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Review article

The state of knowledge on technologies and their use for fall detection: A scoping review

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ABSTRACT

Background: Globally, populations are aging with increasing life spans. The normal aging process and the resulting disabilities increase fall risks. Falls are an important cause of injury, loss of independence and institutionalization. Technologies have been developed to detect falls and reduce their consequences but their use and impact on quality of life remain debatable. Reviews on fall detection technologies exist but are not extensive. A comprehensive literature review on the state of knowledge of fall detection technologies can inform research, practice, and user adoption.
Objectives: To examine the extent and the diversity of current technologies for fall detection in older adults.
Methods: A scoping review design was used to search peer-reviewed literature on technologies to detect falls, published in English, French or Spanish since 2006. Data from the studies were analyzed descriptively.
Results: The literature search identified 3202 studies of which 118 were included for analysis. Ten types of technologies were identified ranging from wearable (e.g., inertial sensors) to ambient sensors (e.g., vision sensors). Their Technology Readiness Level was low (mean 4.54 SD 1.25; 95% CI [4.31, 4.77] out of a maximum of 9). Outcomes were typically evaluated on technological basis and in controlled environments. Few were evaluated in home settings or care units with older adults. Acceptability, implementation cost and barriers were seldom addressed.
Conclusions: Further research should focus on increasing Technology Readiness Levels of fall detection technologies by testing them in real-life settings with older adults.

1. Introduction

Older adults (60 years old and older as defined by the Word Health Organization or WHO) will represent 28% of the global population by 2050 [1]. In, Canada, Western Europe, China and Chile older adults will represent at least 30% of the population in 2050 [1]. In Japan, older adults already represent 30% of the population [1]. Aging is associated with physical, sensory, and cognitive disabilities associated with increased risk of falls. A fall is defined as “inadvertently coming to rest on the ground, floor or other lower levels, excluding intentional change in position to rest in furniture, wall or other objects” [2],p1]. Between 2008 and 2015, worldwide statistics show an annual incidence of 30% [1,2]. Risk of falling increases with age, with 50% of older adults experiencing a fall-related event each year after the age of 85 [1].

Falls are responsible for 85% of older adults’ hospitalizations for injury in Canada [3]. After experiencing a major fall, an estimated 20% of older adults will die within a year [3]. The inability to get up after a fall is associated with injuries and complications (e.g., hip fracture, pressure sores) leading to hospitalizations [4,5]. Adverse outcomes associated with falls in older adults have resulted in an annual cost of $2 billion in Canada [3]. Falls also impact psychological health, (e.g., depression) [1,3] and family caregivers’ quality of life and burden [6–8]. Caregivers of older adults express an ongoing concern related to falls [6,7,9]. As 80% older adults cannot get up after a fall, their ability to reach for a telephone to seek help is hindered [5,10]. Thus, falls are a serious concern in health care and for family caregivers, contributing to increased caregiver burden. Consequently, a wide interest in ways to detect falls is increasing.

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It is widely believed that fall detection fosters aging-in-place [11,12]. Technologies, which can be defined as "the application of information processing involving both computer hardware and software" [13], have been developed to detect falls and reduce the time older adults remain on the floor after a fall. These technologies can be classified according to whether they detect falls automatically or need to be activated by an older adult. Alert technologies, that need to be activated by an older adult, include wall-mounted systems (e.g., warning cord) and wearable systems (e.g., wristwatch alarms) [14,15]. These technologies, however, present limitations; for example, if an older adult is unconscious, confused or has cognitive impairment, he or she cannot activate a non-automatic technology to rise an alert. Moreover, when they wear it, 80% of older adults do not use their alarm button (e.g., pendant linked to a 24/7 call center) after a fall, due to difficulty in activating it, or for fear of disturbing caregivers [5]. Automatic fall detection technologies (e.g., accelerometers) may address this issue by immediately detecting a fall and automatically sending an alert to a caregiver or a call center. The perception of older adults toward automatic fall detection technologies is favorable [16,17].

Automatic fall detection systems remain underused while research and development in this area is burgeoning [14]. Existing literature reviews on fall detection systems [18–20] have limitations. Some present a narrow scope, for example, they focus on one type of technology, or exclusively on studies involving older adults [21–23]. Thus, their reviews provide an incomplete state of knowledge regarding fall detection technologies. Other reviews do not describe search methodology, so could not be replicated, nor did they apply a rigorous approach [19,20,24]. This is the case for the following reviews: Sree Madhubala et al. (2015)[24] describe advantages/disadvantages of wearable sensors, acoustic sensors and computer vision method by emphasizing the technological aspects (e.g., accuracy); Mubashir et al. (2013) [14] provide a classification of fall detection technologies; Pannurat et al. (2014)[20] conclude that most technologies are wearable. These results may be challenged because the authors did not document their methodology. In their review, Atoyebi, Stewart, and Sampson (2015) [18] aimed to do a critical analysis of the literature on the use of information technologies (e.g., wireless sensors) to detect and prevent falls. But in their manuscript, they primarily focused on fall prevention and not on detection, thus, their review was incomplete. These limitations in the literature reflect the scarcity of reviews on fall detection technologies. To address this gap, this scoping review examines the extent and the diversity of current technologies (all types of technologies) for fall detection in older adults.

2. Material and methods

A scoping review design was used, based on Daudt et al.'s [25] modification of Arksey and O'Malley's framework for scoping review [26]. Their definition of scoping review emphasizes that this kind of review must document the key concepts, gaps and the type of sources of evidence regarding one subject, in this case, fall detection technologies. Their recommendations emphasize the benefits of an inter-professional team to ensure comprehensiveness and rigor for sources identification and data extraction; the framework provides guidance on how to divide the tasks while preserving the consistency of the review. Based on these principles, details about our methodology are presented.

A multidisciplinary research team (rehabilitation, gerontology and biomedical engineering) of six co-authors (researchers, PhD candidates) and one research assistant collaborated on this review. The use of Daudt et al.'s framework [25] enables an extensive review on fall detection technologies, e.g., research designs, publications per year, type of technology and outcome measured and highlights the gaps in the literature.

2.1. Scoping review sources and search terms

The research team had several meetings to discuss search terms and search strings. A co-author (NL) and a librarian searched three electronic databases using the search strings (CINHAL, Embase and Medline) in March 2016. The following MesH terms were searched in the title, abstract, keywords and full text: (Fall detector* OR Fall detection* OR Technolog* OR Gerontechnolog*OR Telemedicine OR Telehealth OR Telecare OR Robotic* OR Microsensor* OR Sensor* OR Biosensor* OR Monitoring OR Smart home OR Computer systems OR Biosensing OR Techniques OR Artificial intelligence OR Fall-down detector*) AND Fall* AND (Aged (≠ ab ti) OR Geriatr* OR Geronto* OR Aging OR Older not older than OR Senior OR Elderly OR Health OR services for the aged OR Home for the aged) NOT (Placebo* OR Serotonin* OR Cardiovascular OR Hypertension OR Predictor* OR Prediction* OR Gait analysis OR Predict* OR Heart/heart disease Lung/pneumolog* OR Cancer OR Medication/drug OR Depression). All studies were imported into EndNote reference manager (Version X7 for Mac)[27].

2.2. Selection criteria

Inclusion and exclusion criteria were established by the research team for achieving comprehensiveness [26].

Inclusion criteria:

1) Studies that focus on technologies that:
   a. address falls or have the potential to address falls in older adults;
   b. are at any Technology Readiness Level (TRL)[1] [28];
   c. are embedded or worn on a person;
   d. are used indoor or outdoor.
2) Sources included:
   a. studies regardless of methodologies (excluding reviews) and the positive or negative results;
      i. for clinical papers: studies that included participants aged 50 years and older to include a wide range of studies;
      ii. for research and development papers: no age limit, to avoid excluding papers that present technologies with potential application to older adults.
   b. conference proceedings.

1) Publications in English, French or Spanish.

Exclusion criteria:

1) Studies about assistive technologies except if they included software or hardware for detecting falls.
2) Studies not available in full paper.
3) Studies that did not provide enough information for charting the data.
4) Reviews, theoretical papers, seminar papers or letters to the editor.

2.3. Study selection

The study selection process included four steps: 1) identification of relevant studies in the literature, 2) screening (applying criteria to the abstracts), 3) eligibility (applying criteria to the full papers), and 4) inclusion (re-applying criteria to the full papers during data extraction).

For Step 1 (identification), after a search of databases, duplicates were removed. Prior to steps 2, 3 and 4, two members of the research team, AMRR (rehabilitation) and AMC (Biomedical Engineer) who have experience in conducting literature reviews trained the members of the team NL, NN and the research assistant in paper selection and data extraction. In doing so, three abstracts were randomly selected from those retrieved in phase 1 and were assessed by two researchers and two PhD candidates. Then, for the next steps (2, 3 and 4), two team

[1] Scale to assess the development of technologies according to 9 levels from TRL1 (first stage of development) to TRL9 (most advanced level).