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Pedestrian falls: A review of the literature and future research directions

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ABSTRACT

Introduction: Pedestrian falls (PFs) – falls in public spaces without collisions with other road users – are a significant cause of serious transport-related injuries, amounting to three-quarters of all pedestrians admitted to hospital. *Methods:* This scoping review examined peer-reviewed research on PFs published between 1995 and 2015. Electronic databases (Scopus, SafetyLit, and PubMed) were used to find studies identifying PFs or outdoor falls (the latter also including falls in gardens). *Results:* We identified only 28 studies reporting relevant information on PFs (i.e., 15 prospective, 10 retrospective, and 3 intervention studies). The results show that more walking is related to a lower risk of PFs. Older people, especially older women, have a higher risk of (injurious) PFs. Outdoor fall victims have equally good or better health characteristics and scores on balance tests compared to those who have not experienced such falls. Road factors such as uneven surfaces, busy junctions, stairs, and slippery surfaces seem to play an important role in PFs, but much of the research on these factors is of a qualitative nature. *Conclusions:* PF victims are generally in good health (apart from normal age-related problems) but at risk due to road factors. *Practical applications:* We recommend to adopt a human factors approach. The road system should be adapted to human capabilities and limitations including those of pedestrians. Measures such as preventing uneven surfaces and good winter maintenance seem to be effective. However, we advise more quantitative research on road factors to inform design guidelines and standards for public space authorities given the qualitative nature of current research on road factors.

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1. Introduction

Every year approximately 10% of people aged 65 and over experience pedestrian falls (PFs),[1] (Decullier et al., 2010; Duckham et al., 2013; Kelsey, Procter-Gray, Hannan, & Li, 2012; WHO, 2007), defined by Methorst et al. (2017) as falls in outdoor public spaces without colliding with other road users. Public spaces include roads and sidewalks but also public parks, squares, and stairs if these are part of public spaces. These falls are a significant cause of serious transport-related injuries (Elvik, Høye, Vaa, & Sørensen, 2009; Larsson & Björketun, 2007; Mulder, Bloemhoff, Harris, Van Kampen, & Schoots, 1995; Vaa, 1993). Fig. 1 shows that the great majority of non-fatal pedestrian injuries in traffic are due to PFs. Using data from the Netherlands, Switzerland, and Austria, Methorst et al. (2017) concluded that 4–9 times as many pedestrians are injured in falls than in pedestrian–vehicle collisions. They expect that aging of the population will contribute to an increase of the number of injuries due to PFs. A Dutch estimate indicated that the total costs due to PFs would be around 17% of the total costs of traffic crashes in 2003–2007 (including the costs of PFs; excluding the costs of Property Damage Only crashes; Methorst, Van Essen, Ormel, & Schepers, 2010). If anxiety about falling due to a previous fall or a poorly designed, non-inclusive environment leads seniors to restrict outdoor walking (Ward Thompson, Curl, Aspinall, Alves, & Zuin, 2012; Wijlhuizen, De Jong, & Hopman-Rock, 2007), this could prevent them from taking part in activities and enjoying the major health benefits of related physical exercise (Kelly et al., 2014). PFs are therefore an important public health issue.

Most research on pedestrian injuries has focused on collisions (see e.g. Elvik et al., 2009; Langham & Moberly, 2003; Rosen, Stigson, & Sander, 2011; Schwebel et al., 2014), which is understandable because, in contrast to PFs, these collisions are included in the definition of traffic crashes (the involvement of a vehicle is required to define an accident as a traffic crash; Eurostat, 2009). It is likely that PFs are less known among road safety researchers and practitioners because of their exclusion from the definition and, consequently, from official statistics (Methorst et al., 2017). There are many studies on falls in general (Gillespie et al., 2012), but most of these combine outdoor and indoor falls into one category. Outdoor falls are closely related to PFs but also include falls in gardens because these occur outside buildings. Outdoor falls have been called a neglected, hidden, and under-researched public health problem (Feypell, Methorst, & Hughes, 2010; Gyllencreutz,

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[1] Each year, 29–35% of people over 65 years sustain falls (WHO, 2007); 30–45% of falls among elderly are PFs (Decullier et al., 2010; Duckham et al., 2013; Kelsey et al., 2012).

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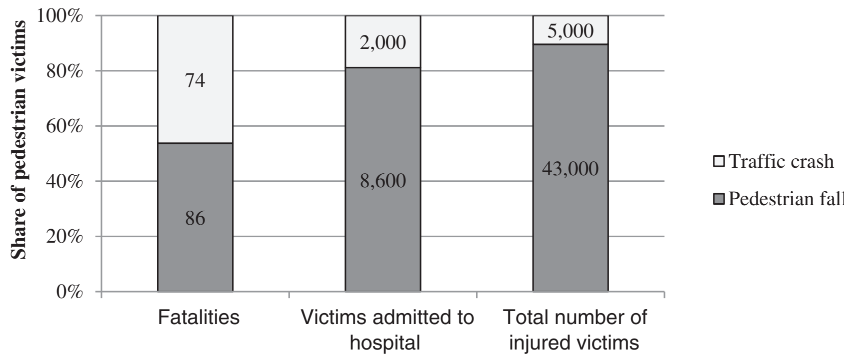

Fig. 1. Pedestrian injuries in the Netherlands in 2011 (Den Hertog et al., 2013; Methorst et al., 2017).

Björnstig, Rolfsman, & Saveman, 2015; Li et al., 2006). Only recently has research interest accelerated due to valuable research initiatives such as the prospective "MOBILIZE Boston cohort study" focusing on fall risks in the elderly (e.g., Li et al., 2014) and studies on risks associated with icy roads in Nordic countries (e.g., Berggård & Johansson, 2010; Gyllencreutz et al., 2015). Previously published review papers focus on falls and fall prevention (Gillespie et al., 2012; Karlsson, Vonschewelov, Karlsson, Cöster, & Rosengen, 2013; Stalenhoef, Crebolder, Knottnerus, & Van Der Horst, 1997), but do not address PFs, even though the related health burden is substantial. As the risk factors and the environment associated with outdoor and indoor falls differ (Kelsey et al., 2010), specific research may be needed to inform public space authorities about adequate preventive strategies and measures for PFs. Directions for recommendations depend on whether the primary contributing factors are related to individual health, behavior, and wearing of suitable footwear or to responsibilities of public space authorities. This review aims to summarize and discuss research on factors contributing to PFs published between 1995 and 2015. It is considered that this period is long enough to allow for the meaningful examination of the extent, range, and nature of research on PFs. In doing so, recommendations for public space authorities are explored and key research areas for future investigations are identified.

The remainder of this paper is organized as follows: Section 2 outlines the methods of this scoping review such as search terms and study inclusion criteria. Section 3 summarizes the characteristics of the included studies and discusses their results. Section 4 discusses the outcomes and directions for future research. Finally, Section 5 shortly lists the main conclusions of this review.

2. Methods

2.1. Literature search

This scoping review (Dijkers, 2015) discusses literature on PFs. Peer-reviewed empirical studies in English language scientific journals published between 1995 and 2015 were identified from electronic databases (Scopus, SafetyLit, and PubMed). The following search terms were utilized: 'outdoor fall,' 'outside fall,' 'pedestrian fall,' 'single-pedestrian,' 'non-motor pedestrian,' and 'pedestrian-only.' The search resulted in a total of 698 (partly overlapping) hits as follows: Scopus: 544, SafetyLit: 26, and PubMed: 128.

2.2. Inclusion criteria and selection process

Based on the article titles, abstracts, and keywords the identified reports were initially evaluated using the following inclusion criteria:

a) The study had to be an observational or intervention study published in a peer-reviewed scientific journal.
b) The study had to distinguish PFs or outdoor falls (i.e., not be restricted to a single 'fall category' combining both outdoor and indoor falls). Studies combining trips and slips (without landing on the ground) with falls into one category were also excluded.
c) The study had to include risk factors related to PFs and was not to be restricted to injury consequences only.

Altogether 29 papers comprising 28 empirical studies were included (one study was described in two papers) and retrieved in full text for detailed evaluation (further referred to as 'the sample'). The studies were divided into prospective observational studies, retrospective studies and intervention studies. Besides the 28 studies on which the main conclusions are based, additional literature is used to provide context, for instance to explain hypotheses tested by researchers.

3. Results

This section discusses the identified 28 studies that included a material relevant to PFs. Section 3.1 describes the design and the quality characteristics of these studies. As road safety is often described in terms of exposure and the risk factors of road users, infrastructure, and vehicles (Elvik et al., 2009; Schepers, Hagenzieker, Methorst, Van Wee, & Wegman, 2014), Section 3.2 deals with the relationship between the amount of walking and PFs while the subsequent Sections 3.3, 3.4, and 3.5 describe the contributions of human characteristics and behavior, road factors, and footwear. This approach is used to structure contributing factors and distinguish between factors related to individual characteristics and behavior and environmental conditions possibly linked to responsibilities of public space authorities.

3.1. Study characteristics and quality

Table 1 presents an overview of prospective observational studies (see Section 3.1.1), retrospective studies (see Section 3.1.2), and intervention studies (see Section 3.1.3).

3.1.1. Prospective observational studies

In the 15 prospective observational studies (see Table 1), participants, most over 70 years, recorded daily fall occurrences on a calendar that they mailed back to the study staff monthly or quarterly. Participants reporting a fall were interviewed. A strength of prospective designs is the reduction of recall bias, a problem caused by the possibility of participants forgetting falls (Cummings, Nevitt, & Kidd, 1988). Another advantage of following a cohort is that there are participants with and without falls who can be compared. The design of the research, therefore, allows for quantitative assessment of the contribution of risk factors.

An important quality criterion for internal validity is providing statistical control for potentially confounding variables (Elvik, 2011).

Table 1
Summary of studies included in the review.

Study	Location	Nr. respondents	Nr. outdoor falls/fallers	Selection criteria participants	Minimum severity	Exposure control	Definition
Prospective observational studies							
Kiely et al. (2015)	US, Massachusetts, Boston	666	NA	>70 years	No minimum level	Hours walked per week	Outdoor fall
Li et al. (2014)	US, Massachusetts, Boston	765	812	>70 years	No minimum level	Kilometers walked	Outdoor with sub-categories
Duckham et al. (2013)	US, Massachusetts, Boston	743	786	>65 years	No minimum level	Kilometers walked	Outdoor with sub-categories
Kang, Quach, Li, and Lipsitz (2013)	US, Massachusetts, Boston	717	495	>70 years	No minimum level	Time spent outdoors	Outdoor fall
Quach et al. (2013)	US, Massachusetts, Boston	763	300 [1]	>70 years	No minimum level	Physical activity	Outdoor fall
Kelsey et al. (2012)	US, Massachusetts, Boston	765	808	>70 years	No minimum level	Dummy for physical activity	Outdoor with sub-categories
Kelsey et al. (2012)	US, Massachusetts, Boston	713	176	>70 years	No minimum level	Dummy for physical activity	Outdoor with sub-categories
Quach, Galica, Jones, Procter-Gray, Manor et al. (2011)	US, Massachusetts, Boston	763	525 [1]	Older adults	No minimum level	Physical activity	Outdoor fall
Decullier et al. (2010)	France	662	353	>75 years	No minimum level	None	Outdoor fall
Kelsey et al. (2010)	US, Massachusetts, Boston	765	524	>70 years	No minimum level	Dummy for physical activity	Outdoor fall
Pajala et al. 2008	Finland	434	132	63–76 years, women	No minimum level	None	Outdoor fall
Menz, Morris, & Lord (2006)	Australia	176	36	62–96 years	No minimum level	None	Outdoor fall
Bergland, Jarnlo, and Laake (2003)	Norway, Oslo	307	171	>75 years, women	No minimum level	Dummy for walking	Outdoor fall
Lord, Dayhew, and Howland (2002)	Australia, Sydney	148	49	>63 years	No minimum level	Physical activity	Outdoor fall
Luukinen et al. (2000)	Finland, Tampere	980	1040	>70 years	No minimum level	None	Outdoor fall
Retrospective studies							
Gyllencreutz et al. (2015)	Sweden, Umeå	NA	242	>65 years	ED treatment	None	Pedestrian fall
Nyman, Ballinger, Phillips, and Newton (2013)	UK	44	88	>65 years	No minimum level	None	Pedestrian fall
Morency, Voyer, Burrows, and Goudreau (2012)	Canada, Montreal	NA	960		Ambulance intervention	None	Pedestrian fall
Lai, Low, Wong, Wong, and Chan (2009), Lai, Wong, Low, Wong, and Chan (2011)	Hong Kong	NA	281	>20 years	ED treatment	None	Pedestrian fall
Naumann, Dellinger, Haileyesus, and Ryan (2011)	US	NA	3781	>65 years	ED treatment	None	Pedestrian fall
Kulmala et al. (2007)	Finland	NA	79	60–85 years; hip fracture history	Hospitalized	None	Outdoor falls
Li et al. (2006)	US, California	2193	297	>45 years	No minimum level	Physical activity	Outdoor with sub-categories
Gao and Abeysekera (2004)	Sweden, Luleå	70	24	20–39 years	No minimum level	None	Pedestrian fall
Bath and Morgan (1999)	UK, Nottingham	444	73	>65 years	No minimum level	Walking for relaxation	Outdoor falls
Björnstig, Björnstig, and Dahlgren (1997)	Sweden, Umeå	NA	415		ED treatment	None	Outdoor falls on ice or snow
Intervention studies							
Berggård and Johansson (2010)	Sweden, Luleå	61	7	30–70 years	Slips [2]	Kilometers walked	Pedestrian fall
Mckiernan (2005)	US, Wisconsin	109	62	>65 years	Slips [2]	None	Pedestrian fall
Haran et al. (2010)	Australia, Sydney and Illawarra	597	389	>65 years	No minimum level	Physical activity	Outdoor falls

[1] Not reported in the paper and estimated from the reported fall rate per person, number of respondents and follow up time.
[2] Both slips and falls were included because analyses on falls only were likely to be underpowered.

Most of the prospective studies met this criterion by providing statistical control for age, sex, and a range of health indicators. It is important to control for exposure to risk (measured by amount of travel) as it explains most of the structural variance in crash counts (Fridstrøm, Ifver, Ingebrigtsen, Kulmala, & Thomsen, 1995; Hakkert & Braimaister, 2002). Kilometers walked seems the most suitable measure for exposure to the risk of PFs, but only 3 of the 15 prospective studies included this variable. Most studies partly controlled for exposure by including the level of physical activity of which walking is part.

The identified prospective studies identify outdoor falls that include a significant number of falls in private gardens, ranging from 6% to 29% of outdoor falls (Duckham et al., 2013; Kelsey et al., 2012; Li et al., 2006). This may somewhat restrict the generalizability to public spaces, but some studies (Duckham et al., 2013; Kelsey et al., 2012; Li et al., 2006) with outdoor falls further split into 'falls on sidewalks, streets, and curbs' or 'while walking,' thereby presenting suitable categories for PFs.

3.1.2. Retrospective studies

The review contained 10 retrospective studies that can be further split in two groups based on how crash data were acquired:

a) 6 studies based on falls recorded in medical registrations without a control group of non-victims;
b) 4 studies based on questionnaires or focus group discussions with PF victims of which 3 also included non-victims.

A strength of several retrospective studies was the inclusion of more severe falls, younger age groups, and in 6 of 10 cases a focus on PFs in public spaces.

3.1.3. Intervention studies

We identified 3 intervention studies, 2 focused on provision of anti-slip devices (Berggård & Johansson, 2010; Mckiernan, 2005), and 1 on single lens distance glasses for wearers of multifocal glasses (Haran et al., 2010). Comparing an intervention and control group improves the ability to infer causality.

3.2. Amount of walking and fall rates

It is difficult to estimate the exposure to risk, for instance kilometers traveled (Mindell, Leslie, & Wardlaw, 2012; Vanparijs, Panis, Meeusen, & De Geus, 2015). This is particularly true in walking because of the under-reporting in travel surveys of short trips by foot such as dog walking, taking a letter to the mailbox, and walking to public transport stops (Rietveld, 2000). The difficulty of estimating kilometers walked may explain why only one study in the sample allowed the comparison of the rate of outdoor falls and kilometers walked (i.e., Li et al., 2014). More walking may contribute to physical fitness thereby decreasing the risk per kilometer walked (Ettinger, 1996). An effect in the other direction is also conceivable. Those at risk due to reduced health may restrict their amount of outdoor physical activity including walking due to a fear of falling and lack of stamina (Nyman et al., 2013; Pajala et al., 2008). Li et al. (2014) used negative binomial regression to estimate rate ratios and associated 95% confidence intervals (CIs). As shown in Fig. 2, the rate of outdoor falls increases as the number of kilometers walked increases, but far less than proportional. For instance, the number of kilometers walked by those in the 0.5 to 1.3 km/week category is some 3 times greater than the number by those in the 0.1 to 0.5 km/week category (0.9/0.3), while the outdoor fall incidence rate ratio is only 1.7 times greater (2.50/1.45). This means that more walking is related to a lower risk of PFs.

3.3. Human characteristics and behavior

3.3.1. Human characteristics

3.3.1.1. Age, gender and race. Laboratory studies have shown that females' and older people's ability to recover from trips and prevent a fall is reduced (Pavol, Owings, Foley, & Grabiner, 1999). With the increase of age, human locomotion balance abilities, and motor function deteriorate (Gao & Abeysekera, 2004). Moreover, the elderly are more fragile (Li, Braver, & Chen, 2003). The elderly, especially older women, are more likely to develop osteoporosis and suffer from osteoporotic fractures (Cummings & Melton, 2002), although it has been suggested that the prevalence of osteoporosis is decreasing (Korhonen et al., 2013).

Three studies including a sufficiently wide age range with pedestrians aged 20 years and older suggest that injurious PFs (treated at an emergency department or needing ambulance intervention) are many times more frequent among elderly (Björnstig et al., 1997; Lai et al., 2009; Morency et al., 2012), for instance 5 times more frequent among those between 60 and 65 years as compared to those under 25 years (Morency et al., 2012). Fig. 3 depicts PF victims treated at an emergency department in Hong Kong (Lai et al., 2009). The aforementioned three studies did not control for kilometers walked. The incidence of walking does not differ much across age groups but slowly decreases at older age (Hallal et al., 2012), meaning that the risk of PFs per kilometer walked is also higher among the elderly.

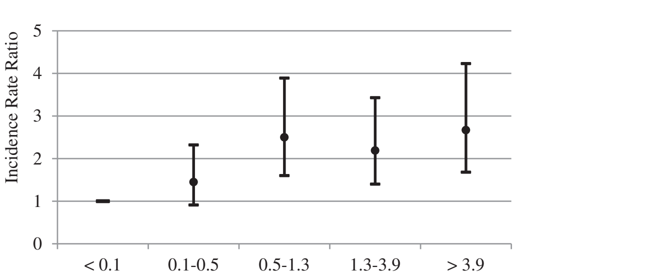

Fig. 2. Incidence rate ratios for outdoor falls by numbers of kilometers walked per week (Li et al., 2014).

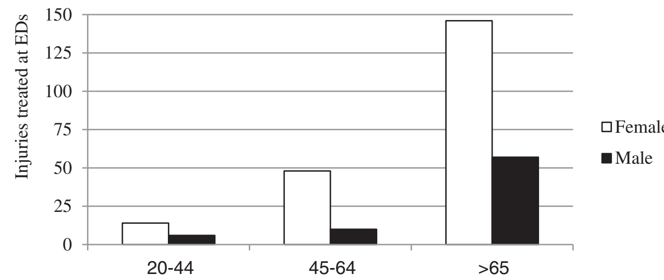

Fig. 3. Injuries treated at EDs for PFs (Lai et al., 2009).

Some of the studies that reported on gender found elevated numbers of PFs among females (Björnstig et al., 1997; Gyllencreutz et al., 2015; Lai et al., 2009; Naumann et al., 2011), while three others found frequencies for men and women were similar (Kelsey et al., 2012; Menz et al., 2006; Morency et al., 2012). The only study that controlled for kilometers walked was by Duckham et al. (2013) who found that older men walked significantly more than older women, a difference of some 50%. Adjusting for kilometers walked, it was found that women were more likely to sustain non-injurious falls on sidewalks, streets, and curbs. Gyllencreutz et al. (2015) and Björnstig et al. (1997) found that if there is a fall, female victims are more likely to sustain severe injuries than males. Similarly, Luukinen et al. (2000) found that women were more prone to sustain a fracture after a fall. This leads us to conclude that older people, especially older women, have an elevated risk of (injurious) PFs.

Kiely et al. (2015) compared falls in older black and white adults. These researchers found only a non-significant difference after controlling for a wide range of potential confounders such as sociodemographic and physiologic risk factors.

3.3.1.2. Vision and balance. Vision is important for negotiating obstacles and plays an integral role in maintaining balance (Black & Wood, 2005). Bergland et al. (2003) found vision impairment in the elderly to be a predictor of PFs. Poor vision was defined as being unable to read a newspaper, even with glasses. Two other studies found that elderly with visual acuity under 0.4 (measured from 10 ft wearing corrective lenses, if used) were equally likely to fall while walking outdoors as those with better vision (Kelsey et al., 2010; Kelsey et al., 2012). Menz et al. (2006) did not find differences in visual acuity and edge contrast sensitivity between those who had and those who had not sustained outdoor falls.

It has been suggested that the reading segment of a multifocal lens impairs visual perception (acuity but also contrast sensitivity and depth) at ground level (Kelsey et al., 2012; Lord et al., 2002). Kelsey et al. (2012) found the number of falls over curbs and single steps to be elevated among those with multifocal or bifocal lenses relative to those with single lenses or no glasses. Similarly, Lord et al. (2002) found that multifocal glasses wearers were more likely to fall outdoors, particularly because of tripping. In an intervention study by Haran et al. (2010), older wearers of multifocal glasses were provided with single lens distance glasses with recommendations for wearing them in walking and outdoor activities. After the intervention there were fewer outdoor falls among more physically active participants but more among less physically active participants. The amount of physical activity did not change after the intervention.

Balance has been included in studies on falls using the Berg Balance Scale (BBS), a clinical test of a person's static and dynamic balance abilities (Berg, Wood-Dauphinee, Williams, & Maki, 1991), different force plate measures, and self-assessed balance confidence. BBS has not been found to differ between those with and without outdoor falls (Kelsey et al., 2010; Kelsey et al., 2012; Kulmala et al., 2007). Of the three prospective studies using force platform balance tests, two found no relation with outdoor falls among older people (Bergland et al., 2003; Pajala et al., 2008), while one study did find a relationship (Kang et al., 2013). Finally, researchers have used self-reported measures of balance confidence such as the Falls Efficacy Scale (FES), a summary measure of the fear of falling that queries levels of confidence in performing certain activities without falling (Tinetti, Richman, & Powell, 1990). None of the studies included found pedestrian falls to be associated with balance confidence (Kelsey et al., 2010; Kelsey et al., 2012; Kulmala et al., 2007).

3.3.1.3. General health characteristics. There were sufficient prospective studies on health available for us to be able to include in Table 2 a summary of the results for a number of health factors. Better health in terms of lower BMI, a higher walking speed, fewer diseases, and the use of medications are associated with more pedestrian falls. The only finding in line with what one would intuitively expect is that a fall history (expressed as having fallen during the year preceding the study) is predictive of outdoor falls.

3.3.1.4. Depression. Depression has been found to increase the number of outdoor falls among older adults (also the number of falls per kilometer walked), and is also one of the few health factors that contributes to both indoor and outdoor falls (Bergland et al., 2003; Kelsey et al., 2010; Quach et al., 2013). The mechanism that underlies the association between depression and falls is not yet clear. Quach et al. (2013) mention possible psychological factors such as impaired concentration, biological factors through effects on vascular pathways or impaired response to hormonal or endocrine stressors. Antidepressant use increases the rate of outdoor falls and partially mediates the association between depression and outdoor falls (Quach et al., 2013). This partial mediation suggests that part of the relationship can be explained by antidepressants, which can impair attention, gait, balance, and blood pressure regulation.

3.3.2. Human behavior

Studies on pedestrian falls have given only little attention to human behavior. Rushing (Lai et al., 2009; Nyman et al., 2013) and not paying attention (Decullier et al., 2010; Gyllencreutz et al., 2015; Nyman et al., 2013) are mentioned as contributory factors by PF victims. Of the studies in the sample, only Gyllencreutz et al. (2015) looked at the use of mobile phones, radios or mp3 players at the time of the fall. This study was restricted to older people, which may explain why no respondents indicated on having used mobile devices prior to the fall. Mobile phone use is particularly frequent among younger pedestrians (Nasar & Troyer, 2013). In two studies, participants with outdoor falls had more frequently high or moderately high alcohol consumption compared to non-fallers (Kelsey et al., 2010; Li et al., 2006). As participants were not asked about alcohol use during the hours prior to their fall it is hard to judge the contribution of this factor.

3.4. Physical environment

3.4.1. Road factors

While most of the risk factors described in the previous sections have been addressed by quantitative research, most knowledge about the role of road factors in PFs comes from qualitative research and relies mostly on victims' interpretations and the study of geographical variations in falls rates. The results of this line of research suggest that road factors play an import role in PFs. Given that most falls are due to slipping and tripping (Bergland et al., 2003; Duckham et al., 2013; Luukinen et al., 2000), it is not surprising that the most frequently mentioned environmental factors are tripping hazards such as uneven surfaces (e.g., curb, loose brick, obstacle, and uneven pavement, stair, and step) and slipping hazards such as wet and slippery surfaces due to ice, snow, oil, etc. (Gyllencreutz et al., 2015; Lai et al., 2011; Li et al., 2006; Naumann et al., 2011; Nyman et al., 2013). It should be noted that slipping on slippery surfaces is not restricted to ice and snow (see also Section 3.4.2). For instance, Lai et al. (2011) found wet and slippery materials and debris on the ground at locations with concentrations of falls (so called fall 'hot spots'). Three studies that aimed to estimate how many PFs were precipitated by environmental factors found shares of three-quarters or more (Gyllencreutz et al., 2015; Lai et al., 2011; Li et al., 2006).

An interesting observation from the focus group study by Nyman et al. (2013) was that PFs frequently occurred when participants were crossing a road and with other people around. Using spatial analysis of falls (with the nearest neighbor hierarchical clustering and standard deviational ellipse techniques), Lai et al. (2009) identified 11 fall hot spots. Almost all occurred in the vicinity of busy junctions with uneven and slippery surfaces. After busy intersections, the next most common locations were often near transit stations and outdoor markets, which attract high volumes of pedestrians. The study did not include pedestrian volumes, but by comparing the hot spots with a map of pedestrian flow issued by the Hong Kong Transport Department, Lai et al. (2011) tentatively concluded that road junctions, even with below-average pedestrian flows, seem to inflict more fall injuries than usual. Mapping PFs by Morency et al. (2012) showed a concentration of outdoor falls in central neighborhoods and on commercial streets in Montréal where there are more pedestrians.

Ascending and descending stairs are challenging and hazardous for older people and frequently results in fatal falls (Startzell, Owens, Mulfinger, & Cavanagh, 2000). The share of falls on stairs in studies in our review varied between 5% and 17% (Björnstig et al., 1997; Duckham et al., 2013; Kelsey et al., 2012; Lai et al., 2009; Li et al., 2006; Morency et al., 2012). Research on falls in general suggests that the risk is highest on descending stairs (Startzell et al., 2000), but as only one study of our sample on outdoor falls distinguished between ascending and descending (Kelsey et al., 2012), we cannot draw any conclusions for PFs.

Insufficient light was only mentioned by a small portion (6–9%) of participants in two studies (Duckham et al., 2013; Lai et al., 2009), but most of the studies did not focus on this factor. This may reflect the focus on elderly people who may be reluctant to travel during darkness, an effect that has also been found among older drivers (Owens & Tyrrell, 1999).

3.4.2. Risk of ice and snow

Of the 28 studies identified in our review, 10 were from countries with cold winters, of which 7 paid attention to the risk of ice and snow on the road. Gyllencreutz et al. (2015) found that, in Sweden, the number of PFs per month among seniors to be some 3 times greater during winter months (November to April) than in other months of the year. Pajala et al. (2008) found a non-significant 8% higher rate of outdoor falls during winter months in Finland. In a Canadian study on PFs needing ambulance intervention during two winter months, three episodes of excess falls were preceded by rain and followed by falling temperatures, or were concomitant with freezing rain. The number of falls during these days was three-fold higher than the average during December and January (Morency et al., 2012). The aforementioned three studies did not account for the amount of walking that has been found to decrease due to inclement weather (Böcker, Dijst, & Prillwitz,

Table 2
Associations between outdoor falls and health characteristics (−, negatively related; −/o negatively related but nog statistically significant; o, unrelated; +, positively related; +/o positively related but nog statistically significant).

	Physical activity	BMI	Gait speed	Multi-morbidity	Number of medications	Fall history
Kelsey et al. (2012)	+	−	+	−	−	
Quach et al. (2011)			+			
Kelsey et al. (2010)	+	−	+	o	−	+
Pajala et al. (2008)	o/+	o	o			o/+
Bergland et al. (2003)		o	+	o	o	+

2013). This suggests that the risk of PFs per kilometer would be even more elevated than the fall rate. Berggård and Johansson (2010) did adjust for kilometers walked and found that the risk of PFs per kilometer on snow and ice (without anti-slip devices) is some 3 times the uncovered-ground risk of PFs.

3.4.3. Injury severity

The studies in our review indicate a number of environmental factors that contribute to injury severity. Duckham et al. (2013) found that the share of outdoor falls while going up or down stairs was 17% for injurious PFs versus 10% for non-injurious PFs. Luukinen et al. (2000) found shares of 19% for falls with fractures versus 9% for falls without fractures. Stairs contributing to injury severity was explained by increased kinetic energy due to fall height (Luukinen et al., 2000). According to Kelsey et al. (2012), falls on hard surfaces were more likely to result in serious injury than those on softer surfaces. Similarly, falls on sidewalks and streets were found twice as likely to result in an injury and nearly 4 times as likely to result in a serious injury that needed medical attention, compared with falls in recreational areas (Li et al., 2014). Slips and falls on slippery surfaces have also been found to be more serious (Gyllencreutz et al., 2015; Luukinen et al., 2000).

3.5. Footwear and anti-slip devices

3.5.1. Anti-slip devices

Use of anti-slip devices during the winter in areas with a cold climate is not yet common (Gao & Abeysekera, 2004; Gyllencreutz et al., 2015). Two intervention studies examined the effectiveness of anti-slip devices on ice and snow. In a study by Mckiernan (2005), older participants were (randomly) assigned to an intervention group wearing Yaktrax Walker, a nonmedical gait-stabilizing device. The rate of slips and PFs for Yaktrax Walker was significantly lower than the rate in the control group. Participants assigned to the intervention group in the study by Berggård and Johansson (2010) were equipped with one of three different types of anti-slip devices: a heel device, a foot-blade device or a whole foot device. Per kilometer walked, users of anti-slip devices experienced 37% less incidents and 36% less PFs per kilometer walked, but these differences were not statistically significant. Anti-slip devices also increase the amount of walking (Berggård & Johansson, 2010; Mckiernan, 2005).

3.5.2. Footwear

Menz et al. (2006) conducted a prospective study focused on footwear characteristics. This may be important as laboratory studies found certain footwear characteristics such as elevated heels impair balance ability. Features such as shoe type, heel height and width, critical tipping angle, sole rigidity and tread pattern were assessed in 176 older people. After controlling for age, gender, and health factors, there were no significant differences in outdoor footwear characteristics between fallers and non-fallers.

4. Discussion

Given the high societal costs of PFs, it is surprising that few studies have focused on this issue. We found only 28 studies published between 1995 and 2015 reporting relevant information on factors contributing to PFs. All studies are from western countries, which can be explained not only by their developed research tradition, but also by their need for research, given their aging populations and the increased risk of severe PFs in the elderly. The great majority of the studies (23 out of 28) used participants above the age of 60. Almost half of the studies (13) were from North America, which can be explained by 9 studies using participants of MOBILIZE Boston, a prospective cohort study of community-dwelling elderly. These prospective studies, and also 3 of the retrospective studies in our sample, contained sufficient participants to allow a quantitative comparison between those who had and those who had not experienced falls (both indoors and outdoors). These studies yielded results on individual contributing factors such as general health, vision, and balance. A substantial share of the studies (11) came from Europe. Although only some 5% of Europe's population lives in Scandinavian countries, 8 of these studies were from Sweden, Finland, and Norway, which can be due to the need to investigate risks associated with ice and snow on the roads and preventive measures such as anti-slip devices. Although 7 of the 10 retrospective studies did not contain a group of non-fallers to permit the quantitative investigation of individual contributing factors, these studies had other strengths (e.g., a wider range of victims' ages and injury severity). Moreover, the qualitative nature of some of the studies (e.g., Gyllencreutz et al., 2015; Nyman et al., 2013) and detailed fall locations recorded in 2 of them (Lai et al., 2009; Morency et al., 2012) were useful in exploring the role of road factors. The studies included in this review provide useful insights into factors contributing to PFs, but there are several research gaps and opportunities for future research that are discussed in the remainder of the discussion. First, Section 4.1 discusses the somewhat counterintuitive findings regarding general health and balance.

4.1. Counterintuitive findings regarding general health and balance

Exercise such as walking improves health and measures of physical fitness such as strength, balance, and flexibility (Ettinger, 1996; Kelly et al., 2014). This may explain that more walking is associated with reduced PF risk (see Section 3.2). However, apart from normal age-related deterioration of health, balance, and motor function, people with below average health were found to have fewer PFs. This counterintuitive finding may result from 'self-selection' in that unhealthy people walk less outdoors and thereby expose themselves less to the risk of PFs. Frail elderly are more likely to stay at home and fall indoors (Kelsey et al., 2010). The studies on health and balance included in this review do not allow causality to be inferred. Research in an experimental setting controlling for potential confounders such as exposure would probably yield results more in line with those expected from a theoretical perspective.

4.2. Areas for future research

Similar to the early days of road safety research when researchers tried to find characteristics of 'accident prone' drivers (Hagenzieker, Commandeur, & Bijleveld, 2014), many studies on outdoor falls focused on characteristics of people prone to falls. This approach has not been very successful. As PF victims are generally healthy people susceptible to normal aging, it is probably more useful to adopt a human factors (also called 'ergonomics') approach as is done in modern road safety research (Hagenzieker et al., 2014). The central question should be how the road system could be adapted to human capabilities and limitations including those of pedestrians.

This view is supported by the finding that road factors play an important role in PFs, for instance on uneven surfaces (e.g., curb, loose brick, obstacle, and uneven pavement). Human factors aspects to consider are visibility, complexity, and expectations (Birth, Pflaumbaum, Potzel, & Sieber, 2009; Schepers et al., 2014). An indication of the importance of complexity is the high frequency of PFs in crowded situations where pedestrians have to divide their attention to negotiate other road users and common sidewalk obstacles such as like poles and advertising signs (Lai et al., 2011). The risk of obstacles and height differences depends not only on aspects such as visibility but also on the extent to which they fit into pedestrians' expectations.

Research on critical locations such as stairs is specific to falls but research on high risk locations like junctions would also be a valuable combination with existing road safety research. Junction design (e.g., zebra markings and speed humps) have received considerable research interest from the perspective of collisions (see e.g. Elvik et al., 2009). Nyman et al. (2013) found that 29% of all PFs in their sample occurred on intersections. As the majority of pedestrian injuries needing hospitalization are due to PFs, this raises the question of whether junction design is optimal from a safety perspective if PF risk is included. For instance, elevated crossings (without height difference for crossing pedestrians) may save as many collisions with pedestrians as PFs.

Future research may also benefit from more attention to behavior, which was hardly included in the studies in this review. Knowledge about this issue is needed to design preventive measures such as education. Therefore, future studies should ask about behavior prior to the fall, for instance whether the victim had used alcohol or drugs during the preceding hours, used a mobile phone or other potentially distracting device, was making an evasive manoeuver to prevent colliding with another road users, was walking alone or in company, was walking a dog, etc.

4.3. Recommendations regarding research approaches

Multi-disciplinary in-depth research such as the study by Davidse et al. (2015) on single-bicycle crashes would be suitable to improve insight into contributory factors. This should include the role of behavior prior to the fall via interviews and PF location visits for measuring dimensions and visibility. Issues to address in an inspection of a fall location are objective measures of visibility (e.g., Fabriek, De Waard, & Schepers, 2012; Schepers & Den Brinker, 2011) and requirements formulated in standards for walkways and accessibility (e.g., ISO 21542, 2011; Nemire, Johnson, & Vidal, 2016; Startzell et al., 2000).

Current research on road factors and PFs is qualitative and this would also apply to in-depth research. Quantitative research is needed to draw firmer conclusions and underpin improvement of standards which is needed according to, for instance, Nemire et al. (2016) who reviewed walkway standards. The case–crossover design recently applied by Teschke et al. (2012) on bicycle crashes seems promising. Victims treated at emergency departments were asked not only about the exact crash location, but also about the route they were traveling prior to the crash to select control locations. As coordinates of crash and control locations are known, spatially explicit modeling approaches (e.g., a hierarchical Bayesian regression) can be applied to account for spatial similarities in exposures between adjacent locations (Vandenbulcke, Thomas, & Panis, 2014).

Finally, we recommend future studies on outdoor falls to focus on or establish a separate category for pedestrian falls in public spaces. The focus on public spaces supports the usefulness of outcomes for road authorities and experts responsible for design guidelines and standards. We advise to include exposure because it can be an important confounder. Current research on PFs is primarily based on a combination of medical data, surveys, and clinical tests. This may be complemented by unobtrusive monitoring of physical activity by accelerometers (Dijkstra, Kamsma, & Zijlstra, 2010; Mcroberts, 2015).

5. Conclusions

From this review study the following conclusions can be drawn on pedestrian falls:

1. More walking is related to a lower PF risk (less PFs per kilometer walked).
2. Older people, especially older women, have a higher risk of (injurious) PFs.
3. Apart from normal age-related problems, outdoor fall victims have equally good or better health characteristics and scores on balance tests compared to those who have not experienced such falls. Research regarding the role of visual capabilities and use of multifocal glasses in PFs is inconclusive. Depression and anti-depressant use are associated with an increased risk of outdoor falls.
4. Road factors such as uneven surfaces (curb, loose brick, obstacle, and uneven pavement), busy junctions, and stairs play an important role in PFs, but these findings are largely based on qualitative research. Snow and ice on the road are associated with an increased risk of PFs which can partially be overcome by the use of anti-slip devices.

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