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Pedestrian Safety and the Built Environment: A Review of the Risk Factors

Philip Stoker[1], Andrea Garfinkel-Castro[1], Meleckidzedeck Khayesi[2], Wilson Odero[3], Martin N. Mwangi[4], Margie Peden[2], and Reid Ewing[1]

Abstract

Urban and regional planning has a contribution to make toward improving pedestrian safety, particularly in view of the fact that about 273,000 pedestrians were killed in road traffic crashes in 2010. The road is a built environments that should enhance safety and security for pedestrians, but this ideal is not always the case. This article presents an overview of the evidence on the risks that pedestrians face in the built environment. This article shows that design of the roadway and development of different land uses can either increase or reduce pedestrian road traffic injury. Planners need to design or modify the built environment to minimize risk for pedestrians.

Keywords

pedestrian safety, risk factors, built environment

Introduction

Road traffic injuries are the eighth leading cause of death globally, and the leading cause of death for young people aged fifteen to twenty-nine (World Health Organization 2013a). Current trends suggest that by 2030 road traffic deaths will become the fifth leading cause of death unless urgent action is taken (Peden et al. 2004; World Health Organization 2013a). In particular, nations such as India, China, and other countries with burgeoning populations and rapidly growing motorization and urbanization face a substantial increase in pedestrian injuries and fatalities (Zegeer and Bushell 2012). Now that over half of the global population lives in cities, the same concern for pedestrian safety is likely wherever urbanization and motorization are causing more people to be on the roads.

Of the over one million road traffic deaths annually, nearly one-quarter (22 percent) are pedestrians, 5 percent are cyclists, 23 percent are motorcyclists, 31 percent are car occupants, and 19 percent are other groups or unspecified (World Health Organization 2013a). Another fifty million people worldwide are injured as a result of traffic collisions (World Health Organization 2013a). Several of the established causes of these fatalities and injuries are related to the built environment: traffic volumes, excessive roadway speed, poor lighting, and urban development patterns. As planners, we need to recognize what risks to pedestrians result from the design of the built environment.

Many of the solutions to reducing these risk factors are within the range of influence and control of planners. However, to effectively address and mitigate risks to pedestrians, planners need to understand the risk factors that affect pedestrian safety. We examine the built environment as a factor that raises or minimizes the probability of pedestrian injury and death, in line with the definition of risk offered in the World Health Report of 2002 (World Health Organization 2002). This literature review synthesizes some of the most recent research on pedestrian safety and the built environment from around the world. This article begins by briefly describing the types of pedestrians. We then present a conceptual model of the relationship between the built environment and the pedestrian safety and present evidence of the risk factors pedestrians face in the built environment. We highlight the connections between the risk factors. This review can serve as a resource for planners to understand the risk factors, and how the risk factors interact, in order to guide safety-oriented policies and design.

Method and Approach

We conducted the literature review on key databases (e.g., SCOPUS, Web of Science, PubMed, and Google Scholar) using the following key words to find relevant literature:

[1] City and Metropolitan Planning, University of Utah, Salt Lake City, UT, USA
[2] Department of Violence and Injury Prevention, World Health Organization, Geneva, Switzerland
[3] School of Public Health, Maseno University, Kisumu, Kenya
[4] Wageningen University, Wageningen, the Netherlands

Corresponding Author:
Philip Stoker, City and Metropolitan Planning, University of Utah, 375 S. 1530 E. #235 AAC, Salt Lake City, UT 84108, USA.
Email: philip.a.stoker@gmail.com

Table 1. Pedestrian Categories.

Pedestrian Type	Description	Relative Risk Factor	Source
Young children	Approximately 21 percent of road traffic deaths involve young children	Very high	Barton and Schwebel (2007), Peden (2004), and Peden et al. (2008)
Young adults	For fifteen- to twenty-one-year-olds, pedestrian fatalities are the leading cause of death	Above average	Hilton (2006)
Male pedestrians	Males are overrepresented in pedestrian fatalities in most but not all studies	Above average	Goren et al. (2005), Durak et al. (2008), and Tom and Granié (2011)
Gender roles	Women and girls in low-income countries walk more and transport more household goods than male counterparts, increasing their risk as pedestrians	Above average	Rosenbloom and Plessis-Fraissard (2009) and Roy (2009)
Elderly	The elderly have the highest risk of mortality of all pedestrians when involved in vehicle collisions	Very high	Assailly (1997), Davies et al. (1999), Vyrostek, Annest, and Ryan (2004), Retting et al. (2003), Gawryszewski and Rodrigues (2006), and Ponnaluri and Nagar (2010)
Low socioeconomic status	A strong inverse relationship is found between socioeconomic status and risk of pedestrian injuries and fatalities	High	Marcin et al. (2003), Cubbin (2002), and Azetsop (2010)
Intoxicated or distracted pedestrians	Intoxication and distraction from mobile devices put pedestrians at higher risk for pedestrian injuries and fatalities	High	Clayton and Colgan (2001), Stavrinos, Byington, and Schwebel (2009), Nasar, Hecht, and Wener (2008), and Hatfield and Murphy (2007)
Disabled pedestrians	Visually impaired pedestrians are elevated at risk from drivers who yield inconsistently and unreliably; disabled youths are especially vulnerable pedestrians	High	Guth et al. 2005 and Xiang et al. 2006
Pedestrians in low-income countries	Pedestrians in low-income countries are particularly vulnerable to injury and death from collisions, attributable to increasing urbanization, and motorization inadequate pedestrian facilities, lack of pedestrian safety education, and access to emergency health care	Above average	Peden and Hyder (2002), Peden et al. (2004), and Bishair et al. (2006)

pedestrian safety, pedestrian accidents, pedestrian injuries, pedestrian fatalities, pedestrian crashes, pedestrian education, pedestrian education in developing countries, and so on. We focused primarily on the most recent research available.

The initial review of research articles and their bibliographies provided a wealth of follow-up citations. Tracing backward, we compiled and reviewed both published and unpublished reports, as well as published academic articles. The literature on pedestrian safety and the relationship between the pedestrian safety and the built environment is vast and our modest effort in this article is to provide an overview of the evidence that may be used for decisions by planners. Apart from the literature on pedestrian safety, there is the issue of the most appropriate way to organize a literature review that cuts across countries at different levels of development as well as varying conditions in the built environment. We explored different options, including focusing on different development contexts or selected themes as the basis to present the literature. We opted to use selected themes in an effort to show some variation in pedestrian road traffic injuries by contextual factors such as countries and rural/urban sites. It is a modest effort at comparative analysis and we hope readers will isolate the key risk factors presented through a mix of contexts from around the world. We believe planners need to appreciate the mix of environments in which pedestrian crashes occur.

Types of Pedestrians

Pedestrians form a mixed group of people with respect to age, gender, travel behavior, and socioeconomic status (SES). This body of research and literature focuses specifically on pedestrians, how they can be categorized, and their relative risk factors. While certain categories of pedestrians are specific to locale (such as low socioeconomic pedestrians or gender-related roles in low-income countries), and although research is typically carried out within regional or national geographies, much research is generalizable to a pedestrian type. Table 1 presents broad categories of pedestrian types, described in detail subsequently, that are at elevated risk for pedestrian-related injuries and fatalities. A general ranking of relative risk is assigned, based on the literature: severity of risk identified by research and the volume of confirmatory research and literature. Sources identified in Table 1 represent major works, and further additional literature is found by types mentioned subsequently.

Young Children and Young Adults

Children are particularly at risk in road traffic crashes (Assailly 1997; Davies et al. 1999; Vyrostek, Annest, and Ryan 2004; Retting et al. 2003; Gawryszewski and Rodrigues 2006; World Health Organization 2009; Ponnaluri and Nagar 2010). Approximately 21 percent of road traffic fatalities are children, resulting in an average of 720 child deaths related to road traffic crashes daily (Peden et al. 2008). Traffic injuries are the second leading cause of death worldwide for young children (Peden 2004) and are the leading cause of childhood disability worldwide (Peden et al. 2008).

Some explanations of why children are at particular risk include their underdeveloped abilities and perceptions (Constant and Lagarde 2010) and greater variability in their actions (Pitcairn and Edlmann 2000). Many children begin to experience mobility and independence at a young age but are not yet cognitively capable of safely navigating traffic conditions (Barton and Schwebel 2007). Compounding this risk is their small size, which makes them both less visible to drivers and more vulnerable to injury and death in collisions (Barton and Schwebel 2007).

Some studies have shown that as a parent's level of education increases, the risk of child pedestrian injury decreases (Agran et al. 1998; Pless, Verreault, and Tenina 1989; Rivara and Barber 1985). However, it is not parental education alone that influences risk. In an experiment testing the effects of parental supervision, Barton and Schwebel (2007) found that parental supervision in pedestrian crossings moderated the risky behavior children exhibited. Interestingly, though, if parents display risky behavior, the children will do the same. In a survey on child–parent interaction, mothers were much more likely than other family members to provide some form of road safety education and set a good example as safe road users while pointing out unsafe behaviors by others (Green et al. 2008).

The school–home journey is a point of considerable exposure and risk for children. Roberts (1995) found strong evidence that children accompanied by an adult during the school–home journey significantly reduce their risk of injury or death. The Walking School Bus and Safe Routes to School are two of a number of school- and community-based programs designed to increase children's safety during the walking journey to and from school (Heelan et al. 2009; Mendoza, Levinger, and Johnston 2009), and while these are generally successful (Boarnet et al. 2005), they have some critics (Collins and Kearns 2005; Kearns, Collins, and Neuwelt 2003). These critics stress that the predominance of motorized travel and design standards to accommodate and prioritize travel by cars outweighs the benefits derived from safe travel programs to and from school. Until design standards are changed, these programs are unlikely to really address the heart of the problem.

Male Pedestrians

Many studies find that male pedestrians of all ages are overrepresented in pedestrian collisions. Almost two-thirds of children killed as pedestrians are male, and they have a death rate of 57 percent higher than of female children (Goren et al. 2005; Durak et al. 2008; Tom and Granié 2011). Some researchers suggest that males are more likely than females to violate pedestrian rules (Tom and Granié 2011). However, other studies find no relationship between a pedestrian's sex and their risk for injury or mortality (Moe 2008; Ibrahim et al. 2012; Dandona et al. 2008). We report findings that have found that male pedestrians are overrepresented in pedestrian collisions. One explanation is a willingness to engage in risky behaviors. However, we follow this section with the "Gender roles" subsection and report findings that in certain situations, women are at greater risk as pedestrians than males.

Gender Roles

In low-income countries, gender-based roles factor enormously in the time men versus women spend as pedestrians. Walking, as a form of transport, falls on girls and women far more than boys and men (Rosenbloom and Plessis-Fraissard 2009). In the forty-five poorest countries in the world, where one-fifth of the world's population lives, women walk more and far more often carry heavy loads of household goods that include children, water, and wood (Rosenbloom and Plessis-Fraissard 2009; Roy 2009); this is particularly so in sub-Saharan Africa. In addition to hazards resulting from roads that are poorly designed, developed, and maintained (Rosenbloom and Plessis-Fraissard 2009), women in developing countries are highly vulnerable pedestrians due to cultural conditions that leave them subject to "sexual harassment, crime, violence ... pollution and noise" (Seedat, MacKenzie, and Mohad 2006, 150).

Despite the load-carrying burdens placed on women in many parts of the world, minimal research has been conducted to date to identify precisely the added risk factors to women under these circumstances. Extrapolating from the literature on the impacts of backpack loads to mobility (see Wang, Pascoe, and Weimar 2001; LaFiandra et al. 2003; Chow et al. 2005; Negrini and Carabalona 2002), it is conceivable that women with portage (loads) are at measurably higher risk for vehicle–pedestrian crashes than are men. The noted lack of research on gendered pedestrian issues in low-income countries continues to leave many questions unanswered (Porter 2002, 2008; Rosenbloom and Plessis-Fraissard 2009).

Elderly Pedestrians

The number of older persons (those who are sixty years and over) is growing steadily in the world. In 2013, there were 841 million older persons in the world (United Nations 2013). This number is expected to more than double, to more than two billion in 2050. It is also projected that older persons are to exceed the number of children for the first time in 2047 (United Nations 2013). There is global variation in the distribution of the population of older persons, with about two-thirds of the world's older persons living in developing countries. It is estimated that by 2050, nearly eight in ten of the world's older population will live in the world's less developed regions (United Nations 2013). There is also variation in the older population. Analysis shows that the population aged eighty years or over is occurring at a faster pace in the less developed regions than in the more developed regions (United Nations 2013). The aging population has implications for transport planning, especially in ensuring safe accessibility of older persons to services and facilities as they fulfil their roles in society.

Walking is the primary mode of transportation for the elderly worldwide (Siram et al. 2011) and an important source of independence for the elderly (Langlois et al. 1997), providing important health benefits, as well (Kerr, Rosenberg, and Frank 2012). As pointed out by Whitelegg (1993), older people need special consideration in the design of the built environment and road traffic environment in which they live and where they access local shops and services such as trips to the doctor, dentist, optician, and other services used intensively by this age-group. Studies on aging and transport also indicate that pedestrian safety is an important safety concern for the elderly (Peden et al. 2004; Whitelegg 2012). Several factors work together to increase the risk of older pedestrians (World Health Organization 2013b):

- Deterioration in visual acuity may have a negative impact on their ability to cross the road safely. In general, older pedestrians look less at traffic and accept significantly smaller gaps in traffic when crossing the road than younger pedestrians.
- Reduced mobility can render older pedestrians unable to react quickly in imminent danger to avoid a crash.
- Underlying health conditions or frailty can result in greater injury severity when a crash occurs.
- Reduced speed when crossing the road: the speed of elderly pedestrians does not itself increase risk; rather, the risk comes from the speed of the traffic and, in particular, from automated signals that do not allow sufficient time for slower pedestrians to cross safely and completely. In many municipalities, the assumed walking speed used to set crossing times at signalized crossings is faster than an older person can walk, leaving them stranded on the road when the signal phase changes to allow vehicle movement (Job et al. 1998). Whitelegg (1993) points out that transport planning and practice based on encouraging motorization and car-based trips achieves its success by stealing time from other groups especially elderly pedestrians who must now spend more time waiting to cross a road or be diverted through an unpleasant underpass; having to negotiate ugly metal barriers that obstruct direct walking routes; or find that local services they prefer to use have closed and they must now travel longer distances to shopping centers, hospitals, or clinic because they have relocated to more inaccessible, pedestrian-unfriendly locations.

The combined effects of the above-mentioned risks are revealed in research, showing that the elderly suffer the highest mortality rates in pedestrian crashes (Small and Sheedy 2006; Bhalla et al. 2009; Zhao et al. 2010; Bartels et al. 2010). Studies unanimously find that the severity of injury from a traffic collision is related to the resilience of the pedestrian (Methorst et al. 2010), with elderly pedestrians likely to experience more trauma than other adult pedestrians (Demetriades et al. 2004).

Low SES Pedestrians

SES is a mediating factor of pedestrian risk and injury (Sharples et al. 1990; Marcin et al. 2003; Cubbin 2002; Azetsop 2010), with a strong inverse association to fatal injuries (Cubbin 2002). A majority of child pedestrian injuries are associated with low income and poverty status (Rivara and Barber 1985). In the United States, children from families earning less than US$20,000/year are seven times more likely to be injured than children from families earning more than US$30,000/year (Mueller, Rivara, and Bergman 1988). Chakravarthy et al. (2010) found that the percentage of the population living in low-income households is the strongest predictor of pedestrian injuries, with pedestrian crashes four times more likely in poor neighborhoods. This finding is repeated in a study that found that the risk of injury for children in the lowest socioeconomic stratum is more than twice that of children in higher SES categories (Roberts et al. 1995). A further study found that the risk of injury for children in the lowest socioeconomic stratum is more than twice that of children in higher SES categories (Roberts et al. 1995). A study of Buffalo, New York, found bicycle and pedestrian crashes were related to some SES factors (ethnicity and educational status) but not all factors (income), and land use played a factor in crashes, while infrastructure impacts were minimal (Delmelle, Thill, and Ha 2012).

While factors related to poverty, such as age, education, language fluency, and population density do not explain the effects of poverty on pedestrian injuries, exposure explains some of the increased risk. A survey of Indian children in Hyderabad reported that as household income increased, the proportion of pedestrian trips decreased and trips by bicycle or motorized two-wheeled vehicles increased, significantly reducing the likelihood of pedestrian injury for children in the highest household income quartile (Dandona et al. 2008). A similar pattern is observed internationally, where higher income countries record lower levels of pedestrian activity and lower levels of pedestrian fatalities, whereas lower- and middle-income countries experience higher levels of both (World Health Organization 2009).

Intoxicated or Distracted Pedestrians

As temporary conditions, these two statuses are combined into a single type of pedestrian, representing high though temporal risk. Research suggests that intoxicated pedestrians are at significantly higher risk of injury (Clayton and Colgan 2001). In a review of Australian studies, Holubowycz (1995) determined that 20–30 percent of pedestrians involved in collisions had blood alcohol content (BAC) levels in excess of 0.15 g/dl, with higher BAC levels more frequently resulting in fatalities. Peden et al. (2004) found that in South Africa, alcohol was a factor in over 61 percent of fatal pedestrian collisions. A recent study in the United Kingdom concluded that nearly half of all pedestrians killed in road traffic collisions had been drinking (Keigan and Tunbridge 2003).

Mobile electronic devices appear overall to present an increased risk to pedestrian safety (Hatfield and Murphy 2007; Nasar, Hecht, and Wener 2008; Neider et al. 2010; Stavrinos, Byington, and Schwebel 2009). Talking on a mobile phone is shown to reduce situational awareness, creating potentially treacherous environments for pedestrians. A study by Nasar, Hecht, and Wener (2008) found that mobile phone users engaging in conversation were significantly more likely to make unsafe road crossing decisions compared to subjects not using mobile devices. The evidence on the safety effects of personal music devices is less clear than it is for mobile phones. One study using a virtual environment found subjects operating a hands-free mobile phone were more likely to make dangerous road crossing decision than those using electronic music devices (Neider et al. 2010). Another similar study found that subjects using either a mobile phone or a music device were at increased risk of being hit in a virtual environment (Schwebel et al. 2012). Walker et al. (2012) found little difference in cautionary behavior between pedestrians using versus not using mobile music devices. Finally, Hatfield and Murphy (2007), Nasar, Hecht, and Wener (2008), and Stavrinos, Byington, and Schwebel (2009) all conclude that the use of cell phones, earphones, and other electronic devices are distractions that increase the risk of injury or death for pedestrians.

Disabled Pedestrians

Pedestrians with physical disabilities do not comprise a high number of pedestrians overall, yet are at particularly high risk for injury or death. Visually impaired pedestrians were found to have greater difficulty navigating higher volume, multiple-lane roundabouts compared to single lane roundabouts (Guth et al. 2005). They also found that drivers were unreliable and inconsistent in their willingness to yield to blind pedestrians, even when using canes or guide dogs (Guth et al. 2005). Research on disabled pedestrians aged five to seventeen found they were five times more likely to be involved in a collision compared to those without a disability (Xiang et al. 2006).

Pedestrians in Low-income Countries

Nearly all countries with the highest absolute numbers and rates of pedestrian fatalities are developing countries (Toroyan 2009). Approximately 96 percent of children killed worldwide due to road traffic injuries live in low- and middle-income countries (Peden et al. 2004). Pedestrians account for 42 percent of all road traffic deaths in Delhi, India, and 38 percent in Colombo, Sri Lanka (Bishair et al. 2006). The continuing levels of growth of urbanization/suburbanization and motorization now occurring in developing nations, pedestrian injuries, and deaths potentially jeopardize the pursuit of health equity (Peden and Hyder 2002; Bishair et al. 2006; Wilkinson and Marmot 2003). Low-income countries are particularly challenged to allocate funding for pedestrian facilities and services (Zegeer and Bushell 2012), making road crossing especially dangerous due to poor lighting, heavy- and high-speed traffic, limited traffic law enforcement, lack of safety education, and poor access to emergency health facilities (Berger and Mohan 1996; Nakitto et al. 2008).

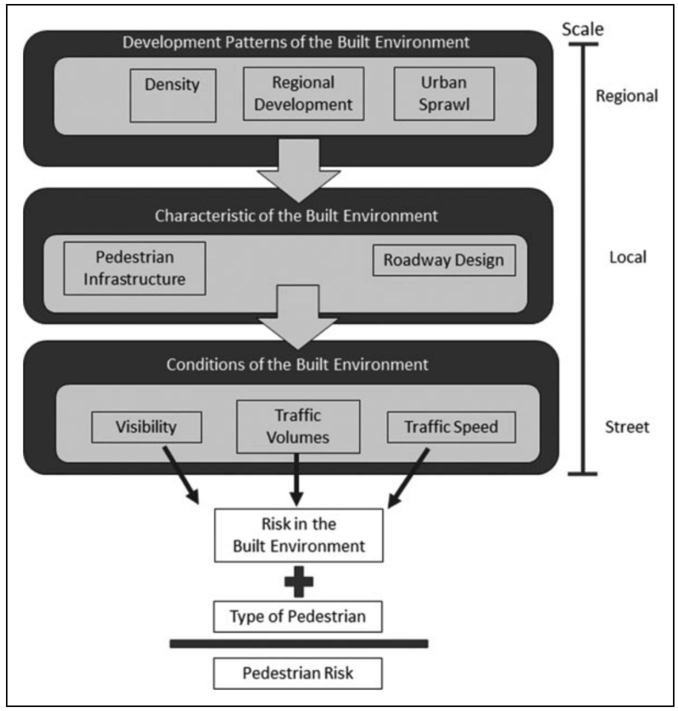

Figure 1. Conceptual framework linking the built environment to pedestrian safety.

The Built Environment and Pedestrian Safety

The physical context of pedestrian safety is the built environment, the focus of this part of the article. The conceptual framework relating the built environment to pedestrian risk is presented in Figure 1. The framework is organized by scale, from regional scale at the top of the figure to street scale at the bottom of the figure. We account for interactions between the spatial and administrative scales: development patterns of the built environment at the regional scale, such as density, urban sprawl, and regional development all produce characteristics of the built environment at the local scale: pedestrian infrastructure and roadway design. For example, in a rural region, there is likely to be little pedestrian infrastructure and roadway designs typically facilitate auto travel but do not accommodate pedestrians. Conversely, in highly dense urban settings, there may be more facilities for pedestrians and the roadway design may be more accommodating to pedestrians. In either case, the characteristics of the built environment at the local scale produce traffic and pedestrian conditions related to pedestrian safety: visibility, traffic volumes, and traffic speed. The visibility of pedestrians may increase or decrease depending on pedestrian infrastructure such as crossing lights. Or there may be characteristics of roadway and urban design that increase visibility such as elevated crossings and street lights. Traffic volumes and traffic speed are affected primarily by roadway and urban design, where traffic conditions at the street scale are a result of the design of the built environment at local scale.

Each of these three conditions has an effect on the risk of collision, injury, and death for pedestrians. Lower visibility for pedestrians increases this risk of a collision, higher traffic volumes increase crash frequency, and higher traffic speed increases the severity of the crash. The overall risk to a pedestrian is the combination of the risk from the built environment plus the risk relative to the type of pedestrian. The literature related to each of the components of the conceptual framework is synthesized subsequently.

Development Patterns: Density

Vehicular and pedestrian traffic tend to increase with development density, as do vehicle–pedestrian collisions. In a California study, Agran et al. (1996) found that the incidence of injury for children living in high-density residential areas was three times higher than that of children living in single-family residences. Similarly, LaScala, Johnson, and Gruenewald (2001) found that pedestrian injuries occurred more often in areas with higher populations and greater cross-street densities. The density of development affects characteristics of the built environment such as roadway design and pedestrian infrastructure. For example, Clifton and Kreamer-Fults (2007) found that transit access, commercial land uses, and high population densities had direct relationships to pedestrian crashes near public schools. These researchers also found that characteristics of the built environment such as roadway design (e.g., the access to driveways) had a significant negative impact on pedestrian safety. Each of these characteristics is related to the density of development at a regional scale.

While there is little doubt that the absolute number of pedestrian crashes increases with development density, the relationship between the two appears not be linear. Collision rates relative to exposure may actually decline with rising densities, and the severity of injuries certainly declines. In a study entitled "Safety in Numbers: More Walkers and Bicyclists, Safer Walking and Bicycling," Jacobsen (2003, 205) tapped several data sources to show that crashes between motorists and pedestrians or cyclists were less likely when people walking or bicycling in the immediate area increased. In an environment with many pedestrians or bicyclists, motorists may be more aware of them and adjust their driving behaviors accordingly. Although plausible, some have criticized the "safety in numbers" theory as simplistic and have argued to focus on local-level characteristics of the built environment: roadway design, speed policies, and increased investment on pedestrian infrastructure (Bhatia and Wier 2011).

Studies that seek to infer causal relationships between density and pedestrian collisions must contend with multiple confounding variables: more residents, more employment, more roads, and more of everything (Ewing and Dumbaugh 2009). As a result, density alone may not be a predictor of the risk in the built environment. Rather, the relationship between pedestrian risk and development density is linked through vehicle miles traveled (VMT). As VMT increases, traffic collisions (of which pedestrians injuries are a substantial part) increase (Ewing and Dumbaugh 2009). Therefore, pedestrian risk is related to the overall VMT generated by the density of development. Research from North America indicates that as development density increases, VMT decreases (Ewing and Cervero 2001). Therefore, the contradiction found in the literature regarding density and pedestrian collisions is clarified by understanding the relationship between density and VMT.

Development Patterns: Regional Development

The rate and severity of crashes tend to be highest wherever the bulk of the population resides. For example, in the United Kingdom, young pedestrians from urban areas were involved in collisions five times more frequently than those in rural areas, and their death rate was twice as high (Petch and Henson 2000). Similarly, Odero, Khayesi, and Heda (2003) found that pedestrians were more likely to be killed in urban areas. Pedestrian fatality and injury rates may differ between urban and rural regions because pedestrian volumes and vehicle operating speeds differ. Consequently, if a region's population is predominantly rural, this is where most of the collisions will occur. Conversely, if a country's population is predominantly urban, most of the collisions will occur in urban areas.

Beyond these facts, the evidence suggests that pedestrians in rural places have higher rates of injuries and their injuries tend to be more severe than pedestrians in urban areas (Mueller, Rivara, and Bergman 1988; Litman and Fitzroy 2005; Ewing and Dumbaugh 2009; Ibrahim and Sayed 2011; Tarko and Azam 2011). For example, in Ghana, residents are 58 percent more likely to die in traffic collisions on rural than on urban roads (Afukaar, Antwi, and Ofosu-Amaah 2003) and in Kenya, a majority of road traffic injuries occur on rural roads (Odero, Garner, and Zwi 1997). In Pakistan, twice as many road deaths occur in rural areas as in urban areas (Shah, Khoumbati, and Soomro 2007). Ma et al. (2010) found that in China, pedestrians commuting in rural contexts were more likely to be injured in a traffic collision than those commuting within urban areas. This is consistent with earlier studies showing generally higher pedestrian injuries in rural areas (Al-Madani and Al-Janahi 2006; Xie et al. 2002).

There are several explanations for why rural areas appear to be more dangerous for pedestrians. One is that the relationship between VMT and traffic fatality rates is roughly linear. VMT per capita are consistently higher in rural areas, with correspondingly higher fatality rates per capita (Litman and Fitzroy 2005; Ewing and Dumbaugh 2009). Rural roads also produce characteristics of the built environment that promote higher traffic speeds than urban roads. Measures to reduce traffic speeds in rural China resulted in improved pedestrian safety (Changcheng et al. 2010). Additionally, pedestrian crashes in rural areas are generally located farther from emergency medical facilities, and emergency services take longer to arrive at the scene of a crash to provide lifesaving medical care (Mueller et al. 1988). Rural roads are also less likely to include complete characteristics of the built environment such as pedestrian infrastructure. Wanvik (2009), for example, found that while pedestrian risk for injury on rural Dutch roads increased 140 percent during nighttime hours on roads with lighting, whereas the risk increased by 360 percent on rural roads without lighting.

Development Patterns: Urban Sprawl

For the same reasons, pedestrian crashes are more likely to be fatal in rural areas, pedestrian–vehicle crashes are more likely to be fatal in sprawling urban areas. Urban sprawl, prevalent internationally and particularly common in North America, is characterized by four dominant qualities: a widely dispersed population and low-density development; the rigid separation of residential, commercial, industrial, and office uses; poorly defined activity centers; and a road network typified by large blocks and poor connectivity (Ewing, Pendall, and Chen 2002). In an extensive study, Ewing, Schweiber, and Zegeer (2003) found associations between the degree of sprawl and traffic fatalities, with each 1 percent decrease in sprawl resulting in 1.49 percent decrease in traffic-related fatalities overall, and between 1.47 and 3.56 percent decrease specifically in pedestrian fatality rates.

Relatively high numbers of miles of arterial roadways and the presence of strip malls and big-box stores (indicative of urban sprawl) are also determinants of traffic injury rates (Dumbaugh and Li 2011). A substantial study by Marshall and Garrick (2011) analyzed 230,000 crashes occurring over eleven years in California, finding that denser street networks with higher intersection counts—the converse of urban sprawl—was associated with fewer crashes across all severity levels. Likewise, vehicle–pedestrian collisions occurring at intersections in neighborhoods with mixed land uses and nearby schools—also the converse of urban sprawl—resulted in lower rates of injury and death compared to collisions in other development types (Zahabi et al. 2011). Again, the link between pedestrian safety and development patterns is VMT.

Characteristics: Pedestrian Infrastructure

Pedestrian infrastructure can reduce pedestrian exposure to vehicular traffic and reduce vehicle speeds (Lonero, Clinton, Sleet 2006; Zeeger et al. 2004; Retting, Ferguson, and McCartt 2003; Peden et al. 2004; Elvik et al. 2009; Sleet, Naumann, and Rudd 2011; Zegeer and Bushell 2012; World Health Organization 2013b). These street treatments are briefly summarized subsequently and organized by reducing pedestrian exposure and reducing vehicle speeds.

Street Treatment: Reducing Pedestrian Exposure to Vehicular Traffic

The specific engineering measures that reduce pedestrian exposure to vehicular traffic by either creating separation between pedestrians and vehicles or reducing traffic volume are sidewalks and footpaths, marked crossings, overpasses and underpasses, and mass transport routes.

Street Treatment: Reducing Vehicle Speeds

As pointed out in several studies and reports (e.g., World Health Organization 2013b), speed is a key risk factor for pedestrian traffic injury. Hence, speed management remains an effective measure to reduce pedestrian traffic risk. The engineering approach to speed management consists of a number of specific traffic-calming measures: physical treatments to roads as well as perceptual treatments and speed limit reductions aimed at reducing vehicle speeds and sometimes traffic volume (Mead et al. 2014). Traffic-calming measures are generally of two types: (a) those that require motorists to change their direction of travel by moving either to the left or right and (b) those that require motorists to change elevation by either going up or down (Vanderschuren and Jobanputra 2009). Traffic-calming measures can vary from a few minor changes, through modifications of local streets, to area-wide changes and major rebuilds (Vanderschuren and Jobanputra 2009). Their effects include moderate speed reductions to street design changes, with various degrees of success in reducing pedestrian crashes and traffic volume (Table 2). A number of studies show a reduction in pedestrian–vehicle conflicts and crashes associated with refuge islands, marked crossings with raised medians, road narrowing, staggered lanes, road humps, and junction redesign (World Health Organization 2013b).

Characteristics: Roadway Design

In general, streets designed to be narrower and for slower speeds experience the lowest rates of vehicle–pedestrian crashes, while wide street lanes and higher operating speeds experience the highest rates (Garder 2004). For these reasons, European roadway engineers design for lower vehicle operating speeds in developed areas (Federal Highway Administration 2001; Lamm, Psarianos, and Mailender 1999; Organisation for Economic Co-operation and Development 1998; UK Department for Transport 2007). In the Netherlands, a "sustainable safety" policy sets roadway speed limits based on road function with this policy potentially resulting in one-third fewer injuries per million vehicle kilometers (Institute for Road Safety Research 1993).

Conversely, roadway expansion and widenings occur at the expense of safety, even after controlling for traffic volumes (Dumbaugh 2005; Harwood 1986; Milton and Mannering 1998; Noland and Oh 2004; Sawalha and Sayed 2001; Vitaliano and Held 1991; Hummer and Lewis 2000). Wide lanes adversely affect traffic safety, particularly in urban areas.

Table 2. Traffic-calming Measures, Their Application, and Impact.

Type	Speed Reduction Can Be Applied to: Arterial Roads	Speed Reduction Can Be Applied to: Local Roads	Impact on Traffic Volume
Speed hump	No	Yes	Possible
Speed table	With caution	Yes	Possible
Raised crosswalk	Yes	Yes	Possible
Raised intersection	With caution	Yes	Possible
Textured pavements	Yes	Yes	Possible
Speed cushion	With caution	Yes	Possible
Rumble strips	Yes	Yes	No
Traffic (mini) circle	No	Yes	Possible
Roundabout	Yes	Yes	Not likely
Chicanes	No	Yes	Yes
Realigned intersection	Yes	Yes	Possible
Tight radii	Yes	Yes	Possible
Centre island narrowing	Yes	Yes	Possible
Chokers	Yes	Yes	Possible
Road diets (i.e., lane reduction)	Yes	Yes	Yes
Speed limits	Yes	Yes	No
Speed alerts, enforcement	Yes	Yes	No
Perceptual design	Yes	Yes	Possible
Warning signs	Yes	Yes	No
Half closure	Yes	Yes	Yes
Diagonal diverters	Yes	Yes	Yes
Lateral shift	Yes	Yes	No
Median barriers	Yes	No	Yes
Gateway treatments	Yes	No	No
Traffic signal coordination	Yes	No	No
Vehicle-activated signs	Yes	No	No

Source: Vanderschuren and Jobanputra (2009).

Noland and Oh (2004) found that wider lanes were associated with statistically significant increases in total and fatal crashes in the state of Illinois. Lee and Mannering (1999) established that while wide lanes reduced the probability of run-off-roadway crashes in rural settings, they were associated with increases in these types of crashes in urban areas. In reexamining the historical literature on lane widths and traffic safety, Hauer (1999) found that research from 1940 forward consistently showed crashes increasing as lanes exceed eleven feet in width. These results are confirmed by Swift, Painter, and Goldstein (2006) who found that after examining thirteen physically built environment characteristics for approximately 20,000 collisions report street width correlated most highly with collision rates, and the safest streets are found to be narrow (twenty-four foot wide) and slow.

Traffic speed, discussed subsequently as impacting injury severity in collisions, can be reduced by narrowing lanes and shortening street sections (Harwood 1990; Farouki and Nixon 1976; Heimbach, Cribbins, and Chang 1983; Clark 1985; Gattis and Watts 1999; Gattis 2000; Fitzpatrick et al. 2001). Drivers on narrow streets generally behave less aggressively, run fewer traffic signals, and drive slower (Untermann 1990). This may be because drivers feel less safe and therefore drive more cautiously on narrow streets (Ewing and Dumbaugh 2009). Studies of "road diet" projects, which reduce the number of traffic lanes on a road, find that traffic crashes decrease as lanes are eliminated (Huang, Stewart, and Zegeer 2002; Knaap and Giese 2001). One possible explanation is that on two-lane roads, prudent drivers set the pace and others must follow, whereas on multilane roads where passing is possible, high-speed drivers set the prevailing speed (Burden and Lagerwey 1999).

One of the strategies developed in the Netherlands for traffic calming is known as woonerf, a residential area (sometimes referred to as a "living yard") that promotes sharing of the street by pedestrians, cyclists, and motorists but giving priority to pedestrians and cyclists. Vehicles are allowed on the streets under the strict conditions of low speed, nonobtrusive parking, and limited traffic (Woonerfgoed Network 2014). The woonerf basically seeks to strike a balance between the life of a community and the movement of vehicles. The woonerf has spread from the Netherlands where it started in the 1970s to other parts of the world. The concern about livable streets and rebalancing the needs of different road users is spreading around the world (Khayesi, Monheim, and Nebe 2010). There are several program initiatives and policy efforts toward this end such as home zone, complete streets, residential zone, shared zone, shared space, and walkable communities.

Conditions: Traffic Volumes

Research worldwide consistently finds that the higher the traffic volume, the greater the frequency of pedestrian injuries (Quaye et al. 1993; Roberts et al. 1995; Agran et al. 1996; McMahon et al. 2002; Hijar, Vasquez-Vela, and Arreola-Risa 2003; Harwood et al. 2008; Chen, Meng, and Wang 2009; Ma et al. 2010). In one study, Roberts et al. (1995) found that the risk of injury for children was thirteen times higher in neighborhoods with the highest traffic volumes compared to those with the lowest. In another, Quaye et al. (1993) found that the probability of a pedestrian injury with a left-turning vehicle varied as a function of traffic volume. And Harwood et al. (2008) demonstrated that higher traffic volumes at signalized intersections were associated with a higher likelihood of pedestrian crashes. Data from crash records in China between 2004 and 2007 result in the finding that arterial roads with heavier traffic volumes tended to have more severe crashes (Ma et al. 2010). Finally, specific peak periods of pedestrian and vehicle traffic volume, such as holidays, are associated with higher levels pedestrian injuries and fatalities (Road Traffic Management Corporation 2009).

Conditions: Traffic Speeds

The risk factor that increases the severity of pedestrian injuries and fatalities is traffic speed (Mohan and Tiwaria 1998; Hijar, Vasquez-Vela, and Arreola-Risa 2003; European Transport Safety Council [ETSC] 1999). Vehicle speeds are repeatedly associated with increased injury severity and death in motor vehicle collisions involving pedestrians (Anderson et al. 1997;

Avineri, Shinar, and Susilo 2012; ETSC 1999; Garder 2004; Grundy et al. 2009; Hijar, Vasquez-Vela, and Arreola-Risa 2003; Kim et al. 2010; Mohan and Tiwaria 1998; UK Department of Transport 1997; Zegeer et al. 2002; Zhao et al. 2010; Zegeer and Bushell 2012). Simple physics tells us that higher vehicle-operating speeds give drivers less time to react to unforeseen hazards, cause drivers to travel farther before stopping when hazards are present, and result in increased force of impact when crashes occur.

Evidence indicates that when struck by a vehicle traveling forty miles per hour (mph; 64.4 km/h), a pedestrian has an 85 percent chance of death, and the fatality rate drops to 45 percent at thirty mph (48.2 km/h) and to 5 percent at twenty mph (32.2 km/h; UK Department of Transport 1997; Zegeer et al. 2002; ETSC 2005). Another study found higher rates of fatalities at even lower speeds (Tingvall and Haworth 1999). An analysis of vehicle impact speeds in pedestrian injuries in China found in cases where the vehicle was traveling less than twenty mph, there were no reported fatalities; collisions where the vehicle was traveling between twenty and twenty-five mph accounted for fewer than 5 percent of all fatalities (Zhao et al. 2010). A key finding in pedestrian safety research is that the single most consequential intervention in reducing pedestrian injury and fatality rates appears to be roadway treatments (Afukaar, Antwi, and Ofosu-Amaah 2003; Grundy et al. 2009; Mutabazi 2010; Methorst et al. 2010; Mohan and Tiwaria 1998; Hijar, Trostle, and Bronfman 2003; ETSC 1999). Vehicular speeds can be reduced by narrowing roadways, using traffic-calming measures, and installing warning signs and frequent stop signs (Peden et al. 2004). These interventions are most certainly within the realm of planners influence.

Conditions: Visibility

Poor visibility is one of the greatest risk factors for pedestrians (Kwan and Mapstone 2006; Ulfarsson, Kim, and Booth 2010; Ackaah and Adonteng 2011). In the United States, 67 percent of all fatal vehicle–pedestrian collisions occur at night or under low-light conditions (Campbell et al. 2004; National Highway Traffic Safety Administration 2007; Zegeer et al. 2010). A systematic analysis of the US Fatality Analysis Reporting System (FARS) data indicates that pedestrian fatalities increase as illumination decreases, holding other factors constant (Owens and Sivak 1996; Sullivan and Flannagan 2002; Griswold et al. 2011). Further analysis of FARS data reveals that twilight and the first hour of darkness typically result in the highest frequency of fatal collisions for pedestrian (Griswold et al. 2011). Because pedestrian volumes are often still high during twilight hours, pedestrian exposure (walking/crossing activity) during these time periods is the most deadly (Griswold et al. 2011).

Roadway lighting can improve the visibility of pedestrians, and proper design and timely maintenance of street lighting can, in turn, help improve the safety of the roadway system. Zhou and Hsu (2009) developed and installed a mobile lighting measurement system in a test vehicle to collect luminance data along a corridor of US 19 in Pinellas County, Florida. Following the assessment, pedestrian crash data were collected for a three-year period. The results of the study demonstrated that nighttime pedestrian crashes were of higher frequency on poorly lit segments of roadway.

The risks of nighttime travel are demonstrably mitigated by the use of handheld lamps, flashing lights, and red and yellow retroreflective materials by pedestrians (Peden et al. 2004). Retroreflective materials are particularly effective when arranged in a "biomotion" configuration, which highlights the movement of the pedestrian (Peden et al. 2004). For nighttime visibility, handheld lamps, flashing lights, and red and yellow retroreflective materials have been found to increase pedestrian recognition (Peden et al. 2004).

Considerations for Future Research

As research on pedestrian safety and the built environment continues, we recommend the following for future research based on our current review of the literature. First, we suggest that researchers employ quasi-experimental research designs whenever possible. Quasi-experimental research designs allow for improved understanding of causality between predictor variables and pedestrian injuries. Cross-sectional or longitudinal designs were the most common research designs we observed (i.e., Jacobsen 2003; Tarko and Azam 2011; Afukaar, Antwi, and Ofosu-Amaah 2003). The insights drawn from studies using cross-sectional and longitudinal designs remain useful but can only offer correlational evidence between risk factors and pedestrian safety. Good examples of quasi-experimental research on pedestrian safety include LaScala, Johnson, and Gruenewald (2001) and Ewing, Chen, and Chen (2013). These studies move researchers and practitioners closer to understanding the causality between risk factors, safety treatments, and pedestrian safety.

We also suggest that qualitative methodologies have much to offer the understanding of pedestrian safety and the built environment. Like quasi-experimental research, qualitative research is well suited to answer research questions that ask why? The majority of studies reviewed are purely quantitative (i.e., Clifton and Kreamer-Fults 2007; Petch and Henson 2000; Changcheng et al. 2010). We observed that some of the best studies we reviewed used mixed methods, employing both quantitative and qualitative research (Hijar, Vasquez-Vela, and Arreola-Risa 2003; LaScala, Johnson, and Gruenewald 2001). These studies moved beyond descriptions and summaries to answer why did a pedestrian injury occur? Employing mixed methodologies would further researcher and practitioner understanding of pedestrian safety.

Conclusion

This review has presented an overview of the evidence on risk factors for pedestrian road traffic injury in the built environment by first examining research on pedestrians by type and risk/safety factors, followed by research focused on different scales and aspects of the built environment. Three major factors that stand out are visibility, pedestrian–traffic interaction, and traffic speed. We conclude this article by reflecting on the question: "What do these findings on risk factors for pedestrians in the built environment suggest planners need to do?"

We are not saying that planners have not made an effort to address pedestrian safety in their work, but only pointing out that these findings remind this group of professionals about the importance of designing the built environment to reduce risks to pedestrians. Specifically, we see the following three implications:

- Risks factors in the built environment interact with each other to increase the probability of pedestrian fatalities and injuries occurring. Hence, the need for planners is to not only understand that these factors interact but also to consider them in risk assessments of the overall built environment during planning, implementation, and evaluation of programs.
- Address these risks during the design and implementation phases. Many pedestrian-friendly environmental features represent no added cost to implement during initial building, meriting consideration, in all settings, whether high- or low-income countries. Because changes to the built environment are costly and difficult, thoughtful planning and design with pedestrian safety in mind becomes a cost-effective approach to reducing risks to pedestrians. Planners can work toward reducing pedestrian risk by promoting strategies that encourage mixed land uses and accessibility. Specific measures to improve pedestrian safety such as reducing vehicle speed, reducing pedestrian exposure to vehicular traffic, and improving visibility between motor vehicles and pedestrians are available in literature (see, e.g., Zeeger et al. 2004; Retting, Ferguson, and McCartt 2003; Elvik et al. 2009).
- Advocate for pedestrian safety. Planners can leverage their unique positions by urging public officials to develop and support policies that recognize the needs of pedestrians and by working with other local planners, designers, and developers to create pedestrian environments that maximize pedestrian safety and well-being.

We have presented an overview of evidence from around the world, and it is up to the planners to utilize the evidence in their local and institutional settings.

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Author Biographies

Philip Stoker is a graduate of the department of City and Metropolitan Planning at the University of Utah. He has a master's degree in Resource and Environmental Management and a Bachelor of Science in Environmental Management. He has conducted environmental and social science research internationally, including work with the World Health Organization, Parks Canada, the National Park Service, and the Vancouver 2010 Olympic Games.

Andrea Garfinkel-Castro is currently completing her PhD in Metropolitan Planning, Policy, and Design at the University of Utah. Her dissertation research examines sociocultural gaps in planning education and practice and how planners, faculty, and communities navigate the need to accommodate growing urban diversity.

Meleckidzedeck Khayesi was born in Vihiga District, Kenya. He is a teacher by profession with a bachelor of education degree (1988), a master of arts degree in geography (1992), and a doctor of philosophy degree in transport geography (1999). He facilitates development, implementation, and evaluation of road safety programs in countries and road safety capacity development.

Wilson Odero is a public health physician and currently dean, School of Medicine at Maseno University, Kenya. After obtaining his MD, he completed masters and PhD in Epidemiology and Public Health at the London School of Hygiene & Tropical Medicine. He later undertook postdoctoral fellowship in medical informatics at Indiana University. He has published widely on various subjects of public health importance, with a focus on road traffic injuries and violence in developing countries.

Martin N. Mwangi is a public health nutritionist and epidemiologist and currently a researcher, School of Public Health and Community Development, at Maseno University, Kenya. He obtained both his MSc in Public Health Nutrition and Epidemiology and PhD in Human Nutrition from Wageningen University, the Netherlands. He was granted a postdoctoral fellowship at Wageningen University and specialized in nutrition, health, and epidemiological research in East and West Africa.

Margie Peden is currently the coordinator of the Unintentional Injuries Prevention unit (UIP) within the Department for Management of Noncommunicable Diseases, Disability, Violence, and Injury Prevention at the World Health Organization in Geneva, Switzerland. She coordinates work in the areas of unintentional injury prevention (including road safety, drowning, and burns prevention), injury surveillance/surveys, and alcohol and drug-related injuries.

Reid Ewing, PhD, is a professor of City and Metropolitan Planning at the University of Utah, associate editor of the *Journal of the American Planning Association*, editorial board member of the *Journal of Planning Education and Research*, and columnist for *Planning* magazine, writing the bimonthly column Research You Can Use. He has extensively studied that relationship between land use patterns, street design, and traffic safety, coauthoring the earlier *Journal of Planning Literature* article "The Built Environment and Traffic Safety: A Review of Empirical Evidence."