REVIEW

New methods for fall risk prediction

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Purpose of review
Accidental falls are the leading cause of injury-related death and hospitalization in old age, with over one-third of the older adults experiencing at least one fall or more each year. Because of limited healthcare resources, regular objective fall risk assessments are not possible in the community on a large scale. New methods for fall prediction are necessary to identify and monitor those older people at high risk of falling who would benefit from participating in falls prevention programmes.

Recent findings
Technological advances have enabled less expensive ways to quantify physical fall risk in clinical practice and in the homes of older people. Recently, several studies have demonstrated that sensor-based fall risk assessments of postural sway, functional mobility, stepping and walking can discriminate between fallers and nonfallers.

Summary
Recent research has used low-cost, portable and objective measuring instruments to assess fall risk in older people. Future use of these technologies holds promise for assessing fall risk accurately in an unobtrusive manner in clinical and daily life settings.

Keywords
accelerometer, accidental falls, assessment, balance, older adults, sensor

INTRODUCTION

Accidental falls remain an important problem in older people. About one-third of people older than 65 years fall at least once a year, and falls are the leading cause of injury-related hospitalization in old age. Falls can be attributed to a wide variety of causes, with poor balance and mobility being the most commonly reported [1,2]. Most falls in older people occur within the home and immediate home surroundings, while older people are undertaking their usual daily activities.

There is clear evidence that falls in older people can be prevented with appropriately designed intervention programmes. In order to start a targeted and tailored fall prevention programme for older people living in the community, a first step is to identify people at high risk and to accurately assess their individual fall risk factors. Various measures of balance and mobility have been associated with an increased risk of falling, especially when assessed under more challenging conditions. However, balance and mobility assessments conducted in a laboratory environment are often only weakly associated with falls. One possible reason for this weak association is that assessments are a one-time snapshot under ideal circumstances dissimilar to those that would lead to falls in an older person's daily environment [3■■]. Because of limited resources of most healthcare systems, regularly repeated assessments or long-term monitoring is not feasible in clinical practice.

Recent technological advances in low-cost, objective and portable measuring instruments hold promise for more regular task-specific assessments. Furthermore, technology might enable more continuous monitoring while people are performing unsupervised directed routines or simply undertaking their daily activities at home. Figure 1 provides an overview on the different settings in which technology-based fall risk assessments can be applied. In recent studies, three-dimensional inertial sensors (i.e., accelerometers and gyroscopes), pressure sensitive mats or boards, three-dimensional depth sensors, laser and radar devices have been used to

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KEY POINTS

- Accidental falls are common in older people.
- The use of low-cost, portable and objective measuring instruments is feasible for use in older adults and has potential to identify people at risk of falls.
- Sensor-based fall risk assessments have the potential to be conducted in the homes of the older adults, through use of a directed routine or by means of continuous monitoring.

measure functional performance in older people and fall risk. This review collates the findings of recent studies that have used such new technologies for fall risk discrimination in older people.

LITERATURE SEARCH AND SELECTION CRITERIA

The literature was searched using ‘PubMed’, ‘Scopus’ and ‘IEEE Xplore’ databases. The following primary search terms were entered: ‘accidental falls’, ‘prediction’, ‘risk assessment’, ‘sensor-based assessment’, ‘accelerometer’, ‘gyroscope’ and ‘inertial sensor’. Articles were included on the basis of the following criteria: a new technology-based method was used to predict falls, the paper reported results on the comparison of fallers and nonfallers, the total sample size was 30 or more, the average age of participants was 60 years or over, the paper was published in English in the past 18 months (between September 2012 and February 2014).

SEARCH RESULTS

A total of eight studies were identified [4–6,7■,8,9,10■,11■■]. Study populations, description of the fall discrimination measure and main findings are summarized in Table 1. The sample sizes ranged from 39 [6] to 152 [8]. Mean age of the participants varied from 62 [9] to 81 years [10■]. All studies involved healthy community-dwelling older adults [4–6,7■,8,9,10■,11■■]. The outcome measure of falls was measured differently across studies, with five studies using a retrospective recall over 12 months [6,7■,8,9,11■■], two studies using a retrospective recall over 5 years [4,5] and one study using prospective fall diaries over 12 months [10■]. Fallers were defined as having at least one fall in the study period in five studies [4,7■,8,9,10■] and at least two falls in three studies [5,6,11■■]. Two studies examined postural sway [4,5], one study examined sit-to-stand mobility [6], two studies examined choice stepping reaction time [7■,8] and three studies examined gait [9,10■,11■■]. Seven studies reported on laboratory assessments [4–6,7■,8,9,10■] and one on home-based assessments [11■■]. Five studies used inertial sensors to acquire the data [4,6,9,10■,11■■], two studies used pressure sensors [5,7■] and one study used a laser sensor [8].

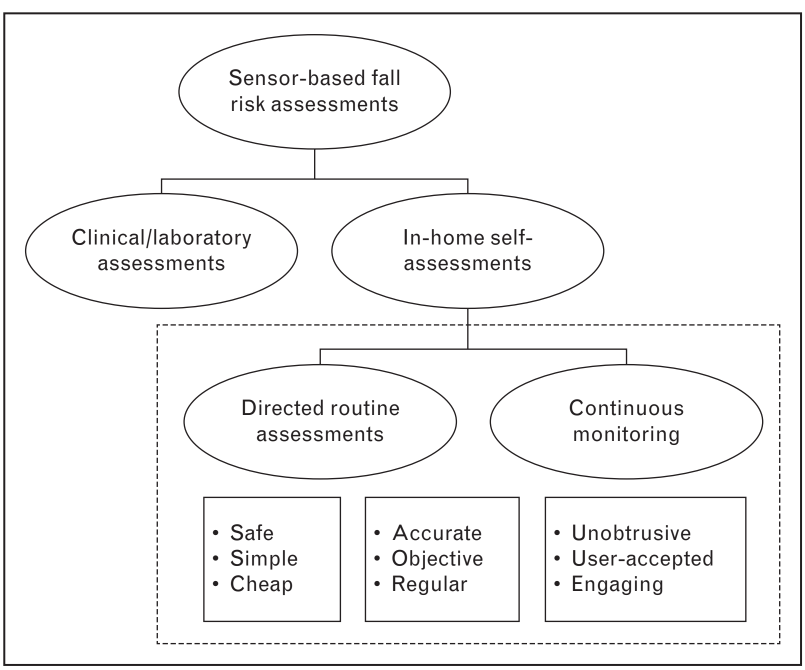

FIGURE 1. Application areas of sensor-based fall risk assessments and requirements for in-home self-assessments.

Table 1. Summary of included studies with more than 30 older participants (mean age > 60 years)

Study	Study design and population	Study period and falls measure	Fall prediction measure	Main finding
Doheny *et al.* [4]	Community-dwelling, $n = 110$, mean age 73 years (SD = 6), 56 fallers	Retrospective recall over 5 years Fallers: at least one fall	Overall measure: postural sway Device: inertial sensor, attached to lower back Assessment: centre of mass displacement in comfortable and semitandem stance position with eyes open, for 35 and 40 s Setting: laboratory	Significant ($P < 0.05$) difference between fallers and nonfallers on sway range, length, velocity and root mean square acceleration
McGrath *et al.* [5]	Community-dwelling, $n = 120$, mean age 74 years (SD = 6), 65 fallers	Retrospective recall over 5 years Fallers: at least two falls, or one fall with specific criteria	Overall measure: postural sway Device: portable pressure sensor matrix Assessment: centre of pressure excursions in semitandem and narrow stance, with eyes open and eyes closed, for 30 s Setting: laboratory	Significant ($P < 0.05$) difference between fallers and nonfallers on sway length, velocity and frequency, especially in eyes-closed condition
Doheny *et al.* [6]	Community-dwelling, $n = 39$, age range 61–88 years, 19 fallers	Retrospective recall over 12 months Fallers: at least two falls, or one fall requiring medical attention	Overall measure: functional mobility Device: two accelerometers, one attached to thigh, other positioned above sternum Assessment: accelerations in Five-Times-Sit-to-Stand test, intraday test-retest reliability Setting: laboratory	Model using statistically reliable (ICC > 0.7) accelerometer-derived parameters classified fallers from nonfallers with 74% accuracy, 80% specificity and 69% sensitivity
Schoene *et al.* [7▪]	Community-dwelling, $n = 103$, mean age 80 years (SD = 5), 29 fallers	Retrospective recall over 12 months Fallers: at least one fall	Overall measure: stepping Device: sensor-based dance pad Assessment: stepping performance in stepping test with high attention component Setting: laboratory	Significant ($P < 0.05$) difference between fallers and nonfallers in total step time and number of step errors
Nishiguchi *et al.* [8]	Community-dwelling, $n = 152$, mean age 74 years (SD = 5), 41 fallers	Retrospective recall over 12 months Fallers: at least one fall	Overall measure: stepping Device: infrared laser sensor, positioned in front of the participant Assessment: temporal and spatial parameters in four-square choice stepping test Setting: laboratory	Significant ($P < 0.05$) difference between fallers and nonfallers in reaction time and step time
Riva *et al.* [9]	$n = 131$, mean age 62 years (SD = 6), 42 fallers	Retrospective recall over 12 months Fallers: at least one fall	Overall measure: gait Device: inertial sensor, located on trunk below shoulder blades Assessment: nonlinear stability measurements, not dependent on step detection, when walking on a treadmill Setting: laboratory	Significant ($P < 0.05$) univariate associations between multiscale entropy (indicator of complexity of gait kinematics) and recurrence quantification analysis measures with fall history
Doi *et al.* [10▪]	Community-dwelling, $n = 73$, mean age 81 years (SD = 7), 16 fallers	Prospective study over 12 months Fallers: at least one fall	Overall measure: gait Device: two accelerometers, attached to lower and upper trunk Assessment: stability measurements, in 10-m walk Setting: laboratory	Significant ($P < 0.05$) difference between fallers and nonfallers on harmonic ratio measurement (indicator for smoothness and stability of trunk movements)

Table 1 (*Continued*)

Study	Study design and population	Study period and falls measure	Fall prediction measure	Main finding
Weiss *et al.* [11■■]	Community-dwelling, $n=71$, mean age 78 years (SD = 5), 32 fallers	Retrospective recall over 12 months Fallers: at least two falls	Overall measure: gait Device: inertial sensor, attached to lower back Assessment: three consecutive days of unsupervised activities of daily living Setting: continuous, in-home	Significant ($P<0.05$) difference between fallers and nonfallers in step-to-step variability, measured as amplitude of dominant frequency in power spectral density

ICC, intraclass correlation coefficient; SD, standard deviation.

FINDINGS AND DISCUSSION

This literature review examined new technological advances in the area of fall discrimination in older people. Large epidemiological studies have identified a range of important risk factors for falling, with impairments in balance, mobility and gait showing strong associations with falls. The identified studies in this review give an insight into which technologies are feasible for use in older people and how measurement outcomes derived from these technology-based assessments are likely to assist in the prediction of falls in the future.

Ageing is associated with decreased ability to maintain postural stability, and an increased postural sway has been associated with future falls [1]. Objective balance measurements using gold standard measures, such as force platforms, are expensive and therefore not always accessible in clinical settings. The availability of low-cost and commercially available sensors (e.g., inertial sensors, Wii Balance Board, Nintendo Co., Ltd, Kyoto, Japan) makes it more feasible to conduct regular balance assessment in clinical practice or in people's homes, similar to methods previously only used in research settings. Within the review period, one study was published measuring postural sway with an inertial sensor [4] and one using a pressure sensor matrix [5] during different stances. Both systems were feasible for use in older adults, and indicated postural sway during quiet stance was significantly increased in fallers compared to nonfallers, in line with laboratory-based studies [4,5].

The ability of a person to take a fast and accurate step has been associated with future falls in older people. Several tests of choice stepping reaction time that require participants to take steps in response to visual cues have been devised in the last decade. Within the review period, one study assessed stepping performance using an infrared laser sensor [8] and another using a sensor-based mat [7■]. Both studies confirmed that fallers had slower reaction times and total step times when compared to nonfallers [7■,8]. An advantage of the mat-based system is the inclusion of selective attention and response inhibition components that test dual-task performance [7■]. The mat-based system further provides an effective home-based method for improving stepping ability and balance in older people [12].

The Five-Times-Sit-to-Stand test is often used as a proxy measure for functional mobility and lower limb strength. In clinical practice, a measure of total time required to complete this test is used as a marker for fall risk, with a slower time indicative of a higher risk of falling [6]. The use of inertial sensors makes it possible to further quantify the smoothness of the sit-to-stand transitions [6]. A small study within the review period suggested that this method can classify fallers and nonfallers with good accuracy. Future work should focus on detecting the sit-to-stand movement during daily life activities, which could then be used for continuous monitoring of functional mobility.

Ageing is associated with changes in gait. Slower gait speed and reduced gait stability have been associated with future falls in older people. Research is increasingly exploring the use of inertial sensors to assess gait [9,10■,11■■,13,14], eliminating the need for more expensive electronic walkways or camera-based systems. However, the remaining challenge in the measurement of spatiotemporal and stability gait measures using inertial sensors is the accurate detection of steps [9]. Within the review period, two papers focused on nonlinear analysis techniques that do not require step detection, and used harmonic ratios as an indicator for smoothness and stability of trunk movements [10■] or multiscale entropy as an indicator of gait complexity [9]. Preliminary results suggested that these new gait measures can detect differences between fallers and nonfallers [9,10■]; findings that will facilitate assessment of gait data during daily life. One study published last year monitored gait continuously for 3 days during daily life using a body-worn inertial sensor attached to the lower back [11■■]. The study showed that fallers had increased step-to-step variability when compared to nonfallers. More research is underway using sensor technology for continuous and in-home monitoring to provide an insight into the daily living of older adults [11■■,15,16].

A few methodological limitations need to be considered. These recent developments in fall prediction methods are largely low-cost, digital versions of existing fall-risk assessment tests. All, but one study, were conducted in a laboratory setting and, therefore, do not provide any information regarding the feasibility of using these new technologies in daily life settings to provide continuous (in-home) monitoring and fall prediction of older people. A recent report of expert opinions found that most experts considered that unsupervised fall prediction is both possible and useful [17■]; however, further research is needed to confirm this. Figure 1 shows general requirements for sensor-based fall risk assessments in unsupervised settings. The included studies used different approaches to discriminate between fallers and nonfallers – that is, varying definitions of fallers and time frames – with only one study using the gold standard prospective method of recording falls. The sample sizes of all studies were also too small to provide any definitive conclusion regarding the accuracy of using these new methods for classifying fallers and nonfallers.

CONCLUSION

Recently, wearable devices using inertial sensor technology have been used to measure the intensity and time of physical activity bouts and different types of activities (e.g., sit-to-stand, walking, stair climbing), as well as the quality of these movements. Such sensors are inexpensive and portable, and research has provided preliminary evidence that sensor-based fall risk assessments can discriminate fallers from nonfallers in a laboratory setting. Unobtrusive monitoring of activities of daily living using these new technologies or regular (e.g., monthly) unsupervised directed routine assessments may have the potential to predict falls in older adults more accurately. Further studies are required to validate the use of these new technologies in the home using prospective methods so as to enable the accurate identification of fall risk during daily life activities and use this information to target interventions accordingly.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

■ of special interest
■■ of outstanding interest

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