



Loop Evidence Summary: Wearable Devices for Fall Prevention

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Key Messages

- **Wearables** are body-worn, internet-enabled electronic devices that monitor a range of fall-related indicators, including balance, posture, gait, locomotion, and gait variability.
- Wearables include one or more **sensors**, devices that record and measure signals emitted by the human body in order to provide feedback about key gait indicators. Current wearables incorporate inputs from multiple sensors to provide a more comprehensive assessment of fall risk.
- Key types of wearables include inertial sensors, electromyography (EMG) sensors, pressure sensors, and proximity sensors. Wearable technologies have also been implanted in hip protectors to detect falls and fall risk.
- There is some debate about the optimal placement of wearable devices, especially inertial sensors, which can be located on the trunk (most common practice) or shins.
- Rapid advances in wearable technologies to **detect** fall risk make aging at home a more viable option for older adults. Wearables for fall detection also serve as a valued support for the caregivers of older adults dwelling at home or in assisted living facilities.
- Evidence supporting the use of wearables to **predict** fall risk and prevent falls is inconclusive. This is partially due to the fact that the vast majority of studies assessing wearable technologies are conducted in laboratory conditions rather than the 'real world' external environments that older adults are required to navigate.
- The increased adoption of wearable technologies for fall prevention and detection requires action to overcome a range of social, economic, behavioural, and legislative challenges.
- The development of wearable technology for fall-related applications is rapidly evolving. Further advances in technology will likely increase the availability and affordability of wearables, which will prompt action to address some of the current barriers impeding their adoption.

Purpose

The purpose of this Loop Evidence Summary is to provide an overview of wearable devices most commonly used for fall prevention. This document covers the key types of wearable devices, their uses, and new developments in this field of research and practice. Recommendations for further research and best practices that could optimize the use of wearables for the detection and prediction of falls among older adults are also provided. Details on the literature evaluating their effectiveness are provided at the end of the document.

Background

According to the World Health Organization (WHO), falls are the second leading cause of unintentional deaths globally, with an estimated 684,000 fatal falls occurring each year.¹ An additional 37.3 million falls are severe enough to require medical attention.¹ In Canada, falls are the leading cause of injury-related hospitalizations and injury deaths among people aged 65 or older.^{2,3} Age is the leading demographic risk factor for a fatal or injurious fall: 30% of individuals over 65 fall at least once a year, and the number increases with age.^{3,4}

The causes of falls in older adults have been linked to age-related physical, cognitive, and sensory changes and the environment. The individual changes include: decreased postural stability, control and reflexes; reduced muscle strength and amplitude of lower limb joint movements; displacement of the centre of gravity; changes in vision; and increased incidence of injuries such as concussions, soft tissue bruises, bone fractures and lacerations.⁵⁻⁷ All of these factors can affect the gait of older adults, putting them at increased risk of fall-related injuries.⁸

Fall-related research is addressing this problem by developing devices that detect changes in human gait. These devices are commonly known as **wearables**: body-worn, internet-enabled electronic devices that monitor a range of fall-related indicators, including balance, posture, gait, locomotion, and gait variability.^{8,9} Wearables include one or more **sensors**, devices that record and measure a physiological property, including signals emitted by the human body, in order to provide feedback about key fall-related gait indicators. The current generation of wearables incorporates inputs from multiple sensors to provide a more comprehensive and holistic assessment of fall risk.⁹

Wearables designed to provide feedback on gait and balance-related indicators enable more effective fall detection and fall prediction. **Fall detection** alerts individuals and their caregivers whenever a fall occurs. **Fall prediction**, the focus of more advanced wearable technologies, prevents or reduces the harmful impacts of a fall by warning individuals about the magnitude of risk before a fall occurs.¹⁰ The increased adoption of wearables can also help create large data sets for trend analysis and modelling, which can guide and inform population-wide fall prevention strategies.⁹

Wearable technology is rapidly evolving and the most widely adopted devices are raising practitioner interest in terms of efficacy for fall detection and prediction.

Methods

To guide the search for relevant literature on wearable technologies for fall detection and prediction, an initial scan on the topic was completed. Then a taxonomy was developed to identify and organize the main categories of wearables and associated devices (i.e., the sensors or technologies embedded in a particular wearable), the placement (i.e., where the wearable is worn on the body) and the fall risk indicators measure by the wearable (e.g., gait variability, gait symmetry, step time, etc.). A full description of the methods used to complete this evidence summary is included in Appendix A along with a table depicting the taxonomy mentioned above.

Categories of Wearable Devices for Fall Detection and Prediction

Inertial Sensors

An **inertial sensor** measures the acceleration and angular velocity of an individual along three perpendicular axes.^{10,11} A wearable inertial sensor for fall risk prediction usually contains one or more of the following devices to measure inertial measurement units (IMUs): an accelerometer, a gyroscope, and a magnetometer. For further details on these devices, see Appendix B.

Inertial sensors can easily be placed on various portions of the body. The number of devices (e.g., accelerometer, gyroscope etc.) on an inertial sensor, and their positioning (e.g., chest, lower limbs), depends on the desired purpose and application.¹²

Inertial sensors using accelerometers and gyroscopes appear to be the most widely adapted wearable technology for fall risk prediction.^{10,13} This is likely due to their relatively low cost, small size and weight, and ease of incorporation into devices such as wrist monitors or Smart Watches.¹⁰ Accelerometers also offer the advantage of consuming less power than other inertial sensing devices, which makes them more suitable for situations where continuous fall risk monitoring is warranted.¹⁰ In addition, several studies have found moderate correlations between the predictive validity of accelerometers and some of the clinical scales used to assess fall risk, such as the Tinetti Balance and Gait Assessment tool.^{10, 14-15}

However, the single use of any inertial sensing device may cause various measurement errors for fall risk prediction. For example, accelerometers alone do not work well when used for dynamic activities, such as stepping over or around obstacles or stair climbing. Gyroscopes, by contrast, do not work well when used for long-lasting activities, such as walking or hiking long distances.¹⁰ So, the combination of an accelerometer, gyroscope and magnetometer within a single wearable inertial sensor is the recommended best practice to provide a more reliable estimation of fall risk.^{10, 12}

There is some debate about the optimal placement of inertial sensors on the body. For additional information on the placement of inertial sensors, see Appendix B.

Despite their growing popularity as a relatively low cost, easy to use option for assessing fall risk, inertial sensors have not yet gained widespread acceptance among clinicians due to the unknown accuracy of IMU-based assessments for gait and balance.¹² Multiple systematic reviews on the efficacy of wearable sensors, including inertial sensors, for fall risk prediction have yielded inconclusive results due to the diversity of methodologies applied to assess sensor precision.^{12, 13, 18, 19} Another key limitation of the studies supporting the use of inertial sensors is that they are generally conducted exclusively in laboratory conditions, and do not, therefore, reflect the ‘real world’ interactions between older adults and socio-environmental fall risk factors.²⁰

EMG Sensors

Electromyography (EMG) sensors measure fall risk through the electrical activity of muscles. EMG sensors are most commonly placed on the lower legs. The muscle groups of the lower legs are of particular importance for their role in walking, controlling stability and maintaining the standing position.²¹

EMG sensors appear to provide critical information for real-time fall risk assessment. A significant advantage of EMG sensors is that sudden changes in EMG patterns due to unbalance is detected and communicated faster than change in inertial sensor patterns.¹⁰

A major drawback of conventional EMG sensors, which require direct application to the surface of the skin next to the target muscle, is that they may cause long-term discomfort, thereby precluding their use on a daily basis.¹⁰ To address this, work was done to design a hybrid polymer EMG sensor (as an alternative to the standard pre-gelled electrodes). This device, which was incorporated into users’ socks, reduced skin irritation while improving biocompatibility, mechanical properties, and signal detection.²² Over time, this innovation may increase the use of EMG sensors for monitoring fall risk in independent living environments.

Pressure Sensors

Pressure sensors, most commonly attached to shoe insoles, can assess gait according to key parameters, including stepping rhythm, step size, weight distribution between heel and foot and the timing of gait phases.⁸ Currently, signals from pressure sensors can be automatically analysed in a mobile phone application that sends results to a central server for observation or direct assistance.⁸

To date, evaluations of pressure sensors have yielded promising results, with some studies indicating that the pressure sensor method of gait detection may be more accurate for fall risk prediction than inertial sensor data.²³⁻²⁴ For example, the evaluation of a new Velostat

(polymetric foil) pressure sensor by Bucinskas and colleagues found that the accuracy of the sensor in detecting abnormal gait reached 94 percent.⁸

While pressure sensors have demonstrated promising results, the technology is relatively novel. Further studies are required to validate pressure sensors with a wider range of tests on individuals of different ages with different levels of health status. Additional effort is also needed to develop a viable product that can be mass produced at an affordable cost.^{8, 25}

Proximity Sensors

Proximity sensors are deployed in fall detection systems. Many of these sensors are traditionally attached to a walking-aid device, including walkers or canes.²⁶ Recent advances in technology have enabled proximity sensors to be combined with fall risk prediction sensors in wearable devices, such as the Sensi Steps tool.²⁷ However, these devices have not yet been subject to extensive testing.

Falls are detected by proximity sensors through the measurement of sudden changes in an individual's movements and their distance from the proximity sensors.²⁶ One of the challenges associated with these devices is their short proximity range: a person stepping away from the device attached to the sensor could be misinterpreted as a fall. In addition, some proximity sensors are too expensive for widespread adoption.²⁶⁻²⁸

Proximity sensors can also be attached to patient beds to enable the detection of falls among older adults in hospital geriatric wards or long-term care facilities. An initial test of one of these sensor systems, the Inexpensive Node for Bed Exit Detection (INBED), found high levels of sensitivity for rising detection and good sensitivity for detecting heavy falls. However, the sensor system generated false positives, where heavy gait steps or bumps against the bed or other objects were interpreted as falls.²⁹

Some ethical concerns have been raised around the involuntary use of proximity sensors and other monitoring devices on older adults.³⁰ Research in this area underscores the need for the development of sensor systems that balance patient safety needs with patient quality of life. For additional information on a study that raised these concerns, see Appendix B.

Hip Protectors

Technological advances have enabled the incorporation of fall risk detection and prediction devices into another wearable product designed to prevent fall-related hip fractures, **hip protectors**. Developed in the United Kingdom, the Fall Safe Assist hip protector includes an embedded tri-axial accelerometer that enables the monitoring of fall direction, speed, and force, the date, time, and location of the fall, and the step length and stepping patterns prior to

the fall. Public consultations about the prototype with 147 older adults and 10 long-term care staff found positive opinions about the utility of the device. However, further work is needed to overcome concerns related to aesthetics, cost, and practicality.^{31,32} The development and adoption of ‘smart’ hip protectors may be contingent on improved hip protector design, given that systematic reviews of the literature have found limited evidence of their utility in preventing hip fractures among older adults.^{33,34} However, work in this area is ongoing and recent innovations, such as the development of ‘stick on’ hip protectors (i.e., secured on the hip with an adhesive designed not to irritate the skin)³² may address the above-mentioned aesthetics and practicality concerns.

Conclusion

Rapid advances in wearable technologies to detect fall risk are helping make aging at home a more viable option for older adults. Wearables for fall detection also serve as a valued support for the caregivers of older adults dwelling at home or in assisted living facilities. These benefits were highlighted in a recent *Toronto Star* article that showcased wearable devices, such as Philips Lifeline™ products and Apple™ Watches, with advanced features that enable fall detection and round-the-clock monitoring.³⁵

While wearables appear to be a popular and proven means of fall detection, evidence supporting the use of wearables to predict fall risk is more ambiguous. Multiple systematic reviews of the literature have failed to make definitive conclusions about the efficacy of wearable sensors for fall risk prediction due to different methodologies to assess sensor precision.^{11, 13, 18, 19} The generalizability of studies assessing the fall prediction utility of wearable sensors is further limited by the fact that the vast majority are conducted exclusively in laboratory conditions rather than the ‘real world’ external environments that older adults are required to navigate.^{10,20}

Nouredanesh and colleagues conducted a narrative review of 24 studies collecting data on the fall prediction efficacy of wearable sensors in ‘free living’ (as opposed to laboratory) conditions. The review assessed studies collecting data from wearable sensors to identify fall-prone older adults in their homes.³⁶ The review found that, while the use of fall prediction wearables in free living conditions was a promising avenue of exploration for fall prevention, evidence of the relationship between key indicator data collected by the wearables (e.g., quantity of daily steps) and falls remained inconclusive. Agreement on standard evaluation approaches is needed before making conclusions on the usefulness of sensors for fall prediction or use by community-dwelling older adults. This agreement should include the establishment of an open access ‘gold standard’ for benchmarking different fall risk assessment technologies.¹⁰

The need for further study on the effectiveness of wearable technologies for fall prevention among older adults in real-world settings was also emphasized by a recent umbrella review (i.e., review of systematic reviews) of wearable devices for preventing and detecting falls. The

review found that wearable devices can be an effective, low-cost means of detecting falls and summoning help after a fall. The review also noted there are significant differences in the effectiveness of devices depending on the type of device and its placement³⁷.

The increased adoption of wearable technologies for fall prevention and detection also requires action to overcome a range of social, economic, behavioural, and legislative challenges. Devine and colleagues summarized the key issues warranting further consideration to ensure the successful integration of sensor-based technology into the consumer wearables market:⁹

- **efficacy in real-world settings** – described above;
- **wearables versus medical devices** – because wearables are generally marketed as consumer accessories or ‘general wellness’ devices rather than medical devices, they are not subject to the same level of government approval or regulatory oversight;
- **manufacturing considerations** – since manufacturing is often conducted in a different jurisdiction from the device developer or target consumer demographic, the ability of the device developer to provide oversight and quality control may be limited;
- **working with existing devices and data** – most wearables do not possess enough processing strength or battery power to analyze data directly; applications that utilize currently existing devices (e.g., Smart Watches), rely on cloud-based services for analysis, and accommodate a range of data formatting have greater odds of adoption in the consumer market;
- **economic considerations** – if price increases to cover the cost of additional or more sophisticated sensor devices serve as a barrier to adoption, then new technologies will only be adopted at the rate that the price can be lowered through economies of scale (i.e., increased production);
- **trust** – there are several aspects of consumer trust affecting the uptake of wearables, including trust in the accuracy of the technology, trust in giving personal data to private, proprietary algorithms and trust in the privacy policies governing the use of this data.

In summary, the ability of wearables to detect falls in real time and summon assistance enables older adults to maintain independence while offering support and reassurance to their caregivers. Wearable technologies are also becoming more predominant in clinical and other settings where fall risk assessments take place. Evidence supporting the effectiveness of wearables for fall prevention is more mixed; however, further research, especially research focused on older adults in real-world settings rather than simulated laboratory conditions, will shed further light on the utility of wearables as part of a comprehensive fall prevention strategy. Further advances in technology will likely increase the availability and affordability of wearables, which will prompt action to address some of the current barriers impeding their adoption.

Appendices

A. Detailed Description of Methodology

To guide the search for relevant literature on wearable technologies for fall detection and prediction, an initial scan on the topic was completed. Then a taxonomy was developed to identify and organize the main categories of wearables and associated devices (i.e., the sensors or technologies embedded in a particular wearable), the placement (i.e., where the wearable is worn on the body) and the fall risk indicators measure by the wearable. This taxonomy, which guided the search for relevant literature as well as the structure of this knowledge product, is depicted in Table 1 (next page).

A literature search of documentation describing and assessing the application of wearable devices for fall detection and prediction was conducted between May 2 and May 6, 2022. The search included database searches and hand searches of references from papers retrieved for the assessment of full text relevance. Initially, the search was limited to documentation published in English from the year 2017 to present (i.e. May 2022). However, references published before 2017 were included if more recent citations addressing the topic(s) of interest were not available.

Database searches included Google Scholar, PubMed and the Cochrane Database of Systematic reviews. The search strategies included a combination of text words and controlled vocabulary spanning the categories of wearable devices (e.g., “inertial sensors and fall detection”). Where available, scoping reviews, systematic reviews and meta-analyses were selected for inclusion to gain a better sense of the efficacy of the different types of wearables.

The search focused on wearable devices designed to detect and/or predict a fall. Accordingly, the search did not include wearable devices for the primary prevention of falls through providing feedback on balance, strength building or conditioning exercises (e.g., pedometers).

Table 1. Taxonomy of Wearable Devices for Fall Detection and Prediction

Wearable Category	Types	Placement	Fall Risk Outcomes
Inertial sensors (measure acceleration and velocity)	Accelerometer	Chest (most widely used - e.g., a wearable pendant)	Gait intensity Gait variability Gait stability Postural stability Gait symmetry Gait smoothness Step time
	Gyroscope	Lower back	
	Magnetometer	Legs (usually lower limbs, calves)	
		Wrist (e.g., Smart watch)	
		Non-specific (e.g., Smartphone apps with accelerometers and gyroscopes to detect falls)	
Electromyography (EMG) sensors (measure electrical signals generated by muscle movement)	EMG sensor devices (can be used in conjunction with inertial sensors)	Lower limbs (most common)	Number of steps taken
Pressure sensors (records changes in plantar pressure of human body during walking)	Wearable insoles	Feet	
Proximity sensors (external sensors that detect falls by measuring sudden changes in movement or distance from proximity sensor)	Wearable pendants	NA	
	Attached to walking aid device (e.g., cane or walker)		
	Chair alarms Bed alarms		
Hip protectors	‘Smart’ Hip protectors with built in technology to detect falls and summon help from caregivers (e.g., Fall Safe Assist Hip protector)	Hips	

B. Additional information on Sensors

Devices on Inertial Sensors

Wearable inertial sensors for fall risk prediction typically contain one or more of the following devices:¹⁰

- a triaxial (i.e., three axes) **accelerometer** that measures the linear acceleration of movement in a sensor-fixed three-dimensional (3D) frame. Measured data include both motion and gravity components.
- a triaxial **gyroscope** measuring angular velocity in 3D space.
- a **magnetometer** measuring the amplitude and direction of the magnetic field in 3D space.

Optimal Placement of Inertial Sensors

There is some debate about the optimal placement of inertial sensors on the body. Rucco and colleagues found that the trunk is the most widely used body segment due to its role in maintaining both static and dynamic stability.¹³ However, this practice was partially contradicted by a meta-analysis of thirteen studies using inertial sensors to assess fall risk among older adults by Montesinos and colleagues, which found that, with a walking test, the most effective means of assessing the risk of falling was velocity with the sensing device placed on the shins. Conversely, device placement in the lower back provided the most effective means of assessing linear acceleration during quiet standing, stand to sit, or sit to stand tests. The meta-analysis also identified four measurements that were significantly higher among fallers: 1. the acceleration during quiet standing with eyes closed, 2. the total number of steps taken, 3. the total time to complete the Timed Up and GO (TUG) test, and 4. the step time during walking.¹⁶

Ethical Concerns with Use of Proximity Sensors

Some ethical concerns have been raised around the involuntary use of proximity sensors and other monitoring devices on older adults.³⁰ A cross sectional study of 672 nurses and 382 health care workers at three Japanese hospitals with long-term care beds surveyed respondents about their attitudes and opinions regarding the use of connected sensor devices on older adults to prevent falls.³⁰ Respondents expressed concerns that connected sensors caused a sense of restraint and restriction on the behaviours of older adults, distress to older adults and their family members, and feelings of guilt regarding forced restraint among the health care providers. The study underscored the need for the development of sensor systems that balance patient safety needs with patient quality of life.³⁰

Key Loop Resources on Wearable Devices for Fall Prevention

Webinars

Predicting and Preventing Falls using Technology (2018)

Promoted through Loop, this webinar was delivered by Dr. Steve Robinovitch, Professor, Simon Fraser University, Department of Biomedical Physiology and Kinesiology and School of Engineering Science, on July 5, 2018. The webinar provided an overview of new technologies under development to predict, detect and prevent falls and fall-related injuries in long-term care environments. It also discussed how real-life data, acquired both through networks of video cameras and with wearable sensors is being used to predict falls.

<https://preventfalls.ca/recorded-webinar-predicting-and-preventing-falls-using-technology/>

Loop Discussion Threads

Falls Prevention App (Last Activity – September 30, 2020)

<https://www.fallsloop.com/discussions/10460>

This discussion post was prompted by one Loop member looking for fall prevention app recommendations. Several Loop members responded providing recommendations and sharing that their parents used apps and liked them. Loop's Knowledge Broker, Alison Stirling, prepared a summary of the discussion collating member suggestions and providing relevant external sources and Loop resources.

Use of Seat Belts for Wheelchairs (Last Activity – September 11, 2020)

<https://www.fallsloop.com/discussions/11325>

One Loop member inquired about fall prevention strategies other than restraints and regular monitoring for wheelchair users in long-term care. They note trying alarming belts and weight activated chair sensors without much luck. Several Loop members commented with suggestions on where to find solutions and more information.

News Release – Falls Risk Innovation (December 1, 2017)

<https://www.fallsloop.com/discussions/10775>

The Champlain LHIN, in partnership with GE Healthcare Canada, launched a new screening tool to reduce the rate of falls among seniors. The new screening tool, the Quantitative Timed Up and Go (QTUG), was developed by GE HealthCare. Older adults who are screened with the tool wear sensors on their shins over clothing, and their movements are tracked and analyzed.

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