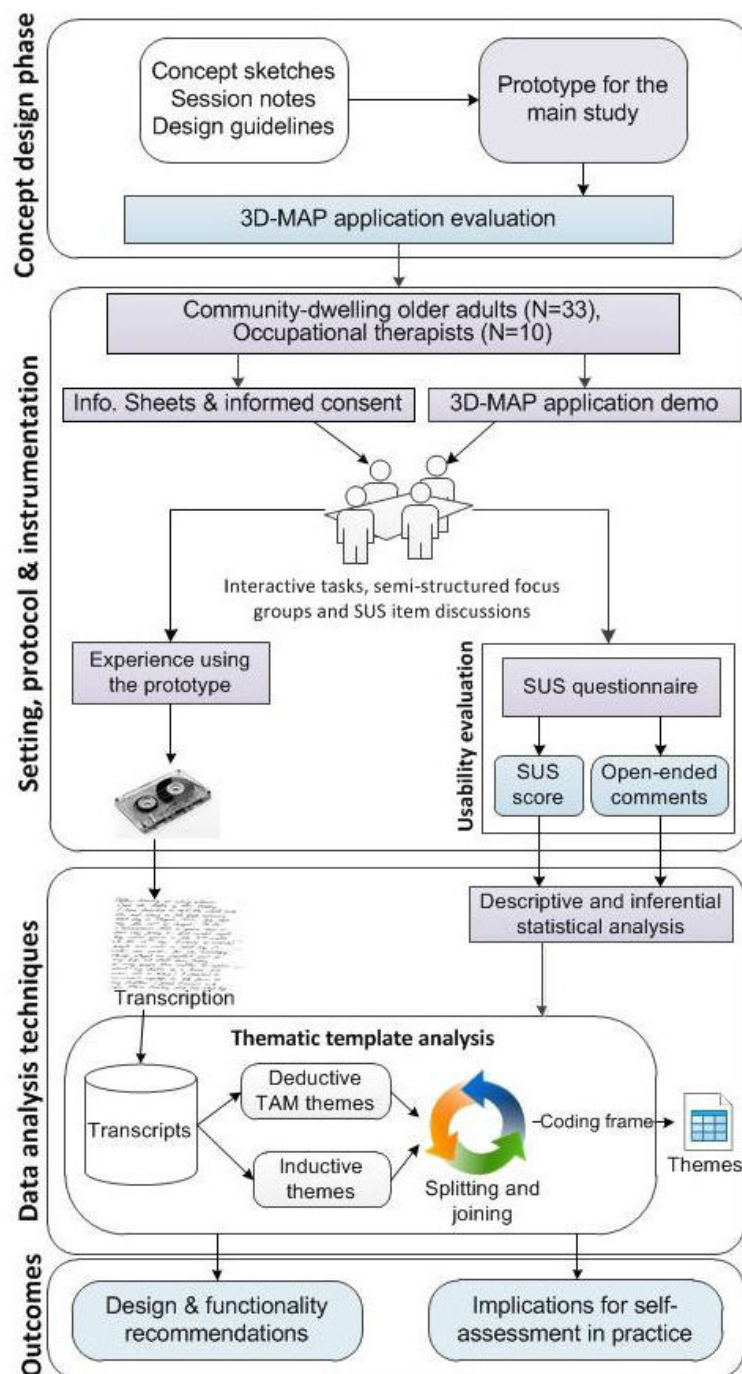
The application enables users to input home furniture measurements via the use of the arrow prompts augmented with sound instructions (UR8). The application is flexible in relation to the interface used, the visualization capability and audio cue options provided to users are also optional for those who feel they have grasped the use of the application and no longer require audio assistance.

Methods

Overview

This section provides details of the data collection and analysis methods used to explore the perceptions of community-dwelling older adults regarding the use of the 3D-MAP application as a self-assessment tool within AEPP in practice. [Figure 9](#) presents an overview of the study design, methods, and research instruments employed to produce study outcomes and recommendations for practice.

Figure 9. Overview of the session, methods, and process.



Participants

A purposive sampling strategy was used for recruitment of participants for this study, for which a total of 33 community-dwelling older adults were recruited. This was in line with a posthoc power analysis that was performed, which indicated that a similar sample size of 33 participants was sufficient (power=0.80) to detect a large effect (0.5) with alpha set at .05, 2-tailed. Participants were recruited through a number of different sources. In the first instance, managers of leisure centers that run exercise classes for 50+ groups were contacted as gatekeepers to disseminate invitations to older adults. A total of 18 participants were recruited through the “active 50’s” group

at Brunel University and 15 participants through the “active lifestyles” group in the area of South West London. A financial incentive of a £10 voucher was offered in acknowledgement of participants who agreed to take part. The inclusion criteria for selection were that participants were over the age of 50 years, familiar with or had basic skills of using technology (eg, the use of desktop computers, laptops, mobile phones), and considered themselves as active and healthy. Each participant reported their familiarity with touchscreen technology used within their personal and in some cases professional lives. Twenty-three of the participants were female (70%, 23/33) and 10 (30%, 10/33) were male; (23 females; 10 males, mean age=71.2 years, range=56-89, standard deviation=8.3). The

majority of participants were retired or semiretired with the exception of 2 who were in full-time employment. This sample had no prior exposure to using self-assessment tools for the AEPP, however, 5 participants reported to have second-hand

experience of family members having their home adapted due to ageing changes. [Table 1](#) provides the demographics and summary of participant profiles for this study.

Table 1. Summary of participant profiles.

Part. ID	Gender	Age in years; mean (SD), range	Occupation	Group number
#F1-#F8	2 F ^a , M ^b , 5 F	66.2 (7.7), 52-75	6-retired, aircrew, flight manager, administration	1
#F9-#F14	M, 2 F, 3 M	75.2 (7.9), 65-86	Retired	2
#F15-#F18	M, F, M, F	71.0 (3.7), 66-75	Retired	3
#F19-#F27	M, F, M, 2 F, M, 3 F	70.6 (9.6), 54-89	Retired	4
#F28-#F33	6 F	76.2 (6.4), 68-87	Retired	5

^aF: female.

^bM: male.

Protocol and Instrumentation

Participant sessions were conducted on a one-to-one basis for the main interaction task, followed by a series of focus group sessions to discuss participant experiences of using the 3D-MAP application. The total duration of each session were approximately 90 min. Each session consisted of five key stages: (1) issue information sheet, question and answer, and complete consent form (individual); (2) provide a demonstration of the 3D-MAP application and answer questions (individual); (3) carry out the interactive task using the 3D-MAP application (individual); (4) administer system usability scale (SUS) questionnaire and retrospective think-aloud discussion (individual); and (5) follow-up focus group discussions about individual SUS items and perceptions and experiences of using the application (group).

An information sheet was given to participants on arrival before taking part in the session; this provided a background, aim of the study, and listed tasks that participants were expected to perform during the session. The content was worked through

with each participant. They were continuously given the opportunity to ask questions to resolve any misunderstandings or queries. Informed consent was obtained by asking participants to complete a consent form, which explained their ethical rights to withdraw from the study at any time without having to provide any reason. Participants were given a brief demonstration of the 3D-MAP application, which included showcasing key features of the application, inputting measurements, and generating assessment reports. At this point, further information was provided regarding the application and participants were allowed to practice using it, while being individually supervised by a facilitator who answered any questions as they arose. The participants were allowed to provide their thoughts and feedback on their first impression of the application during the demonstration. Subsequently, participants were then set up with the application on their Android tablet and were asked to use the application, and were given written instructions outlining a series of tasks to perform using the application. [Textbox 1](#) presents the key steps involved in interacting with the 3D-MAP application.

Textbox 1. Written instructions for the interactive task.

Instruction sheet for participants

- Start the application
- Select a home furniture from the main menu screen
- Rotate 3D model left or right and up or down
- Zoom in and out using the pinch touch gesture
- Click on arrows to activate the audio prompt
- Measure the 5 home furniture items
- Enter measurements using the virtual popup keyboard
- Click on the main menu button (move on to the next furniture item)

For the interactive task, participants were asked to use the application and to manipulate the viewpoints or position of the 3D furniture models to obtain the necessary depth of clinical guidance to measure the 5 home furniture items. Participants were encouraged to verbalize their thoughts immediately after interacting with the application, while adopting a retrospective

think-aloud approach (otherwise known as think-after [58]) immediately after interacting with the application [59]. This provided insights into the usability of the application, thus resulting in additional qualitative data. The think-aloud approach is a well-established technique used for gathering thoughts of users while they are interacting with a software application. The

technique is particularly useful to gain insights and understand the reasoning behind participants' preferences and thoughts. It is most commonly used in usability testing studies and has been employed to study older adults' interactions with user interfaces (UIs) and ways in which they structure their tasks when using the interface [60]. Variants of the technique such as concurrent think-aloud has limitations when being used with this user cohort, particularly those who exhibit cognitive impairments, find unfamiliar interfaces challenging to use, and employing the technique can hinder the completion of the task [60,61]. With this in mind, retrospective think-aloud was, therefore, adopted to get participants to explain their behavior after completing the tasks [58]. Users were reassured that there was no urgency in completing the task and were encouraged to take as long as they felt necessary to verbalize their thoughts while interacting with the application. Think-aloud prompts such as "what did you think at this moment?" and "what were you thinking?" were used after completing the task and whenever there were long periods of silence [62]. Furthermore, participants were encouraged to use the application to stimulate think-after thoughts. Participants were asked to complete a SUS questionnaire [63] on completion of the interaction task, which was used to evaluate the general usability of the 3D-MAP prototype. SUS is a 10-item questionnaire instrument that asks users to rate a system against a list of items on a 5-point Likert scale from 1="strongly disagree" to 5="strongly agree." The word "cumbersome" in SUS item 8: "I found the system to be very cumbersome to use" was replaced with "awkward" to increase comprehension as suggested by Bangor et al [64]. Each SUS item was further modified by replacing "system" with "3D-MAP application" to assist users in scoring the application accurately. Such changes to SUS are standard practice and have no impact on the questionnaire's validity or reliability [65]. The SUS produces a score that represents a quantitative measure of the general usability of a system (for this study 3D-MAP application). After completion of the SUS instrument, participants were asked to discuss the score they attributed to each respective SUS item. Focus groups were conducted in a semistructured format with participants who were asked to discuss their experience of using the application with respect to each individual SUS statement, and then more generally about their perceptions of the opportunities and challenges of the 3D-MAP prototype as a self-assessment tool in practice. In total, 5 focus groups were undertaken and the number of participants in each group varied (n=8, 6, 4, 9, and 6, respectively). The number of focus groups and sample of participants in each group is in line with the minimum 4 focus group rule and the recommended 4-12 participant threshold [66] that is considered to be suitable numbers for conducting focus groups within a health care context [67]. Written notes were being taken by moderators to supplement the analysis of later discussions held at the end of the sessions.

Data Analysis

IBM SPSS statistical software package version 20.0.0 was used to analyze the SUS responses collected for this study. The quantitative data collected in this study was subjected to descriptive and inferential statistical analysis. To better understand and interpret the SUS scores, the adjective [68] and

curved grading scales [69,70] were used to analyze and interpret the SUS scores. This involved calculating a SUS score from the completed questionnaires, and generating a value on a 100-point rating scale, which may then be mapped to descriptive adjectives (best imaginable, excellent, good, OK, poor, and worst imaginable), an acceptability range (acceptable, marginal-high, marginal-low, and not acceptable), and a curved grading scale (F=absolutely unsatisfactory to A+=absolutely satisfactory). *These baseline ranges and grading are derived from a sample of over 3000 software applications that provide the comparative baseline [68].* Until recently practitioners viewed SUS as unidimensional until Lewis and Sauro [65] concurrently with Borsci et al [71] proposed SUS is composed of a two-factor structure in which 2 subscales, namely, usability (SUS items S1, S2, S3, S5, S6, S7, S8, and S9) and learnability (SUS items S4 and S10) underpin the SUS instrument. Additional statistical analysis was performed using one-sample *t*-test to establish whether there were significant differences between the respective mean SUS scores and the midpoint value of three (of the 5-point Likert type scale responses) for each individual SUS item and for the usability and learnability constructs.

Audio recordings of SUS item discussions, retrospective think-aloud sessions, and associated focus groups was transcribed verbatim into text format by a professional transcriber for subsequent thematic template analysis. Thematic analysis is a qualitative analysis method used for searching and identifying themes that occur within textual datasets [72]. Using this method enabled patterns in the dataset to be identified and categorized. Analysis of the semistructured interview data was both inductive as the development of the themes were data driven and deductive, beginning with predefined (a priori) themes that are theory driven and linked to the analytical interest of researchers [73]. The first stage involved creating a template that used the predefined codes specified by the TAM. Hence, analysis considered the participant perceptions of the 3D-MAP application in the context of the two high-level TAM themes: PU and PEOU, and themes that emerged in addition to these. Carrying out the analysis in this way conforms to what is considered to be a contextual constructivist approach to thematic analysis [74]. The entire dataset was then read and comments were assigned to the two predetermined TAM themes and other high level themes that emerged, moving similar texts into one place and rereading segments to ensure that connections were justified. The dataset was then examined iteratively through several stages of splicing, linking, deleting, and reassigning subthemes within each predetermined high-level theme. Subthemes in the context of individual participants' accounts were considered, as well as examining the data across participants. Subthemes were included because of their relevance to the research question and not necessarily because of their prevalence across the data set, as is acceptable in qualitative research.

Ethical Considerations

Ethical clearance was obtained from Brunel University research ethics committee before any data collection. Informed consent was therefore sought from each participant before taking part in the focus group interviews. Participants who took part in the

study was assured of their confidentiality and anonymity and informed both verbally and in writing of the purpose of the study and of their right to withdraw at any time.

Results

This section presents the results of an initial usability evaluation of the 3D-MAP prototype and the associated follow-up focus groups.

System Usability Scale (SUS) Evaluation Results

The overall SUS results for 3D-MAP revealed a mean score of 65.8 (SD 16.05) on a 100-point scale. According to the SUS scoring matrix [68] this indicates that the application delivers “marginal-high” (acceptability range), “good” (descriptive adjectives), and “grade C” (curved grading scale) levels of usability. The results were analyzed with regards to the SUS usability and learnability subscales [65,71], which revealed scores that were significantly above the midpoint benchmark of 3.00: 4.02 ($P=.004$) and 4.27 ($P=.001$), respectively. This shows that participants were positive about the application’s usability and learnability. The Cronbach measure of consistency for the 2 constructs (0.67 and 0.63, respectively) achieved scores

above the threshold of acceptable reliability of 0.6 for studies with small sample size [75]. A Spearman rho correlation was performed to determine the correlation between age and SUS scores. There was no significant correlation between age and SUS score ($r=-0.041$), which indicated that the 3D-MAP was considered usable independent of age. The study, therefore, continued with a follow-up analysis of the individual SUS items against the midpoint of 3.00, to identify any usability issues that the users in the sample experienced during the interactive task. To conduct this analysis, the negative SUS items (S2, S4, S6, S8, and S10) were reversed so that scores above 3.00 indicated a positive response. Table 2 presents a breakdown of the results of this analysis, accompanied by the full SUS item open-ended responses that participants provided.

Mean scores for all 10 SUS items, in absolute terms, were above the neutral midpoint of 3.00, which indicates that participants tended to be positive about the 3D-MAP application in terms of the SUS items. Furthermore, in terms of statistical significance, mean responses to all 10 SUS items were significantly higher than the midpoint benchmark. The results of the statistical comparison of the SUS scores and midpoint are now considered alongside the open-ended responses provided for each respective SUS item.

Table 2. Mean system usability scale (SUS) score and midpoint comparison.

SUS ^a item	Midpoint	3D-MAP ^b , mean (SD)	Gap score	Df ^c	<i>t</i> test values	<i>P</i> value (2-tail)
S1: I think that I would like to use this 3D-MAP application frequently.	3.00	3.42 (1.062)	0.42	32	2.30	.03 ^d
S2: I found the 3D-MAP application unnecessarily complex. ^e	3.00	4.09 (0.879)	1.09	32	7.13	<.001 ^d
S3: I thought the 3D-MAP application was easy to use.	3.00	3.88 (1.083)	0.88	32	4.66	<.001 ^d
S4: I think that I would need the support of a technical person to be able to use this 3D-MAP application. ^e	3.00	3.91 (1.234)	0.91	32	4.23	<.001 ^d
S5: I found the various functions in this 3D-MAP application were well integrated.	3.00	3.94 (0.933)	0.94	32	5.78	<.001 ^d
S6: I thought there was too much inconsistency in this 3D-MAP application. ^e	3.00	4.19 (0.873)	1.19	32	7.62	<.001 ^d
S7: I would imagine that most people would learn to use this 3D-MAP application very quickly.	3.00	3.94 (1.435)	0.94	32	3.76	.001 ^d
S8: I found the 3D-MAP application very awkward to use. ^e	3.00	4.26 (0.682)	1.26	32	10.28	<.001 ^d
S9: I felt very confident using the 3D-MAP app.	3.00	3.82 (1.211)	0.82	32	3.88	<.001 ^d
S10: I needed to learn a lot of things before I could get going with this 3D-MAP application. ^e	3.00	4.39 (0.747)	1.39	32	10.71	<.001 ^d

^aSUS: system usability scale.

^b3D-MAP: 3D measurement aid prototype.

^cDf: degrees of freedom.

^dIndicates statistically significant $\geq .05$ confidence level.

^eResponses of negative items were reversed to align with positive items, higher scores indicate positive responses.

Responses to item S1 indicated that participants tended to agree with the statement that they would like to use the 3D-MAP application frequently (mean=3.42, $P=.03$). However, when analyzing the open-ended responses to this item, it was apparent that some participants noted that they did not anticipate taking

home measurements would be a task that they would have to carry out frequently. One participant disagreed with the notion of frequently using the application, as they reported having arm mobility issues that made using the handheld tablet device difficult.

Well hopefully we wouldn't have to use it frequently, if we don't need too many things. This is just mainly for ordering things to help us round the home isn't it? [F14]

I wouldn't use the 3D app frequently because, well it's hard to hold...but it's easy to use. [F22]

Participants tended to disagree with S2, that is, that they found the application unnecessarily complex (mean=4.09, $P<.001$). Participants did, however, highlight difficulties with rotating the 3D furniture models but felt that the other functionality of the application offered an easier way to record measurements compared with paper-based counterparts, as it did not require writing and that some of the other measurement arrows clearly showed exact areas to measure on furniture items.

Although I do find that rotation a bit of a pain...It's not complex, you don't have to do the writing and it gives you the arrows, it's showing you where you have to measure across. [F3]

Participants tended to agree that the application is easy to use (mean=3.88, $P<.001$). There were, however, usability issues expressed particularly relating to items that had multiple measurement entry arrows and in relation to rotating the 3D models using the touch gesture. One participant noted that the difficulties encountered were not associated with using the application or understanding the instructions given by it but rather, with the physical task of taking the actual measurements.

I think it needs some more development, but I would be happy to use it. I think the concept is really good...things like the toilet, when you've only got one measurement, you can get the link on that very quickly and easy. It's when you've got multiple measurements to do the screen doesn't seem...sensitive to what you need. [F3]

It's better than it would be because you've got clear arrows and everything to show you where you've got to measure. My problem is, if like me and a couple of other people, who live on their own and have, and are elderly, it's hard to measure, it really is hard to measure. [F7]

Responses to S4 indicated that participants did not feel that a technical person was needed to help them use the application (mean=3.91, $P<.001$). Nevertheless, some participants noted that they felt other user groups may require such assistance, depending upon factors such as age, functional abilities, and previous exposure to technology.

...it depends on age and whether you are, you know, you have like tablets. And it depends what your history is with you know with computer stuff. [F2]

It depends very much on the individual person using it, but for me, no...it gives a bit of explanation for what you need. If you were using it with other patients it's going to be a very wide range of abilities. [F21]

There was a tendency to agree that the various functions of the application were well integrated (mean=3.94, $P<.001$). Some participants, however, commented that they had difficulty determining the measurement status of some items, that is,

whether a measurement had already been entered or was still required.

It was integrated but I was hitting the screen avidly trying to get a measurement and it was already there but we couldn't see it you know that sort of thing...a little measurement box. [F9]

For S6, participants tended to disagree that there was too much inconsistency in the application (mean=4.19, $P<.001$). Nevertheless, some participants felt that the positioning of some of the measurement guidance arrows (particularly for the chair) could be further optimized and, in some cases, reported that the functionality appeared to be unresponsive.

It's the responsiveness. It's just that some of the arrows wasn't responsive all the time. [F11]

...the only one I would say I was a bit confused about was the chair...it's sort of measuring the depth of it, you know where the chair is but the arrow was underneath it. [F9]

Participants tended to agree with S7 that most people could learn to use the application very quickly (mean=4.19, $P=.001$). One participant, however, considered that a step-by-step wizard type interface would be a useful design feature to reduce the amount of learning necessary to be able to use the interface and ensure that all measurements were collected as needed.

I think if they were taken through it bit by bit, like...a little icon to touch that says move to the next bit once you've answered the first bit. [F18]

Responses to S8 tended to disagree that the application was awkward to use (mean=4.26, $P<.001$). Some participants commented that the 3D models were easier to use and comprehend than their 2D counterparts. One participant reported issues with rotating the 3D models and suggested that on-screen rotation buttons may help this task.

It's certainly better than having a picture. [F6]

I had it back to front or upside down (the 3D-model). if it had...a little button with the arrows going four ways...you could turn your 3D thing round better than trying to do it with your fingers. [F30]

Participants tended to agree with S9, that they felt confident using the application (mean=3.82, $P<.001$). However, one participant noted that their confidence could have been related to having used this with the study facilitator present, which would not be the case if it were used, as intended, independently within the home setting.

Well, because we've got someone with us, probably if we were doing it on our own, we'd be a little bit, ooh did I do that right, that sort of thing. [F23]

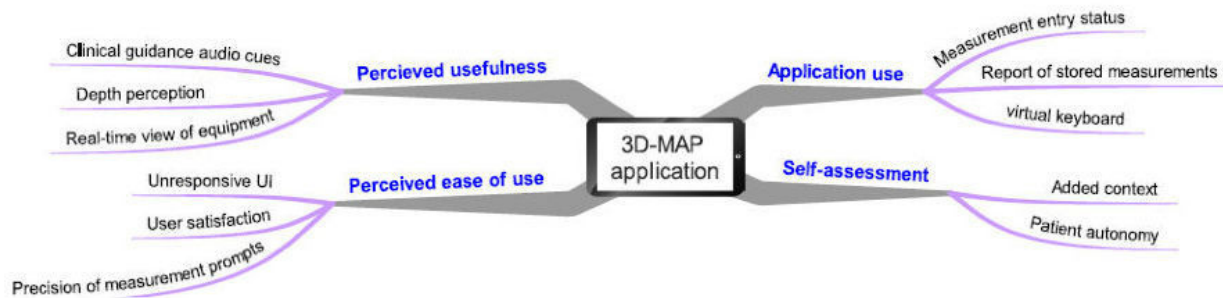
The results for S10 show that participants tended to disagree that they had to learn a lot of things before they could start using the application (mean=4.39, $P<.001$) although the application demonstration provided at the start of the session was noted as being useful by one participant (F5).

Semistructured Focus Group Discussion Results

Four high-level themes emerged as a result of the inductive and deductive thematic template analysis carried out on the data

collected from the focus group discussion sessions. These themes were: (1) PU, (2) PEOU, (3) application use (AU), and (4) self-assessment (SA). An overview of the high-level themes and associated subthemes are presented in Figure 10.

Figure 10. Thematic mind map of core themes and associated sub-themes.



Perceived Usefulness

Participants felt that the clinical guidance audio cues functionality was useful and made the 3D-MAP application easier to use. They commented that the audio cues provided useful instructions on how to take measurements and complemented the measurement arrows. However, some participants suggested that the 3D-MAP would have been even more straightforward to use if there were more audio cues to assist in the use of the application. Other participants also noted that the measurement arrows overlaid onto the 3D models were a useful aid in identifying the precise points that needed to be measured.

If there was the voice command throughout it would have been easier. [F8]

Participants commented that the 3D models offered realistic representations of real-life items that were to be measured. They suggested that the 3D models afforded improved depth perception of the discreet points that should be measured for the task and improved the visual quality of the measurement guidance, compared with the paper-based equivalents. Other participants were enthusiastic about the capabilities that 3D visualization provides with respect to the clarity of the illustrations and differences between inner and outer length measurement arrows.

You need to have a diagram like this to show you the depth of the object...and the arrow showing you what you meant by the depth. [F5]

Providing that 3D view so you know you can see where to measure...makes it more clear and distinguish whether to measure the inside length or the outside length. [F32]

As an additional feature to enhance the usefulness of the application, there was discussion about adding some sort of augmented reality feature to the application that could deliver a real-time view of assistive equipment in place within the home. Participants felt that such a feature could help them to better understand what home adaptations (and items of assistive equipment) may look like when fitted and indeed what their function may be.

...whether you could input in the measurements of the room and where you ask to put something and then superimpose to see whether it would go and which best position for it in that particular space that you want to put it in. [F6]

Perceived Ease of Use

Numerous issues were identified in relation to the usability of the application by this user cohort. Participants reported on the application's unresponsive UI, particularly the difficulties that they experienced with some of the measurement arrows not responding to touch gestures. For example, clicking to insert measurement information for 3D models that contained multiple measurement arrows triggered a slow response by the application. Similarly, sluggish response times were noted when attempting to rotate 3D models that had multiple superimposed measurement arrows.

...the arrows for the measurements wasn't always responsive. Some of them were fine, but the ones with say 4 you couldn't input all of them. But the voice was very useful... [F3]

In general, however, participants reported that they enjoyed using the application; to the extent that they expressed their interest of using it again within a home setting. Some participants elaborated on this point, suggesting that the application showed potential for use in practice, enabling patients to feel more involved in decisions and activities related to the provision of assistive equipment.

Actually I loved it. Because I've never measured anything before and put it in. so I'm not familiar with this measurement. So I loved it...I'll go home and practice. I'll get my Ipad out. [F7]

I think it shows great potential for use in the field...and the patient would feel more involved. That is a good thing. [F9]

One particular 3D model was regarded as being problematic in terms of providing ambiguous measurement guidance, that is, the 3D model of the chair. The measurement arrows for the chair and toilet were highlighted as a need for more precision if it is to have a much-desired effect in terms of users accurately

interpreting the measurement guidance based on the use of precise visual prompts.

The chair, was I thought...more difficult, the width of the chair is it to the outer arms or it's more likely that the seat position is...It's that degree of precision. [F26]

Application Use

Participants were positive about using this application in practice and were enthusiastic about using it as a guide to taking measurements within the home setting. However, in terms of current interface design features functionality, participants suggested some adaptations that they felt would improve the user interaction experience, and hence, the potential of using it in practice. Measurement entry status was identified as a feature that required improvement. Participants noted the importance of more clearly signposting when a measurement has been input successfully, for example, in addition to the current feature that superimposes the measurement onto the arrow once it has been input, it was suggested that a clear change in color of the input arrow would help to signify the measurement had been provided. An option to generate a report of stored measurements was also put forward as a valuable additional feature. It was foreseen that the benefits of such a feature included the service user being able to review all the measurements that had been provided but also the potential to enhance the level of dialogue between service users, clinicians, and assistive equipment providers after the measurements had been taken.

...the capacity to be able to save your measurements and refer to them you know once you've sat down with the practitioner or whatever so ok that's what you've measured...and to be able to refer...back and look at it again and say are you sure you got the measurement right. [F30]

Although participants reported being satisfied with the process of inputting measurements via the full Android virtual keyboard, some issues were raised about the type and size of the virtual keyboard. The launch of the full Android keyboard obstructed the view of the 3D model screen and consequently, suggested having a small numeric keyboard to enter measurements values was proposed. It was suggested that if a unit of measurement could be selected prior to inputting the values (ie, centimeters, millimeters, or inches) the full keyboard would no longer be necessary and could be replaced by a simple numeric keyboard.

There's a problem we've got here. When you have a touch screen or you touch the arrow you want and if you know you're only going to put inches in or something like that, then you wouldn't need to have a full keyboard...if you do you just need to have a small sort of standard dialler type touchscreen rather than the big one. But that's how it suddenly occurred to me you know that the limitation of the device is probably causing some confusion there because it covers the screen when it comes up you see. [F7]

Self-Assessment

The notion of patient autonomy was raised as a direct consequence of utilizing the 3D-MAP application. The process of enabling users to carry out self-assessment for the subsequent

prescription and fitment equipment was seen as an opportunity to reduce the typical waiting time necessary for a clinician or technician to carry out the home assessment process and for the necessary items of equipment to be installed more rapidly. Indeed, the view shared by the majority of the participants was that deploying such an application in this way would be of benefit in this regard.

It's the fact that you can do this yourself and you're not waiting for somebody to say, ooh we can't come until four weeks' time to do the measurements for you, isn't it (group agreement). [F11]

Having this (the 3D-MAP application), you know, could help get equipment for the bed...stairs...handrails and obviously the chair...all the things that sort of promote independent living. [F28]

Whereas participants were generally enthusiastic with respect to the concept of the 3D visualization approach to better interpret measurement guidance for the purpose of accurately gathering measurements, opportunities to extend the application's functionality were also suggested. For example, recording or mapping the dimensions of the room and the other items therein were seen as a way of carrying out more in-depth falls risk assessments and hence may have added benefits in order to prevent extrinsic fall risks. Participants believed that the added context in which the furniture item is placed should be considered in conjunction with taking measurements of furniture items.

Rather than individual items, measuring height width and other things. If you had a bedroom...that would have been easier to see (all of the risks). Because then you could assess where your bed is and where your other furniture is...then you could think ways of other preventing falls. [F31]

You're measuring this and you're measuring that. Surely you should measure the rooms...the places it's got to go in. I mean a bath is fine so you measure that. Shouldn't that be used in conjunction with something to do with room measurements. [F30]

Discussion

Principal Findings

This study presented a novel mobile application that uses 3D visualization technology, designed to guide and assist older adult service users in the taking and recording of measurements as part of the assistive equipment provision process. A total of 33 older adults used the 3D-MAP application to engage in a measurement task of items of home furniture that are known to be associated with falls and are routinely measured as part of the AEPP. Based on the analysis of the quantitative SUS, data revealed that the sample of older adult participants attributed a score of 65.8/100 for its usability, which indicated that the application may be described as having “marginal-high” (acceptability range), “good” (descriptive adjectives), and “grade C” (curved grading scale) levels of usability. In terms of the two SUS subscales, OTs also tended to agree with statements

relating to the usability and learnability of the application. The SUS results, therefore, indicate that there was agreement that the application was easy to use and that learning to use the application was also straightforward for this user cohort. However, despite some promising results and the outcome that the older adults who took part in this study were enthusiastic about the prospect of using the application within the home setting to carry out self-assessments, the findings indicate that there are improvements to be made to the application that may contribute to the successful adoption of such an application by an older adult cohort in practice. There was no significant correlation between age and SUS scores. However, this could perhaps be a consequence of the older adults in this sample being more familiar with using tablets or mobile phones, which

may have mitigated any significant age-related effects. This also may explain why age was not found to be a factor involved in how users perceived the usability of the application. Analysis of the individual SUS items and associated open-ended comments, along with think-aloud and semistructured interview data provided detailed study outcomes relating to the perceived feasibility, usability, challenges, and opportunities of the application being deployed in practice. Table 3 presents a summary of the key study outcomes, and categorizes these in terms of the implications for deployment in practice and design and functionality considerations. Each outcome is mapped to its respective source, that is, the individual SUS item (S1-S10), and the high-level theme that emerged from the analysis of the semistructured interviews: PU, PEOU, AU, and SA.

Table 3. Study outcomes.

Areas of focus	Study outcomes	Source
Implications for self-assessment in practice		
	Confident using the application without assistance or supervision	S4, S9, S10
	Still some service user concerns about measuring furniture items independently	S3
	Valuable tool for self-assessment, patient involvement, and patient empowerment	SA, S1, PU ^a
	Sharing furniture measurements with clinicians	AU ^b
	Reduced time and resources overhead	SA ^c
	Provides an improved ability to visualize and understand measurement guidance	S8, PU
	Useful multimodal interaction features for clear measurement guidance	PU
	Indicate exact areas to be measured on furniture items	PU
Design and functionality recommendations		
	Provide usage instructions and short demo of key features	S4
	Develop improved 3D rotation function to improve visualization guidance	S4, PU, S3, S8
	Precise and unambiguous measurement arrow prompts for multiple measurements	S6, PEOU ^d
	Brighter visual interface	AU
	Provide context of the furniture items	SA
	Visualize equipment installations in real-time in context of the home	PU
	Provide smaller-sized numeric keyboard for measurement entry	AU

^aPU: perceived usefulness.

^bAU: application use.

^cSA: self-assessment.

^dPEOU: perceived ease of use.

In terms of the implications for self-assessment in practice, older adults reported that they felt comfortable using the application without any assistance or supervision (S3, S9, and S10). One participant reported to a feeling of apprehension with regards to the physical task of taking measurements on their own, in part due to advanced ageing factors (S3). However, a recent update of the health care act stipulates that “capacity must be assumed” for those responsible for carrying out ADL around the home and that patients must take ownership of their own care within reason, if they are capable of doing so [76]. Therefore, despite the development of applications such as 3D-MAP, designed specifically to provide enhanced levels of guidance and support (compared with traditional paper-based

equivalents), there still appears to be some demand for more personalized support for some user types. The application was seen as a useful tool to promote independent living and to empower older adults to take ownership and be involved with parts of the AEPP (SA, S1, and PU). Some participants viewed the recording of measurements as being a valuable feature to have in order to send to clinicians as part of the equipment provision process, which could enable patients to take part in crucial aspects such as taking measurements of their home furniture (AU). This has potentially significant positive implications on the outcomes of current practice, particularly given that older adults who are empowered to participate in technology-assisted interventions are more likely to contribute

to decisions made pertinent to them personally [77] which, in turn, could improve overall patient satisfaction, quality of life, and, ultimately, the level of engagement with assistive equipment [78]. There is also a potential time-saving advantage associated with this technology-assisted self-assessment approach, which means that patients can go ahead with assessments without having to wait for a clinician to conduct a home visit. Waiting times were also seen as another component in adopting the 3D-MAP application to facilitate self-assessment (SA). This is particularly advantageous given the growing demands on clinicians' time, coupled with the increasing strain on publicly available health care resources [7]. Notably, participants remarked that they saw benefits of using 3D visualization, which they believe provides improvement in the depth perception required to improve the way in which the guidance is perceived (S8, PU). The application was perceived as a useful solution as compared with the existing 2D paper-based self-assessment tools. It provided a rich set of multimodal interaction features (ie, both visual and audio) to help interpret the measurement guidance and enable the recording of accurate furniture measurement (PU). Previous studies have shown that the combination of visual aids and audio features are both useful and effective in enhancing older users experience while interacting with software applications, particularly for those who have lower health literacy [79,80]. This is a promising and important outcome given that 50% of assistive equipment is abandoned by patients, partly due to inaccurate measurements being collected using the current 2D paper-based guidance [24]. Older adults viewed the application as a promising and practical tool, which they felt, enhanced the visualization of measurement guidance and helped to more accurately indicate the precise areas on furniture items that must be measured for the purpose of self-assessment (PU).

Several design and functionality recommendations emerged from this study, providing insights into how the application prototype could be further developed to align it with the needs of older adults if it is to be successfully suited to and adopted in practice by the intended user group. It was suggested that some users may require more detailed usage instructions and a short application demonstration (S4). This is in line with existing research focused on overcoming barriers to technology use and adoption by older adult users, which suggests that challenges often stem from lack of confidence as a consequence of being unfamiliar with some mobile technologies [81]. Other studies have found ways to assist older adults in addressing the lack of confidence is through adequate training, demonstrations, and providing built-in assisted features, which heightened competence and confidence levels when using technology [82]. Participants expressed experiencing difficulties while rotating some of the 3D models and found that the rotation controls were occasionally difficult to manage when they manipulated the perspective view of the 3D models (S4, PU, S3, and S8). This aspect of the functionality therefore requires further development, as it impacts the interpretation of measurement guidance. Participants commented on the need for clearer and unambiguous visual prompts to measure furniture items, as some prompts (particularly for the chair that has multiple inputs) seemed less clear and could compromise the reliability of older users effectively perceiving the guidance for accurate

measurement entry (S6, PEOU). This requirement is particularly crucial given that the application was developed to enhance the visual quality of measurement guidance via the use of annotated 3D models to sufficiently locate end-to-end points on the measurement arrows. It was also commented upon that the interface needed brighter visuals as it impacts on one's confidence and attitude while using the application (AU). Moreover, the current design of the arrows appeared to require more effort than expected to input measurements, which seems to impact participants' level of confidence in using the application independently without support. Indeed, a body of research concerning the design and development of interfaces suited for older adults suggest a set of design guidelines for this particular older user cohort and infers that many usability issues can be addressed by adhering to those guidelines, whereas also assessing the effectiveness and efficiency of system functionality [60,83]. Other participants felt that measurements of the context in which the furniture item is located should be equally considered as gathering the dimensions of home furniture (SA). As an extension to this idea, one participant suggested a potential feature to visualize assistive equipment installations in real-time in the home before prescriptions are given (PU). Providing visual sense by overlaying virtual objects onto the real-world environment (in camera view), thus augmenting older users' imagined changes to their home environment before it is physically adapted by AEPP, can decrease cognitive load, promote continuous engagement in health care interventions, and improve health outcomes [84]. Interestingly, there is evidence from a study investigating the application and effects of augmented reality in exercise interventions for fall prevention, which found an improvement on falls efficacy, gait, and balance [85]. Superimposing 3D models of assistive equipment within the home was viewed as having potential to increase the reality effects and participation during the intervention, giving patients the capability to visualize imagined changes to their home environment before it is physically adapted within the assistive equipment provision process. Participants expressed the need for smaller numeric keyboard style interface for measurement entry, as the full sized alphanumeric keyboard obscured the 3D model screen, which in turn could impact the integrity of the input and users forgetting what measurements they are inputting (AU). Previous research has shown older adults' preference for onscreen numeric-style keyboards [86] and suggests that data entry should be kept to a minimum. The type of keyboard interface chosen should be relative to the amount of data entry activities performed by older adults [87]. There is also further evidence of onscreen numeric keyboard as the preferred interface for accurately recording numerical values and reducing the number of input errors in a health care setting [88,89].

Limitations

Older adults recruited for this study were sourced primarily from active ageing exercise groups and hence, the sample in this study is likely to have been susceptible to selection bias. Furthermore, participants reported to be healthy, active, and familiar with the use of desktop computers, laptops, and mobile phones and also had some level of familiarity with touchscreen technology. Whereas this represents a skewed sample, it enabled the study to focus on evaluating the application and its

functionality as opposed to the focus of perceptions being limited to basic usability issues that may arise from not having a basic understanding of the platform on which the application was deployed. Nevertheless, it is important to note that this sample may not be representative of the typical groups of older adults that OTs frequently engage with, and therefore should be taken into consideration when interpreting the results. The typical older adult patient profile is changing, as younger and more technologically aware generations make the transition into the older adult category, so the typical level of familiarity with ICT of this cohort will increase over time. Therefore, although the sample in this study is biased, such participants were recruited with the motivation of gaining insights from a sample, that may to some extent, better represent the more technologically aware older adult user group of the future. In relation to the TAM model, the deductive approach implemented in the analysis of qualitative datasets, via the two core TAM constructs, could be considered a limitation of this study. Adopting the thematic template approach in this study may have minimized the coverage of themes that would have emerged if a solely inductive approach was employed. Having said this, the approach enabled the analysis to be partly data driven, as well as focus in more detail on factors associated specifically with technology acceptance, which was in line with part of the aim of this study. Furthermore, it should be noted that no formal spot checks were carried out to ensure that participants adhered closely to the directions and guidance provided by the application. There is, therefore, a possibility that the lack of adherence observed when patients utilize paper-based guidance could similarly be a challenge to the tablet-based version of the guidance and something that should be taken into account when considering the results.

Conclusions

This study investigated the experiences and views of 33 community-dwelling older adults who engaged in an interaction task with a custom built 3D-MAP application developed as a

tool to engage in self-assessment tasks and assist them in taking and recording measurements as part of the AEPP. The usability of the 3D-MAP application was evaluated via the statistical analysis of participant responses to the SUS instrument. Perceptions regarding the feasibility, benefits, and challenges of using this application in practice were evaluated via the thematic analysis of individual interview and focus group discussions that were held after participants carrying out an interaction task. Based on the results, several implications for deployment of this application in practice were identified. Furthermore, numerous design and functionality recommendations were identified, which exemplify the interaction challenges that this cohort experienced with this 3D visualization technology. Overall, community dwelling older adults believed that the application delivered an improved visualization of the measurement guidance provided by traditional 2D paper-based guidance leaflets. The multimodal nature of the measurement guidance was also noted as a valuable benefit to deploying guidance via the mobile application. Furthermore, older adults were confident using the application without assistance and saw several benefits to deploying such an application in practice. Some of these included a perceived value in assisting with the self-assessment process, but also as a tool that could encourage patients to engage more fully in the delivery of their own care and collaboration with clinicians and associated decision making about their care. Further research is needed to establish whether such an application may be feasibly used by occupational therapists, family members, and regular care givers. It is also necessary to carry out further research to establish the clinical utility of this application in terms of the efficiency, effectiveness, and the relative accuracy and reliability of measurements that are recorded by older adults using the 3D-MAP application compared with 2D paper-based guidance leaflets. Furthermore, future research is needed to consider the use of an experimental design to empirically test the application against its 2D counterpart, to enhance and provide further insights into the findings presented here.

Conflicts of Interest

None declared.

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Abbreviations

2D: two-dimensional
3D: three-dimensional
3D-MAP: 3D measurement aid prototype
ADL: activities of daily living
AEPP: assistive equipment provision process
AU: application use
ICT: information and communication technologies
NHS: National Health Service
OT: occupational therapist
PEOU: perceived ease of use
PU: perceived usefulness
SA: self-assessment
SUS: system usability scale
TAM: technology acceptance model
UI: user interface

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Original Paper

Iterative User Interface Design for Automated Sequential Organ Failure Assessment Score Calculator in Sepsis Detection

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Abstract

Background: The new sepsis definition has increased the need for frequent sequential organ failure assessment (SOFA) score recalculation and the clerical burden of information retrieval makes this score ideal for automated calculation.

Objective: The aim of this study was to (1) estimate the clerical workload of manual SOFA score calculation through a time-motion analysis and (2) describe a user-centered design process for an electronic medical record (EMR) integrated, automated SOFA score calculator with subsequent usability evaluation study.

Methods: First, we performed a time-motion analysis by recording time-to-task-completion for the manual calculation of 35 baseline and 35 current SOFA scores by 14 internal medicine residents over a 2-month period. Next, we used an agile development process to create a user interface for a previously developed automated SOFA score calculator. The final user interface usability was evaluated by clinician end users with the Computer Systems Usability Questionnaire.

Results: The overall mean (standard deviation, SD) time-to-complete manual SOFA score calculation time was 61.6 s (33). Among the 24% (12/50) usability survey respondents, our user-centered user interface design process resulted in >75% favorability of survey items in the domains of system usability, information quality, and interface quality.

Conclusions: Early stakeholder engagement in our agile design process resulted in a user interface for an automated SOFA score calculator that reduced clinician workload and met clinicians' needs at the point of care. Emerging interoperable platforms may facilitate dissemination of similarly useful clinical score calculators and decision support algorithms as "apps." A user-centered design process and usability evaluation should be considered during creation of these tools.

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KEYWORDS

automation; organ dysfunction scores; software design; user-computer interface

Introduction

As electronic medical records (EMRs) have propagated through the US health care system, they have brought both great promise and great problems [1,2]. One unintended consequence of increasing EMR adoption that has been recently characterized

is physician burnout associated with EMR-associated clerical tasks [3]. The high clerical burden of these tasks may be a consequence of variable attention given to usability and user-centered design by vendors [4,5]. Health information technology interfaces that are not well adapted to clinician workflow can both increase clerical workload and potentially

pose safety risks to patients [6-8]. As in other industries, medicine has sought to overcome task-related inefficiencies through automation [9].

Automation of computer interaction in clinical medicine can take many forms. Automated information retrieval is commonly utilized to generate shift hand-off and inpatient rounding reports, significantly reducing time spent on information retrieval tasks [10-12]. Automating clinical guideline implementation through clinical decision support rules has also been done to reduce practice variability by promoting standards of care [13,14]. A recent change in the definition of sepsis has opened a challenge to create and implement clinical decision support that could reduce the clinician workload of information retrieval and processing specific to the sequential organ failure assessment (SOFA) score [15].

In March 2016, the operational definition of sepsis was updated to include a change in SOFA score ≥ 2 compared with baseline (Δ SOFA) [15]. The updated definition has been controversial [16-20]. The SOFA score, which assesses organ dysfunction in six domains, was created in 1996 to describe sepsis-related organ dysfunction [21]. Originally, the SOFA score was calculated at admission [21]. With time, usage has been extended to include serial recalculation using the most abnormal values during the preceding 24 h [22]. However, the new sepsis definition suggests that the SOFA score would need more frequent recalculation to identify sepsis in real time.

The prospective time-drain imposed by the new definition may not be trivial; previous studies have indicated a time-cost of about 5 min for information retrieval and manual score calculation per patient [23]. Consequently, methods to include automated SOFA score calculations in daily clinical reports have been created [24,25]. EMR interfaces have advanced since those studies and the time-drain of manual SOFA calculation may have changed. Additionally, these previous automated SOFA score calculators were used in printed daily reports and have not been adapted to meet clinician needs for real-time use at the bedside.

The goals of this study were to (1) quantify the current time-drain of manual SOFA score calculation and (2) describe the user-centered design process and usability evaluation of an EMR-integrated real-time automated SOFA score calculator interface.

Methods

Setting

This study was performed at Mayo Clinic Hospital, St Marys Campus in Rochester, Minnesota. The study protocol was reviewed and approved by the Mayo Clinic Institutional Review Board.

Time-Motion Analysis

Internal medicine residents were observed calculating baseline and current SOFA scores during their medical intensive care unit (ICU) rotation over a 2-month period. Residents utilized Mayo Clinic's locally developed EMR for data retrieval. The instrument (website, mobile phone app, etc) utilized to perform

the calculation was at the clinician's discretion. Total calculation time and calculation instrument were captured for each observation. The total time-cost was calculated using average task completion time, assuming one SOFA score calculation or patient day, and extrapolated to the total number of patient medical ICU days at St Marys Hospital in Rochester, MN during a 1-year period.

Interface Development and Usability Evaluation

The user interface was designed using an agile development process involving stakeholders from critical care medicine and information technology. Agile software development is a user-centered design process where programs are built incrementally in many short development cycles. These development cycles are analogous to plan-do-study-act cycles utilized in clinical quality improvement. In contrast with traditional "waterfall" linear software development, end-user testing and feedback is performed during each agile developmental cycle rather than during the last phase of the project. Agile software development utilizes close collaboration between developers and end users to guide improvements during each cycle—this feature allows early customization of the user interface (UX) to meet the clinician end user's information needs. Close involvement of clinician end users throughout the development process has been shown to improve usability and end-user utilization of the resulting product [26,27].

The algorithm underlying the SOFA score calculator was previously validated for daily score calculation [25] and updated to facilitate more frequent recalculation every 15 min. With each recalculation, the 24-h calculation frame is shifted by 15 min. During the initial planning phase, clinician stakeholders were interviewed to determine essential and nice-to-have user interface features and how to display information for each SOFA subcomponent. Next, a UX mockup was constructed using Pencil (Evolus, Ho Chi Min City, Vietnam), an open-source multi-platform graphical user interface (GUI) prototyping tool, and returned to clinician stakeholders for review and comment. To complete the cycle, changes were made to the UX prototypes by developers and returned to clinicians for review and feedback. We continued iterative UX development cycles until a consensus was reached on interface design. The interface underwent a total of four iterative development cycles spanning 2 weeks before consensus was reached. The final UX was integrated into clinical workflow through our institution's ICU patient care dashboard by adding indicator icons to our unit-level multipatient viewer. The indicator icon changes when the Δ SOFA criteria have been met but does not trigger a visual alert. A mouse-click on the indicator displays the automated SOFA score calculator interface (Figure 1).

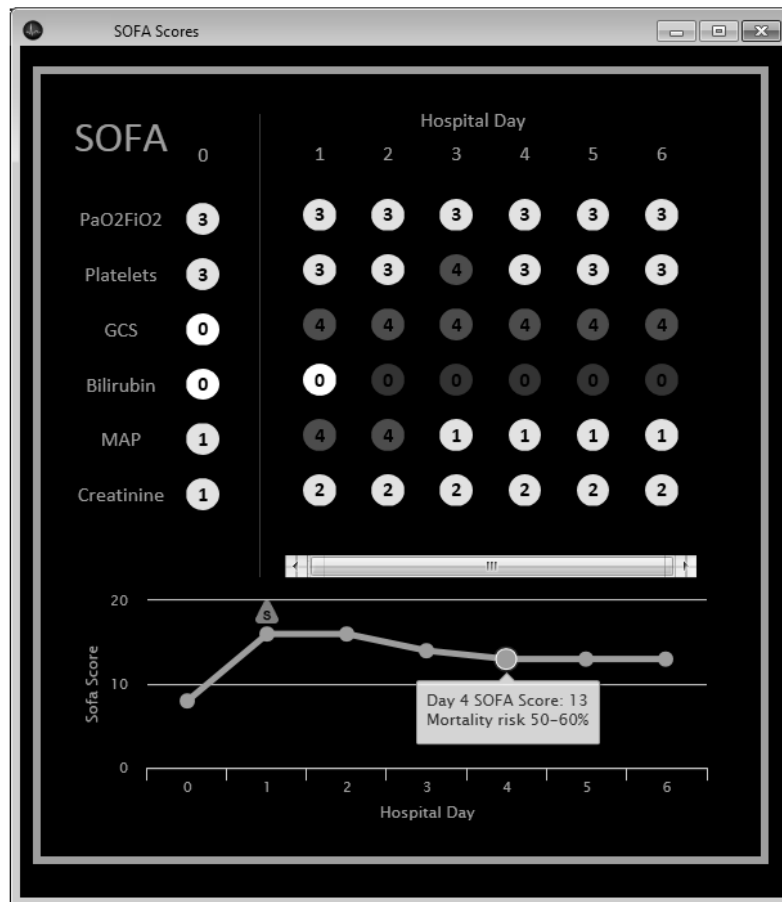
The final UX was evaluated with the Computer Systems Usability Questionnaire administered through REDCap [28,29]. The questionnaire was sent to all potential end users not involved in UX development who were scheduled to work during the 2 months after the interface had been made available for clinical use. A 5-point Likert scale was used for each item. Responses to each item were categorized as favorable (4-5), neutral (3), or unfavorable (1-2). Each question item belonged to one of three domains—system usability, information quality,

and interface quality [28]. The proportion of question items categorized as favorable, neutral, and unfavorable was calculated for the overall questionnaire and within each domain.

All statistical analysis for study was performed with R version 3.3.1 [30]. For the time motion analysis, linear regression was

performed to assess the relationship between hospital day and calculation time. Descriptive statistics were used to describe the survey participants' clinical roles and the proportion of responses within each usability domain.

Figure 1. Example of the automated sequential organ failure assessment (SOFA) score calculator's final implemented user interface.



Results

Time-Motion Analysis

Fourteen internal medicine residents were observed calculating 35 baseline and 35 current SOFA scores for patients admitted to the medical ICU under their care. The overall mean (SD) calculation time was 61.6 s (33). The time required to calculate the current SOFA score was significantly lower than the baseline score (39.9 s [8.3] vs 83.4 s [36.0]; $P < .001$). Most participants (9/14, 64%) manually entered data points into a Web-based score calculator; the remainder used a mobile phone app. There was a significant linear association between current hospital day and time to calculate baseline score ($P < .001$, $R^2 = .54$). If we extrapolated the time-cost to an entire year within our institution's 24-bed medical intensive care unit, the cumulative time required for one extra manual SOFA score calculation for each patient day (6770 patient days) would be about 116 (64) hours. This amounts to almost 5 extra hours of work per ICU bed distributed among our medical intensive care clinicians.

Interface Design and Usability Evaluation

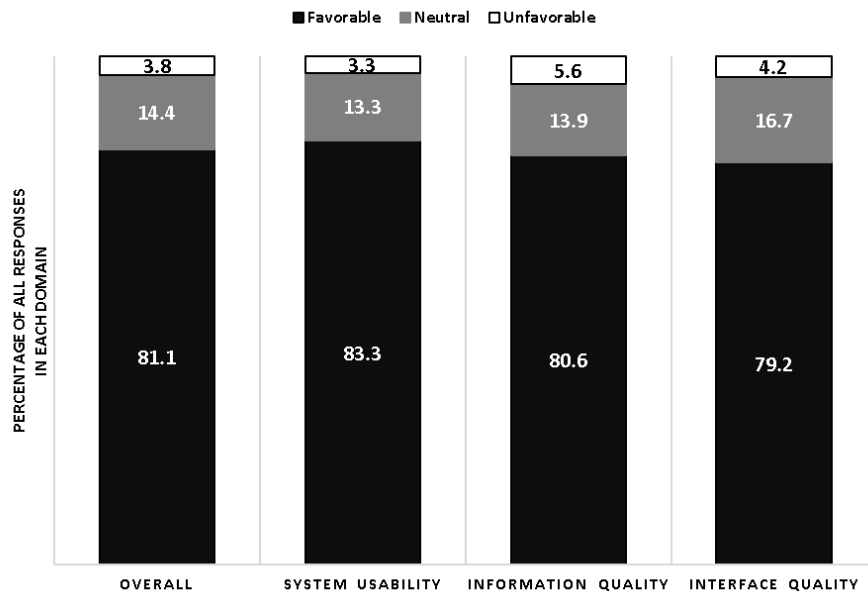
Clinician stakeholders identified several key features during the initial stakeholder analysis. Essential needs identified by clinicians reflected their clinical information needs: (1) ability to quickly identify when the $\Delta\text{SOFA} \geq 2$ (vs baseline) threshold had been passed; (2) ability to quickly view current, baseline, and previous SOFA scores from the current hospitalization, broken down by SOFA score component; (3) ability to quickly identify when data was missing for each SOFA component and if data was carried forward; (4) ability to quickly identify the source data used for each SOFA component calculation; and (5) high accuracy. Items 3-5 reflect the concerns several stakeholders expressed about the potential for automation bias with this tool [31]. One nonessential need was identified: Displaying prognostic mortality risk associated with each SOFA score. All identified information needs were incorporated into the initial UX mockup. Major UX changes during the development process included (1) formatting and coloring changes to highlight extreme or missing data for each SOFA component, (2) changes to the ΔSOFA threshold indicator, and

(3) changes to limit the quantity of daily SOFA scores visible for prolonged hospitalizations.

Fifty computer systems usability questionnaires were distributed to clinicians who had the opportunity to use the tool in clinical

practice during the 2-month period. We received 24% (12/50) responses. The questionnaire was completed by 11% (1/9) residents, 17% (4/24) fellows, and 42% (7/17) attending physicians. A summary of user usability feedback is shown in Figure 2.

Figure 2. Percent of responses categorized as favorable, unfavorable, or neutral within each domain from the postimplementation computer usability scale questionnaire (respondents=12).



Discussion

Principal Findings

The first part of our study estimates the time-drain of manual SOFA score calculation with a modern EMR system and describes an attempt to mitigate these inefficiencies with an EMR-integrated automated SOFA score calculator created through a user-centered design process. Our time-motion analysis found that the current time required for manual calculation using a modern EMR has improved compared with a study performed 5 years prior [23]. However, these efficiencies may be obscured by the need for repeated calculation under the new sepsis definition. Real-world usage would likely dictate more frequent recalculation and consequently automation would be more desirable as the cumulative time requirements increase.

The second part of our study describes the iterative, user-centered design process for an EMR-integrated automated calculator “app” for the SOFA score. Clinician stakeholders worked closely with developers throughout the rapid UX development process. The resulting interface was favorable to clinician end users in all three usability domains assessed (system usability, information quality, and information quality).

Comparison With Prior Work

Several other clinical scores have been automated for clinical practice—examples include APACHE II [32,33], APACHE IV [34], CHA₂ DS₂-VASc [35], Charlson comorbidity score [36], and early warning systems [37]. These studies primarily focused on algorithm validation rather than information delivery. The information delivery needs for clinicians using these clinical

scores depends on the clinical context; many clinical scoring systems are used at decision points in patient care and clinical practice guidelines (CPG). Clinicians’ poor CPG adherence has been recognized for many years [38]. Consequently, user-centered design processes have been utilized to improve CPG adherence through clinical decision support—ranging from surgical pathways to guideline implementation—with favorable results [26,39-42].

Future Directions

Future demand for SOFA score calculation in clinical practice may be dependent on policy from the Centers for Medicare and Medicaid Services (CMS), which is still recommending the use of the previous definition of sepsis outlined in the Severe Sepsis or Septic Shock Early Management (SEP-1) bundle because of concerns about increasing cases of missed sepsis under the new definition [16,17,19]. CMS adoption of the new sepsis definition would likely spur a significant increase in the usage of the SOFA score by linking quality metrics and payments. Because of the time-cost of score calculation in an otherwise busy clinical setting, manual SOFA score recalculation may only be performed after the clinician has already suspected new onset sepsis due to physiologic changes noted at the bedside. In this situation, application of the Δ SOFA definition (≥ 2 over baseline) would be confirmatory and not predictive—counter to the Surviving Sepsis Campaign’s goal to improve early recognition of sepsis [43]. However, by automating the SOFA score calculation process and repeating the calculation as new clinical information becomes available, the Δ SOFA criteria could effectively function as a sepsis sniffer. Further studies would be needed to compare the effectiveness of the Δ SOFA criteria

as a “sepsis sniffer” against other “black box” sepsis detection algorithms being developed [37,44-48]. The application of the Δ SOFA criteria as a “sepsis sniffer” does have promise—a recent retrospective study demonstrated that SOFA has greater discrimination for in-hospital mortality in critically-ill patients than either quick SOFA (qSOFA) or systemic inflammatory response syndrome (SIRS) criteria [49].

The pairing of the automated SOFA calculator algorithm with the user-centered UX design may hold advantages over these machine-learning based “black box” algorithms—our underlying algorithm is based on a familiar, well-validated clinical score and the visualization of each SOFA component allows clinicians to “look under the hood” to explore the source data behind each item’s value. The ability to verify the source data within the UX reflected the information needs of our clinician stakeholders identified during the agile software development process. With the “black box” algorithms of artificial neural networks and other machine learning techniques, a comparable level of transparency is not possible. Finally, traditional externally validated clinical scores, like SOFA, may be more generalizable than machine-learning algorithms [50]. The external validity of these machine learning algorithms is dependent on the diversity of the data sources used for training and cross-validation, whereas traditional clinical scores adopted into CPGs have already been externally validated. Consequently, researchers may have an opportunity to translate and distribute traditional clinical scoring models as automated computerized algorithms through interoperability platforms.

The emerging “substitutable medical apps, reusable technology” (SMART) on “fast healthcare interoperability resources” (FHIR) interoperable application platform is a promising avenue to bridge the gap between standalone applications and EMR integration [51]. Additionally, the platform offers a means to reduce the 17-year gap between clinical-knowledge generation and widespread usage [52]. Under this platform, interoperable applications can be developed and widely distributed like popular mobile phone apps. Calculator apps and other forms of clinical decision support are currently being “beta-tested” on this platform [53]. In the future, researchers developing clinical

scores or computer-assisted decision algorithms may be encouraged to develop similar interoperable applications. In the “app” domain, whether on a mobile phone or integrated into the EMR, usability is an important feature that must be balanced with functionality to encourage widespread adoption. The agile development process described in this paper involved clinicians in the development process early and often, leading to an EMR-integrated “app” that met both clinician information and usability needs within a concise 2-week timeline.

Limitations

The primary limitation of this study is that the clinician stakeholders are from a single institution and their needs might not match the needs of clinicians elsewhere. However, a similar user-centered design and evaluation process could be utilized at other institutions to create and customize a similar tool. Second, clinician survey response rate was low. We aimed to include residents, fellows, and critical care attending physicians with exposure to the tool to obtain perspectives from a wide variety of clinical roles. However, nearly all survey responses were provided by critical care attending physicians and fellows. The tool appeared to meet the usability needs of these content experts.

Conclusions

The incorporation of SOFA scoring into the sepsis definition potentially adds about 1 min per patient (calculation) to an intensive care clinicians’ workload—an amount that is compounded when recalculation is performed multiple times daily to confirm if Δ SOFA criteria have been met. This added workload can be eliminated through automated information retrieval and display. To generate the information display for an EMR-integrated automated SOFA score calculator, we utilized a user-centered agile design process that resulted in a user interface with >75% of usability features receiving favorable ratings across the system usability, information quality, and interface quality usability domains. Usability evaluations are important as clinical decision support algorithms are translated into EMR-integrated applications.

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Conflicts of Interest

One or more of the investigators associated with this project and Mayo Clinic have a financial conflict of interest in technology used in the research and that the investigators and Mayo Clinic may stand to gain financially from the successful outcome of the research.

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Abbreviations

CMS: Centers for Medicare and Medicaid Services
CPG: clinical practice guideline
EMR: electronic medical record
FHIR: fast healthcare interoperability resources
GUI: graphical user interface
ICU: intensive care unit
qSOFA: quick SOFA
SEP-1: Severe Sepsis or Septic Shock Early Management Bundle
SIRS: systemic inflammatory response syndrome
SMART: substitutable medical apps, reusable technology
SOFA: Sequential Organ Failure Assessment
UX: User Interface

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