Global Telehealth 2014
A.J. Maeder et al. (Eds.)

Monitoring falls in elderly people: Lessons from a community-based project

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Abstract. *Objectives.* This paper describes an evaluation of a community-based fall-detection project using smart phone based tri-axial accelerometry to identify factors that affect adoption and use of such technology by elderly people. *Methods.* A mixed methods study using questionnaires and semi-structured interviews was conducted to evaluate attitudes of the elderly people participating, as well as project stakeholders involved in the project. Information registered in a web-based fall management system was analyzed both qualitatively and quantitatively, using an adapted version of Unified Theory of Acceptance and Use of Technology (UTAUT). *Results.* Adoption rate was 61.7% and attrition rate was 57%, the most common reasons for attrition being health deterioration (50%) and problems with the device and the network (26.2%). *Conclusion.* We identified a number of challenges that affected the success of this project, including problems with the software, usability issues with the device, coverage of the network, training of participants, and inadequacy of providing participants with a strong sense of safety and security.

Keywords Tri-axial accelerometer, falls, evaluation, usability, telemonitoring

Introduction

Assistive technology solutions based on wearable devices and mobile computing have become very popular recently, particularly for "hospital in the home" types of situations such as patients in recovery or rehabilitation, chronic disease sufferers, and disabled or elderly living independently. With the trend of taking technology applications for healthcare from the laboratory to real life settings, there is clear need to evaluate and understand where the main challenges reside and how this technology is appreciated and used. The Telehealth Research & Innovation Laboratory (THRIL) at University of Western Sydney (UWS) was involved in a project on detecting falls in community-dwelling elderly people using tri-axial accelerometers in 2012. By evaluating this project, we aimed to get insight into important factors that affect the "adoption and use" of the fall detection technology by elderly people, and the "challenges" involved in a community-based project.

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1. Study Context

The evaluated fall detection project was conducted in the Australian Capital Territory (ACT) for six months from May 2012 to October 2012. Three organizations were involved in the project: a Clinical Partner (Anglicare), a Research Partner (University of Western Sydney (UWS)) and a technology Partner (Mediinspect). The Clinical Partner is a charity organization and its agencies work in close cooperation with other community organizations. It receives funding from Federal, State and Local Governments to provide a wide range of health and social services including residential and community aged care. The Clinical Partner was the administering agency under a grant from Australian Government to set up the fall detection project. The Research Partner was involved in the project to provide research advice and support, with a view to test the fall detection technology and collect characteristics of participants' use of the technology from a real world setting. The Technology Partner is a Czech Republic company, which provided the tri-axial accelerometer device for movement and fall monitoring and related data collection software.

In this setting, the Clinical Partner recruited the elderly participants; obtained their informed consent; captured their relevant clinical information; deployed the device for their use; educated them on how to use the system (in collaboration with UWS); set up a call centre to support the project; monitored the movement data collected; and responded to fall and emergency events detected by the fall detection technology. Recruitment took place through advertising in ACT using two main screening criteria: age 65 and over, and living independently in the community. The project coordinator was responsible for managing the call centre and arranging visits to the participants regularly and irregularly whenever it was necessary, for example in case of losing connection. The Technology Partner developed the tri-axial accelerometer application for falls detection, the central data repository, and the fall management web-based system. It also customized the technology and provided remote technical support. Their fall management system was used exclusively for monitoring detected events (including notifications of possible fall events). UWS hosted the fall management system and the data repository via the THRIL computing infrastructure; installed and configured the fall detection software on devices; provided local technical advice and research support for the Clinical Partner; and liaised for technical issues between the two other partners. UWS was also responsible for supporting research and analyzing the collected data.

The architecture of the project consisted of software to detect over-acceleration from a waist-mounted device containing tri-axial accelerometer technology (installed in a smart phone), a communicating mechanisms to transfer data packets from the smart phone to the fall management and data storing systems over a network, and a call centre for monitoring recorded Possible Fall (PF) and Emergency Alarm (EA) events of the participants. The fall detecting software was installed into a smart phone with capability to detect movement using tri-axial accelerometers. The system was able to detect over-accelerations (>27 m/s2) due to PFs and broadcast them to the fall management system over a GSM digital cellar network. The technology included an "alarm" functionality that allowed sending alert messages to the call centre either automatically in case of sustained fall, or manually through touching a red touch-button on the device's touchscreen. Following detection of PF or EA events, the system also sent SMS messages to a clinical caregiver (the project coordinator) for follow up.

A web-based fall management system was used for listing broadcasted events despatched by the smart phones. Each participant had a personal profile held in the fall management system database. This profile included the elderly person's basic demographic data, important medical history (including fall history), and a record of all the sentinel events received from his/her smart phone. The project coordinator had access to this system and was in charge of monitoring the received events and handling them. Four types of sentinel events were recorded in the system: possible fall (PF), emergency alarm (EA), low battery, and lost connection. The coordinator contacted the participants to gather information about each of their events registered in the system, confirmed if a real fall had happened, collected information regarding each of the recorded events, and inserted comments on them on the subject's profile.

2. Theoretical Background

A major focus in our study was understanding the experiences of the users of the fall detection technology (the elderly people) and the way they responded to this technology. Many theories have been advanced to understand how users adopt and use innovative technologies. Unified Theory of Acceptance and Use of Technology (UTAUT) combines different theories in this field based on principles of Technology Acceptance Modeling (TAM) to explain users' intentions to use a technology and their subsequent behaviour in using the technology [1]. This theory has been used to evaluate technology adoption and utilization in various fields' areas of mobile technology and information technology [2, 3]. Therefore, we selected UTAUT as an appropriate theory to interpret our findings in this study.

Considering specific characteristics of our users (being elderly, having no previous experience with similar technology, and volunteering to use it), we adapted the theory for our purpose. Figure 1 provides a summary of the influential factors in our UTAUT approach. "Behavioural Intention" in UTAUT terms is a subjective probability that a person will engage in a given behaviour [4]. In the adapted form of UTAUT, there were three main determinants for "Behavioural Intention": "Performance Expectancy" which is defined as 'the perception or belief that using a system will enhance or improve person's quality of life performance'; "Effort Expectancy" which is defined as 'the degree of ease associated with the use of a system'; "Social Influence" which is defined as 'the degree to which an individual perceives that important others believe he or she should use the new technology'.

"Facilitating Conditions" is defined as a degree to which an individual believes that organizational and technical infrastructure exists to support use of the system. "Behavioural Intension" and "Facilitating Conditions" are considered the main determinants of actual "Use Behaviour" and continuing with a technology use [1]. Gender is considered as one user characteristic that might influence actual "Use Behaviour" by affecting "Performance Expectancy", "Effort Expectancy", and "Social Influence".

In interpreting the results of the study, a socio-technical perspective was adopted. This frame of reference states that it is not only the technology and its qualifications that determine the outcome of its implementation and use in a real world environment. The final outcome results from the interactions between the technology and the social, organizational, and cultural characteristics of the implementation environment [5, 6]. If not managed properly, these socio-technical interactions can add up to the existing technical complexity and aggravate the effects of technical shortcomings [7].

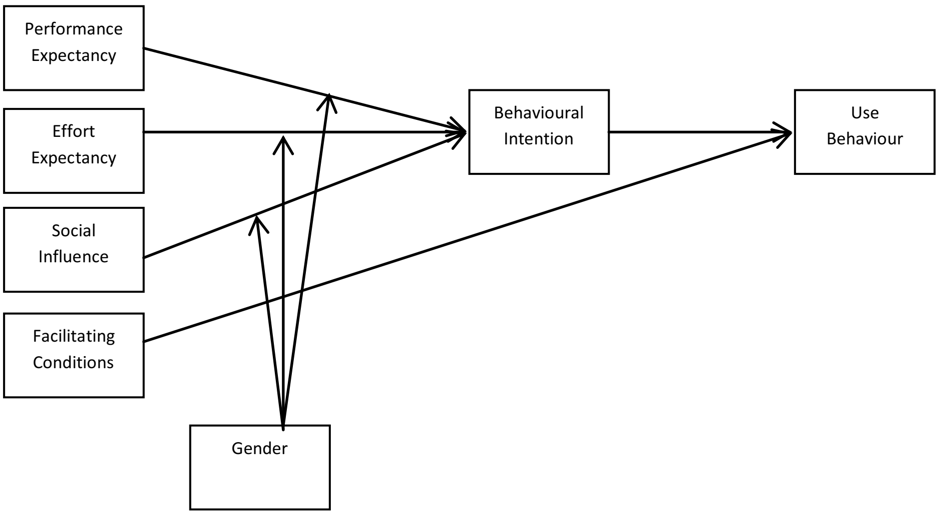

Figure 1. Adapted UTAUT model for use in the study.

3. Study Methodology

This was a cross sectional mixed methods evaluation study, using qualitative and quantitative research methodologies as follows.

3.1. Data Collection

Qualitative data were collected through two questionnaires (one for the participants and one for the project stakeholders), and interviews (with project stakeholders). In addition, three semi-structured, face-to-face, and one-on-one interviews were conducted with the project stakeholders, each one lasting from 10 to 35 minutes. Another source of data was the web-based fall management system. By the end of the project, a wealth of information about each of the participants and their recorded sentinel events was registered in the system.

All participants who received the devices and managed to use them for all or part of the project, were included the study. Three project members from UWS, the project contact person from Mediinspect, and the project coordinator from Anglicare were also included. The fall detection project ended in October 2012; the evaluation study started in May 2013. Data collection, including interviews, surveys, and data extraction form the fall management system, took 4 months. The questionnaire used for the elderly people was intended to evaluate their satisfaction and problems in using the device as well as to learn from their feedback on how the project could be better. The questionnaire did not collect any identifying information from the subjects. There were

11 questions with yes/no/not sure answers, 1 multiple choice question, and 3 open ended questions.

The project coordinator, who had developed a close relationship with the elderly and could provide them with further explanation about the questions, distributed and collected the questionnaires. The questionnaire for the stakeholders included 10 open-ended questions and was intended to learn about the project objectives from different stakeholders' point of view, the organization of the project, and the main challenges and problems that they encountered during the project. Further follow up questions or interviews were organized in case more information or clarification was needed. The interviews were focused on elaborating upon the concepts came from the stakeholders' questions. For example, more specific questions were asked from the project coordinator about difficulties experienced in following up the registered events in the system. From the fall management system, the elderlies' demographics, their fall history, notes about each registered event, and information registered concerning the elderlies' problems during the project or their reasons for leaving the study were of interest. Data with respect to the participation changes in the course of the project were also collected from the fall management system.

3.2 Data Analysis

The demographics data and information collected from the fall management system were used to provide an overview about the project with descriptive statistics. The number of the participants and their changes over the course of project were also obtained from the fall management system. Adoption rate of the technology and attrition rate of the participants were calculated and their differences between the two genders were tested using two-sample z-test at a significance level of 0.05. Reasons for attritions, PFs, and EAs were categorized and frequency of each category provided. Categorization of the registered PF events and their clinical relevance was performed considering previous studies [8, 9]. Written comments and answers for the open-ended questions from the questionnaires, written notes on the fall management system, and transcripts of interviews were pooled and analyzed qualitatively. Inductive method of qualitative data analysis (grounded theory) was used to recognize important themes appeared in "adoption and use of the fall detection technology" and "challenges" of the project. Themes found through inductive analysis related to the concepts from the adapted UTAUT. The findings were discussed between the authors to reach agreement.

4. Quantitative Results

Before the project started 120 (F:M= 90:30) elderly people were interviewed and agreed to participate in the trial. Of these, 74 people (F:M=56:18) ultimately were issued with the device and commenced participation in the study. The average age of the participants was 81 years (F:M=80.4:82.4). 29 participants (53.7%) had a history of one or more previous falls. The total adoption rate of the technology was 61.7% (74/120). Comparing the adoption rate between female (56/90) and male (18/30) genders, using a two-sample z-text, showed no significant difference ($p>0.05$).

Of the 74 participants who received the devices, 42 stopped using the device and left the trial for several different reasons (attrition rate=57%). Health deterioration (e.g., myocardial infraction, and worsening dementia) was recorded as the most common reason (50%) for leaving the trial. The second common reason (26.2%) was problems with the device and the network (Table 1). Comparing the attrition rates between female (47/56) and male (15/18) participants, using a two-sample z-test, showed no significant difference ($p>0.05$). Of the 32 participants who stayed in the project, only 14 (18.9%) termed 'consistent users' had their data recorded consistently in the system throughout the trial period (F:M=9:5).

Table 1. The number of participants that left the project and their reasons for leaving.

Reasons for leaving the project	Number	Percentage
Health deterioration (e.g., heart attack)	21	50
Problems with the device and network	11	26.2
No special reason determined/stated	6	14.3
Personal reasons (e.g. going on holiday)	4	9.5
Total	42	100

The participant questionnaire and results are presented in Table 2, for 54 participants who responded. Most of the respondents (87%) did not have any problem with their activity data being collected and thought that the device did not restrict them during their daily activity. Many of them (61%) were satisfied with the device in general. However, only 37% found the device easy to understand; only 27% found it easy to use, and many of them (65%) did not feel more comfortable when using a mobile phone. The majority (91%) felt that they were contacted as often as they needed during the project; however, only 43% thought that the device would be of benefit in their life and only 35% stated that they felt safer while wearing the device. Many (65%) thought that even with 24/7 call centre the device would not help them to live longer in their home.

Table 2. Questionnaire used for 54 elderly people who completed the trial.

	Question	Yes %	No %	Not sure %
1	Did you feel you were limited in your daily activities whilst you were wearing the device?	13	87	0
2	Do you believe the device would be of benefit to you in your daily life?	43	43	14
3	Did you find the device easy to understand?	37	59	4
4	Overall were you satisfied with the device used in the study?	61	35	4
5	Do you believe the hilly terrain of Canberra affected the efficiency and reliability of the device?	35	39	26
6	Did you feel safer whilst wearing the device?	34	66	0
7	Do you currently or have you ever used a medical alarm service?	34	66	0
8	Did you feel that you were contacted as often as you needed to be during the project?	91	8	1
9	Do you feel comfortable with having your activity data collected and sent to your health care team?	87	13	0
10	Did using the device during the study make you feel more comfortable when using a mobile phone?	35	65	0

11	Do you think with a 24 hour call centre the device would help you to live independently for longer in your own home?	35	65	0
12	Did you find the smart phone device which is fitted with the touch screen easy to use?	57	39	4

5. Qualitative Results

Many sociotechnical issues were encountered during the project, which have been grouped under six relevant themes related to adoption and use of the technology.

5.1. Device Issues

There were many problems with the device that contributed to its full function during the trial. Some of them were related to the fall detecting software but many others were related to the smart phone used in the project. All stakeholders of the project agreed that they had difficulties in getting the software ready to be used in the trial. The software was not prepared specifically for the project purpose and the decision on using it on a smart phone rather than a custom wireless communications platform was a last minute decision. The software was in Beta release and had to be debugged repeatedly before a reliable version was attained. The inbuilt algorithm detected many of the elderlies' daily routine activities (e.g., walking down stairs, picking up something from a shelf, or sitting on a chair) as possible falls events.

After the Alarm button was touched, the software responded by playing a voice message for the user telling them what they should do in case of an emergency. However, this message was sometimes unintelligible because of hearing problems, and also confusing for some users. A participant stated that: "Often it speaks, but I could not hear or understand what it was saying". There were also many notes from the coordinator in the fall management system stating that a device was "chattering and needed resetting". It was not clear why this happened but in many cases the coordinator had to reinstall the software. Moreover, the participants had 7 real falls that were not recorded in the system: all happened while they were not wearing the device. There was no way to make sure whether they were wearing the device on a regular basis.

There were also a number of physical aspects of the smart phone complicating the above-mentioned problems further. Perhaps the most important issue was the short battery life of about 1 day. The phone needed to put on charge immediately when it stated "battery low", otherwise it turned itself off and needed turning on again after it had finished charging. More often than not, the participants forgot to recharge the phone and in some cases it remained off until the coordinator noticed and contacted them. Another issue was the sensitive touch screen of the phone. The Alarm went off very easily, for example as a result of bumping against something or bending down.

Using a smart phone with touch screen and multiple functionality (including normal cell phone functionalities) made understanding and using the device difficult for participants. They stated that it was hard for them to read the screen (because of their poor vision), and use the Alarm button. One elderly stated that: "It was over my head". Many stated that they would rather to have a real button instead of 'touch button' on the screen. Moreover, the phone's other functionalities were interfering with its fall detection purpose. One participant stated that: "It was a multifunctional device and received messages and telephone calls not relating to the trial". Some participants suggested that the project could be improved if the device was "more simple and serving as a unique fall detector and not a multifunctional one".

The phone was waist-mounted with the use of a belt and a pouch. This method turned out to be problematic too, as phones were not sitting firmly in place and could slip out frequently. Dropping the device was a common reason for PFs, and happened more frequently when users were changing their clothes e.g. before bedtime and when they were visiting the toilet. Some participant found it inconvenient using the belt and the pouch and preferred to put the device in their pocket instead. In responses to the questionnaire, it was suggested that a better way of attaching the phone was needed.

5.2. Network Issues

Some of the participants in our study were living in a mountainous area with patchy GSM network coverage, which turned out to be a big issue. This caused a problematic data collection and monitoring in some cases as the phone connection was going on and off. Loss of connection was annoying for some participants and an important reason for them to quit. In one case the project coordinator noted: "Reception to the network at her home was poor. The device had to be turned off and on again each day and did not always see the network anyway. She has had enough of dealing with the device and asked that I collect it."

5.3. Training Issues

The project coordinator provided a training session for each of the participants before delivering the phone. The training continued as needed each time the coordinator visited. Nevertheless, lack of enough and appropriate training and education was an important complaint in many cases. A participant stated: "Occasionally the phone would ring and I didn't know how to answer it. Was I not told?" Many of the participants proposed increasing training sessions as a way of improving the project too.

5.4. Sense of safety and security

The Clinical Partner as an active community organization and as a project authority invited the participants to join the project and use the technology. The objective of the project was only monitoring of the elderly and no intervention was intended. With this monitoring, the project was expected to increase the feeling of safety and security in elderly people lived at their own home. However, lack of good understanding of the phone and feedback from the project team detracted from this and the participants lost faith in the technology and the project gradually. A participant stated that: "It gave me no feeling of security because I did not understand what it was recording and even if it worked." In some cases the phone even created an extra source of stress for them. The project coordinator noted: "It made her aware of her balance problems and constantly trying to correct them was stressful for her. Her blood pressure at this time also became uncontrolled and she needed extra medication".

5.5. Organization of the project

Shortage of grant funding overshadowed many aspects of the project. For example, there was not enough money to buy a better smart phone, or to recruit more people to work in project support. Only one person was recruited to work as the project coordinator, as well as fulfilling the roles of system operator, and participant educator. The stakeholders commonly agreed that better results could be achieved if a call centre with more operators was set to work 24/7 and to communicate with participants immediately after an event was detected. Participants commented that they felt they needed more training. The start-up training might have been more useful if it was followed by refreshing sessions. The project did not have any planned intervention, but, our findings showed that the participants were expecting more than just monitoring.

Besides the above-mentioned problems, there were also difficulties with respect to coordination between the project stakeholders. The project stakeholders were located in different geographical locations (in different countries and in different cities) which disrupted ease of coordination and efficient progression throughout the project. This problem was more notable between UWS and Mediinspect, as they worked together a lot to get the fall detection application up and go, and to keep it working smoothly. A stakeholder stated that: “UWS and Mediinspect spent a lot of time talking and many skype sessions were needed to get briefed and communicate software faults”.

5. Discussion

With the perception that the technology would benefit elderly persons’ health (positive “Performance Expectancy”) and with Anglicare’s invitation (positive “Social Influence”), the technology received good attention. The participants developed positive “Behavioral Intention” and the adoption rate of the technology was good. The social Influence of Anglicare played a very important role in the high adoption rate. Previous studies have shown when elderly people become increasingly dependent on external help such as health and social services, people from those services take strong opinion formers and advisor position for the elderly [6]. However, in the course of the project, the users confronted with many problems which were rooted in the quality and performance of the technology (i.e., the fall detection software, the smart phone usage, and the network) and elderlies’ physical and mental abilities to use the technology. Those problems attenuated the early positive “Performance Expectancy” and “Social Influence” factors. In the context of insufficient training, many of them found the device hard to understand and use, and therefore developed a negative “Effort Expectancy” towards the technology. This negative attitude was augmented by poor “Facilitating Conditions” because of insufficient support throughout the project. Therefore, despite the early positive “Behavioural Intention”, the actual “Use Behaviour” of the technology was affected negatively. We believe this chain of events explains the high attrition rate of the participants throughout the project. There was no significant difference ($p>0.05$) in adoption and attrition rates between female and male participants in our study. This finding showed that in our study, gender did not have a noteworthy impact on adoption and use of the fall detection technology.

For the project stakeholders, recruiting participants was not a big issue. The real challenge was to keep them in the project and to motivate them to continue wearing the device. Only a few of the participants remained loyal to the project and used the device throughout the trial regularly. Through analyzing the qualitative data, we were able to recognize five main categories of challenges that negatively affected the continuation of use. They were: device issues, network issues, training issues, failure to provide sense of security and safety, and issues with organization of the project.

One of the important challenges of the project was using software which was not specifically developed to be used on a smart phone and had not been tested in real life settings previously. As a consequence, during the project many customizations were required to the software and the fall detection algorithm. These types of problems are not rare for a technology that is being used in a real world setting for the first time. However, as they take unexpected time and energy from the project investigators, they can be discouraging if they are too frequent. Therefore, for better results, it is recommended that the software stability and its functionality should be tested in a small-scale pilot before launching the main trial. The same argument is true for the GSM network. In our study, the network coverage should have been tested in different residential locations of the participant, and appropriate solutions for poor coverage of the network had to be planned before launching the trial.

Another important challenge was the choice of smart phone. It was not an appropriate choice in many respects. The device's design and its usability characteristics were inappropriate for the elderly people. This inappropriateness created unexpected complex sociotechnical problems and caused the majority of the EAs and many of the PFs events to be recorded. Considering elderly people's physical and mental abilities and what they value in use of a new technology is critically important in the technology's successful adoption and use. Previous studies indicated that in adoption and use of a technology, elderly people would value services that can make their everyday life and tasks easier and provide added safety [6]. Therefore, a simplified usability characteristic with good functionality (e.g., real alarm button) is preferred over the state-of-the-art technology (e.g., touch screen alarm button). Proper education, training, and practice are very important too. Recently, researchers also showed that, contrary to the deterioration of perceptive abilities and memories of elderly people, through proper instruction, training, practice, iteration and communication, elderly people can maintain their cognitive abilities and benefit from new technology or services [11]. The survey of the elderly showed that the majority of them (87%) had no problem with recording their movement data and many of them (61%) mentioned that they were happy with the device in general. This satisfaction was related to the objective of the device (and the project) and not to the choice of the smart phone, as they also found the phone hard to learn (59%) and not easy to use (69%).

Health related issues and multiple morbidities in elderly people are a very important challenge to continuation of technology use. Dealing with and managing these issues properly is necessary to keep the involved participants in the project and to prevent high attrition rate. In our project, 50% of the attrition was due to health issues. This high attrition rate could be prevented if the project was part of their health problems' solutions, for example by providing necessary medical advice whenever they needed. Such a health related intervention was necessary to preserve the users' trust in the project. If fall-detection projects are expecting to prevent psychosocial damage of fall in elderly and to increase sense of safety and security for elderlies who live at their own home, they need to have a plan on how to handle their different health related issues in the course of the project.

The current tri-axial accelerometer based fall detection technology needs further development, due to typically very high false positive rates. Managing false positives while making sure that no real alarm is missing is a resource intensive task. In the long term, too many false alarms can bring 'alarm fatigue' and undermine the objectives of the fall monitoring projects [10]. Therefore, the number of alarms has to be reduced in an appropriate way. Many elderly people may suffer from medical conditions (for example total knee replacement) that affect their gait. Therefore, the technology need to be adjusted based on elderly people' individual medical conditions. The current technology is one-for-all and the possibility of easy adjustment to the needs of different groups of participants was not foreseen in its development. It might be necessary to produce different versions of fall detection algorithms and software to choose the appropriate ones among them based on each participant's physical and mental characteristics. Another problem that should be addressed through further development of the fall detection technology is feedback on wearing the device. The technology needs to accommodate a complementary mechanism to show whether or not a person has worn the device. Such wearing feedback is especially helpful when the device does not detect any movement data.

Conclusion

This study had many limitations which should be considered in interpreting and generalizing its findings. First, the survey for participants was not standard, and it was not designed to test UTAUT. Therefore, we could not fully determine the constructs of the UTAUT concepts, nor could we determine the weight of each concept on actual use behaviour. Moreover, it was not possible for us to interview participants and therefore we missed an important source of qualitative data in our study. A lot of information that we analyzed came from the notes on the fall management system which were written by the project coordinator. The workload of the project coordinator and the post-hoc nature of the notes leave much possibility for bias and omission.

"Performance Expectancy" and "Social Influence" play important roles in acceptance of the fall detection technology and joining of the elderlies to the project. However, continuation of the use depends very much on "Effort Expectancy" and "Facilitating Conditions". Continuation of a technology use can benefit from its simplicity (less complexity), ease of use, and considering elderly people's physical and mental limitations in its usability design and training programs. Support of users is also important. This support should include not only the technical aspects of the use, but also a plan on how to handle elderly persons' health related issues to reduce the negative effects on their continuation of use.

Acknowledgement

The research project reported here was conducted by Anglicare and University of Western Sydney, and supported by the ACT Government (Australia) under the ACT Health Promotion Grants Programme.

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