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Social vulnerability: A review of the literature on pedestrian crash risk in lower-income and minority communities

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Abstract: Lower-income and minority populations in the United States are at disproportionate risk of being injured or killed while walking. This review synthesizes the literature to understand the magnitude of this risk, as well as the underlying factors that may best explain it. On average, lower-income areas experience 3 times the number of per capita pedestrian fatalities as affluent areas. With respect to race, Hispanic people are 1.6 times as likely to be killed as are White non-Hispanic people, while Black people are 1.7 times more likely to be killed, and Indigenous persons are fully 4 times as likely. Despite the consistency of these findings, none of the prevailing explanations, such as increased exposure or increased likelihood of walking under the influence, are supported by the literature. Instead, the primary difference pertains to trip purposes. Affluent households walk primarily for leisure and recreation. If an environment is perceived as being unpleasant or unsafe, they can shift the trip to another location or forego the trip entirely. Lower-income households, by contrast, walk principally for utilitarian reasons, making them less able to avoid unsafe environments. This paper concludes by discussing the need to better account for social vulnerability in planning and project development processes.

Keywords: Pedestrian, crashes, inequality, road safety, urban form, social vulnerability

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1 Introduction

With 12.8 traffic fatalities per 100,000 people, the United States has the highest traffic fatality rate of any developed county. And beyond this distinction, the United States is the only developed country where traffic fatalities are rising (Yellman & Sauber-Schatz, 2022). Of particular note is the rapid increase in fatalities involving pedestrians and bicyclists, which has nearly doubled over the last 15 years, increasing from 4,722 fatalities in 2009 to nearly 9,000 in 2022 (National Highway Traffic Safety Administration, 2024).

This increasing risk is not equally distributed in the United States; lower-income and minority populations are disproportionately likely to be injured or killed while walking or bicycling. Several recent reviews have examined pedestrian and bicyclist safety (Buehler

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& Pucher, 2021; Stoker et al., 2015; Tiwari, 2020), though none has focused on the role of race or income on pedestrian death and injury. This article fills a critical gap in the literature by providing systematic, multi-disciplinary review of the role of race and income on pedestrian safety outcomes. Specifically, it seeks to understand the magnitude of the disproportionate risk experienced by lower-income and non-White populations, the underlying factors that may contribute to it, as well as the types of policies or countermeasures that may be applied to address it.

1.1 Selection of studies

To select studies for inclusion in this review, we accessed two research databases: Transportation Research International Documentation (TRID) and Google Scholar. To identify candidate articles, we combined primary terms such as "Race," "Ethnicity," and "Income" with secondary terms such as "Crash," "Collision," "Pedestrian." We then applied two exclusion criteria. First, we excluded non-peer reviewed articles, such as conference papers or professional report. Because race is a social construct that establishes biases and prejudices, we include only studies focusing on the United States. To ensure we did not miss any influential articles, we further applied a snowball selection method in which we examined the citations in the already selected papers for additional relevant articles. Our final database contained 82 peer reviewed articles ranging in publication date from 1966 to 2024. In addition to the reference list, the full database of selected articles is provided as an appendix (Appendix), listed in reverse chronological order with additional information such as discipline, dependent variable, and geography.

2 Risk disparity by income and race

Lower-income and non-White populations are far more likely to be injured and killed while walking than are affluent, White populations. With respect to income, Dumbaugh, Stiles, et al. (2024) developed risk ratios finding that lower-income block groups reported fully 3 times the number of pedestrian injuries and deaths, per capita, than did affluent block groups. In a study of Census tracts in Orange County California, Chakravarthy et al. (2010) found that the strongest predictor of pedestrian injuries was the percentage of the population below the poverty level, followed by the percentage of the population with less than a high school education. Pediatric pedestrian injuries in Chicago were found by Statter et al. (2011) to be spatially concentrated in lower-income, higher-density Black neighborhoods, while Epperson (1995) found that area poverty explained higher rates of Black cycling crashes in Dade County, Florida. Pedestrian crashes of individuals walking the roadway were found to be related to area signifiers of poverty such as unemployment and single parent households in North Carolina (McMahon et al., 1999).

Yuan and Wang (2021) observe that low-income and minority communities both have higher levels of freight traffic and more freight crashes. Braun et al. (2021) measure both crash risk and exposure to pollution for cyclists in Los Angeles, finding that communities marginalized through race, ethnicity, or income bear both burdens disproportionately.

With respect to race, the literature has consistently found that Black, Hispanic, and Indigenous populations experience higher rates of pedestrian injuries and deaths than do White populations. Table 1 summarizes the research detailing the relative risk, by race.

Considering the literature as a whole, Black populations, on average,[1] are 1.7 times more likely to be killed as a pedestrian than are White populations, Hispanic populations are 1.6 times as likely, and Indigenous populations are fully 4 times as likely. Male pedestrians are consistently more likely to be killed than females. Issues of race and income are often correlated, and it is difficult from the literature to parse out the magnitude of the risk attributable to income effects, and those more associated with race. Nonetheless, three studies that have examined the income of race and income together have found that even after accounting for the effects of income, Black populations experience worse pedestrian and bicycle safety outcomes than White populations (Dumbaugh et al., 2022; Dumbaugh, Saha, et al., 2024; Lin et al., 2019). Goddard et al. (2015) found that motorists were twice as likely to yield for a White pedestrian than a Black one. Coughenour et al. (2017) added income area comparisons, finding cars in high-income areas passed Black pedestrians in the midst of crosswalks over five times more frequently than in a low-income area; however, they were slightly more likely to yield to Black pedestrians if they were waiting at the intersection.

Table 1. Estimates of pedestrian risk for minority groups compared to White group

Black		**Hispanic**		**Indigenous**			
IRR		**IRR**		**IRR**		**Location**	**Citation**
1.7	*Child fat.*	N.A		N.A.		US National	Waller (1989)
1.2	*Child fat.*	N.A		N.A.		Birmingham AL	King & Palmisano (1992)
N.A		1.7/1.2	*M/F fat.*	3.7/2.8	*M/F fat.*	New Mexico	Schiff & Becker (1996)
N.A		2.1	*Inj.*	N.A.		Orange Cnty CA	Agran et al. (1998)
1.7/1.0	*M/F fat.*	1.5/1.1	*M/F fat.*	N.A.		Los Angeles CA	Demetriades et al. (1998)
1.8/3.9	*U/R fat.*	1.3/0.6	*U/R fat.*	6.1/6.8	*U/R fat.*	Arizona	Campos-Outcalt (2002)
2.1/1.7	*M/F fat.*	2.2/1.6	*M/F fat.*	4.3/2.8	*M/F fat.*	US National	Naumann & Beck (2013)
1.7/1.2	*Fat./inj.*	1.2/0.9	*Fat./inj.*	1.5/1.9	*Fat./inj.*	US National	Hamann et al. (2020) *
2.8	*Inj.*	N.A.		N.A.		North Carolina	Harmon et al. (2021)

*N.A. = Not Available; Fat. = Fatality; Inj. = Injury; M/F = Male/Female; U/R = Urban/Rural; * Indigenous was included as part of "Multiracial" category*

3 Alcohol and drugs

The National Highway Traffic and Safety Administration estimates that 31% of pedestrian fatalities involve a pedestrian under the influence of alcohol (NHTSA, 2023). The use of alcohol by pedestrians can impact a pedestrian's ability to accurately estimate the speed of an approaching vehicle (Oxley et al., 2006) and has been observed to increase the likelihood that pedestrians will cross the street against a signal or at unprotected, midblock locations (Dultz et al., 2011). Collectively, this has led to a tendency to infer that pedestrian use of alcohol is an explanatory cause of pedestrian crashes, and that the higher rates of pedestrian crashes observed in lower-income and minority environments may be attributed, at least in part, to attributable to higher rates of drug and alcohol use.

[1] To derive average fatal crashes, we averaged the rates for fatal male and female pedestrians, where data was divided by sex. Where data were divided into urban and rural categories, we considered only urban fatalities, as most pedestrian fatalities occur in urban areas.

Nonetheless the evidence to support this assertion is inconclusive, at best. In a study of Albuquerque, Long and Ferenchak (2021) found that 58% of nighttime pedestrian crashes tended to occur within a quarter mile buffer of bars or restaurants that serve alcohol, while Nesoff et al. (2019) found a correlation between the number of to-go alcohol outlets with pedestrian injuries. Correlation is not causation, and proximity to bars and restaurants does not necessarily equate to pedestrians being under the influence of alcohol when struck by a vehicle. Studies that have examined observations of alcohol use[2] paint a far more nuanced picture. Dumbaugh, Stiles, et al. (2024) compared police reports of pedestrian and bicycle crashes for lower-income areas in South Florida against higher-income ones, finding the pedestrians involved in a crash in lower-income areas were suspected of having been under the influence of alcohol in only 5% of crashes, compared to 9% for pedestrians struck in affluent communities. Lower-income areas also had far larger concentrations of Black residents (35% of the population, on average) than did affluent ones (6%). Stated another way, pedestrians stuck by a vehicle in lower-income and minority areas were only half as likely to be under the influence of drugs or alcohol than those in whiter, more affluent areas. The associated negative binomial models found that the presence of bars and nightclubs were associated with increased pedestrian death and injury only in affluent areas, not in lower-income ones.

With respect to race, a national study of FARS data found no statistically-meaningful relationship between race and pedestrian drug or alcohol use among pedestrians killed in a traffic crash (Thomas et al., 2019), while two studies found that Black pedestrians involved in a crash were *less* likely than White people to have been reported to be under the influence of alcohol (Campos-Outcalt et al., 2003; Sanders & Schnieder, 2022). Hispanic male pedestrians, but not females, were found to be slightly more likely to be under the influence of alcohol than White pedestrians involved in a crash. Ortiz and Ramnarayan (2017) and Sanders and Schneider (2022) found Hispanic pedestrians 1.2 times more likely than non-Hispanic people to be under the influence alcohol when struck by a vehicle. The authors of the latter article note that "walking while intoxicated is not illegal and is not in itself a factor that would likely lead to a pedestrian fatality in an otherwise low-speed environment" (Sanders & Schneider, 2022, p. 8). Moreover, even if alcohol were a prevailing factor, observed differences in alcohol use alone does not adequately explain the magnitude of the increased risk experienced by Hispanic pedestrians, who are, on average, 1.7 times more likely to be killed than White people.

Indigenous populations, on the other hand, are far more likely to be under the influence of alcohol than all other population groups, with two studies finding Indigenous pedestrians to be twice as likely as White to be under the influence of alcohol (Ortiz & Ramnarayan, 2017; Sanders & Schneider, 2022). A third, by Campos-Outcault et al. (2003) found them to be nearly 10 times as likely. The authors attribute the heightened crash risk to Tribal laws that prohibit the sale of alcohol on reservations, resulting in Indigenous pedestrians walking longer distances to obtain alcohol. This, in turn, suggests a second factor often used to explain disproportionate risk: exposure.

[2] These studies use police reports of alcohol use when determining alcohol involvement, which may or may not be accompanied by measurements of blood alcohol concentration. Nonetheless, an examination of trauma center victims found that police assessments of accident use in accident reports were largely accurate (Grossman et al, 1996).

4 Exposure

Higher rates of walking among lower-income and minority populations are often used to explain higher rates of pedestrian injury and death. Yet exposure has been challenging to adequately measure and model (Merlin et al., 2020). Instead of using measures of distance traveled by walking, studies asserting that exposure is a cause use proxy measures, the most common of which is the lower rates of automobile ownership among lower-income populations. The presence of zero-car households is associated with more pedestrian deaths and injuries, leading to the inference that households with limited access to a car must be substituting automobile trips with walk trips, resulting in more exposure (Al-Mahameed et al., 2019; Chimba et al., 2018; Kravetz & Noland, 2012; Loukaitou-Sideris et al., 2007; Noland et al., 2013). Similarly, both bus stops and transit trips to work are associated with more pedestrian crashes, which is likewise presumed to be associated with exposure, as transit facilities are often accessed by walking (Cottrill & Thakuriah, 2010; Dumbaugh, Saha, et al., 2024; Lin et al., 2019).

While the exposure explanation would seem to have a great deal of face validity, studies of actual behavior do not support this assertion. The lowest-income households make 50% fewer trips than the most affluent households and, in the absence of a car, are far more likely to share a ride with a friend or family member than to walk or take transit (Bricka et al., 2024). A study using National Household Travel Survey data that accounted for actual miles of travel found that the most affluent households are the ones that actually walk the longest distances. Indeed, the lowest-income households appear to adapt to the lack of access to an automobile not by shifting to walking or transit, but by foregoing trips altogether (Yang & Diez Roux, 2012).

Using data from the 2017 National Household survey, Raifman and Choma (2022) sought to understand whether there were notable differences in walking and cycling by race. On a person miles per capita basis, Black people walked 12% fewer miles than White people, and Hispanic people walked 21% fewer miles. When looking specifically at urban areas, Black people only walked 10% more miles than White people, but were 113% more likely to be killed on a per mile walked basis. Hispanic people walked 4% fewer miles but were 70% more likely to be killed on a per mile travelled basis.

5 The built environment

If neither exposure nor alcohol use meaningfully explain differences in pedestrian risk, what about the built environment? The built environment, which includes both the transportation network and surrounding development, establishes the physical context in which crashes occur. The sections below briefly summarize the general findings on a variety of specific built environment characteristics, much of which is conflicting, followed by a broader discussion of their implications.

5.1 Transportation network characteristics

5.1.1 Arterial highways, multilane streets, and traffic volume

Arterials and multilane highways have been consistently associated with increased crash risk for lower-income pedestrians. A national study of pedestrian hotspots found that 75% were located on arterials with nearby concentrations of lower-income populations (Schneider et al., 2021). Streets operated by states and counties, which are typically arterials focused on regional and inter-regional travel, were associated with

more pedestrian crashes (Kravetz & Noland, 2012), as were streets with 4 or more lanes (Haddad et al., 2023; Sanders & Schneider, 2022) or 5 or more lanes (Dumbaugh, Saha, et al., 2024). Higher traffic volumes were likewise associated with more pedestrian collisions, whether measured as average annual daily traffic (Cotrill & Thakuriah, 2010; Loukaitou-Sideris et al., 2007), the number of vehicles entering an intersection (Miranda-Moreno et al., 2011), or vehicle miles traveled (Roll & McNeil, 2022). Relatedly street networks with higher concentrations of local streets were associated with fewer pedestrian crashes (Hwang, 2017).

While these findings are consistent with the pedestrian safety literature more broadly (Ewing & Dumbaugh, 2009; Stoker et al., 2015), interesting differences emerge when one compares pedestrian crashes between lower-income and affluent areas. A study of Orange County, Florida, found that arterials pose three times risk of pedestrian death or injury in lower-income environments than in affluent ones (Dumbaugh et al., 2022). Another study of Southeast Florida found that higher traffic volumes and the presence of 5-or-more lane roads were only problematic for lower-income populations; in higher income areas, average annual daily traffic had not meaningful effect on pedestrian deaths and injuries, and the presence of 5-or-more lane streets were associated with *fewer* pedestrian injuries or death (though only at the 85th percentile level of statistical confidence). This suggests important differences in the environmental risk factors for lower-income and affluent populations, differences which will be further examined below.

5.1.2 Vehicle speeds

Pedestrian crash severity is a direct function of kinetic energy; higher speeds increase the energy absorbed in a crash, which in turn results in more severe injuries. Nonetheless the literature is mixed on whether vehicle speeds themselves are associated with an increased incidence of pedestrian death or injury. McMahon et al. (1999) found that higher posted speeds limits were associated with more walking along roadway crashes. Lin et al. (2019) found that block groups with a higher share of lower-speed streets have fewer pedestrian crashes, though the authors do not define what constitutes a lower-speed street. In a statewide study of census tracts in Oregon, Roll and McNeil (2022) report that pedestrian injuries increase in census tracts with more miles of streets with posted speeds of 35 MPH and higher, but decrease in tracts with more miles of streets 45 MPH or greater. Al-Muhammed et al. (2019) found that corridors with posted speeds of 35 MPH or higher reported fewer pedestrian crashes than lower-speed corridors. It should be observed that posted speed limits often correspond to a street's functional class and developmental context, suggesting that the contradictory findings for vehicle speeds may reflect factors other than speed.

5.1.3 Intersections/crossings

Intersections are consistently associated with more pedestrian crashes. Haddad et al. (2023) found that pedestrian crashes increase with the number of 4-leg intersections in a block group. and that majority Black block groups have more 4-way intersections than majority White neighborhoods. Similarly, Dumbaugh, Stiles, et al. (2024) found that that number of intersections in a block group were associated with more crashes in lower-income areas, but not for more affluent ones. Lin et al (2019) found that the majority of pedestrian crashes (65%) occurred at intersection locations, and Hwang et al., (2017) that child pedestrian crashes near schools are associated with the presence of crosswalks. That intersections and crosswalks are associated with more pedestrian rashes should not be

surprising; these are locations where pedestrians and vehicles necessarily interact and would thus be expected to be associated with increased crash frequency.

5.1.4 Sidewalks

The effects of sidewalks on pedestrian collisions are inconsistent in the literature. McMahon et al. (1999) found that more walking along roadway crashes on streets that lacked sidewalks, and Long and Ferenchak (2021) report there are pedestrian hotspots in areas with fewer sidewalks. More common is the finding that that the presence of sidewalks is associated with increased pedestrian crash frequency in lower-income areas (Al-Mahameed et al., 2019; Chimba et al., 2018; Dumbaugh, Stiles, et al., 2024). Nonetheless, this, like the contradictory findings for speed, are likely due to exogenous factors that correspond with the presence of sidewalks.

5.1.5 Bicycle facilities

There was not much literature that examined bicycle facilities as they relate to lower-income or minority populations, though Barajas (2018) found that bicycle infrastructure and reduced traffic volumes do not protect Black or Hispanic cyclists to the extent that they protect White cyclists. Lusk et al. (2019) examined the perceptions of bicycle facility safety, which includes both crashes and exposure to crime, in low-income communities in Boston, finding that residents prefer wide, but less isolated, two-way paths.

5.1.6 Transit

Where transit was considered, the presence of transit was consistently associated with an increase in pedestrian crashes. The percentage of persons commuting by transit (Haddad et al., 2023; Roll & McNeil, 2022) and the number of bus stops in a community (Dumbaugh, Saha, et al., 2024; Lin et al., 2019; Miranda-Moreno et al., 2011; Roll & McNeil, 2022) are associated with increased pedestrian crash risk.

5.1.7 Lighting

Lin et al (2019) report that the majority of pedestrian crashes—72%—occur at night, and of these, 22% occur on streets without lighting. Sanders and Schneider (2022) examined the issue of lighting with respect to race and found that Black pedestrians are more likely to be injured and killed at night than are White people.

5.2 Development characteristics

5.2.1 Developmental density

Higher population and employment densities are generally associated with more pedestrian crashes, but not consistently so. Kravetz and Noland (2012) found that higher concentrations of people per square mile to be associated with fewer pedestrian crashes, though Dumbaugh, Stiles, et al. (2024) did not find it to have a statistically meaningful relationship to pedestrian crashes in lower income areas (2024). Nonetheless, several studies have found more population density to be associated with more pedestrian crashes (Chimba et al., 2018; Cottrill & Thakuriah, 2010; Lin et al., 2019; Loukaitou-Sideris et al., 2007; Siddiqui et al., 2014). Similarly, two studies have found higher employment densities to be associated with more pedestrian crashes in lower-income areas (Al-

Mahameeed et al., 2019; Kravetz & Noland, 2012), though a third found employment density to be associated with fewer pedestrian crashes (Roll & McNeil, 2022).

5.2.2 Land use

Commercial land use is a key predictor of pedestrian crashes, with studies consistently finding it to be associated with more pedestrian crashes, injuries, and deaths (Dumbaugh et al., 2022; Hwang et al., 2017; Kravetz & Noland, 2012; Miranda-Moreno et al., 2011). Several studies have disaggregated the commercial category to identify the specific commercial uses that may prove most problematic. Dumbaugh, Stiles, et al., 2024 found that restaurants and commercial shopping centers were both associated with more pedestrian injuries and deaths, while Lin et al. (2019) found that grocery stores, convenience stores, fast food restaurants, discount stores, and Wal-Mart were all associated with increases in pedestrian crashes. Guo et al., (2017) further found that more severe pedestrian crashes occurred near supermarkets and department stores.

These high-risk land uses are all household-supporting uses, with food access featuring prominently. Groceries and restaurants have obvious connections to food. But discount stores, convenience stores also provide food access, particularly in lower-income areas that lack access to a large grocery (Ver Ploeg et al., 2017). Wal-Mart, in addition to being a discount retailer, also functions as a community grocery.

6 Understanding the nature of crash risk for lower-income and minority populations

As detailed above, lower-income populations experience three times the number of pedestrian deaths and injuries as do affluent populations, and non-White populations are between 1.6 and 4 times as likely to be killed while walking, on average. The conventional explanations used to explain these differences—that these populations walk more or are more likely to be under the influence of drugs or alcohol—is not supported by the literature. In general, lower-income and minority pedestrians do not walk more than their more affluent counterparts and, in most cases, are less likely than affluent White people to be under the influence of alcohol when struck by a vehicle.

The literature on the built environment does not, by itself, provide a particularly satisfying explanation, particularly when the specific variables on crash risk are considered in isolation. Arterials are problematic for lower-income and minority populations, but they are problematic for all other groups as well (Ewing & Dumbaugh, 2009; Stoker et al., 2015). Density is sometimes associated with fewer pedestrian crashes, sometimes more. Sidewalks, presumed to be a pedestrian safety feature, tend to be associated with more crashes, while vehicle speeds, which produce the kinetic energy that results in death and injury, has no clear relationship with pedestrian crashes.

One of the problems with examining individual variables like these in isolation is that they can be misleading, particularly when attempting to understand complex systems where variables are interconnected and interdependent. Taking a step back and examining this literature holistically, a clearer pattern emerges. The issue isn't whether low-income people walk more than affluent ones, nor whether they are more likely to walk under the influence of drugs and alcohol (if anything, the opposite is generally true). Instead, the real question is this: is there something about the *nature* of lower-income walk trips that makes them more hazardous than other types of walk trips?

A key difference between lower-income and higher-income populations—and one which points to a more meaningful understanding of differences in crash incidence—is

the *purpose* of their trips. For affluent households, walking is principally a recreational activity. If an environment is perceived as being unpleasant or unsafe, affluent persons can simply drive to another, more comfortable location for exercise and recreation, or they can simply forego the walk or bicycle trip entirely. Walk trips undertaken by lower-income households, by contrast, are not recreational trips, such as getting exercise or walking the pet dog. They are *utilitarian* trips intended to accomplish a basic, household-supporting objective, such as accessing work, school, or some household-supporting trip end, such as obtaining food (Bricka et al., 2024; Yang & Diez Roux, 2012). Unlike recreational trips, utilitarian trips have fixed points of origin and destination—they are trips with a clear objective—and thus have comparatively little route flexibility. If the most viable route between an origin and destination entails traveling along an arterial, which is where local land-use ordinances typically locate groceries, shops, and restaurants, then the walk of bike trip will use the arterial, regardless of whether the route is perceived as safe or pleasant.

It is the difference in *trip purpose* that almost certainly explains the observed differences in pedestrian risk. Arterial thoroughfares are three-times more hazardous in lower-income areas than affluent ones (Dumbaugh et al., 2022) not because affluent people are inherently more responsible as pedestrians—in point of fact, they were twice as likely to be suspected of walking under the influence of drugs or alcohol—but because affluent people can choose to avoid walking on them.

This assertion is supported by a study of southeast Florida that examined differences in environmental risk factors for lower-income and affluent populations (Dumbaugh, Stiles, et al., 2024). For lower-income block groups, the environmental risk factors that explain increased pedestrian and bicycle crash risk are the variables one would expect: higher traffic volumes, streets with 5 or more lanes, restaurants, and bus stops. These are all variables associated with attempting to accomplish utilitarian trips on an unsafe street network.

But what of affluent populations? Interestingly, neither traffic volumes nor multi-lane streets had any relationship with pedestrian crashes, an unsurprising finding given that their trips are recreational in nature. Recreational activities concentrate on places that are safe and comfortable (Gehl, 2010). Environments with disamenities such as arterials and heavy traffic volumes can be readily avoided. Instead, the primary risk factors for affluent block groups were concentrations of bars, restaurants, and hotels—recreational uses associated with nightlife and entertainment, rather than utilitarian travel.

The role of trip purpose is further supported by research findings on mode to work. While the low share of walk to work trips makes it an imperfect proxy for measuring pedestrian exposure (Merlin et al., 2020), walk trips are inherently utilitarian trips with fixed points of origin and destination. Correspondingly, if utilitarian trips are a risk factor for lower-income populations, then one would expect higher shares of walk to work trips to be associated with more pedestrian crashes, at least in lower-income areas. And indeed they are, with studies consistently finding that pedestrian crashes increase as a function of the percentage of people who walk to work (Al-Mahameed et al., 2019; Chimba et al., 2018; Cottrill & Thakuriah, 2011). Like household-supporting shopping trips, work trips have a fixed origins and destinations that determines the trip's route.

Trip purpose further explains the otherwise seemingly anomalous findings with respect to transit. The percentage of persons commuting by transit (Haddad et al., 2023; Roll & McNeil, 2022) and the number of bus stops in a community (Dumbaugh, Stiles, et al., 2024; Lin et al., 2019: Mianda-Moreno et al., 2011; Roll & McNeil, 2022) were consistently associated with increased pedestrian crash risk. Nonetheless, there is nothing inherently hazardous about bus stops per se, and bus transit is the safest mode of surface travel, by far (American Public Transportation Safety Association, 2016). The problem

appears to be that, like shopping trips and work trips, transit stops are trips with fixed origins and destinations taken for utilitarian purposes.

7 Conclusion: Considering social vulnerability

There has been a tendency to view the increased rate of pedestrian deaths and injury in lower-income and minority areas as a function of higher-risk behaviors of these populations. This has led to often patronizing recommendations that shift the responsibility for crash preventions onto the victims themselves, such as the development of "culturally sensitive" education programs in Black communities (Daniels, 2002) or the development of Spanish language educational materials (Agran et al., 1998; Harper et al., 2000).

Yet a broader review of the literature reveals that it is *social vulnerability* that best explains the heightened pedestrian crash risk in lower-income and minority communities. While urban arterials lined with strip commercial uses are inherently unsafe, these *latent hazards* only translate into pedestrian deaths and injuries when they are actively used. The utilitarian walk trips undertaken by lower-income and minority populations must often traverse these environments, transforming these latent hazards into deaths and injuries. Lower-income populations are three times more likely to be injured or killed on arterials not because these populations fail to understand the potential hazards of these environments, but simply because they are less able to avoid walking in them. Whatever the benefits of education or enforcement in moderating vehicle speeds or ensuring compliance with traffic laws, neither approach can do much of anything to address the need for utilitarian travel in environments that are inherently unsafe.

Which leads to the important matter of addressing these vulnerabilities. There is a clear need to move beyond conventional "3E"-type programs to begin to address the underlying social nature of crash risk. Vision Zero programs and Safe Systems approaches have emerged in response, seeking to redirect the focus of safety programs onto the needs of vulnerable road users, such as pedestrians and bicyclists. Yet, in application, these programs tend to treat any speed management or pedestrian infrastructure investment as a safety enhancement, regardless of where they are applied. In practice, this often results in safety investments being directed towards pedestrian improvements in affluent areas (Dumbaugh, Stiles, et al., 2024), investments which are unlikely to result in meaningful reductions in pedestrian crashes because of their already-low baseline levels of pedestrian crash incidence. This redirection of resources to lower-risk areas may help explain why Vision Zero programs in the United States have been largely unsuccessful in reducing pedestrian deaths and injuries (Zipper, 2022).

Meaningfully addressing pedestrian safety necessitates that we consider not only the potential risk embedded into specific environments, but also the social vulnerabilities responsible for translating latent hazards into pedestrian injuries and deaths. Looking forward, the link between demographics, trip purpose, and pedestrian crash risk suggest promising new opportunities for integrating safety considerations into transportation planning and project development processes. Indeed, pilot studies have shown that the data used in the development of long-range transportation plans can be reliably used to predict future crash incidence at both the zonal and corridor levels (Dumbaugh, Saha, et al., 2024; Washington et al., 2006). We conclude with the hope that the results of this review, which provides estimates of relative risk by race and income, will be used to direct future transportation investments to the areas where pedestrian safety improvements are most needed.

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Appendix

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