Falls Prevention in the Home: Challenges for New Technologies

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ABSTRACT
Approximately 1 in 3 people over the age of 65 fall each year; therefore it is of little surprise that falling is often accepted as a natural part of the aging process. Many falls are simply managed using alarm pendants to notify others when a falls event occurs. However, falls technology extends beyond simple notification; technology can be used to screen for falls risk, or to prevent a fall from occurring. In this chapter, we review the latest best practices for the identification of falls risk. We review the technology, if any, developed to support these practices, and discuss the challenges of using technology for in-home falls prevention, risk assessment and falls detection. Recommendations and suggestions for future research directions are discussed.

KEY WORDS:
Falls risk assessment, Falls prediction, Falls detection, Interventions, Wearable, Gait, Balance, Neurocardiovascular
INTRODUCTION

Falls are of significant social and economic concern, due to the high incidence of falls among the rapidly growing “old” and “old old” populations and the direct and indirect cost of each fall. Approximately 28-35% of people aged 65 and over fall each year, increasing to 32-42% for those over 70 years of age (World Health Organization, 2008). However, it is the impact rather than the occurrence of falls in older adults which is of most concern. Older adults are typically frailer, more unsteady, have slower reactions and thus are more likely to be injured than toddlers and athletes, who also fall regularly. Approximately 40-60% of all reported falls in older adults lead to injuries, of which 30-50% are minor injuries, and 5-6% result in fractures. Most older adults who sustain a fracture following a fall report never regaining previous levels of mobility, and 20% of falls-related hip fractures result in death within 1 year. An injurious fall in a person over 65 can cost the healthcare system US$1049 in Australia (Hendrie et al., 2003) or US$3611 in Finland (Nurmi I. & Lüthje P., 2002). If falls rates are not reduced in the immediate future, the number of injuries caused by falls is projected to double by 2030 (Kannus et al., 2007).

Falling also incurs social and psychological consequences. Socially, a fall can lead to loss of independence and loss of social engagement, as well as broader societal costs and consequences. Psychologically, 54% of people aged over 70 express a fear of falling (G. A. R. Zijlstra et al., 2007), resulting in reduction in their physical and social activities. The main consequences of fear of falling are a decline in physical performance, a decline in mental performance, an increased risk of falling, and progressive loss of health-related quality of life. A fall event can also affect the spouse, family and friends of the person who falls, in particular generating concern for the safety of their loved one. This can result in an increased focus on caring for the older person including considering hiring a carer. It is unsurprising, given the incidence of injury and development of fear of falling, that a recent fall is one of the primary reasons given for moving into nursing homes.

The majority of falls do not result in injury, and many minor trips and stumbles are not reported and are quickly forgotten. However, multi-factorial fall risk assessment is recommended if a fall results in a soft tissue or fracture injury, two or more falls events within a year (recurrent falls), difficulties in walking and balance, or fear of falling are reported. A multi-factorial fall risk assessment can reveal factors that put an individual at risk of falling and can help identify the most appropriate interventions. The risk of falling increases dramatically as the number of risk factors increase. Technologies associated with the falls arena can generally be classified as assisting with detection, assessment, or prevention, and further sorted by the setting to which they belong – acute hospital, nursing home or domiciliary. A variety of falls technologies exist for non-fallers, recent fallers, and recurrent fallers, although the technology requirements vary for each group. An alarm pendant to summon help which may be very useful for a recurrent faller is unnecessary for a non-faller or someone who experiences an occasional accidental fall. Similarly, a challenging balance training game which reduces the risk of falling in non-fallers would be dangerous for a recurrent faller with balance issues.

In the background section of this chapter, we review the strategies developed to identify and treat falls risk factors. We then discuss the role of technology in quantifying and treating these risk factors. In some situations, falls cannot be prevented but the impact of the fall can be reduced through an appropriate
application of technology. We then discuss the challenges of developing falls technology for the home and suggest some future research directions. Although older persons in long-term care or older persons with cognitive impairment are at high risk of falling, technology developed specifically for these populations is outside of the scope of this chapter.

BACKGROUND

There is no standard definition for a fall, but the most commonly adopted definition is “an event whereby an individual comes to rest on the ground or another lower level with or without the loss of consciousness”. Each fall event can be further classified (Kenny et al., 2009) according to their self-reported mechanism (explained/unexplained), objective mechanism (extrinsic/intrinsic), severity (non-injurious/injurious) and frequency (single/recurrent). The definition of a faller also varies in the literature but a faller is usually described as someone who has fallen at least once within a set period of time. The latest AGS guidelines (American Geriatrics Society, in press) recommend screening older persons for falls every 12 months.

There are several reasons why older adults fall. Some reasons such as age and gender cannot be modified, and others such as medications, muscle weakness and vision can be modified. Table 1 categorizes the most common falls risk factors according to their objective mechanism, and whether or not they can be modified. The presence of more than one risk factor is common, and several studies have shown that the risk of falling increases dramatically as the number of risk factors increases. A recent Cochrane review on falls interventions (Gillespie et al., 2009) found that multi-factorial interventions were the most beneficial in reducing falls; however, the most successful interventions only reduced falls by 35%.
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<td>Cardiovascular status (e.g. blood pressure, heart rate and rhythm)</td>
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*Table 1. Common falls risk factors.*

There are several evidence-based clinical guidelines that prescribe clinical pathways for fall assessment and interventions. The NICE (National Institute for Clinical Excellence (NICE), 2004), ProFaNE Clinical Assessment Tool (Profane), and AGS Guidelines (American Geriatrics Society, in press) prescribe screening all older adults (aged over 65) for recent falls and/or poor gait/balance (Figure 1). If these preliminary risk factors are identified, a multi-factorial risk assessment and intervention are prescribed. A health professional or team should conduct this fall risk assessment, and directly implement the interventions or ensure that the interventions are carried out by qualified healthcare professionals. Technologies that can be used to quantify many of these risks and support falls interventions are described in the next section.
FALLS TECHNOLOGY
Alarms and Falls Detection

There has been significant interest in falls both from a research and commercial perspective for many years. A variety of approaches have been taken technologically towards falls detection with varying degrees of success. Falls detection devices can be categorized as Wearable Alarms and Passive Sensing Alarms.

Wearable Alarms
The most commonly known falls technologies are devices that a faller can manually use to summon help following a fall event. These alarms typically consist of an alarm button and a wireless transmitter or
transceiver, which are worn by the faller as a pendant or a bracelet. When a falls event occurs, the user presses the alarm button, which wirelessly connects to an alert unit installed in the faller’s house, which in turn notifies a remote monitoring center (such as the Philips Life Line (Philips) or MedicalAlarm.com (Connect America) monitoring centres) via a telephone or broadband connection. However this approach does have a significant drawback, as it is unsuitable for individuals who are unable to activate the alarm due to physical impairment or forget to activate the alarm due to cognitive impairment. A manual alarm is also of little use where loss of consciousness follows the fall, as the user cannot activate an alarm until they regain consciousness, and no data about the person (e.g. changes in blood pressure) or circumstances (e.g. duration of the event) are recorded.

There are also a variety of commercially available automatic fall detectors that do not require human intervention (Chubb, Tunstall, Tynetec UK). Wearable fall alarms contain a sensor and a transmitter or transceiver, and are typically worn on the chest, hips or waist, wrist or forearm, knee or thigh (Rajendran et al., 2008). Most automatic wearable fall detectors are designed to detect sudden impact on the floor usually indicated by a significant downward acceleration towards the floor followed by a person remaining in a horizontal orientation (determined by a gyroscope or tilt sensor) for a specified period of time. The use of multiple sensors helps to reduce the number of false positives (e.g. distinguishing a fall from someone sitting down quickly). Researchers at the University of Singapore have demonstrated pre-impact detection with body worn sensing with an average lead time of 700 ms, 100% specificity and a sensitivity of 95.2% using a combination of a tri axial accelerometer and 2D gyroscope (Nyan et al., 2008).

Wearable falls alarms rely on seamless integration between the body worn sensor and the call centre. The typical approach requires an intermediate device which receives the alarm from the sensor wirelessly and forwards the alert to a call centre over a telephone line or some form of broadband connection. The intermediate steps are obvious points of failure due to various forms of communication failures (e.g. radio interference). Such systems can only work when the person is located in their home or in close proximity (limited by the range of the sensor’s radio). Research has focused on integrating 3G communications into the sensor platform to provide reliable and flexible communications not restricted by time or location. The EU 6th Frame project HEBE (Azkoitia, 2004) focused on the detection of falls and monitoring of older people using a GPS locating device with a bi-axial accelerometer, all connected to a call centre using GSM/GPRS technology. For body worn devices to be effective, user compliance is of critical importance especially when the person is moving during their normal daily activities. Conspicuous fall alarms that are worn on the body can often be perceived by the users as stigmatizing them as fallers among their peers. Significant opportunity remains to improve their aesthetic design such as their inclusion into everyday objects e.g. Philips Lifeline Tempo Watch (Philips) and Emporia Life Plus mobile phone.

**Passive Sensing Alarms**

Video monitoring systems use cameras that attempt to detect a fall event using image-processing algorithms and that are programmed to identify unusual inactivity, which may occur following a fall. The fall detectors under this category are passive as the older person does not have to wear any device. This form of approach remains an active area of research within the academic community focusing design variations in image-processing algorithms and monitoring/transmission systems. The UbiSense project
(Lo, 2005a, 2005b) at the Imperial College London is focused on developing a non-contact, unobtrusive health-monitoring system for the older person by using embedded vision techniques to detect changes in posture, gait, and activities. Privacy issues are addressed in UbiSense by filtering the images at the device level into blobs. These blobs only contain the person's silhouetted outline and motion information. As images are not stored or transmitted, the original image cannot be recreated, therefore ensuring privacy. Pham et al. (2008) have demonstrated a multifunctional video monitoring system which supports real-time posture discrimination to determine emergency situations such as a fall event. Alternatively an alarm can also be triggered by suspected immobility in an unusual location. Privacy is supported by the utilization of a silhouetting technique. An alternative approach to standard video cameras which addresses many of the privacy issues is the SIMBAD system reported by the University of Liverpool. The Smart Inactivity Monitor Using Array-Based Detectors (SIMBAD) fall detector is based on a low-cost array of infrared detectors to capture low-level images of the resident and analyze the subject’s motion to detect a fall event (Sixsmith & Johnson, 2004). Falls are detected using a neural model based on the velocity and acceleration of the tracked object. The findings indicated good specificity in terms of low false-alarm rates; however the model could only detect 30% of emulated falls. Despite the ability of video-based fall-monitoring systems to automatically detect falls with no user intervention, the fear of intrusion of privacy is extremely prominent in this approach. Although a variety of solutions have been developed to ensure privacy, people in homes still experience the feeling of “being-watched”, making the technology unacceptable in many cases.

Floor vibration solutions fall into two categories: Acoustic Sensing Solutions and Vibration Sensing Solutions. Acoustic detection of falls events has generated recent interest. This approach uses an accelerometer in combination with a microphone to detect the sounds made when a person falls and contacts a solid object or surface, such as the floor. There are limitations to the technique associated with surfaces such as concrete with carpet overlay, for example. Doukas and Maglogiannis (2008) reported a system which wirelessly transmits acoustic data from a microphone to a monitoring unit, where Short Time Fourier Transform (STFT) and spectrogram analyses are applied. Support Vector Machines were utilized for event classification. They report 100% success in the detection of falls events. Litvak et al. (2008) report similar results with a system of a microphone and an accelerometer attached to the floor. The sensors are connected to a data acquisition unit which then transmits the signals at 16 KHz to a PC. They report detection of falls events with a sensitivity of 97.5% and specificity of 98.5%. The second type of floor vibration solution uses conversion of the mechanical energy that is generated when a person impacts an object/surface such as a floor; the energy is converted into electrical energy using piezoelectric sensors. The selectivity of the sensors is based on the hypothesis that the vibration signature of the floor generated by a fall is significantly different from those generated by normal daily activities such as walking, and that the vibration signature of a human fall is significantly different from those of falling objects. The Medical Automation Research Centre (MARC) at the University of Virginia has demonstrated a sensor based on this approach. In controlled experiments using a dummy, this fall detector attained 100% true positives and 0% false alarms with a detection range of 20 feet (Alwan et al., 2006). The significant disadvantage of both video and floor vibration approaches is that they only detect falls that occur within the home environment and only in rooms within the home that have the cameras or sensors installed in them. Controlled environments and small participant numbers curtail generalizability of results.
Assessing Falls Risk Factors

Balance Assessment

Balance can be defined as the ability of an individual to maintain the position of the body or more specifically, its centre of mass, within specific boundaries of space. Maintaining balance requires the integration of sensory information of the body relative to the surroundings, and the ability to generate forces to control body movement. As we age, the sensory inputs required for balance deteriorate; the processing system, which informs anticipatory and reactionary movements, is slower and sometimes incorrect; and the musculo-skeletal systems, which are required to maintain balance, can be weaker and painful. These age-related deteriorations can be further exacerbated by illness and disease. Static balance, also known as postural sway, describes the small movements and corrective actions required to keep the body standing upright. Balance is typically assessed in a clinical setting using functional performance scales (Tyson & Connell, 2009), such as the Berg Balance Scale, or the Performance-Orientated balance and Mobility Assessment (POMA). These assessments require the older person to perform a series of tasks which require steady state or anticipatory postural control. Their ability to complete these tasks is subjectively scored by a clinician.

Technological methods to assess and quantify balance are rare in falls clinics, but force plate, pressure measuring, and posturography equipment can be found in specialist rehabilitation and motion analysis laboratories. Force plates are measuring instruments that measure the ground reaction forces generated by a body standing on or moving across them, to quantify balance, gait and other parameters of biomechanics. Force plates measure three-dimensional components of the force applied to the surface of the force plate, the centre of pressure, and the vertical moment of the force. Pressure measuring systems also quantify centre of pressure, but do not directly measure the applied force vector. These systems are useful for quantifying the pressure patterns under a foot over time but cannot quantify horizontal or shear components of the applied forces. Posturography is used to objectively identify abnormalities in the three sensory systems (visual, vestibular, somasensory) and balance processing system by measuring anterior-posterior sway and response time when the individual sensory inputs required for balance are challenged.

NeuroCom developed a range of products (Equitest®, BalanceMaster®, VSRTM), which use dual force plates with rotation capabilities to challenge the balance and measure the vertical forces exerted by the patient's feet. These products provide a number of methods to assess and rehabilitate patients with balance and mobility disorders. The Metitur Good Balance System is a triangular force platform made of fiber glass composite material, which is used to measure postural control in different static and dynamic testing conditions. This system then uses visual and auditory biofeedback to aid rehabilitation of balance and asymmetric posture. TechScan develops pressure measurement systems that measure the underfoot pressure using insoles, sensor mats and sensor walkway. They have developed a Sway Analysis Module (SAM) add-on and a centre of mass module (CoM’alysis®) add-on to supplement their gait analysis products. Accelerometry has been shown to be a reliable method for the assessment of balance and gait in the clinic (Moe-Nilssen, 1998). In a recent study, O’Sullivan et al. (2009) demonstrated that a commercial tri-axial accelerometer (ActivPAL Trio) can distinguish between sway responses between fallers and non-
fallers, and demonstrated a high correlation between accelerometry and standard clinical assessments (Berg Balance Scale and Timed Up and Go). The Nintendo Wii has brought fitness gaming to the mass market. The Wii Balance board accessory uses 4 pressure sensors to measure the user's center of balance and weight. The associated WiiFit games challenge the user to maintain or move their centre of balance in a controlled manner. The WiiFit software has features to allow the users to track improvements/decline in their balance, thus encouraging continued use of the system. Ross (2009) recently compared the Wii Balance Board to the Force Plate and found that the Wii Balance Board is a valid tool for assessing standing balance.

Force-plate based systems require careful installation, and are typically only found in specialized motion analysis laboratories. The TechScan and Metitur products are less specialized and are targeted towards physiotherapists, chiropractors, and falls clinics. Kinematic sensing (accelerometers and gyroscopes) offer a low-cost, reliable, and portable method to objectively measure balance in any setting. However, to date there is no commercial clinical product which uses accelerometry to assess balance. The WiiFit system has focused attention on the topic of balance training in the home. It has been readily adopted by all generations, including older adults, who wish to improve their balance. The games were not developed for the rehabilitation of fallers and the Wii does not claim to be a rehabilitation device; in fact, it is possible that the challenging games may be unsafe for those who have serious balance issues. Researchers at the University of Aberdeen and NHS Grampian in Scotland began a study in early 2009 to investigate if people aged 70 years and older can improve their balance through regular use of the WiiFit.

Gait Assessment

Human gait is a complex balance challenge, in which a person must initiate a fall forward and recapture their momentum through the appropriate placement of their leading foot. Deficits in balance and gait are the most predictive risk factors for falls. The potential for loss of balance during walking is significant, and it is not surprising that over 50% of falls in older adults occur during walking (Lord et al., 2007). Stumbles are increasingly common among older adults, as foot clearance is lower and slower during the swing phase of gait. Slower reaction times, due to impaired processing of sensory inputs, painful joints, and increased muscle risks, further increase the risk of falling. The risk of falling is higher in people with Parkinson’s, due to the increased incidence of orthostatic hypotension, freezing mid-motion, and “hurrying gait”, and following a stroke, due to muscle weakness and difficulties in coordination. Gait impairments can be assessed using a number of methods, ranging from optical motion systems in motion analysis labs, to subjective observation of a person walking over a short distance.

A popular approach to gait analysis is stereophotogrammetry, based on either conventional photography/video (Wang et al., 2003) or optoelectronic sensors image processing systems (Cappozzo et al., 2005). Systems such as CODA from Codamotion (Charnwood Dynamics Ltd.), and Vicon have gained popularity for Gait Analysis (Lee & Hidler, 2008; Monaghan et al., 2006). The Codamotion optical systems consist of body worn markers that have in-built infra-red LEDs. These markers are attached to the body in different positions depending on the clinical protocol. As the person moves, the position of the markers is tracked at 42 µsec intervals using tripod-mounted motion capture units (CX1). The resulting data are connected to a data acquisition unit and then finally to a PC where the measurement information can be displayed in real-time and derived variables, such as joint angles, moments and
powers, are calculated. Optical motion analysis systems can be further enhanced by integrating then with other devices such as force plates and EMG systems. The GAITRite system from CIR System Inc is one of the most popular methods for the objective measurement of Gait parameters in a clinical setting (Besser et al., 2001; Bilney et al., 2003). The GAITRite system automates the measurement of the temporal (timing) and spatial (distance) parameters of Gait via an electronic walkway connected to a PC. The standard GAITRite system is approximately 366 cm long and contains 13824 sensors spaced at 1.27 cm apart. As the patient walks across the walkway the system dynamically captures pressure data with respect to each footstep and calculates both temporal and spatial parameters for the walk.

The major advantage of these laboratory based assessments is their ability to provide objective and quantitative measurement of gait. However a major drawback is the need for a permanent laboratory setting with skilled personnel to run them. A second major disadvantage is that gait sample, captured in the lab, is often not truly representative of the environment leading to a fall in the home (W. Zijlstra & Aminian, 2007), which contains many physical and cognitive obstacles. ‘White coat’ syndrome is often evident in the laboratory, and people significantly improve posture and gait during the period of the test. In an effort to address some of these limitations, there has been growing interest in the use of kinematic sensors as a low cost alternative for Gait analysis (Aminian & Najafi, 2004; Daniele, 2006; Giansanti et al., 2005; Mayagoitia et al., 2002; Narayanan et al., 2007). Accelerometers are commonly used to measure acceleration of body segments in 3-D. Miniature gyroscopes, which use a vibrating mechanical element to sense angular velocity, are also commonly employed. A third approach is pressure sensors or foot switches attached to the shoe or foot sole; these can be used to detect contact of the foot with the ground. Goniometers have also been utilized to measure a person’s range of motion (Carnaz et al., 2008; Piriyaprasarth et al., 2008). The goniometer is attached to the joint segments, and produces a voltage output that is proportional to the angle between these two axes. The key advantage of the body worn sensing approach is the ability to record objective data in non tethered conditions. Thus, the distance or location of a clinical gait assessment can be altered without moving or purchasing additional equipment. Wearable sensors can also be worn at home for an extended period of time to provide a true measurement of the person’s normal gait pattern. The body worn sensing approach to gait analysis is clearly advantageous; however, further development of such systems is required to provide reliable temporal and spatial parameters of gait with turnkey ease of use. Nonetheless, extended use in a home environment has many of the limitations associated with body worn falls detection devices.
The TRIL Centre developed a gait analysis system (Figure 2) which uniquely combines a floormat sensor, body worn sensors, video capture, and a software user interface for clinicians. The SHIMMER wireless sensor platform (McGrath D et al., 2009) was used to record gait and heart rate. O’Donovan et al. (2009) reported favorable comparison between gait analysis measured using SHIMMER kinematic sensors and gold standard optical (Coda motion) measurement. The SHIMMER (Barton & Jung, 2009; Lorincz et al., 2007; Patel et al., 2007) sensors are controlled by and communicate data to a master PC via a Bluetooth radio stack. The application software was developed using the BioMOBIUS (2009) software environment that supports data capture at rates up to 100Hz for kinematic SHIMMERs and up to 500Hz for ECG SHIMMERs. During clinical trials three SHIMMERs are worn by the subject: two kinematic SHIMMERs, one attached to each leg, are used to determine the temporal parameters of gait; and a third ECG SHIMMER unit attached to the chest is used to determine heart rate. A floor-mat sensor, developed by Tactex Technologies, was used to measure underfoot pressure as the older adults walked along the floormat. The 457cm floormat consists of 1296 pressure points spaced 2.5cm apart. The floor sensor measures pressure under the foot as the person walks along the walkway. The sensor can therefore be used to detect the location and timing of each footfall, as well as dynamic pressure changes under the foot during gait. The system’s user interface allows clinicians to select and adjust what data are being collected and how the data is processed. The software encapsulates data acquisition and signal processing modules, and allows customization of the sensors (K. O'Donovan et al., 2008).
Neurocardiovascular Assessment
Postural hypotension can result in a loss of balance due to low blood pressure and associated cerebral hypoperfusion. It can occur due to dehydration as well as medication, and is common in people with Parkinson’s disease. Postural hypotension is a transient event that is diagnosed by measuring beat-to-beat blood pressure when lying, moving from sitting to standing, and standing. It is difficult to detect this condition, as the drop and subsequent recovery in blood pressure following a postural transition may occur too quickly for traditional arm-cuffs to detect. The bedside Finometer and portable Portapres (Finapres Medical Systems) measure beat-to-beat blood pressure using a small finger cuff inflated to a pressure equal to the pressure in the artery. The cuff incorporates an infra-red transmitter on one side of the finger and a receiver on the opposite side. The transmission of the infra-red light through the finger is measured and found to oscillate with the cardiac cycle. The cuff pressure that produces the largest amplitude oscillations corresponds to the mean finger arterial pressure. This equipment is specialized and requires clinical expertise to interpret the results. There is currently no equipment capable of measuring beat-to-beat blood pressure in the community or the home.

Abnormal heart rhythms are common among older adults. Some people may experience these abnormalities continually, thus the abnormality is still present during a post-fall assessment. However in some people these abnormalities occur intermittently. In these cases, it is difficult to establish if an intermittent abnormality is the cause of a fall, as the clinician does not have access to a recording of the faller’s heart rhythm at the time of the fall and the abnormality may not occur during the post-fall assessment. Portable heart rate monitors (Holter monitors), which can record a person’s heart rate and heart rate variability for extended periods (24 hours to 2 weeks), are given to fallers when a clinical ECG appears to be normal and an intermittent heart rhythm is suspected. If an abnormality is not captured in this time period, an implantable device, such as Reveal (Medtronic), is inserted under the skin above the breast. These devices can record heart rhythms for up to 18 months, but require a minor operation to insert and remove. Wearable wireless sensors, such as the Intelesens Vitalsens platform (Intelesens), can integrate into existing home monitoring stations, and can warn if changes in vital signs are detected.

Falls prevention
Education & Peer-support
All falls prevention programmes include education components, intended to raise awareness about risk factors and interventions that reduce risk, for the purpose of preventing future falls. There is no evidence that education alone reduces falls, but it is a vital part of any multi-factorial intervention. The internet has become an expedient tool for dissemination of knowledge among falls experts and their peers, from falls experts to fallers, and among fallers. Resources, such as the Profane discussion board (www.profane.eu.org), allow falls researchers to share their expertise and latest findings among their peers, thus reducing unnecessary duplication, and ensuring that falls knowledge is collectively progressed. The internet is also a useful resource for fallers and their carers to learn more about falls, falls risk factors, and coping strategies. Although the current generation of older adults typically relies on a healthcare professionals for advice and support; future generations, beginning with the baby boomer generation, will question medical advice, and actively seek more information and methods to empower themselves. It is important, therefore, that information published online regarding falls interventions is safe and targeted to the person reading it. The Balance Training website
Exercise

Exercise programs are a recommended falls prevention strategy, both on their own and as part of a multifactorial intervention (Gillespie et al., 2009). The style of exercise (tai-chi/yoga, group balance and strength training, OTAGO) and delivery method (group training or one-on-one training) is dependent on the balance status of the older person. To be successful, a falls prevention exercise program must include a combination of strength, gait and highly challenging balance training (Sherrington et al., 2008). Exercise should take place at least twice a week for a minimum of 6 months, and should be progressed as the individual improves. Walking is contra-indicated, and a walking program may actually increase the risk of falling for an individual with poor balance. Wellness training, such as yoga and tai-chi, are useful for maintaining and improving balance in older adults who do not have balance issues. In a systematic review of exercise interventions, Sherrington et al. (2008) concluded that Tai Chi was an “effective program” for the reduction of falls and falls risk for those with mild deficits of strength and balance. Tai-chi reduces fear of falling and improves self efficacy but does not reduce falls in people with a history of falls. The Otago Exercise Programme is an in-home strength and balance training program developed by a research team at the University of Otago Medical School, New Zealand and evaluated in both research and routine healthcare services in 1016 people aged 65 to 97 living at home. This program is prescribed by trained health/fitness professionals and tailored to the ability of the individual. The exercise is progressed as appropriate during the 6-month program. Overall the exercise program was effective in reducing by 35% both the number of falls and the number of injuries resulting from falls, and was most successful in training adults aged over 80.

Tai-Chi, Yoga, and balance training DVDs specifically developed for falls prevention are available to purchase on the internet and from specialist shops. DVDs are useful to guide an older adult through an exercise program, and provide correct pacing, sequence and instruction not available from a paper-based exercise program. However, DVD-based exercise programs developed for the generic market are less likely to be adapted to the abilities and disabilities of an older individual. As a passive system, a DVD has no method of tracking whether the person is doing the exercises correctly or has completed any exercises. Another method of self-prescribing exercises is to download an exercise program from the internet. The Balance Training (www.balancetraining.org.uk) website provides a tailored exercise program for older adults after they have filled in a questionnaire describing their health, balance and falls status. However, there is no method to ensure correct completion of the exercise or to progress the exercise program. In-home exercise with biofeedback was a small specialized area until Nintendo launched the Wii and WiiFit products to the mass market. These products were not developed for falls prevention and/or risk reduction, but following its widespread adoption by older adults and community care settings, the benefits of the Wii for balance training in older adults are now being investigated.
FALLS PREVENTION TECHNOLOGY - THE CHALLENGES

Issues, Controversies, Problems

Scientifically, there are still many challenges in falls prevention. Currently, there is no worldwide consensus on what a fall is, although the Profane and NICE definitions are increasingly being adopted; nor is there a standard definition for a “faller”. The recently published AGS guidelines may be adopted by the research community in future studies. Previously, the definition of a faller was defined within the scope of individual studies, where a faller is labeled as a person who has experienced a fall within a fixed period of time. Profane recently published a falls prevention classification system (Lamb et al., 2007), which aims to standardize the reporting of falls, and outcome measures from fall interventions. If adopted by the falls community, this system should make the task of rating efficacy of interventions easier.

There has been little progress in falls research in recent years, with many new studies simply reiterating previous knowledge. Consequently, there has been little progress in falls technology in recent years. Despite understanding the main risk factors for falls, the most risky periods of the day for falls, and the most common location for falls, there is still no method to predict that a fall event is likely to occur and understand the cause of that particular fall. A clearer understanding of the circumstances which influence falls events in the home (time, contributing factors, and changes in behavior prior to a fall) across a large population is required before falls can be understood and subsequently predicted. Falls diaries are the most common method to record the details of a fall; however, they are ineffective if someone blacked out and does not remember their fall. What if someone is too embarrassed to admit falling and claims that they tripped? What if someone has poor memory (40% of over 80 year olds) and forgets that the event has occurred? Wearable and/or ambient technology can provide more objective descriptions of a fall event than a self reported description. However, there are also difficulties in acquiring these data due to the multi-factorial nature of falling and the difficulty in capturing a fall in the community. To capture the precise moment of a fall, the faller would have to be monitored continually; and a large number of people would have to be observed to develop a sufficiently large database. Following recent sensor technology advances, there are few technological limitations to undertaking such a study, but there are several scientific questions to be answered. For example, what risk factors should be measured? Should these be tailored to the type of faller? How frequently should these factors be measured? Should they be measured continually? What is the diurnal variation of falls risk factors? The Falls BioRhythms study carried out by the TRIL Centre is designed to answer some of these questions. This study assessed 20 fallers and 20 non-fallers in their homes for one day. Each subject was assessed for five falls risk factors (gait, balance, continuous blood pressure, heart rate variability and attention) at four time points throughout the day. Preliminary results from this study indicate more pronounced blood pressure drops in fallers following lunch. This finding has implications for the timing of clinical assessment, home monitoring, timing of medications and treatment of fallers.

Older people who fall are unlikely to label themselves as “fallers” and many do not hear this word until they interface with the health system following an injurious fall. Even those who are aware of the label “faller” are unwilling to apply it to themselves. It is not uncommon to hear a 70 year old, who has previously experienced an injurious fall to say “older people fall, not me”. The social stigma associated with falling affects the reporting of falls and the uptake of falls interventions, often with negative consequences. It is not uncommon for health care professionals to be dismissive of falls –“what do you expect at your age?” (The Economist Intelligence Unit, 2009). If someone who frequently trips or
stumbles does not consider themselves to be a faller, they are unlikely to receive treatment until a serious event occurs. If falling is destigmatized, use of falls prevention and prediction technology should in turn be destigmatized. Lack of knowledge of technology and lack of access to technology are common issues among older adults, and compliance with known technologies, such as falls alarms, is generally poor. There are many issues that affect compliance: many older adults fear that using falls technology labels them as “old”, “incapable”, or “frail”; the technology may be too complicated, difficult, or “boring” for them to use; or they may simply forget to use the device. Falls prevention is a life-long process so it is imperative to properly understand the factors that motivate a faller to carry an alarm as well as the factors that dissuade him/her from doing so. Ethnographic research and a collaborative user-centered design process are required to develop a device which users are motivated to use all day, every day, for the rest of their lives.

**Solutions and Recommendations**

Falls are inevitable and it is unlikely that any falls prevention or prediction strategy will be able to prevent the occurrence of all falls. It is therefore imperative that falls research focuses on reducing the impact of falls as well as reducing the occurrence of falls. Mechanical solutions such as hip protectors, soft floors and wearable airbags have all been implemented to distribute the force of an impact, thus preventing hip fractures. If a fall occurs, strategies such as getting up correctly following a fall or keeping warm until help arrives can reduce the side-effects associated with a long period of lying immobile. Multi-factorial interventions, which include tailored strength and balance program, medication review, and home modifications, have been shown to be the most successful method to reduce falls risk (Gillespie et al., 2009). However, if these interventions are not part of a lifelong lifestyle change, the risk of the individual falling will return to pre-intervention levels within months of ceasing the intervention. Patient compliance is one of the greatest challenges facing in-home interventions. Once the initial novelty of the intervention has abated, and the user feels that they have been “cured” of falling they are unlikely to maintain their new lifestyle. Interactive technology, which engages the user though tailored feedback, challenging targets and interaction with others may be the solution to this issue, as the unexpected adoption of the Wii platform by older adults demonstrates.

Screening for falls risk must become as common as screening for blood pressure among at-risk populations. This screening should be more sophisticated than simply asking “Did you fall in the last year?” as awareness and early treatment of the symptoms of falls risks could prevent a serious fall event from ever occurring. The latest AGS guidelines (American Geriatrics Society, in press), recommend that all older adults are screened for falls risk every 12 months, by asking if the individual (1) reported recurrent falls in the previous 12 months or had to seek medical attention following a fall, (2) has experienced difficulties in walking or balance, or (3) has a fear of falling. If the individual screens positive for any of these risk factors they are then referred for multi-factorial risk assessment. This screening mechanism is open to individual interpretation, particularly for those who have not fallen yet; thus many “worried well” individuals may be needlessly referred for further evaluation, while some who require evaluation may not be referred. An objective, repeatable, and reproducible screening tool for assessing falls risk is clearly required. Unfortunately, “no prospective study has been published that permits selection of a specific test of balance and gait, nor is there adequate validation of cut-off score for any of the tests for identification of future falls” (American Geriatrics Society, in press). A large, longitudinal, prospective study is required to validate existing scales (e.g. Timed Up and Go, Berg
Balance Scale, Performance-Orientated Mobility Assessment, or Gait Assessment) or to develop a new falls risk assessment tool. This study should periodically assess the user’s falls risk, over a period of years, to track improvements/decline in their scores. Supplementing these assessments with sensors will improve objectivity, ensure repeatability and reproducibility, and perhaps extract new features from these assessments which could not be measured otherwise. An objective screening tool, which has been proven to predict increased falls risk, could prevent a serious fall by enabling early referral for specialist assessment and intervention.

The underlying mechanisms of falls are not well understood - what caused a person to fall at that particular time and at that particular place? Was it an intrinsic or extrinsic risk factor or an accumulation of risk factors? Currently, we prescribe interventions based on the retrospective, and often self-reported, identification of risk factors which the individual has in common with other fallers. Whether these risk factors contributed to a particular fall event is not always clear. Large-scale, longitudinal research, which continuously monitors the main risk factors for falling, is required to further understand the mechanism of falls. While gait and heart rate can be readily assessed through kinematic and ECG sensors worn on or embedded in clothing, continuous neurological measurement would require visible sensors, which may dissuade potential subjects from wearing them, and there is currently no method for the continuous measurement of beat-to-beat blood pressure. Availability of an unobtrusive, beat-to-beat, 24hr continuous ambulatory blood pressure monitoring device would greatly enhance our knowledge of cardiovascular falls mechanisms. Meanwhile, a comprehensive, well-defined study measuring gait and heart rate continuously over a period of one year would help us identify the mechanisms leading to falls and whether or not these mechanisms were identified as risk factors during “care as usual”. In addition, such a study could help to determine which parameters are worth tracking and which are not, the time and frequency of measurements, and to identify the diurnal variation of falls risk factors. Successful completion of such a study would rely heavily on the design of the sensor technology: it must be discreet, comfortable, and easy to use to ensure 24-hour compliance for an extended period.

It is clear that many fundamental research questions regarding falls still remain. To answer these questions, it is important that a collaborative, multi-disciplinary approach is taken. The TRIL Centre is a coordinated collection of research projects addressing the physical, cognitive and social consequences of ageing, all informed by ethnographic research and supported by a shared pool of knowledge and engineering resources. Active research collaboration between engineering, ethnographic and clinical disciplines challenges preconceptions, inspires new viewpoints, and helps to ensure that the faller’s best interests are central to all decisions.

Until recently, technology development for biomedical research required significant hardware and software development time before a hypothesis could be tested. Advances in reusable and interoperable sensors such as the SHIMMER platform (McGrath & Dishongh, 2009), modular software platforms, for example, the free BioMOBIUS platform (McGrath & Dishongh, 2009) and standards for interoperability of medical devices (the Continua Health Alliance) have enabled rapid development of research prototypes to test clinical hypotheses, thus maximizing the time spent answering the research question and reducing the need for new technology.
FUTURE RESEARCH DIRECTIONS

Prospective validation of a falls risk assessment scale is an important step in identifying people requiring further assessment and measuring improvements/decline in their risk of falling following interventions. A sensor-based risk assessment scale is preferable as it would ensure objective, repeatable and reproducible measurements. A first step in achieving this task is to objectively measure existing falls risk scales using sensors to identify which parameters give these scales their predictive strength. These parameters must be measured several times over a number of years in a large older cohort and an appropriate threshold measure must be identified at which further assessment of falls risk and supervised intervention will be required. These parameters must be incorporated into screening tools which are suitable for use by frontline healthcare staff. Early identification and treatment of falls risks might prevent a fall from occurring, thus preventing the physical, financial, and emotional costs of falling.

Self-management of falls risk will become more important as healthcare resources are increasingly stretched. A method of assessing falls risk and educating individuals on falls risk and interventions must be developed for the general population. In healthy individuals who are at low risk of falling, this system might be as simple as a factsheet/webpage that gives older adults a number of simple balance tasks to assess their own falls risk. If they are unable to perform these tasks, they should be prompted to seek further assessment by a doctor. For those who have been diagnosed as having an increased risk of falling, a tailored in-home intervention and monitoring package might be developed to measure individual risk factors, such as blood pressure, and interventions such as medication prompting may be supported. If this is a telemonitoring package, results from this monitoring and intervention package can be remotely viewed by a healthcare professional, who can intervene if an increased falls risk is detected.

Hybrid fall alarms, which combine automated fall detection and an alarm button, should replace manual alarm systems. Falls alarms are a vital tool for recurrent fallers; however their indiscreet design, limited coverage, and the incidence of false alarms affect compliance with these devices. Improved compliance is therefore dependent on practical and discreet design, support for mobile telephony, and improved algorithm development. Ideally, alarms could predict the onset of a falls event and warn the faller in real-time or near real-time of an increased risk of falling, thus allowing them to take protective measures and prevent injury. However, until the mechanics of falls are fully understood, through continuous recording of multiple parameters before, during and after a fall event, prediction of a falls event is still in the future.

CONCLUSIONS

Rapid global aging means that societies or economies can no longer afford “usual care”. Technology can support and enable large scale studies required to answer outstanding questions about falls. As the ratio of clinical resources to older adults requiring those resources increases, technology will be necessary to streamline clinical assessments while maintaining quality of care. The aging baby-boomer generation will have the technical literacy and desire to educate themselves and self-manage their falls risks, but technology must be in place for them to do so. Front-line medical staff will require screening technology to identify those requiring a referral to specialist assessment centers. To achieve significant reduction in falls incidence, a holistic life-long approach combining cognitive, social and physical activities will be required. The challenges are significant; but with close collaboration between fallers, falls experts, and technical experts they are achievable.
REFERENCES


**Additional reading**


