THE IMPACT OF THE NEIGHBORHOOD ENVIRONMENT ON FALLS AMONG OLDER ADULTS

A Dissertation

by

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ABSTRACT

Falls are substantial barriers to walking outside and outdoor physical activity among older adults. Although health and behavioral risk factors for falls were well explored, neighborhood environmental factors for the risk of falling remain poorly understood. The over-arching goal of this dissertation is to understand the heterogeneity of falls in relation to neighborhood environmental features through multifaceted research approaches. This dissertation contains three independent studies, consisting of one systematic review paper and two quantitative studies with one as a cross-sectional study at the neighborhood level and another as a longitudinal study at the individual level.

The first systematic review paper was to examine the risk factors of indoor and outdoor falls in relation to biological/ health, behavior, and socio-economic status through a systematic review. Findings from this study showed that the occurrence of indoor falls tended to be associated with being female and being frail, while outdoor falls are more common among males and those who are physically active.

The second study explored the characteristics of neighborhood environments associated with fall injuries reported to emergency medical services (EMS) from 2011-2014 in the city of San Antonio (TX, USA) at the census tract level. The study showed that neighborhoods with higher residential density with a higher vacancy rate were associated with increased counts of fall injuries. Neighborhoods with higher residential stability captured as the percent of those who lived in the same house as the previous year were shown to be associated with a decreased count of fall injuries.

Finally, the third study used data from the National Health and Aging Trends Study (NHATS). This prospective study examined prospective associations of changes in environmental perceptions (e.g., street conditions, walking surfaces, and physical disorders) with changes in fall occurrence through a longitudinal study. The results showed that safe and well-maintained outdoor environments helped prevent falls among those older adults who actively engage in outdoor activities.

In the conclusion, the findings of this dissertation have underscored the importance of studies examining the risk factors of falls and fall prevention in relation to neighborhood environmental and policy interventions. Thus, environmental interventions to reduce the risk of falling should be considered by public health professionals, gerontologists, environmental psychologists, and urban planners interested in helping older adults reduce fall incidents.

DEDICATION

I dedicate this dissertation to my family.

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NOMENCLATURE

ACS	American Community Survey
CDC	Centers for Disease Control and Prevention
EMS	Emergency Medical Services
GIS	Geographic Information Systems
NHATS	National Health and Aging Trends Study
SAFD	San Antonio Fire Department
WHO	World Health Organization

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1. INTRODUCTION

1.1. Background and Significance

The demographic proportion of the aging population is rapidly increasing. The United States is no exception. Population growth between 1946 and 1964, the so-called baby boomers who will be between 54 and 72 years old in 2018, is a key proportion of the current aging population. By 2050, the population aged 65 and over is estimated to increase to 83.7 million, accounting for more than 20 percent of the total population in the United States (Ortman, Velkoff, & Hogan, 2014). With the increasing aging population and extended life expectancy, active aging or healthy aging has become increasingly significant in the process of optimizing opportunities for physical health and social and mental well-being (Walker, 2002). According to the Centers for Disease Control and Prevention (CDC), healthy aging refers to the "development and maintenance of optimal physical, mental and social well-being and function in older adults" (Lang et al., 2006).

To maintain older adults' active and healthy lifestyles, participating in regular physical activity is a key component. Moderate levels of daily physical activity reduces the risks of high blood pressure, heart disease, colon cancer, and diabetes, as well as depression (Nelson et al., 2007). Walking is one of the most popular forms of physical activity and is an affordable way to achieve recommended levels of activity (Pucher & Dijkstra, 2003). The CDC has recommended that older adults engage in 2.5 hours of moderate physical activity per week to maintain healthy aging. Despite the various benefits of walking, walking in an inappropriate posture and in an unsafe neighborhood are the most common fall-related activities among older adults.

Globally, falls are the second most serious cause of death from unintentional injuries with approximately 690,000 deaths reported in 2012 according to the WHO (2016), and every year 37 million injuries from falls requiring medical care occur (WHO, 2012c). Every year, a fourth of the people aged 65 years or older in the United States experience falls, which are the leading cause of both fatal and nonfatal injuries (Stevens et al., 2012; Stevens & Sogolow, 2005). One out of five falls causes a serious injury, such as head trauma, broken bones, or hip fractures (Sterling, O'Connor, & Bonadies, 2001). These fall-based injuries are known to be negatively associated with individual health and behavior outcomes. Thus, older adults who experienced falls tend to have difficulty in their daily lifestyle and mobility due to decreased physical activity, social withdrawal, and loss of confidence (Ageing & Unit, 2008).

A neighborhood environment is a fundamental area for older adults' daily activities. Unlike adults who have to go to a workplace outside of the neighborhood, older adults usually stay within the neighborhood boundary since they have no regular and fixed destinations and lack mobility options (Glass & Balfour, 2003). Especially after retirement, people tend to spend more time enjoying recreational activities and community facilities. And although many aging people own and maintain their own cars, there are increasing numbers of older adults with limited vision or chronic diseases who are no longer able to drive (Edwards, Lunsman, Perkins, Rebok, & Roth, 2009). For these reasons, their daily lifestyles and mobility could be influenced by what a neighborhood provides. Physically, diverse aging-related facilities (senior centers, nursing homes), amenity facilities (parks, shopping malls, public transit), daily life-related facilities (retail shops, grocery stores, pharmacies), and health-related facilities (medical centers, hospitals) could influence the lifestyles of older adults. Socially, a safe environment and familiar social networks such as family, friends, and neighbors are closely related to reducing the social isolation of older adults. In addition to these amenities, affordable and suitable housing options cause older people to have to decide whether to remain in or move out of their neighborhood environment.

1.2. The Knowledge Gap

Despite well-established findings regarding the risk factors for falls, there is a variation in risks by location for fallers. Indoor falls were usually defined as those occurring inside homes, parking garages, and other buildings. Outdoor falls, on the other hand, include falling incidents that occurred on sidewalks, curbs, streets, outdoor stairs, and other outdoor places (W. Li et al., 2006). A few studies identified the different characteristics of falls by location reporting significant differences between indoor fallers and outdoor fallers (Jennifer L Kelsey et al., 2010; W. Li et al., 2006). Indoor fallers tended to be associated with being female and being frail, while outdoor fallers were more likely to be related to being male and being physically active (W. Li et al., 2014). However, few consistent results between studies have been examined in terms of the risk factors for indoor and outdoor falls.

Also, there has been a lack of empirical evidence on the effects of neighborhood environments on fall-related injuries despite the increasing importance of the association between neighborhood environments and individual health. The physical and social characteristics of neighborhoods were known to not only influence whether older adults remain in their communities or leave, but also influenced their physical activities (Fisher, Li, Michael, & Cleveland, 2004; Saelens & Handy, 2008) and mobility (Balfour & Kaplan, 2002). For example, a high density level of a place, the presence of green and open spaces, accessibility to shops, and physical activity resources were known to be significantly associated with physical activity among older adults (Berke, Koepsell, Moudon, Hoskins, & Larson, 2007). Older individuals living in a deprived neighborhood with poor conditions (excessive noise and inadequate lighting), and high safety concerns tended to have a higher likelihood of mobility limitations (Balfour & Kaplan, 2002; Rasinaho, Hirvensalo, Leinonen, Lintunen, & Rantanen, 2007b).

Environmental factors have been known to be one of the causes of falls in the elderly together with individual risk factors, such as age, comorbidity, mobility limitations, and lack of physical activity (Rubenstein, 2006). Environmental factors refer to "all that which is external to the human host" which covers physical, chemical, biological, and social factors (Prüss-Üstün & Corvalán, 2006). As most studies indicated that relatively more than 50% of falls among older adults occurred due to home environments, reducing home environmental hazards would be important for fall prevention (Nevitt, Cummings, Kidd, & Black, 1989; Sattin, Rodriguez, DeVito, & Wingo, 1998; Tinetti, Speechley, & Ginter, 1988). Such home environmental hazards include poorly maintained stairways, poor lighting, hard surfaces, and a lack of grab bars or other safety devices. Yet, there is little literature examining the association between outdoor environmental risk factors and fall-related injuries. Given the importance of walking as a form of outdoor physical activity, research on identifying outdoor environmental risk factors for falls and designing strategies to reduce falls holds promise for healthy aging.

1.3. Theoretical Background

To better understand the neighborhood environmental factors contributing to fall risks among older adults, this dissertation extends the ecological model of aging proposed by Lawton

(1977) and the Social Determinants of Health (Solar & Irwin, 2007). Figure 1 presents the conceptual framework for the interactions between neighborhood environmental factors and individual factors influencing fall incidents among older adults. The fundamental relationship between neighborhood environments and falls is based on the transaction between environmental press/buoying and personal competencies. According to Lawton's person-environment fit model, maladaptive behavior occurs when environmental press exceeds individual competence (Lawton, 1977). Although studies regarding the direct associations between neighborhood environments and falls are scarce, previous studies found that imbalance, inflexibility, or slips leading to a fall account for the broken balance between the physical environment and health status. For example, frail older adults who have a low level of personal competence are susceptible to even a low level of environmental press (minor physical barriers, social stress, insecurity, and resource inadequacy). Whereas, healthy older adults who have a high personal competence capacity are less vulnerable to falls influenced by a low level of environmental press (Nyberg, Gustafson, Berggren, Brännström, & Bucht, 1996). This person-environment fit could explain why maladaptive behavior (falls) occur, but it does not fully explain the different environmental relationships with falls by location (indoor and outdoor falls).

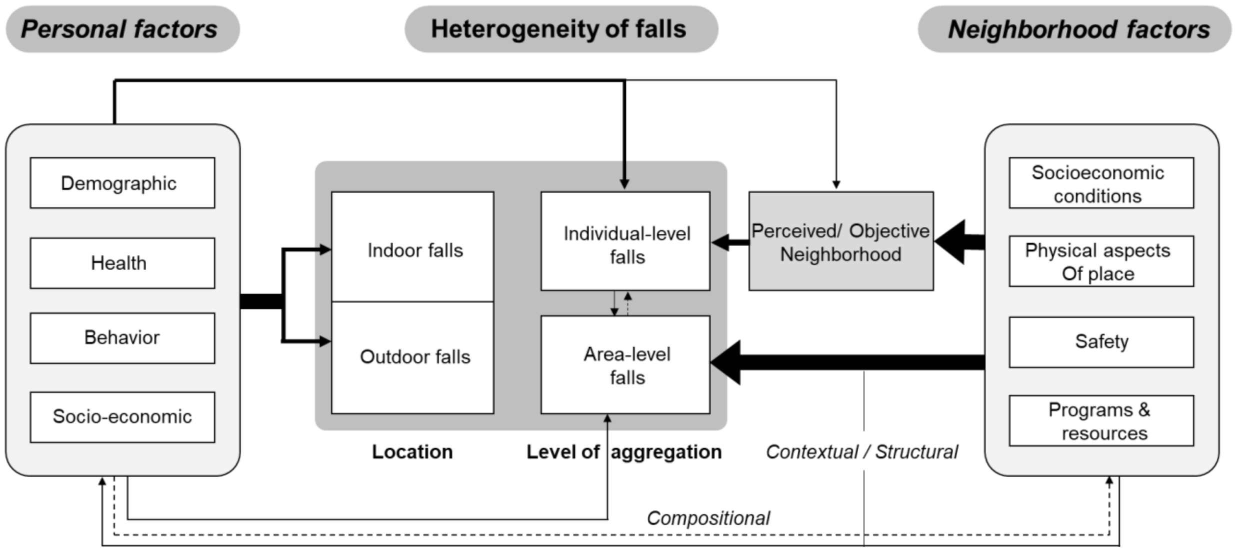

Figure 1 Conceptual Framework: The relationships between neighborhood and falls by location

Considerable research has indicated that neighborhood environments, including access to amenities, the physical aspects of the place, and neighborhood safety have been shown to be associated with individual outdoor physical activity and the decision of whether or not to go outside (Chad et al., 2005; F. Li et al., 2005). Negative neighborhood features, including long distances to destinations, low safety from crime, and inadequate pedestrian infrastructure limit older adults' time outside and lead to a lowered physical activity level among older adults (Balfour & Kaplan, 2002; de Leon et al., 2009). The individual decision of whether or not to go outside, as a mediating variable, could help better explain why a certain built environment has an effect on the location of falls. For example, those who live in a neighborhood with good accessibility to amenities but with poor street conditions might go outside but have a high-risk possibility of outdoor falls. At the same time, older adults who live in areas with neighborhood deprivation and a high level of crime might not spend much time outside and are at a high-risk for indoor falls. We should consider individual physical capability and safe environments to promote individual physical activity as well as facilitate safe walking without the risk of falling.

Several studies have reported the association between the socioeconomic characteristics of place and the health or well-being of older adults. Social determinants of health highlight the environmental factors (e.g., stressful living conditions) and structural contexts (e.g., housing policies) that influence individual socioeconomic position and health outcomes (Marmot, 2005; Solar & Irwin, 2007). Although the explorations of the socioeconomic effects of neighborhoods on falls are scarce because of the difficulty in accessing population-based data, certain socioeconomic characteristics have been documented. West et al. (2004) examined the relationships between rates of hospital admissions for falls/hip fractures and socio-economic deprivation at the census tract level, and indicated that there were high levels of hospital admissions for falls in deprived areas.

Unsafe physical conditions, including a change in levels, uneven surfaces, litter, and other hazards might directly influence fall incidents among older adults. Studies of the determinants of home environmental hazards were relatively well-documented, showing that poorly maintained stairways, poor lighting, hard surfaces, and lack of grab bars or other safety devices were risk factors (Lord, Menz, & Sherrington, 2006a; Mary E Northridge, Nevitt, Kelsey, & Link, 1995). However, few empirical studies examined the outdoor environmental risk factors for outdoor falls. Li et al. (2006), used a case-control study with large samples, and found that uneven and wet surfaces were associated with outdoor falls. Qualitative studies showed that older individuals reported uneven walking surfaces, inadequate maintenance, poor lighting, and traffic patterns as perceived risk factors (Chippendale & Boltz, 2015a; Nyman, Ballinger, Phillips, & Newton, 2013a). Lai et al. (2009) adopted a spatial approach to examine where outdoor falls occur, and showed that areas with wet surfaces were related to a concentration of falls. A recent study conducted by Curl et al. (2016) has developed an audit checklist to assess outdoor fall risks using seven dimensions: changes in level, path condition and smoothness, path material, obstructions, road crossings, street lighting, and weather (Curl, Thompson, Aspinall, & Ormerod, 2016).

In addition to physical barriers, the environment may create individual safety concerns from traffic or crime, which potentially lead to imbalanced walking and injury from falling. Since older adults have difficulty in crossing streets with heavy traffic and short traffic signals, pedestrian-vehicle accidents are a potential outdoor fall risk in neighborhoods (Chippendale & Boltz, 2015a). Also, fear of going outdoors or fear of crime were known to prevent older adults from going outside and engaging in outdoor physical activity, which subsequently increases the risk of indoor falls (Rantakokko et al., 2009; Wijlhuizen, de Jong, & Hopman-Rock, 2007).

Several studies have identified the effects of evidence-based programs on preventing falls. Because of a reduced social network, older adults are highly dependent on community resources (Glass & Balfour, 2003). However, accessibility and availability of useful programs and resources are not equally distributed across neighborhoods (Mary Evelyn Northridge & Freeman, 2011). Despite the lack of correlational studies between the distribution of fall prevention programs and fall incidents, previous studies found that accessibility to physical activity facilities was highly associated with physical activity among older adults (Fisher & Li, 2004; F. Li et al., 2005). In other words, such physical activity facilities and programs would encourage older adults to go outside and increase their physical capacities, which is critical for reducing falls and promoting healthy aging (Chippendale & Bear-Lehman, 2011).

Either an individual approach to increase personal capacity or an environmental intervention to create a safe environment is not enough to reduce indoor and outdoor falls. Given the person-environment fit, older adults with low vision might be unable to perceive an obstacle such as a dropped curb (Salonen & Kivelä, 2012). Also, because of a decrease in the ability of dual tasking, high traffic volume could increase the risk of falls when older adults combined foot placement with watching for road traffic (Beauchet et al., 2009; Chu, Tang, Peng, & Chen, 2013). Thus, neighborhood design and environmental interventions should consider the transaction between age-related weaknesses and environment barriers and create design guidelines to modify environmental hazards and to help educate older adults about how to use their neighborhood environments. Finally, a multidisciplinary approach between public health professionals, gerontologists, environmental psychologists, and urban planners to consider neighborhood environmental interventions to reduce indoor and outdoor falls as well as to promote physical activity would be a good start.

1.4. Structure of the Dissertation

This dissertation attempts to fill this gap of knowledge and understand the relationships between the heterogeneity of falls and neighborhood environments by using different research questions, data characteristics, and research designs. Figure 2 illustrates the structure of the dissertation, which consists of three sections. The following are the specific research aims and research hypothesis for each chapter:

In Section 2, a systematic review of relevant studies identifies which variables are associated with indoor and outdoor falls, respectively, in terms of four domains (biological/health, behavioral, social, and environmental) to understand the different risk factors of falls by location. The hypothesis is that the risk profiles for falls by location types would be different in terms of biological/health, behavioral, and social factors and the prevalence of indoor and outdoor falls would vary according to the methodological differences across studies.

Section 3, using administrative data from Emergency Medical Services (EMS) records, addresses whether neighborhood environments influence risk factors for falls among older adults and examines the prospective associations of changes in neighborhood environmental attributes with changes in falls. The hypothesis of this section is that older adults whose outdoor environments near home become more negative would likely be associated with the increased likelihood of falling over time.

Finally, in Section 4, this dissertation used a secondary survey data, the National Health and Aging Trends Study (NHATS), in order to find prospective evidence on the relationships between neighborhood environments and fall incidents. Specifically, this section examines whether and to what extent neighborhood environments are associated with injurious falls among older adults stratified by age group at the community level. The main hypothesis is that neighborhoods with unsafe environments and higher residential instability are associated with a higher fall incidence.

The conclusion, Section 5, summarizes the key findings of the three studies and discusses the major contributions and practical implications for future studies.

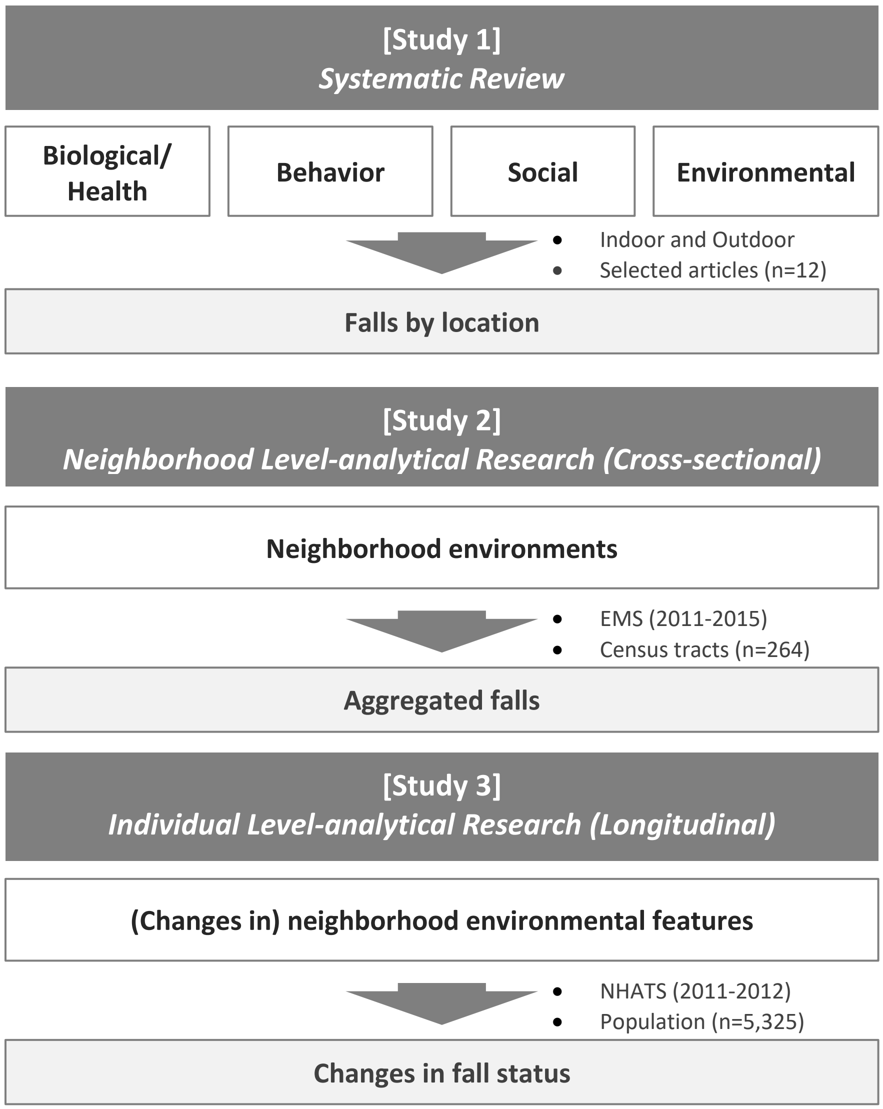

Figure 2 Structure of Dissertation

2. RISK FACTORS OF INDOOR AND OUTDOOR FALLS IN OLDER ADULTS: A SYSTEMATIC REVIEW

2.1. Synopsis

Falling is a major health problem among older adults, resulting from complex interactions of risk factors at both personal and environmental levels. Although the etiology of general falls has been well understood, location specific risk profiles have not been sufficiently examined. This literature review study aims to (1) assess the methods by which fall locations are classified as either indoor or outdoor; (2) study the prevalence of indoor and outdoor falls; and (3) identify different risk factors related to indoor versus outdoor falls.

Six databases—Medline, Cinahl, CSDR, Embase, Ageline, and PsyINFO—were systematically searched, and selected articles were evaluated based on PRISMA guidelines.

A systematic search identified 14 relevant studies examining older adults. All 14 studies investigated biological/health-related risk factors. Seven of those studies focused on behavioral risks, while another seven explored social factors. No studies considered environmental factors. The biological/health-related fall risk factors were: activity limitations, cognitive impairments, health conditions, comorbidity, and balance impairments. Behavioral risk factors included physical activity and walking. Indoor fallers tended to have higher levels of comorbidity, more balance problems, and lower levels of physical activity when compared to non-fallers. Outdoor falls were associated with frequent outdoor exposure and high levels of physical activity and walking.

The review provides a comprehensive overview of different profiles for indoor and outdoor falls. These findings can guide the development of tailored guidelines for fall prevention based on the locations where falls occur and the location-specific population profiles.

2.2. Background

Falls are common injuries especially for older adults that occur when one engages in daily activity or walks around the neighborhood. Every year, one-fourth of people aged 65 years or older in the United States experience falls, making them the leading cause of both fatal and nonfatal injuries (Stevens & Sogolow, 2005). One out of five falls causes a serious injury, such as head trauma, broken bones, or hip fractures (Sterling et al., 2001). These fall-based injuries are negatively associated with individual health and behavior outcomes. Older adults who have experienced fall incidents tend to face difficulty in terms of daily lifestyle and mobility due to decreased physical activity, social withdrawal, and loss of confidence (Bryant, Rintala, Hou, & Protas, 2015).

Fall risk factors are generally categorized as either intrinsic or extrinsic. Intrinsic factors include advanced age, gender, general health and functioning, balance problems, and behavior, whereas extrinsic factors originate outside of personal characteristics, affecting the individual through medication or hazardous environments (Steinweg, 1997). These intrinsic and extrinsic risk factors are further subdivided into the following classifications: biological (e.g., age, gender, race, or chronic illness), behavioral (e.g., lack of exercise or excess alcohol intake), socioeconomic (e.g., low income, inadequate housing, or lack of social interaction), and environmental (e.g., poor home design, slippery floors, or stairs) (Ageing & Unit, 2008).

There is increasing evidence to suggest that the risk factors associated with falling may vary depending on where older adults tend to experience these falls. To capture more accurate risk profiles, recent epidemiologic studies have generally classified falls by location, distinguishing between indoor and outdoor occurrences. The former tend to occur inside homes, parking garages, and other buildings. Outdoor falls, on the other hand, include incidents on sidewalks, curbs, streets, outdoor stairs, and other outdoor locations (W. Li et al., 2006). Previous studies have suggested that indoor falls share a correlation with younger age, being female, and having a frail disposition, whereas outdoor falls were associated with older age, being male, and active behavior (Bergland, Pettersen, & Laake, 1998; Weinberg & Strain, 1995).

However, there are few consistent results among studies examining the risk factors of indoor and outdoor falls, particularly due to the field's heterogeneous methodology. The variation among study procedures that examine risk profiles of indoor and outdoor falls includes information on data source origin and outcome measurements of indoor or outdoor falls in the context of design setting. Although the etiology of general falls has been well understood with meta-analyses, there is no systematic review to comprehensively identify the different risk profiles of falls based on location.

The purpose of this review was to use the published literature to 1) assess the measurement of fall outcomes based on location, 2) understand the prevalence of indoor and outdoor falls, and 3) synthesize the cumulative results of fall risk factors according to indoor and outdoor environments. Understanding the different risk factors between indoor and outdoor falls will facilitate the development of effective injury prevention strategies specific to each spatial setting. This review has followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009).

2.3. Methods

2.3.1. Search Strategy

As the basis for our review, we searched the following databases in July 2017: MEDLINE (1983-2017), CINAHL (1986-2017), Cochrane Database of Systematic Reviews (1990-2017), EMBASE (1983-2017), Ageline (1978-2017), and PsycINFO (1951-2016). We used three search terms: 1) accidental fall,* fall,* falling,* or faller;* 2) aged, aging, elderly, older, or senior; and 3) indoor* or outdoor.* In this systematic review, we focused on elderly persons aged 65 years or older.

2.3.2. Eligibility

Titles and abstracts were initially reviewed, followed by assessments of full-text versions using standard checklists, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, & Altman, 2010). There were no regional restrictions. Studies were eligible for review if they (a) were peer-reviewed journal articles written in English, (b) described empirical studies, (c) focused on populations aged 65 years or older, and (d) discussed comparable outcomes of falls based on location with relevant risk factors. We only included studies that had both indoor and outdoor fall-related outcomes, and studies were excluded if they considered fall locations to be predictor variables rather than outcome variables because the purpose of this systematic review was to identify the heterogeneity of risk factors that influence fall incidents based on location. Because our target samples were intended to examine older adults, studies that targeted individuals younger than 65 years were excluded; however, some studies were included if at least 75% of their samples were composed of individuals aged 65 years or older. Studies were also excluded if they did not provide sufficient and supportive analysis results. There were no analysis limitations; we included studies that conducted multivariate tests, in addition to studies that used bivariate tests, t-tests, and ANOVAs, which show only the correlation between dependent and independent variables. We excluded articles that used identical study settings and data sources, but we included some articles that contained additional risk factors in terms of fall classifications. When choosing among articles that used the same study source, we prioritized the article that was published first.

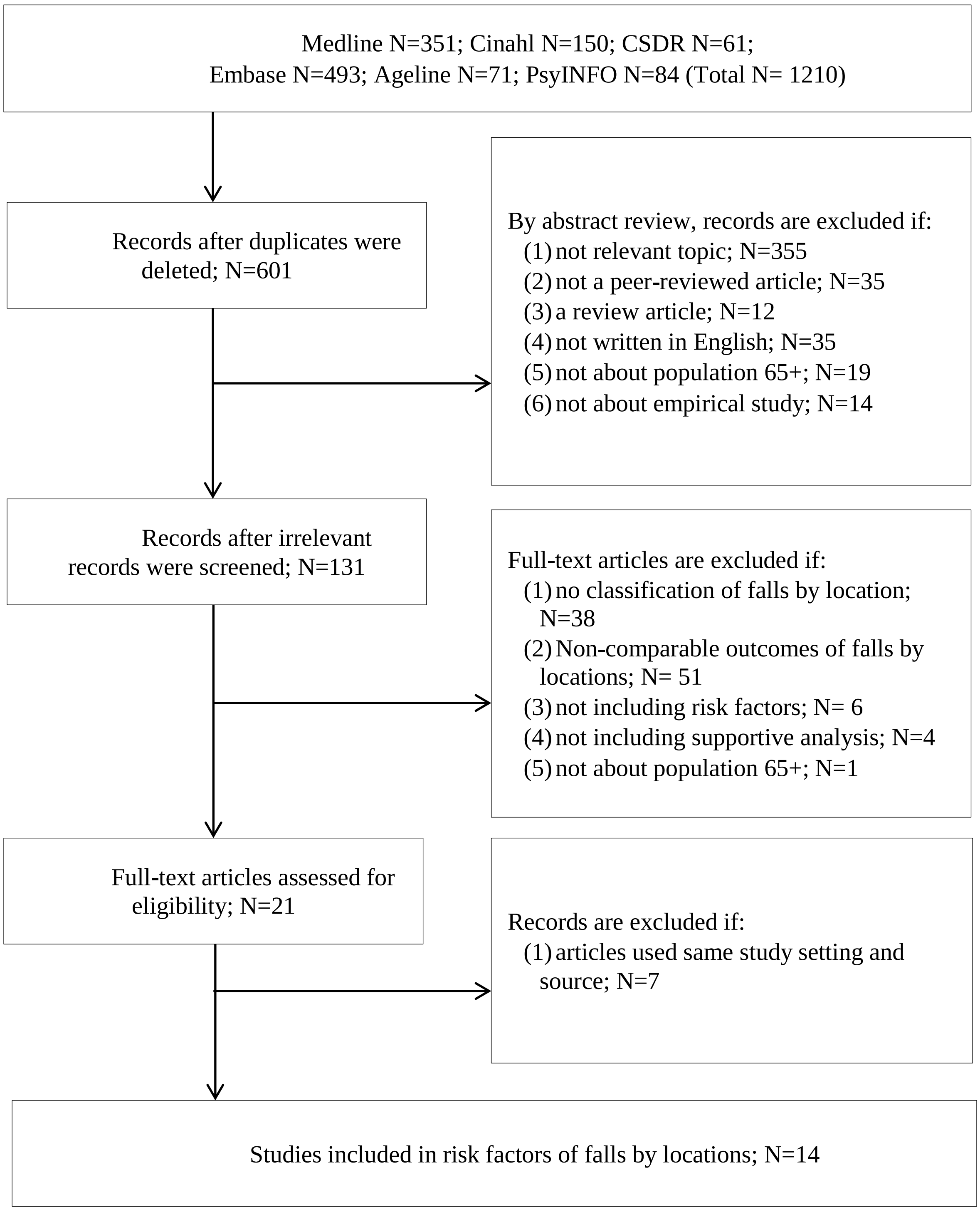

Figure 3 Article Selection Process

2.3.3. Data extraction

Data on study location, study design, baseline characteristics of the study sample (e.g., mean or median age of study sample), statistical analysis, measurements of fall outcomes (e.g., category of falls based on location, fall count, and fall type), methods used to record falls, and prevalence of falls was abstracted from each report In this review, we primarily considered the outcomes of both indoor and outdoor fallers through use of three categories: 1) indoor fallers vs. outdoor fallers, 2) indoor fallers vs. non-fallers, and 3) outdoor fallers vs. non-fallers. Because fall-related outcomes by location were slightly different among articles due to variance in study design, we combined fall classifications by location together with the following factors: sample composition, types of outcomes (i.e., number or rate), degree of severity (i.e., injurious fall or not), and fall count (i.e., one fall or multiple falls considered). Indoor and outdoor risk factors were categorized as either biological, behavioral, or socioeconomic. We used the outcomes from bivariate and multivariate analyses to indicate the risk factors for indoor and outdoor falls. Multivariate outcomes were preferable, but bivariate outcomes were used when multivariate outcomes were unavailable. Selected variables from the included studies were considered statistically significant as risk factors only if the p-values were below 0.05.

2.3.4. Quality assessment

Each article that met the inclusion criteria was blinded for the authors' names, affiliations, journal names, publication dates, funders, and acknowledgments. Afterwards, they were independently assessed for quality by one of the authors (SL) and an assistant researcher mentioned in the acknowledgements (JN). We then checked the methodological quality of eligible studies, adopting the quality assessment tool for systematic reviews of observational studies (Wong, Cheung, & Hart, 2008) and validating fall risk assessment protocol (Stalenhoef, Crebolder, Knottnerus, & van der Horst, 1997). A score of 10 was assigned to each study (Supplementary Table 1). Two researchers independently determined the quality ratings, and disagreements were resolved by consensus.

2.4. Results

2.4.1. Selection of Articles

From the 1,210 studies available through the search databases, we excluded 609 duplicates and 470 irrelevant studies by review of titles and abstracts, and 131 articles were reviewed as potential candidates. After full-text review, 21 out of 131 reports were retained based on the first inclusion and exclusion criteria. The other 110 articles were excluded because these studies did not provide sufficient information to statistically and systematically explore the different risk factors related to indoor and outdoor falls. We then excluded another seven articles from the 21 because of identical study settings (MOBILIZE Boston study). As a result, only 14 articles were ultimately synthesized for our systematic review (Figure 3). Among them, four studies were retained because they used different risk factors—two were based on FITSA, and the other two were conducted by the MOBILIZE Boston study.

2.4.2. Assessment of Validity

From a range of 0 to 10, five studies received high-quality scores of 7 to 10, and nine studies received middle-quality scores of 3 to 6. All selected studies were considered to be qualified. The results of the quality assessment are provided in Appendix Supplementary Table 2.

2.4.3. Characteristics of Included Studies

The overall characteristics of the studies are shown in Table 1. Seven were conducted in Europe, and five were conducted in North America, specifically four from the United States and one from Canada. Additionally, one article from Asia and one from South America were included. Most studies included both male and female subjects (N=11), and only a few studies comprised only female subjects (N=3). Eight cross-sectional and six longitudinal studies investigated risk factors for both indoor and outdoor falls. Sample sizes varied from 209 to 46,096. Nine studies compared indoor and outdoor falls in terms of risk factors, and ten studies compared non-fallers with indoor and outdoor fallers, respectively.

Table 1 Characteristics of included studies (n=14)

Characteristics	No.	% of 14
Region of study location		
Asia	1	7.1
Europe	7	50.0
North America	5	35.7
South America	1	7.1
Study design		
Cross-sectional study	8	57.1
Prospective cohort study	6	42.9

Table 1 Continued

Characteristics	No.	% of 14
Statistical analysis		
Both bivariate and multivariate analysis	3	21.4
Only bivariate analysis	7	50.0
Only multivariate analysis	4	28.6
Sample size		
0 – 399	4	28.6
400 – 699	5	35.7
700 – 999	3	21.4
1000 +	2	14.3
Female		
Both male and female	11	78.6
Female only	3	21.4
Fall outcome measurement		
Fall rates	4	28.6
Number of falls	4	28.6
Number of Fallers	6	42.9
Count of falls		
One fall	10	71.4
Multiple falls	4	28.6
Inclusion of sample		
Only fallers (or falls)	5	35.7
Both fallers and non-fallers (or falls)	9	64.3
Degree of Injuries		
General falls	10	71.4
Injurious falls and fatal falls	4	28.6
Methods of collecting falls data		
Recall (phone, interview, or questionnaire)	5	35.7
Fall calendar	5	35.7
Medical report, outpatient report, or death certificate	4	28.6
Prevalence of indoor and outdoor falls		
Indoor > Outdoor	8	57.1
Indoor < Outdoor	6	42.9

2.4.4. Measurements of indoor and outdoor falls

Table 2 presents a summary of 14 studies with information on study characteristics, results of the methodological quality assessments, and associations of each variable with indoor and outdoor falls. In terms of fall outcome measurement, the number of fallers was used to represent fall outcomes in some studies (N=6). However, four studies instead used rates of falling, such as the average number of falls per person per year of follow-up or the number of falls per person per month. Participants who have experienced falls cannot be exclusively classified as either indoor fallers or outdoor fallers, as some older individuals may have experienced both types within a study period. Also, four studies used the number of falls to represent outcomes because their samples included only fall incidents, showing that each indoor or outdoor fall incident could exist exclusively based on location. In terms of data collection method, five studies used fall calendars and post-fall interviews via telephone or door-to-door visit, and five studies relied on respondent recollection through phone interviews or door-to-door visits. The remaining studies collected fall outcomes from secondary databases, including outpatient reports, death certificates, examiner's reports, emergency department data, and medical reports from trauma registries. In terms of outcome characteristics, most studies (N=10) used general falls as outcomes, while others considered the injuries that resulted from these falls. Three studies used injurious falls to represent their outcomes, and one study even used fatal falls derived from death certificates. In terms of fall count, most studies (N=8) only included one recent fall that occurred indoors or outdoors, but some studies (N=4) considered multiple falls.

Table 2 Characteristics of the reviewed studies

Ref.	Authors (Year)	Study design, year, characteristics of sample; sample frame	Sample Size (N); Mean age (M); Gender (G)	Location; characteristics of sample	Measurement of fall (M); Degree of Injury (I); Number of falls (N)	Collecting method for outcome	Prevalence of falls (I:O=indoor falls vs. outdoor falls)	Considered variables	Associations		
									Indoor falls vs. Outdoor falls	Indoor falls vs. non-fallers	Outdoor falls vs. non-fallers
1	Loughlin et al (1994)	Prospective Cohort study; 1987-1988; both fallers and non-fallers	N=417; A=65+; M=74.8; G=Both	Canada; Community-dwelling	M=Fall rates; I=General Falls; N=Multiple Falls	Recall-Interviewed by phone	51:49	*Biological* Age*, female*, history of falls*, comorbidity*, mobility limitation*, activity-limitation*, hearing problem* *Behavior* Alcohol consumption*, multi-medications*	NA	*Biological* mobility limitation*(+), activity-limitation*(+) *Behavior* Alcohol consumption* (-)	*Biological* hearing problem*(-)
2	Bergland et al (1998)	Cross-sectional study ; 1994-1995; both fallers and non-fallers	N=431; A=67+; M=76.4; G=Both	Norway; Community-dwelling	M=Number of Fallers; I=General Falls; N=Single Fall	Recall-face to face interview	41:59	*Biological* Age, female	*Biological* Age(+)	NA	NA
3	Bath and Morgan (1999)	Prospective Cohort study; 1985 (Baseline), 1989 (follow-up); both fallers and non-fallers	N=444; A=65+; M=75.6; G=Both	UK; Community-dwelling	M=Number of Fallers; I=General Falls; N=Single Fall	Recall-face to face interview	38:62	*Biological* Age*, female*, obesity*, activity-limitation*, fair health status*, gait speed* *Behavior* Multi-medications*, smoke status*, utilitarian walking*, recreational walking*	NA	*Biological* Activity-limitation*(+), fair health status* (+), gait speed* (-)	*Behavior* Multi-medications* (+), recreational walking*(+)

Table 2 Continued

Ref.	Authors (Year)	Study design, year, characteristics of sample; sample frame	Sample Size (N); Mean age (M); Gender (G)	Location; characteristics of sample	Measurement of fall (M); Degree of Injury (I); Number of falls (N)	Collecting method for outcome	Prevalence of falls (I:O=indoor falls vs. outdoor falls)	Considered variables	Associations		
									Indoor falls vs. Outdoor falls	Indoor falls vs. non-fallers	Outdoor falls vs. non-fallers
4	Bergland et al (2003)	Prospective Cohort study; 1997 (Baseline), 1998 (follow-up); both fallers and non-fallers	N=307; A=75+; M=80.8; G=Female	Norway; Community-dwelling	M=Fall rates; I=General Falls; N=Multiple Falls	Fall calendar and Post-fall interview by phone	42:58	*Biological* Obesity, history of falls*, activity-limitation, performance-limitation*,fair health status, depression*, hearing problem, vision problem*, cognitive impairments*, Comorbidity*, balance problem*, gait speed* *Behavior* Multi-medication, outdoor exposure*	NA	*Biological* history of falls*(+), activity-limitation(+), performance-limitation*(+), cognitive impairments*(+), Comorbidity*(+), balance problem*(+), gait speed*(-) *Behavior* Multi-medication(+)	*Biological* history of falls*(+), depression*(+), vision problem*(+), gait speed*(+) *Behavior* outdoor exposure*(+)
5	Pajala et al (2008)	Prospective Cohort study; 2000-2001 (Baseline) 2003-2004 (follow-up); both fallers and non-fallers	N=434; A=63-76; M=68.5; G=Female	Finland; Community-dwelling	M=Number of Fallers; I=General Falls; N=Single Fall	Fall calendar and Post-fall interview by phone	30:70	*Biological* Age, obesity , history of falls, mobility-limitation, activity-limitation, fear of falling, cognitive impairment, comorbidity, balance problem, gait speed *Behavior* High physical activity, multi-medications	*Biological* Obesity(+) , history of falls(+), mobility limitation(+), activity-limitation(+), comorbidity(+), balance problem(+) *Behavior* multi-medications(+)	*Biological* obesity(+),history of falls(+),mobility limitation(+),activity-limitation(+), balance problem(+) *Behavior* multi-medications(+)	-

Table 2 Continued

Ref.	Authors (Year)	Study design, year, characteristics of sample; sample frame	Sample Size (N); Mean age (M); Gender (G)	Location; characteristics of sample	Measurement of fall (M); Degree of Injury (I); Number of falls (N)	Collecting method for outcome	Prevalence of falls (I:O=indoor falls vs. outdoor falls)	Considered variables	Associations		
									Indoor falls vs. Outdoor falls	Indoor falls vs. Outdoor falls	Indoor falls vs. Outdoor falls
6	Mänty et al (2009)	Prospective Cohort study; 2000-2001 (Baseline) 2003-2004 (follow-up); both fallers and non-fallers (with mobility limitation)	N=376; A=63-76; M=68.5; G=Female	Finland; Community-dwelling	M=Number of Fallers; I=General Falls; N=Single Fall	Fall calendar and Post-fall interview by phone	27:73	*Biological* age, obesity, history of falls, fear of falling, cognitive impairment, comorbidity, hearing problem, vision problem, balance problem, gait speed *Behavior* Multi-medications, outdoor exposure *Socio-economic* education	*Biological* obesity(+), history of falls(+), balance problem(+) *Behavior* outdoor exposure(-)	*Biological* obesity(+), history of falls(+),vision problem(+) *Behavior* outdoor exposure(-)	*Biological* history of falls(+)
7	Ranhoff et al (2010)	Cross-sectional study; 2007-2009; only fallers	N=769; A=65+; M=84.3; G=Both	Norway; Community-dwelling patients from long-term care	M=Number of Falls; I=Injurious Falls; N=Single Fall	Outpatient report	78:22	*Biological* Age, female, OBESITY, history of falls, cognitive impairment, comorbidity, activity-limitation, hearing problem, vision problem	*Biological* Age,(+) female(+), cognitive impairment(+), comorbidity(+), activity-limitation(+)	NA	NA

Table 2 Continued

Ref.	Authors (Year)	Study design, year, characteristics of sample; sample frame	Sample Size (N); Mean age (M); Gender (G)	Location; characteristics of sample	Measurement of fall (M); Degree of Injury (I); Number of falls (N)	Collecting method for outcome	Prevalence of falls (I:O=indoor falls vs. outdoor falls)	Considered variables	Associations		
									Indoor falls vs. Outdoor falls	Indoor falls vs. Outdoor falls	Indoor falls vs. Outdoor falls
8	Kelsey et al (2010)	Prospective Cohort study; 2005-2007 (baseline) 2008 (follow-up); both fallers and non-fallers	N=695; A=70+; M=78.1; G=Both	USA; Community-dwelling	M=Fall rates; I=General Falls; N=Multiple Falls	Fall calendar and Post-fall interview by phone	51:49	*Biological* Age, female, White†, obesity†, history of falls†, activity-limitation†, fair health status†, depression†, vision problem†, cognitive impairment†, comorbidity†, balance problem†, gait speed†, foot problem† *Behavior* High physical activity†, multi-medications†, alcohol consumption† *Socio-economic* education†	*Biological* Age(+), female(+), white, obesity(+), activity-limitation(+), fair health status (+), comorbidity(+), balance problem(+), gait speed(-) *Behavior* High physical activity(-), multi-medications(+) *Socio-economic* Education(-)	*Biological* history of falls† (+), activity-limitation† (+), fair health status† (+), depression† (+), comorbidity† (+), balance problem† (+) *Behavior* High physical activity† (-), multi-medications† (+), *Socio-economic* Education† (+)	*Biological* white† (+), obesity† (-), history of falls† (+), depression† (+), gait speed† (+) *Behavior* High physical activity† (+), multi-medications† (-), alcohol consumption † (+) *Socio-economic* Education† (+)
9	Bleijlevens et al (2010)	Cross-sectional study; NR; only fallers	N=333; A=65+; M=74.9; G=Both	Netherlands; Community-dwelling older adults visited the Accident & Emergency department	M=Number of Fallers; I=Injurious falls; N=Single Fall	Recall-Interviewed by phone	45:56	*Biological* Age, female, activity limitation, fair health status, fear of falling *Socio-economic* Living situation, education	*Biological* Age(+), activity limitation(+)	NA	NA
10	Landy et al (2012)	Cross-sectional study; 2005-2007; only fallers	N=209; A=65+; M=NR; G=Both	USA; Community-dwelling	M=Number of Falls; I=Fatal Falls; N=Single Fall	Death certificate or examiner's report	75:25	*Biological* Age*, female*, White* *Socio-economic* Living situation*	*Biological* Age*(+)	-	-

Table 2 Continued

Ref.	Authors (Year)	Study design, year, characteristics of sample; sample frame	Sample Size (N); Mean age (M); Gender (G)	Location; characteristics of sample	Measurement of fall (M); Degree of Injury (I); Number of falls (N)	Collecting method for outcome	Prevalence of falls (I:O=indoor falls vs. outdoor falls)	Considered variables	Associations		
									Indoor falls vs. Outdoor falls	Indoor falls vs. Outdoor falls	Indoor falls vs. Outdoor falls
11	Li et al (2014)	Prospective Cohort study; 2005-2007 (Baseline) 2005-2009 (Follow-up); both fallers and non-fallers	N=765; A=70+; M=78.1; G=Both	USA; Community-dwelling	M=Fall rates; I=General Falls; N=Multiple Falls	Fall calendar and Post-fall interview by phone	54:46	_Behavior_ utilitarian walking†, recreational walking†, outdoor exposure†	NA	-	_Behavior_ Utilitarian walking†(+)
12	Kim (2016)	Cross-sectional study; 2011-2014; only fallers	N=46,096; A=65+; M=75.7; G=Both	South Korea; patient with emergency department injuries	M=Number of Falls; I=General falls; N=Single Fall	Reported data from emergency department	58:42	_Biological_ Age, female, cognitive impairment _Socio-economic_ education	_Biological_ Age(+), female(+) _Socio-economic_ Education(-)	NA	NA
13	Chippendale et al. (2017)	Cross-sectional study; 2013-2015; only fallers	N=712; A=55+; M=74.9; G=Both	USA; patient from the trauma registry	M=Number of Falls; I=Injurious falls; N=Single Fall	Medical report from the trauma registry	71:29	_Biological_ Age, female, White, obesity, mobility limitation	_Biological_ Age(+), female(+)	NA	NA
14	Nascimento et al. (2017)	Cross-sectional study; 2010; both fallers and non-fallers	N=1188; A=60+; M=NR; G=Both	Mexico; Community-dwelling	M=Number of Fallers; I=General Falls; N=Single Fall	Recall-questionnaire	59:41	_Biological_ Age*, female*, White*, cognitive impairment*, comorbidity*, Performance-limitation* _Socio-economic_ Education*	NA	_Biological_ Age*, female*(+), White*(+), cognitive impairment*, comorbidity*(+) _Socio-economic_ Education*	_Biological_ Age*(+), female*, White*, cognitive impairment*, comorbidity* _Socio-economic_ Education*

Note: : *means adjusted variable for multiple analysis; † means partially-adjusted variables (Kelsey et al. 2010: adjusted for age and female; Li et al. 2014: adjusted for Age, female, White, obesity, history of falls, activity-limitation, health status, depression, vision problem, cognitive impairment, comorbidity, balance, gait speed, foot problem, alcohol consumption, multi-medications, and other health variables)

2.4.5. Prevalence of indoor and outdoor falls

All studies reported the prevalence of indoor and outdoor falls. Studies on indoor falling reported prevalence data between 27% and 78%, while studies on outdoor falling reported between 22% and 73%. Out of 14, eight studies reported that indoor falls were more frequent than outdoor falls, but six studies indicated that outdoor falls were more prevalent than indoor falls.

2.4.6. Risk factors of falls

Table 2 shows details related to risk factors for indoor and outdoor falls, with the number of studies that addressed each variable. Findings on risk factors were clustered into biological/medical (N=14), behavioral (N=7), and socioeconomic risk factor categories (N=7). We included the variables at least two counted in the selected studies. 25 total variables were selected. 17 variables were classified as biological/medical risk factors, including the following: old age, female sex, white racial identity, obesity, history of falls, mobility-limitation, activity-limitation, activity-limitation, fair health status, fear of falling, depression, hearing problems, vision problems, cognitive impairment, balance impairment, and gait speed. Six variables were investigated as risk factors related to behavior: high physical activity, multi-medications, alcohol consumption, utilitarian walking, recreational walking, and outdoor exposure. Finally, two variables—education and living situation—were considered under the category of socioeconomic status. The risk factors (+), protective factors (-), and non-significant associations for each comparison—indoor versus outdoor falls, indoor versus non-falls, and outdoor versus non-falls—are summarized in Table 3.

Table 3 Associations of risk factors for indoor and outdoor falls

Categories of risk factors	Indoor falls vs. Outdoor falls			Indoor falls vs. non-fallers			Outdoor falls vs. non-fallers		
	Insignificant	**Protective Factors (-)**	**Risk Factors (+)**	**Insignificant**	**Protective Factors (-)**	**Risk Factors (+)**	**Insignificant**	**Protective Factors (-)**	**Risk Factors (+)**
Biological Risk Factors									
Age	5/6		2,7,8,9,10*,12,13	1*,3*,5/6,14*			1*,3*,5/6		14*
Female	2,9,10*		7,8,12,13	1*,3*		14*	1*,3*,14*		
White	8,10*,13			8*		14*	14*		8*
obesity	7,8,13		5/6,8	3*,4,8*		5/6	3*,4,5/6	8*	
history of falls	7,8		5/6	1*		4*,5/6,8*	1*,5		4*,6,8*
Mobility-limitations			5			1*,5	1*,5		
Activity-limitations			5,7,8,9			1*,3*,4,5,8*	1*,3*,4,5,8*		
Performance					4*,14*		4*,14*		
Fair Health status	9		8	4		3*,8*	3*,4,8*		
Fear of fall	5/6,9			5/6			5/6		
Depression	8			4*		8*			4*,8*
Hearing problem	6,7,8			1*,4,6			4,6	1*	
Vision Problem	6,7,8,9			4*,8*		6	6,8*		4*
Cognitive impairment	5/6,8,12		7	5/6,8*,14*		4*	4*,5/6,8*,14*		
Comorbidity	6		5,7	1*,5/6		4*,8*,14*	1*,4*,5/6,8*,14*		
Balance Impairment			5/6,8	6		4*,5,8*	4*,5/6,8*		
Foot problem	5/6		8			8*	8*		
Behavioral Risk Factors									
Gait speed	5/6	8		5/6,8*	3*,4*		5/6,3*		4*,8*
High physical activity	5	8		5	8*		5		8*
Multi-Medications	6		5,8	3*,6		4,5,8*	4,5/6	8*	3*
Alcohol consumption	8			8*	1*		1*		8*
Utilitarian walking				3*,11*			3*		11*
Recreational walking				3*,11*			11*		3*
Outdoor exposure		6		4*,11*	6		6,11*		4*
Socio*-economic *Risk Factors									
Education	6,9	8,12		6,14*		8*	6,14*		8*
Living situation	8,10*								

Note: *=result of adjusted analysis

References: 1= Loughlin et al (1994); 2= Bergland et al (1998); 3= Bath and Morgan (1999);4= Bergland et al (2003); 5= Pajala et al (2008); 6= Mänty et al (2009);7= Ranhoff et al (2010);8= Kelsey et al (2010);9= Bleijlevens et al (2010);10= Landy et al (2012);11= Li et al (2014); 12=Kim (2016); 13= Chippendale et al (2017); and 14= Nascimento et al. (2017)

2.4.6.1. Indoor falls versus Outdoor falls

Nine studies investigated the risk characteristics of indoor and outdoor falls among older adults. Most studies (N=6) were conducted with cross-sectional analyses. Indeed, three studies also compared indoor and outdoor falls over time, although these studies were conducted with longitudinal analysis and constant follow-up.

2.4.6.1.1. Biological Risk Factors

All studies included biological status as the primary category of risk factors for indoor and outdoor falls. Within this category, the variables of old age, female sex, activity-limitation, comorbidity, and balance impairment were consistently and significantly associated with indoor falls. Old age and female sex were typically regarded as primary biological risk factors for falls in the studies that examined indoor and outdoor fallers. Most studies (N=7) indicated that indoor fallers tended to be older than outdoor fallers. Four out of seven studies also showed that indoor fallers were more likely to be female than outdoor fallers. Despite the variety of instruments that were used to measure activity limitation (e.g., self-surveyed activity-limitation days, number of physical difficulties, ADL/PADL/IADL score, etc.), the included studies (N=4) showed a stronger association between activity limitation and indoor falling than between activity limitation and outdoor falling. Obesity, however, has been highly reported as a risk factor for indoor and outdoor falling in these studies (N=6), but only two databases indicated that indoor fallers were more likely to be obese than were outdoor fallers. Cognitive impairment has also frequently been considered, but four out of five studies found no association. Histories of falling have also typically been highly associated with increased risk for future falls (Ambrose, Paul, &

Hausdorff, 2013), but although previous falls were frequently investigated in these studies, no significant difference between indoor and outdoor fallers was found in terms of fall history—only two studies from the same database showed such differences between indoor and outdoor fallers (Manty et al., 2009; Pajala et al., 2008). On the other hand, most studies found strong associations with comorbidity and balance impairment among indoor fallers when compared to those of outdoor fallers, although these were only reported in three studies.

2.4.6.1.2. Behavioral Risk Factors

Only a few studies (N=3) considered behavioral risk factors when comparing indoor fallers with outdoor fallers. Use of multi-medication was the most frequently considered variable in this category, and two out of three studies showed that indoor fallers took more prescribed medication than did outdoor fallers. Two studies considered high levels of physical activity, and one study found that indoor falling was more often associated with lack of physical activity than was outdoor falling. Although outdoor exposure was not frequently considered in these included studies, one study suggested that indoor falling was more associated with low outdoor walking activity than was outdoor falling. Only one of three studies found that slow gait speed was more associated with indoor falls than with outdoor falls.

2.4.6.1.3. Socio-economic Risk Factors

Only two socioeconomic risk factors—education and living situation—were studied using bivariate analysis, and two out of four studies identified high education as a risk factor for higher frequency of indoor falls than outdoor falls.

2.4.6.2. Indoor falls versus no falls and Outdoor falls versus no falls

Eight studies examined the risk factors for indoor fallers and outdoor fallers, respectively, when compared with non-fallers. Seven prospective studies and one cross-sectional study were included, and five multivariate analyses were used to estimate the risk factors for indoor falls.

2.4.6.2.1. Biological Risk Factors

Most biological risk factors were highly associated with indoor fallers, while only a few biological risk factors were related to outdoor fallers. Although old age and female sex were the main risk factors for indoor falls compared to outdoor falls, most studies on indoor falling and outdoor falling were unable to find these associations when both indoor and outdoor fallers were compared to non-fallers. Only one cross-sectional study from Mexico found a higher prevalence of outdoor falls among the oldest age group (80+) and a higher prevalence of indoor falls among female subjects, after adjusting for socioeconomic factors (do Nascimento, Duarte, Lebrao, & Chiavegatto Filho, 2017). Obesity was also frequently reported in the included studies (N=5). Two longitudinal studies from the same database in Finland (Manty et al., 2009; Pajala et al., 2008) even found that indoor fallers tended to be more obese than non-fallers, and another longitudinal study in the United States showed that outdoor fallers tended to be less obese than non-fallers (J. L. Kelsey et al., 2010). Although no differences were found between indoor fallers and outdoor fallers in terms of falling history, most studies consistently found that histories of falling were more prevalent among indoor fallers and outdoor fallers than non-fallers. Depression was not frequently considered in the included studies (N=3), but both indoor and outdoor falls were associated with depression when compared to non-fallers. On the other hand, physical conditions and diseases such as activity limitation, comorbidity, balance impairment, and fair health status were only associated with indoor fallers and not outdoor fallers when compared to non-fallers.

2.4.6.2.2. Behavioral Risk Factors

Most behavioral risk factors were simultaneously associated with indoor and outdoor fallers. Studies showed that indoor fallers tended to exhibit less positive health-related behavior, while outdoor fallers were likely to exhibit more positive health-related behavior when compared to non-fallers. Half of the 14 studies (N=7) investigated behavior-related risk factors such as physical activity, medication use, alcohol consumption, utilitarian walking, recreational walking, and outdoor exposure. Multi-medication use was the most frequently cited risk factor (N=5) when examining the profiles of indoor and outdoor fallers. Three studies that included this variable presented results that consistently indicated a positive association between multi-medication use and indoor falling (A. Bergland, G. B. Jarnlo, & K. Laake, 2003; J. L. Kelsey et al., 2010; Pajala et al., 2008), and one of these studies remained significant after multivariate analysis (J. L. Kelsey et al., 2010). For outdoor fallers, the association with multi-medications produced mixed results: one multivariate analysis found higher levels of multi-medication use among outdoor fallers, while another multivariate analysis found lower levels. Other variables had differing associations between indoor and outdoor falls. For gait speed, two out of five studies indicated that indoor fallers tended to have slower gait speed than that of non-fallers, while outdoor fallers were more likely to have higher gait speed than that of non-fallers.

Likewise, other lifestyle and habits, such as alcohol consumption, utilitarian walking, recreational walking, physical activity, and outdoor exposure were associated differently with indoor fallers and outdoor fallers. Frequent alcohol consumption, higher rates of walking and physical activity, and more exposure to the outdoors were found among outdoor fallers. For indoor fallers, less frequent alcohol consumption, lower rates of walking and physical activity, and less exposure to the outdoors were found, as compared to non-fallers.

2.4.6.2.3. Socio-economic Risk Factors

Only one socioeconomic variable was found in three studies: education. Although half of the studies found associations between high education and indoor falls, as compared to outdoor falls, only one out of three studies indicated that high education was significantly associated with both indoor and outdoor fallers when compared to non-fallers.

2.5. Discussion

The aim of this systematic review was to understand the risk factors and protective factors associated with increases in indoor and outdoor falls among older adults. We found that a wide range of biological, behavioral, and social factors are associated with increased indoor and outdoor falls. The findings indicated that some variables were highly significant and consistent when comparing the risk profiles of indoor and outdoor fallers. The main biological-related risk factors contributing to indoor and outdoor falls were activity-limitations, cognitive impairments, functional impairments, health conditions, chronic comorbidity, and balance impairments biological factors. The main behavioral risk factors were physical activity and walking. Thus, the findings provided comprehensive understanding of different profiles related to indoor and outdoor falls: indoor fallers tend to have more chronic comorbidity, more balance problems, and lower levels of physical activity, whereas outdoor fallers were associated with higher levels of physical activity and longer walking times.

Also, our findings showed that outdoor falls were as frequent as indoor falls, even though older adults tend to spend the majority of their time indoors. Six out of the selected fourteen studies showed that outdoor falls were more prevalent than indoor falls. The variation in the reported prevalence of indoor and outdoor falls stems from the wide diversity of study designs. First, each study was conducted in a different country. In Europe, six out of seven (85%) showed higher prevalence for outdoor falls than indoor falls, but all other included studies conducted in North America (N=5, 100%), South America (N=1, 100%), and Asia (N=1, 100%) suggested that indoor falls were more frequent. Perhaps older adults in Europe are more likely to engage in moderate to high intensity activity than are older adults in the U.S., partly due to their different residential settings (Hagströmer, Troiano, Sjöström, & Berrigan, 2010). Second, the higher prevalence of indoor falls found in two studies may be explained by the characteristics of falls collected from medical reports and emergency departments (Landy, Mintzer, Dearwater, Graygo, & Schulman, 2012; Ranhoff, Holvik, Martinsen, Domaas, & Solheim, 2010). Injurious falls refer to any falls accompanied by physical injury; therefore, older adults with relatively high levels of physical impairment tend to suffer from injury after falling. This implies that injurious falls are more associated with indoor falls than outdoor falls. Another possible reason why two studies showed higher prevalence for outdoor falls at rates between 70% and 73% is that the ages of participants in the two studies were relatively young (63-76 years), given the fact that young-old groups tend to frequently engage in outdoor activity with having more possibility of falling outside than middle-and oldest-old groups (W. Li et al., 2006).

Furthermore, some methodological issues require further discussion. Current studies did not fully control for the confounding issues in analyzing the different indicators of indoor and outdoor falls—for instance, only a few studies have included the outdoor exposure variable (A. Bergland, G.-B. Jarnlo, & K. Laake, 2003; Jefferis et al., 2014; Mänty et al., 2009). Given that the amount of time spent outdoors is highly associated with outdoor falling, it is possible that the indoor falls experienced by older adults stem merely from their lack of opportunity to travel outside; thus, it is impossible to compare the two groups under identical conditions (O'Loughlin, Boivin, Robitaille, & Suissa, 1994; Quach et al., 2011). If we do not control for outdoor exposure issues, we are likely to misunderstand the precise influences of indoor and outdoor falls. To accurately control for these exposure issues, further studies would be needed to account for the subject's time spent indoors versus outdoors as a main confounding variable.

In addition to methodological differences, the paucity of previous studies comparing indoor and outdoor falls possibly stems from inconsistent definitions and the currently dichotomous classification of locations. Although etiologies of falls became well identified after adopting the concept of the indoor-outdoor dichotomy, this exclusive classification of falls based on location may ignore other factors related to how older individuals interact with space in terms of daily mobility and activity. Even within the same category of indoor falls, the risk characteristics of falls inside homes and falls inside other buildings are different; similarly, the conditions between private gardens and public walkways are different, even though these two areas are often classified under the same category of outdoor locations. One study found a significant difference between falls that occur just outside one's home and falls that occur far away from home (Bleijlevens et al., 2010). Another study indicated that active older adults tend to fall both outdoors and indoors, the common factor being that most incidents occurred far away from home (Kelsey, Procter-Gray, Hannan, & Li, 2012). Considering that individual physical activity and mobility level are associated with fall locations, it may be more helpful to adopt a continuum of place and life-space mobility assessments to understand the different profiles of fallers based on location (Lo et al., 2016).

2.6. Conclusion

This review provides a comprehensive outline of current research approaches regarding the identification of different risk factors for falls based on location. Understanding the different risk factors associated with indoor and outdoor falls is necessary for developing location-tailored strategies of fall prevention. For indoor fallers, especially home-based fallers who have health problems or activity limitations, it is imperative to provide health programs and regular examinations to sustain and check their health, function, and quality of life. Also, family attention and social interests that prevent isolation of frail older adults in their own homes are important to prevent serious injuries after indoor falling. For outdoor fallers, it is more important to promote safer neighborhood environments by helping older adults engage in outdoor physical activities and walking, even though they may be exposed to risk of outdoor falls. Improvement of environmental hazards may include even walking surfaces, adequate lighting, complete sidewalks, short crosswalks, and other safe neighborhood elements, all of which could reduce falling and even help older adults successfully recover from potential injuries.

3. NEIGHBORHOOD FACTORS AND FALL-RELATED INJURIES AMONG OLDER ADULTS SEEN BY EMERGENCY MEDICAL SERVICE PROVIDERS[1]

3.1. Synopsis

Falls are serious health problems among older adults, and are the leading cause of fatal and nonfatal injuries treated by emergency medical services (EMS). Although considerable research has examined the risk factors of falls at the individual level, relatively few studies have addressed the risk factors at the neighborhood level. This study examines the characteristics of neighborhood environments associated with fall injuries reported to EMS providers.

A total of 13,163 EMS records from 2011 to 2014 involving adults aged 65 and older in the city of San Antonio (TX, USA) were analyzed at the census tract level (n = 264). Negative binomial regression was used to identify significant census tract-based neighborhood environmental variables associated with the count of fall injuries in each census tract.

Adjusting for exposure variable and the size of the census tract, neighborhoods with higher residential stability, captured as the percent of those who lived in the same house as the previous year were associated with decreased count of fall injuries. Neighborhoods with higher residential density and having a higher vacancy rate were associated with increased count of fall injuries. The study highlights the importance of stable and safe neighborhoods in reducing fall

[1] This section is part of an open access article, International Journal of Environmental Research and Public Health: Lee S, Lee C, Rodiek S. Neighborhood Factors and Fall-Related Injuries among Older Adults Seen by Emergency Medical Service Providers. *International Journal of Environmental Research and Public Health*. **2017**; 14(2):163.

risks among older adults, which should be considered a prerequisite for promoting age-friendly environments.

3.2. Introduction

Falls are a common and serious health concern as people age. Every year, a fourth of people aged 65 years or older in the United States experience falls, and 20% to 30% of these falls result in nonfatal or fatal injuries (Sleet, Moffett, & Stevens, 2008; Stevens et al., 2012). In 2014, 2.7 million older adults were treated in emergency rooms for nonfatal falls ("National Center for Injury Prevention and Control. Web–based Injury Statistics Query and Reporting System.," 2014), which typically lead to a decrease in physical activity, quality of life, and social interaction; in the same year, 27,180 adults aged 65 and older in the United States died from serious falls. There are also age differences in risk of falling, with adults aged 85 years or older having greater risk of falling due to the deterioration in their overall health and functional status, compared to those 65-84 years of age (Grundstrom, Guse, & Layde, 2012).

Several risk factors are related to falls through a complex interaction of intrinsic and extrinsic pathways (O'Loughlin, Robitaille, Boivin, & Suissa, 1993). Intrinsic factors for falls include advanced age, muscle weakness, gait or balance problems, visual deficits, mobility limitations, and cognitive impairments (Bueno-Cavanillas, Padilla-Ruiz, Jimenez-Moleon, Peinado-Alonso, & Galvez-Vargas, 2000). Extrinsic factors related to falls include medications, assistive devices, and hazardous environments (e.g., an uneven surface, litter, and poor lighting) (Steinweg, 1997). These risk factors have been determined in previous studies using survey-based fall assessment tools at the individual level. The fall-prevention strategies also tend to focus on individualized approaches, such as exercise, footwear, or individual home safety

(Larsen, Mosekilde, & Foldspang, 2001; Luukinen et al., 2007; Simek, McPhate, & Haines, 2012).

To better understand where, why, and how falls occur, the contexts of residential environments where older adults live and are involved in activities should be taken into account, in addition to attributes of individuals. Studies have shown that physical and social characteristics of the neighborhood not only influence whether older adults remain in their communities or leave, but also influence their physical activities (Fisher et al., 2004; Saelens & Handy, 2008) and mobility (Balfour & Kaplan, 2002). What is less known is whether and to what extent falls are associated with community-level factors in terms of demographic, socioeconomic status, and physical environments.

Meanwhile, sociologists and urban planners have long identified the importance of neighborhood context as a structural factor that influences individual lives and access to opportunities (Massey, Gross, & Eggers, 1991). Concentrated disadvantages, including residential instability, social segregation, and poverty have been investigated from socio-ecological perspectives and shown to influence various social outcomes such as fear of crime and child development (Leventhal & Brooks-Gunn, 2000; Sampson, Morenoff, & Gannon-Rowley, 2002). Increasingly, epidemiologists and public health experts have also become aware of geographical inequality and the importance of places on health (Robert, 1998; Wen, Browning, & Cagney, 2003). In recent research, neighborhood characteristics such as family stability, crime, unemployment, and housing conditions have been shown to be associated with overall mortality, disease prevalence, health behaviors, and mental health outcomes (Foster & Giles-Corti, 2008; Kubzansky et al., 2005). A growing body of research examining the spatial clustering of mortality, homicide, and accidental injury has enabled researchers and practitioners to identify geographic hot spots linked with a wide range of health outcomes, enriching the discussions on the neighborhood-level risk factors (Elliot, Wakefield, Best, & Briggs, 2000; Langen, Ogden, & Schwarting, 2009).

Injuries among older adults have plausible associations with the neighborhood environment because most age-related falls occur in residential areas. Due to the combination of increased physical and psychological vulnerability, mobility limitations, and changing patterns of spatial use with age, neighborhood environments play an important role in maintaining health and mobility among older adults (Balfour & Kaplan, 2002; Rasinaho, Hirvensalo, Leinonen, Lintunen, & Rantanen, 2007a). A decrease in physical and cognitive capacity such as visual, balance, and cognitive impairment can result in older adults failing to cope with hazardous environments, and can lead to nonfatal and fatal injuries (Yen, Michael, & Perdue, 2009a). Neighborhoods with low socioeconomic status and high socio-physical disorder such as vacant buildings and crime tend to have poor maintenance conditions (Ross & Mirowsky, 2001), which may be associated with fall risks in vulnerable older adults with visual or balance impairments.

Several conceptual models describe neighborhood context as a risk factor associated with injury-related outcomes. The Haddon matrix, a commonly used tool in the injury prevention field, has been employed to identify factors related to environmental attributes as well as personal and agent attributes (Haddon Jr, 1968). The social determinants of health model highlights the environmental factors (e.g., stressful living conditions) and structural contexts (e.g., housing policies) that influence individual socioeconomic position and health outcomes (Marmot, 2005; Solar & Irwin, 2007). Such frameworks of neighborhood effects help explain the association between geographical measures of neighborhood contexts (e.g., social class, socioeconomic status, accessibility to community resources) and the clustering of injury outcomes (Diez Roux, 2001). For example, Baker and his colleagues (1987) found geographical variations in motor vehicle mortality rates associated with population density and capital income at the county level (Baker, Whitfield, & O'Neill, 1987). Some studies on falls found regional variations in demographics of residents hospitalized for falls, and identified high-incidence areas at the county level (Towne, Smith, Yoshikawa, & Ory, 2015). However, these studies did not identify the effects of neighborhood context on the clustering of falls. Determinants of fall clustering have not been well explored in terms of neighborhood characteristics, such as demographic, socioeconomic status, residential stability, socio-physical disorder, and land use.

Given the limited availability of spatially-based fall data and the difficulties in identifying the location and health information of fall injury patients, this research used fall data reported by emergency medical services (EMS). EMS provides identifiable, objective, and representative data on fall-related injuries. The aims of this study are to (a) examine the spatial inequality of fall-related injuries, and (b) estimate the effects of neighborhood contexts on fall injuries among older adults by different age groups (65-84 versus 85 years and older) at the census tract level. Although the census tract is still an aggregated geographic unit of analysis, it is much more fine-grained than those used in previous studies (e.g., County) and tracts have often been used as an acceptable neighborhood unit for large population studies lacking individual-level data (B. A. Lee et al., 2008). A central hypothesis that underlies these aims is that fall-related injuries do not occur evenly across areas. We also hypothesized that certain neighborhood contexts (e.g., socioeconomic status, rates of frequent residential mobility, and socio-physical disorders) are associated with the clustering of fall injuries

3.3. Methods

3.3.1. Data Source

This study used data from several sources. We used fall-related injuries data (2011-2014) reported by the EMS and the San Antonio Fire Department (SAFD) in the city of San Antonio, Texas. For the purpose of this study, we restricted the analysis to fall events of people aged 65 and older with a mean age of 80.6 reported from 2011 to 2014 (n=13,178). For the neighborhood variables, we used the 2013 American Community Survey (ACS) data from the US Census, the parcel-level land use data from the Bexar County Tax Appraisal District, and the property crime incidence data from the San Antonio Police Department. Geographic Information System (GIS) was used to generate the residential land use from the parcel data. The ACS data provided information about the socio-demographic and -economic status (i.e., median household income, number of aging residents), residential stability (i.e., owner-occupied housing rate, and the rate of residents living in the same house as the previous year), household structure, housing condition, dwelling types, and vacancy rate. The property crime data included all reported property crime incidents from 2011 to 2014. The spatial unit of analysis was the census tract; we used all 264 census tracts within the city of San Antonio for the neighborhood-level analysis after excluding census tracts that had missing data or < 500 residents.

3.3.2. Dependent Variable

To ascertain whether neighborhood context was associated with the count of fall-related injuries at the neighborhood-level, we used the total count of fall injuries by older adult groups stratified by age (≥65 years, 65-84 years, and ≥85 years) during the period of 2011 through 2014 at the census tract level as the outcome. Initially, the fall data reported by EMS was injuryentailed events which are different from general falls that broadly encompass light slips or trips without injuries. Since this dataset was pulled from the medical reports, it shows the number of actual patients who required medical treatment when EMS providers arrived at the scene. Thus, the count of neighborhood falls used in this study is the aggregated count of fall injuries occurred among different age groups collected by EMS providers at each census tract.

The fall location data contained the street name and zip code without the street number, which generated incompletely geocoded cases. Although the dataset did not allow us to find point-based fully geocoded locations, it enabled us to assign cases to street-based geocoded address lines depending on the street name and zip code. Those street-based geocoded address lines were then assigned to the census tract. Table 4 showed the number and percentages of fall injuries in the City of San Antonio by age category and geocoded status. More than half (n=8,720; 66.25%) of the street-based geocoded lines with fall incident(s) were contained within a single census tract, while the rest ran across two or more census tracts. These two types of address lines are not distributed at random, because most local and residential streets are short while arterial/collector roads and highways often travel across multiple census tracts (Marshall, 2004).

For the incompletely geocoded cases (n=4,443; 33.75%) we used a geographical imputation method to assign street-based geocoded cases to census based on the proportion of the street overlapping each tract and the aging population accounted for by each census tract. Although several geographic imputation methods have been used to reduce non-geocoded error, those imputation methods were conducted to assign non-geocoded cases to census tracts based on ZIP code centroid (Curriero, Kulldorff, Boscoe, & Klassen, 2010; Henry & Boscoe, 2008). Since street-based geocoded line within ZIP code is more accurate than ZIP code centroid, we adopted this imputation strategy after considering population density of the census tract, consistent with previous studies (Henry & Boscoe, 2008). For example, if .3 miles of the street-based geocoded line with a fall incident was located in census tract A that had 90 residents aged 65 and over and .7miles in census tract B having 140 older residents, an imputed fall count weighted by aging population density was assigned to .6 for census tract A and .4 for B.

Table 4 Number and percentages of fall injuries in the City of San Antonio, by age category and geocoded status, 2011-2014

Count of fall injuries	**(aged 65+) N=13,163**		**(aged 65 -84) N=8,237**		**(aged85+) N=4,926**	
	N	**%**	**N**	**%**	**N**	**%**
Completely geocoded cases	8,720	66.25	5,080	61.67	3,157	64.09
Incompletely geocoded cases	4,443	33.75	3,157	38.33	1,769	35.91

3.3.3. Independent Variables

To analyze the neighborhood environmental factors and other neighborhood safety conditions, eleven independent variables were included, classified into five groups: demographic and socioeconomic status, residential stability, household structure, housing condition, dwelling type, and socio-physical disorder. First, as part of demographic and socioeconomic status, we included net population density, median household income, and poverty rate in older adults at the census tract level. Residential density is typically associated with housing conditions and residential dwelling types, and injurious falls among older adults are disproportionately likely to be associated with home hazards. Households with lower incomes and houses in low income neighborhoods tend to lack fall prevention devices (stair handrails, grab bars) and have poor and hazardous conditions (poor stair design and dim lighting) for older residents (Krieger & Higgins, 2002). Second, residential stability was identified by the degree to which neighborhoods were stable, and included the proportion of owner-occupied housing units and the proportion of the residents that had lived in the same house for a year (Morenoff, Sampson, & Raudenbush, 2001). Given the negative impact of unsustainable forms of residence on health and well-being among older adults (Beard et al., 2009), housing stability may be an important consideration in understanding the risks in falling at the neighborhood level. Third, we added household structure because older adults living alone tend to have greater fear of falling and fall-related injuries compared to those living with others (Kumar, Carpenter, Morris, Iliffe, & Kendrick, 2014). In addition, several studies have indicated that older buildings have lower levels of maintenance, which in turn may lead to fires, collapse, or other injuries (Shai, 2006). Since injurious falls were associated with types of living environment, we included dwelling type as an independent variable. Finally, to capture neighborhood socio-physical disorders, we included vacancy rate and property crime (Ross & Mirowsky, 2001) that occurred between 2011 and 2014, a period that was consistent with the outcome data. These socio-physical disorders are well known to be associated with decreased physical activity levels as well as being proxy measures of poorly maintained neighborhood and housing conditions. We excluded pedestrian infrastructure or street condition associated with outdoor falls, because most EMS-based fall injuries occurred within the home.

3.3.4. Control Variables

Since we targeted fall incidents occurring among older adult groups, we added number of residents stratified by age as an exposure variable to account for the exposure issue, as census tracts having more older adults will likely have more fall incidents by older adults, regardless of the neighborhood conditions. Also, the spatial size of census tracts varies, with larger census tracts being generally located in the periphery of metropolitan areas with low population density (Dumbaugh & Rae, 2009). To control for the statistical effects of different census tract sizes on the possibilities of fall incidents, we included census tract acreage as a control variable. To help mitigate the previously reported limitation with the fall location data missing the street number, we further included an incompleteness rate variable, calculated as the number of partially geocoded falls using the proportional allocation method out of total fall counts within the census tract.

3.3.5. Analytical Approach

Due to the skewed distribution and overdispersion of the dependent variable of total fall injuries in the census tract, we used a negative binomial model according to age categories (model 1: age 65+, model 2: age 65-84, and model 3: age 85+). Each of the independent variables was tested by adding them one at a time after being controlled for confounding variables in each model. Independent variables with a P-value $<.05$ were then considered for the final multivariate analysis after being checked for multicollinearity. The analysis was conducted with STATA IC 12.0 (Stata Corp, College Station, TX). The incidence rate ratio (IRR) and 95% confidence intervals were reported. The IRR typically reports the estimated rate ratio of the incidence occurrence for a one unit increase in the independent variable (Srikanth et al., 2005). Negative binomial regression is adaptable for modeling count variables and can easily generate the estimates of prevalence. In this study, we used fall counts instead of fall rates (total falls divided by population or area) as the outcome variable due to ease of interpretation.

3.4. Result

3.4.1. Prevalence of Neighborhood Falls and Characteristics of Neighborhood Contexts

From 2011 through 2014, a total of 26,901 fall-related injuries were reported by EMS agencies in San Antonio, Texas. About half (n=13,163, 48.9%) of those incidents involved older adults aged 65+. Among them, 8,237 (62.6%) and 4,926 (37.4%) of incidents were based on adults aged 65-84 and aged 85 or older respectively. Table 5 illustrates univariate descriptive statistics for all variables used in the analysis at the census tract level. The count of fall injuries among people aged 65 and older between 2011 and 2014 within the census tracts was spatially over-dispersed (mean=51.50, standard deviation=35.76), which meant that the fall events were not distributed normally or equally across the city. In other words, certain contextual factors were contributing to the geographically inequitable distribution of fall incidents. The census tract level geographic distribution of fall incidents (counts of falls among the residents aged 65 and older) is presented in Figure 4.

Table 5 Descriptive Statistics of Study Variables for 264 Census Tracts in San Antonio, TX

Variable	Definition	Mean	SD	Min	Max
Dependent variable					
Fall injuries (aged 65+)	Imputed total fall count among residents by age groups between 2011-2014	51.50	35.76	3.77	224.35
Fall injuries (aged 65-84)		32.68	19.85	3.61	112.08
Fall injuries (aged 85+)		18.81	18.46	0.00	116.20
Confounding variable					
Incompleteness rate (aged 65+)	Count of incompletely geocoded fall cases / total imputed fall counts within census tract by age groups	0.37	0.27	0.00	1.00
Incompleteness rate (aged 65-84)		0.38	0.27	0.00	1.00
Incompleteness rate (aged 85+)		0.36	0.29	0.00	1.00

Table 5 Continued

Variable	Definition	Mean	SD	Min	Max
Population aged 65+	Number of population by age groups (Exposure variable)	504.98	258.42	62.00	1401.00
Population aged 65-84		437.43	217.75	62.00	1305.00
Population aged 85+		67.55	66.84	0.00	448.00
Areas (acres/1,000)	Size of each census tract (acres/1,000)	0.87	1.00	0.18	11.46
Demographic and socioeconomic status					
Net population density	Total population/ residential land acreage	17.74	7.79	2.23	78.31
Median household income ($/10,000)	Median household income ($/10,000)	4.67	2.51	0.98	18.59
% older adults below poverty level	Residents aged 65+ living at poverty level/ total residents aged 65+ × 100	13.90	11.65	0.00	57.60
Residential stability					
% owner-occupied	Owned housing units /total housing units × 100	20.00	7.00	2.24	39.02
% residence 1 year and over	Residents living in the same house 1 year ago/total residents × 100	81.10	10.56	34.75	97.97
Household structure and housing condition					
Percent living alone	Living alone households/ family households × 100	36.52	13.96	3.21	85.60
% older housing	Housing units built before 1950/ total housing units × 100	21.39	31.71	0.00	94.17
Dwelling type					
% single-family units	Single-family housing units/ total housing units × 100	78.35	26.93	1.57	120.80
% multi-family units	Multi-family housing units/ total housing units × 100	31.78	29.53	0.00	126.89
Socio-physical disorder					
% vacant housing units	Vacant housing units/ total housing units × 100	10.28	5.93	0.00	33.08
Property crime (N/1,000)	Total property crime count between 2011-2014 (N/1,000)	2.63	1.65	0.23	11.82

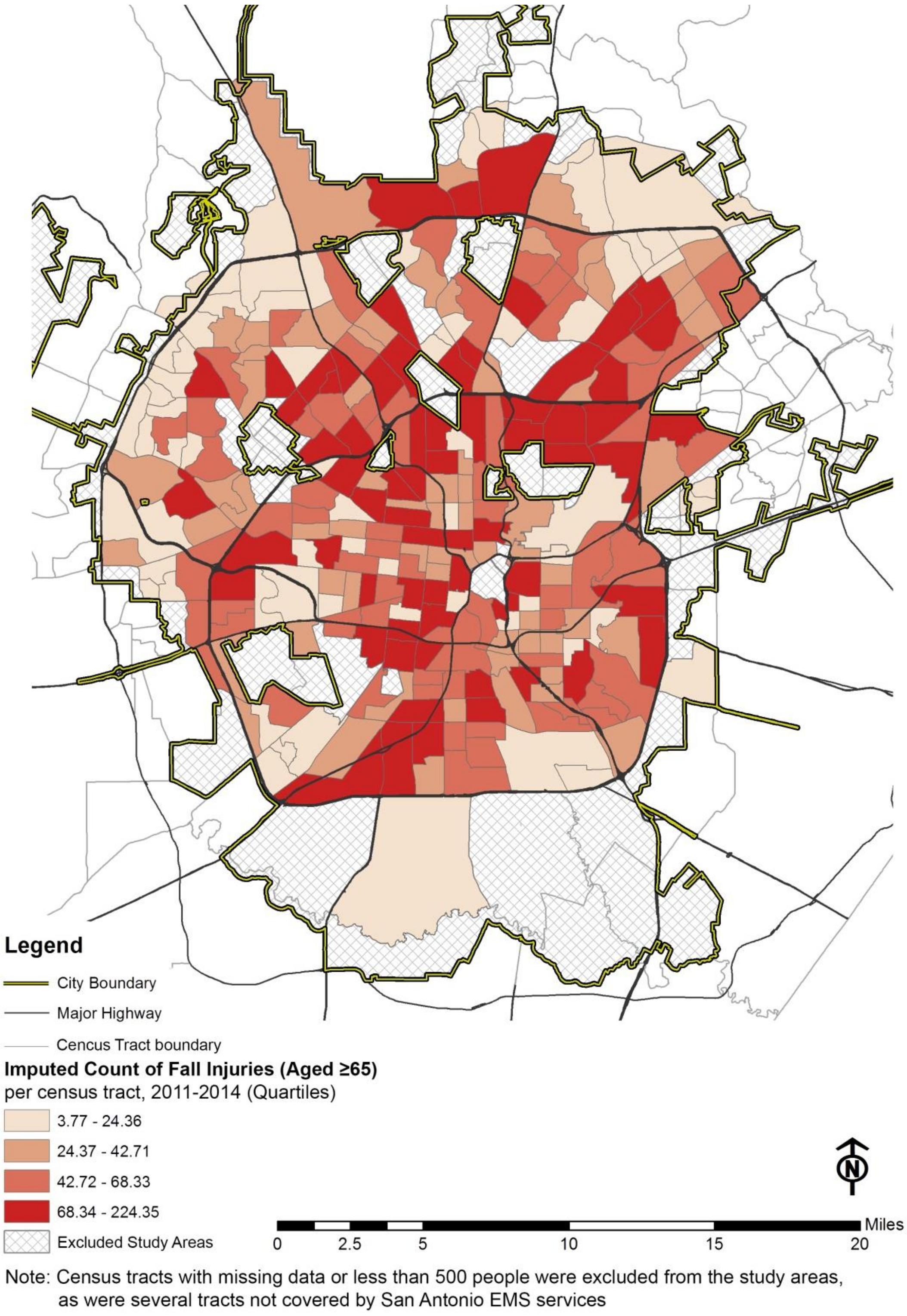

Figure 4 EMS Recorded Fall-Related Injuries (Aged ≥ 65) per census tract, City of San Antonio, 2011-2014

3.4.2. Neighborhood Contexts Associated with Counts of Falls at the Neighborhood Level

Table 6 shows the partially adjusted model for the relationship between neighborhood contexts and fall-related injuries by age groups. The factors influencing the fall injuries that occurred among the age 65-84 group slightly differed from those affecting the fall injuries that occurred among the age 85+ group. After adjusting for exposure and confounding variables, median household income and percent of household living alone were significantly associated with the count of fall injuries in the aged 65 + group model 1 and aged 65-84 group model 2, but not in the 85+ group model 3. However, percent of older adults below poverty level was highly and significantly associated with the count of fall injuries in the aged 85+ group model only. Other variables, such as percent of owner-occupied, percent of residence 1 year and over, percent of single- and multi- family units, percent of vacant housing units, and property crime, were strongly associated with count of fall injuries in 65+ group model, 65-84 group model, and 85+ group model independently.

In the 65+ group model, the areas with high residential stability were significantly associated with a decreased count of fall injuries. The percent of those who lived in the same house as the previous year (IRR=.980, CI=.975-.985, $p<.01$) and the percent owner-occupied housing (IRR=.972, CI=.965-.979, $p<.01$) were shown to be associated with a decreased count of fall injuries. Neighborhoods with a higher percent of older adults below poverty level (IRR=1.308, 95% CI=0.984-1.739, $p<.05$), a higher percent of household living alone (IRR=1.006, CI=1.000-1.010, $p<.01$), a higher percent of vacant housing units (IRR=1.033, CI=1.024-1.043, $p<.01$), and a higher property crime incidence (IRR=1.077, CI=1.036-1.119, $p<.01$) were associated with higher fall incidence. The magnitude of influence that property crime had on total falls, however, was not strong, with each additional property crime in 1,000 increasing the count of fall injuries by only 7.7%. In addition to residential stability and neighborhood quality, neighborhoods with lower percent of single-family units (IRR=.992, CI=.990-.994, p<.01) and higher percent of multi-family units (IRR=1.008, CI=1.007-1.010, p<.01) were associated with higher fall incidence.

Table 6 Partially Adjusted Analysis: Neighborhood Context and Count of Fall-related Injuries at the Census Tract Level (n=264)

	Model1 Count of fall injuries (aged 65+) [a]		**Model2 Count of fall injuries (aged 65 -84)** [a]		**Model3 Count of fall injuries (aged85+)** [b]	
Variable	**IRR (95% CI)**	**P-value**	**IRR (95% CI)**	**P-value**	**IRR (95% CI)**	**P-value**
Demographic and socioeconomic status						
Net population density	1.021** (1.014-1.029)	<0.001	1.021** (1.014-1.028)	<0.001	1.018** (1.005-1.031)	0.006
Median household Income ($/1,000)	0.947** (0.923-0.972)	<0.001	0.941** (0.918-0.965)	<0.001	0.963 (0.914-1.015)	0.159
% older adults below poverty level	1.308* (0.984-1.739)	0.020	1.257 (0.962-1.641)	0.094	2.077* (1.045-4.129)	0.037
Residential stability						
% owner-occupied	0.972** (0.965-0.979)	<0.001	0.972** (0.966-0.979)	<0.001	0.977** (0.963-0.99)	0.001
% residence 1 year and over	0.980** (0.975-0.985)	<0.001	0.984** (0.979-0.988)	<0.001	0.978** (0.968-0.987)	<0.001
Household structure and housing condition						
% living alone	1.006** (1.000-1.010)	0.007	1.007** (1.002-1.011)	0.002	1.003 (0.995-1.011)	0.449
% older housing	1.000 (0.999-1.003)	0.486	1.001 (0.999-1.003)	0.305	1.001 (0.997-1.005)	0.615
Dwelling type						
% single-family units	0.992** (0.990-0.994)	<0.001	0.993** (0.991-0.995)	<0.001	0.992** (0.988-0.995)	<0.001
% multi-family units	1.008** (1.007-1.010)	<0.001	1.007** (1.005-1.008)	<0.001	1.009** (1.006-1.012)	<0.001

Table 6 Continued

	Model1 Count of fall injuries (aged 65+) [a]		**Model2 Count of fall injuries (aged 65 -84)** [a]		**Model3 Count of fall injuries (aged85+)** [b]	
Variable	**IRR (95% CI)**	**P-value**	**IRR (95% CI)**	**P-value**	**IRR (95% CI)**	**P-value**
Socio-physical disorder						
% Vacant housing units	1.033** (1.024-1.043)	<0.001	1.026** (1.016-1.035)	<0.001	1.042** (1.024-1.06)	<0.001
Property crime (N/1,000)	1.077** (1.036-1.119)	<0.001	1.073** (1.035-1.112)	<0.001	1.075* (1.008-1.147)	0.029

Note: ** P <0.01, *0.01≤ P <0.05; Adjusted by negative binomial model for confounding variables: incomplete rate, population (older adults) stratified by age (exposure variable), areas; [a] N=264; and [b] N=239

3.4.3. Multivariate Analysis of Risk Factors for Counts of Fall-Related Injuries at the Neighborhood Level

Table 7 displays adjusted incidence rate ratios from the multivariate analysis according to different age group model. Percent older adults below poverty level, percent owner-occupied, percent single-family units, and percent vacant housing units were dropped from further analyses due to multicollinearity. Also, percent older housing was excluded from the multivariable-adjusted analysis because of statistically low significance (P>.05). In the aged 65+ group model 1, three variables were significantly associated with the count of fall injuries after controlling all other significant variables. Increased residential density was significantly associated with an increased count of fall injuries. This may be because neighborhoods with low residential density tend to have better housing conditions, compared to areas with high residential density. For residential stability, each one percentage point increase in the population 1 year and over by length of residence was associated with a 1.1% decrease in the count of fall injuries (IRR=.989, 95% CI: .983-.995, p<.01), while holding all other variables in the model constant. The housing vacancy rate (IRR=1.022, 95% CI: 1.012-1.032, p<.01) also remained significant. For each one percentage point increase in vacancy rate, the count of fall injuries that occurred among those aged 65 and over increased by 2.2%. Finally, socio-physical disorder was more strongly associated with the fall injuries that occurred among those aged 85+ (% vacant housing units: IRR=1.032, 95% CI: 1.013-1.052, p<.01), compared to those aged 65-84 (% vacant housing units: IRR=1.015, 95% CI: 1.005-1.024 p<.01) in the comparison between model 2 and model 3.

Table 7 Multivariable- Adjusted Analysis: Neighborhood Context and Count of Fall-Related Injuries at the Census Tract Level (n=264)

	Model 1 Count of fall injuries (aged 65+) [a]		**Model 2 Count of fall injuries (aged 65 -84)** [a]		**Model 3 Count of fall injuries (aged85+)** [b]	
Variable	**IRR (95% CI)**	P-value	**IRR (95% CI)**	**P-value**	**IRR (95% CI)**	**P-value**
Incompleteness rate (aged 65+)	0.852 (0.688-1.055)	0.779	-	-	-	-
Incompleteness rate (aged 65-84)	-	-	0.862 (0.699-1.062)	0.163	-	-
Incompleteness rate (aged 85+)	-	-	-	-	0.611** (0.419-0.891)	0.010
Population aged 65+	(Exposure)	-	-	-	-	-
Population aged 65 -84	-	-	(Exposure)	-	-	-
Population aged 85+	-	-	-	-	(Exposure)	-
Area (acres/1,000)	0.959 (0.898-1.023)	0.202	0.995 (0.935-1.059)	0.880	0.904 (0.797-1.026)	0.117
Net population density	1.010* (1.002-1.019)	0.020	1.012** (1.004-1.021)	0.003	1.006 (0.99-1.022)	0.481
Median household Income ($/1,000)	0.993 (0.959-1.029)	0.708	0.976 (0.943-1.009)	0.153	1.019 (0.943-1.101)	0.634
% residence 1 year and over	0.989** (0.983-0.995)	<0.001	0.993* (0.987-0.998)	0.011	0.986* (0.974-0.998)	0.022
% living alone	0.996 (0.990-1.002)	0.198	0.996 (0.991-1.002)	0.169	0.996 (0.985-1.007)	0.460

Table 7 Continued

	Model 1 Count of fall injuries (aged 65+) [a]		Model 2 Count of fall injuries (aged 65 -84) [a]		Model 3 Count of fall injuries (aged85+) [b]	
Variable	**IRR (95% CI)**	P-value	**IRR (95% CI)**	**P-value**	**IRR (95% CI)**	**P-value**
% Vacant housing units	1.022** (1.012-1.032)	<0.001	1.015** (1.005-1.024)	0.002	1.032** (1.013-1.052)	0.001
Property crime (N/1,000)	1.035 (1.000-1.071)	0.050	1.032 (0.999-1.067)	0.056	1.059 (0.995-1.127)	0.070

Note: **P<0.01, *0.01≤ P <0.05 N=264; Model1 (LR Chi2=1458.81; P-value<0.001); Model2 (LR Chi2=552.95; P-value<0.001); Model3 (LR Chi2=1454.81; P-value<0.001); a N=264; and b N=239

3.5. Discussion

This paper explores characteristics of fall-vulnerable areas in terms of demographic and socio-economic status, residential stability, household structure/ housing condition, dwelling type, and socio-physical disorder. The findings indicate that low income areas have more fall injuries than high income areas, because housing in low income areas tends to have poor maintenance, lack of opportunities to participate in fall-prevention programs, and lack of home-safety devices for seniors. The finding that the areas with high residential stability were negatively associated with fall-related injuries suggests the importance of stable neighborhood environments in preventing fall injuries among older adults. Generally, residential stability at the neighborhood level is known to be associated with neighborhood quality and psychosocial stressors (Marmot, 2005; Ross, Reynolds, & Geis, 2000). Previous studies showed that length of residence and housing ownership, as measures of residential stability, may also influence the level of familiarity with one's home and surroundings (Lawton, 1989; Liben, 1981). In other words, low residential stability due to decreased financial resources after retirement, and desire to be closer to family, health care, or amenities, may contribute to an increased exposure to unfamiliar residence or neighborhoods among older individuals, and could possibly increase the likelihood of injuries from falls (Phillips, Walford, Hockey, Foreman, & Lewis, 2013).

In addition to residential stability, the results also indicated that improving neighborhood security and reducing socio-physical disorder could help prevent fall injuries. High vacancy rates, daily exposure to threatening environments, fear of property crime, and anxiety about neighborhood crime could make older adults avoid going outside, which could result in reduced physical and social activities (Loukaitou-Sideris & Eck, 2007; Rantakokko et al., 2009). Such reduced activities could lead to mobility impairments and unintentional falls inside the home (Stevens & Olson, 2000). Despite the lack of studies directly examining the relationship between socio-physical disorder and falls, several previous studies have supported the idea that threatening and hazardous environments characterized by crime, danger, and incivility would be associated with other health-related outcomes such as increased fear, physical inactivity, and decreased walking (King, 2008; Ross & Mirowsky, 2001).

Findings from the multivariate model suggest that urgent attention to fall prevention is needed in areas with a large population of older adults, short residential duration, and high vacancy rates. People living in such neighborhoods are prone to lack sufficient social ties or are vulnerable to the risk of crimes as well as injuries from falls (Sampson et al., 2002). Thus neighborhood interventions to promote stability, decrease mobility and displacement, and mitigate vacancy rates may serve an important role in preventing falls among older adults at the neighborhood level. For example, a rental stability program could offer a senior tenant an opportunity for longer lease terms (Chase, 2010), and might be helpful in preventing or reducing fall injuries. Also, strategies for stronger markets, such as foreclosure prevention programs and rehabilitation for sale, could assist owner and renter occupants to remain in their homes (Foros, 2004) and therefore contribute to reducing the risk of fall incidents among older adults.

This study also found that fall injuries among the 85+ group tended to be less influenced by household structure (% living alone), compared to fall injuries among the 65-84 age group at the neighborhood level. However, residential stability (e.g., housing ownership and length of residence) and socio-physical disorder (e.g., vacant housing units and property crime) were both associated with fall injuries among the 65-84 age group and the 85+ age group. Given the fact that risk of falling in those 85 years and older appears to be greater than in those 65-84 years of age at the individual level, the intrinsic factors of fall injuries, such as health status, mobility limitations, and gait or balance would be more associated with oldest-old group compared to young- and middle- old group (Grundstrom et al., 2012). However, neighborhood- based extrinsic factors or social determinants of fall injuries are both highly related to those aged 65-84 and 85+, while different neighborhood intervention strategies would be necessary in areas where fall injuries occurred among those aged 65-84 and those 85+ years of age.

While this study has provided insights into potential preventive strategies to reduce neighborhood fall-related injuries, some limitations should be acknowledged. This study failed to incorporate individual-level variables such as health conditions, balance impairments, cognitive problems, and other health factors that would be important determinants of individual fall incidents. The Health Insurance Portability and Accountability Act (HIPPA) privacy rule protects access to individual medical records (AC, 1996). Further studies could examine within- and between- neighborhood variability in fall incidents employing multilevel modeling approaches. This study also relied on a cross-sectional approach that failed to draw causal inferences between variables. A longitudinal study should be undertaken to determine the relationship between the duration of where people live, and fall incidence.

The EMS-based fall data have both strengths and limitations. First, the population-based data enable researchers to estimate the relationship between neighborhood environments and fall-related injuries. Compared to a self-surveyed measurement of falls that relies on sample participants, falls collected by EMS providers were more reliable and systematic, providing fairly accurate location data. However, the data of falls seen by EMS providers were somewhat limited in locational accuracy to be precisely geocoded at this time, as the released address data lacked the street number. Thus, we were not able to use a smaller unit of analysis and had to use the census tract as the spatial unit.

Moreover, it was not possible to distinguish between indoor and outdoor falls in our analysis. In the EMS data at the county and state level, the locations of fall incidents were documented, but the location information was not released at the census tract level. People who experienced falls in homes versus outdoors such as on sidewalks or streets have different risk profiles: indoor fallers tend to be female, have worse health status, and have balance impairment, while outdoor fallers are more likely to be physically active (Bath & Morgan, 1999). Moreover, the outdoor neighborhood environment, such as walkability, street connectivity, and other street conditions are relevant to outdoor falls only (W. Li et al., 2006). Not surprisingly, most fall incidents seen by EMS providers occurred in homes, according to the Texas EMS/Trauma Registry. City-specific EMS-based fall data are limited but the regional data combining the City of San Antonio and Bexar County showed only 3.06% of the total falls among people aged ≥65 years occurred in streets or sidewalks. Further research is needed to analyze the relationships between outdoor built environments and outdoor falls, due to the scarcity of available information, compared to the literature on indoor and personal risk factors for falls. Relying on the census tracts as a proxy of neighborhoods is another limitation. Using census tracts may not fully reflect a meaningful definition of neighborhood, and the variability of fall incidents within the census tract could not be examined.

Despite these limitations, the study provides information about “fall hot spots” where falls among older adults are spatially concentrated. Our identification of fall hot spots suggests that EMS providers, gerontologists, public health experts, and policy makers can further explore why fall incidents occur and are concentrated in certain places, making it possible to develop effective fall prevention strategies to mitigate falls and subsequent injuries. For example, with the information on a fall hot spot map, fire departments and EMS providers can prepare medical treatments and provide ambulances to respond immediately and adequately to the fall injury patients. Transportation and urban planners can help find ways to minimize the arrival time of ambulances and increase accessibility to hospitals in areas prone to fall incidence. Also, policy makers could use this map to locate EMS or medical facilities appropriately, considering fall incidence rates in addition to other population and health-related conditions.

3.6. Conclusions

Given the high prevalence and healthcare costs related to injuries from falls, it is important to comprehensively approach fall prevention at both the individual and neighborhood levels. The findings from this study suggest that multifaceted community interventions to create stable and safe neighborhoods could play a significant role in preventing fall-related injuries. These findings help identify fall-related risk factors in the neighborhood environment; this can be especially beneficial to the health and quality of life of older adults, who are at the highest risk of falling and being injured from falls. These findings can also help policy-makers, healthcare/EMS providers, and urban planners consider fall-related injuries in their efforts toward promoting healthy aging and creating age-friendly neighborhoods.

4. ASSOCIATIONS BETWEEN CHANGES IN THE NEIGHBORHOOD ENVIRONMENTS AND CHANGES IN THE RECENT FALL STATUS AMONG COMMUNITY-DWELLING OLDER ADULTS OVER TIME: 1-YEAR PROSPECTIVE COHORT STUDY

4.1. Synopsis

Falling, the most frequent cause of injury among older adults, poses a substantial barrier to walking and physical activity. Neighborhood environments have been increasingly associated with fall incidents and the fear of falling. However, little is known about the causal impact of neighborhood environments on falling. Through longitudinal analysis, this prospective observational study identified whether changes in outdoor environmental attributes influenced changes in falls.

We used interview data taken from community-dwelling adults aged ≥65 years listed in the 2011 and 2012 National Health and Aging Trends Study (NHATS), a nationally representative sample selected from 35.3 million Medicare beneficiaries aged ≥65 years living in the United States. Neighborhood environmental barriers were assessed by the interviewers. Using the subset of the sample that did not report falling in 2011, logistics regressions were estimated to identify time-varying neighborhood risk factors linked to the odds of experiencing a more recent fall in 2012.

Almost one out of ten (9.7% of 4,802) subjects reported experiencing recent falls in 2012. After sociodemographic, health, and walking-related behavioral covariates were adjusted, the fallers were found to be more likely to reside in neighborhood environments that contained

obstructions on sidewalks/streets in both 2011 and 2012 (OR = 1.894, 95% CI = 1.187-3.021) and that saw an increase in uneven walking surfaces or broken steps in the area surrounding their homes from 2011 to 2012 (OR = 1.422, 95% CI = 1.007-2.009), after adjusting for socio-demographic, health, and walking-related behavioral covariates.

Our findings suggest that safe and well-maintained outdoor environments may help prevent falls among older adults who engage in outdoor activities. Policy and planning strategies implemented to mitigate fall-related hazards would help public health experts, gerontologists, and urban planners create safe, barrier-free neighborhoods that promote and maintain the health, mobility, and well-being of all residents, especially older adults.

4.2. Background

Falling is especially prevalent among elderly individuals who engage in daily activities or walk around their neighborhoods. Every year, one-fourth of people aged 65 years or older in the United States experience falling, and one-fifth of falls cause serious injury such as head trauma, broken bones, or hip fractures (Sterling et al., 2001). These fall-based injuries are substantial barriers to walking and healthy aging among older adults. Older adults who have suffered from prior fall incidents tend to experience restricted outdoor mobility, decreased physical activity, social withdrawal, and loss of confidence, prompting them to spend most of their time at home (Ageing & Unit, 2008).

Falls typically occur in particular environmental settings (e.g., on the floor or near stair steps) through certain interactions between personal factors (e.g., age or comorbidities) and behavioral situations (e.g., walking, standing up, or sitting down) (Clemson, Mackenzie, Ballinger, Close, &

Cumming, 2008). Older adults who possess functional limitations, comorbidities, or anxiety, as well as those who do not engage in physical activity, tend to face high risk of falling. Also, because older adults tend to spend the majority of their time indoors, reduction of home environmental hazards (such as poorly maintained stairways, poor lighting, hard surfaces, and lack of handle bars or other safety devices) would likely help to prevent falls (Lord, Menz, & Sherrington, 2006b; Mary E Northridge et al., 1995).

Increasing amounts of evidence suggest that poor neighborhood environmental factors such as residential instability, threat of crime, and physical hazards may not only affect the risk of falling but also the overall health outcomes of people throughout their lives (S. Lee, Lee, & Rodiek, 2017). Due to the increases in physical and psychological vulnerability and mobility limitation as well as the changing patterns of spatial use that come with age, neighborhood environments play a major role in maintaining health and mobility among older adults (Balfour & Kaplan, 2002; Rasinaho et al., 2007b). Decreases or impairments in physical and cognitive capacities such as vision, balance, and cognition result in older adults failing to cope with unhealthy and hazardous environments, leading to both nonfatal and fatal injuries (Yen, Michael, & Perdue, 2009b). Also, previous research has indicated that poor street conditions such as uneven pavements and long crosswalks can directly influence the risk of falling.

Moreover, previous studies have shown that approximately half of falls among community-dwelling older adults occur outdoors, often in the yard or on the street. For example, older adults tend to fall in response to changes in ground level, uneven surfaces, litter, and other outdoor environmental hazards. Recent studies have supported this notion that outdoor falls are influenced by outdoor environmental risk factors. Li et al. (2006) conducted a case-control study with large samples and found that uneven and wet surfaces were associated with outdoor falls

(W. Li et al., 2006). Qualitative studies have shown that older individuals reported uneven walking surfaces, inadequate maintenance, poor lighting, and unsafe traffic patterns as perceived risk factors (Chippendale & Boltz, 2015b; Nyman, Ballinger, Phillips, & Newton, 2013b). Lai et al (2009) adopted a spatial approach to examine where outdoor falls occur and showed that areas with wet surfaces often had higher concentrations of falls (Lai, Low, Wong, Wong, & Chan, 2009). A recent study conducted by Curl et al. (2016) developed an audit checklist to assess the risk of outdoor falling using seven dimensions: changes in level, path condition and smoothness, path material, obstructions, road crossings, street lighting, and weather (Curl et al., 2016).

Neighborhood environments have increasingly become associated with falling, yet there is an inadequate amount of longitudinal research that examines the relationship between changes in neighborhood environments and changes in fall status over time. Age differences also factor into the risk of falling, as adults aged 85 years or older tend to face higher risks of falling because of decreases in overall health and functional conditions in comparison with younger individuals who are 65-84 years of age (Grundstrom et al., 2012). However, few studies have explored the differential influence of environmental factors on the risk of falling across age groups.

The objective of this study was to address whether changes in outdoor environmental attributes influence changes in falls among older adults through longitudinal analysis (a 12-month prospective cohort study). This study also examined the variable of age and its influence on the risk of falling over time. Given the ecological perspective, we first hypothesized that older adults who frequently encountered environmental barriers would experience an increased likelihood of falling than those who lived in places with fewer environmental barriers (i.e., litter, broken windows, or broken steps/uneven pavement). Second, we hypothesized that for the oldest subset of adults (85+ years), environmental barriers would function more effectively as an indicator of falling risk than for older adults between the ages of 65 and 74.

4.3. Methods

4.3.1. Study design, setting, and sample

The data for the present study were taken from the National Health and Aging Trends Study (NHATS)—an ongoing longitudinal study that surveys a nationally representative sample of 35.3 million Medicare beneficiaries aged 65 or older who reside in the United States. The sample frame of NHATS relies on Medicare enrollment and receives funding from the National Institute on Aging (NIA), which aims to explore late-life disability trends in terms of social and environmental living conditions as well as individual health and behavior. Data are collected by trained personnel through annual in-person interviews and assessments. In round one, 8,245 participants joined the survey from among 12,411 selected individuals (weighted response rate = 71.6%). In round two, 6,113 individuals participated in the survey on the condition that they had responded during round one (weighted response rate = 84.9%). Since our study sought to investigate the relationship between falling and outdoor environments near the home among community-twelling residents, we excluded respondents who resided in nursing homes (n=468) or other similar settings (n=412) and non-self respondents (n=517) represented as proxy respondents due to health problems, resluting in a sample of 6,680 community-dwelling older adults at baseline. At the follow-up year, 5,659 of the 6,680 repondents were interviewed again and we excluded those who moved to non-community-dwelling housings (n=332), resulting in 5,327. Finally, we excluded responses from participants that claimed never to move outside (n = 36) at the baseline because our interest focused on whether the outdoor environment was associated with the risk of falling. Of the 5,291 participants, 4,802 (90.8%) did not fall within a month at baseline.

4.3.2. Dependent variables

Self-reported recent fall incidents were provided by respondents at each survey period (2011 and 2012). Respondents were asked whether they had fallen in the last month and whether they had fallen more than once. In this questionnare, a "fall" referred to any slip or trip that caused respondents to lose their balance and land on the floor, the ground, or another lower level. This definition was consistent with that of previous research from the Kellogg International Work Group (1987), which defined a fall as "an event which results in a person coming to rest inadvertently on the ground or other lower level." (Gibson, 1987) These outcomes did not separate indoor and outdoor falls. Change in fall status was operationalized in the longtitudinal analysis as the history of falls at follow-up minus the history of falls among those who did not fall at baseline (increased falling versus no falling). We used near-fall events during a one-month period as the outcome instead of yearly-based fall events to be more accurate and to correspond with the measurement of the following outdoor environmental variables.

4.3.3. Outdoor environmental conditions

The five outdoor environmental barriers that were hypothesized to correlate with the risks of falling were classified under three domains: a) environmental obstruction (litter or trash on sidewalks), b) neighborhood disorder (graffiti, vacant houses, or broken windows), and c) problems related to walking surfaces (uneven walking surfaces or broken steps). These environmental conditions were derived from an environmental checklist completed by the interviewer before the in-person interview by observing the outdoor environment around each participant's home. Each outdoor environmental barrier was specifically measured using a four-scale response ("none," "a little," "some," and "a lot") to three items: 1) the amount of litter, broken glass, or trash found on the sidewalks and streets, 2) the amount of graffiti on buildings and walls, and 3) the amount of vacant/deserted houses or storefronts around the participant's home. These three variables were dichotomized ("none" versus "a little," "some," and "a lot") for analysis because of an inadequate distribution. Also, two dichotomous responses ("no" versus "yes") were included to measure perceived outdoor environmental conditions based on the following items: 4) whether there were many broken or boarded-up windows and 5) whether there were many uneven walking surfaces or broken steps around each participant's home.

4.3.4. Covariate measures

Several sociodemographic, health, and walking-related behavioral determinants for falling were selected based on previous studies (Ambrose et al., 2013; Patel et al., 2014). For the sociodemographic dimension, we included age, sex, race/ethnicity (non-Hispanic white and others), marital status, and job status. For the health dimension, the following factors were included: obesity (normal: $BMI < 25$, overweight: $25 \leq BMI < 30$, and obese: $BMI \geq 30$), self-reported health conditions (excellent, very good, good, fair, and poor), fear of falling in the last month (yes or no), history of falling (yes or no), depression ("none" versus "several days of feeling depressed," "more than half of the days of feeling depressed," or "nearly every day of feeling depressed"), balance impairment in the last month (yes or no), mobility limitations within a quarter-mile (yes or no), and difficulty associated with traveling outside (yes or no). Vision impairment (no or yes) was also assessed based on the following three questions addressing whether participants 1) were legally blind; 2) had trouble reading newspaper print with glasses, contact lenses, or visual aids; and 3) were able to see a television across the room with the use of glasses or contact lenses. Three medical conditions (arthritis, stoke, and dementia) were also included. Finally, the walking-related behaviors were measured by four dichotomous questions (yes or no) about the use of a walking aid when traveling outside, walking to move to different outside locations in the last month, vigorous activity in the last month, and the frequency of outside travel in the last month (0-4 days per week versus more than 5 days per week). We measured both time-invariant (baseline age, sex, and race/ethnicity) and time-variant (marital status, job status, obesity, self-reported health condition, history of falls, fear of falling, depression, balance impairment, mobility limitation, difficulty with traveling outside, vision impairment, arthritis, stroke, dementia, use of a walking aid, walking to move to different places, vigorous activity, and frequency of traveling outside) confounders.

4.3.5. Statistical analysis

The characteristics of the participants at baseline and follow-up were reported using descriptive statistics. Differences in the distribution of sample characteristics between stable falls and increased falls among those who had no history of falling within the past month at the baseline year were investigated using the χ^2 statistic. Bivariate and multivariate logistics regressions were performed to obtain unadjusted and adjusted risks, respectively, and 95% confidence intervals (CIs) of the outcome variable (change in fall incidents from 2011 to 2012) in relation to changes in neighborhood environment variables. A value of $p < .05$ was considered statistically significant for all analyses. To examine the prospective association between changes in environmental perception and changes in fall occurrence, we also used a change outcome (increased number of falls from baseline to follow-up) after adjusting for both time-variant and time-invariant covariates in the longitudinal study. All statistical analyses were carried out using Stata IC 12.0 (Stata Corp, College Station, TX).

4.4. Results

4.4.1. Participants' Characteristics by Fall Status

Table 8 shows samples with no falls at baseline (n = 4,802) by fall status during a follow-up year: 90.3% had no falls during a follow-up year, and 9.7% fell during a follow-up year. On average, the participants were 76.5 years of age (SD = 7.3). The age group of the sample was wide: 43.9% were aged between 65 and 74 years (youngest age group), 40.6% were aged between 75 and 84 years (middle age group), and 15.5% were aged 85 years or older (oldest age group). The majority of the sample was female (56.8%) and non-Hispanic white (69.5%). During the follow-up year, most of the sample was unemployed or retired (87.8%). Nearly half (50.4%) had never been married, divorced, widowed, or separated. When asked to report their obesity status, 37.5% of participants responded as overweight, and 27.1% responded as obese. Less than a third of participants reported health problems, including fair-poor health conditions (23.4%), fear of falling (27.3%), mobility limitations (27.5%), and difficulty with traveling outside (12.0%). The majority of participants reported being diagnosed with arthritis (58.0%). A few participants reported being diagnosed with vision impairment (7.5%), stroke (10.6%), or dementia (3.4%). Most participants reported not using walking aids to travel outside (74.8%), not being involved in vigorous activity (61.5%), and traveling outside more than 5 days per week (84.8%). Half of participants (50.0%) reported walking to move to places outside.

Table 8 Characteristics of the Study Samples

	Baseline	**Follow-up**			**p-value (Between two groups)**
	Total (n=4,802)	**Total (n=4,802)**	**No falls (n=4,337)**	**Increased falls (n=465)**	
socio-demographic					
Age					<0.001
65-74	2110 (43.93)	-	1930 (91.47)	180 (8.53)	
75-84	1951 (40.62)	-	1768 (90.62)	183 (9.38)	
85+	742 (15.45)	-	639 (86.23)	102 (13.77)	
Sex					0.446
Male	2073 (43.17)	-	2614 (89.67)	301 (10.33)	
Female	2729 (56.83)	-	1722 (91.3)	164 (8.7)	
Race/Ethnicity					0.455
Non-Hispanic White	3335 (69.45)	-	3005 (90.1)	330 (9.9)	
Others	1467 (30.55)	-	1332 (90.8)	135 (9.2)	
Marital status					0.343
Married	2466 (51.41)	2382 (49.61)	2161 (90.72)	221 (9.28)	
Never married, or divorced, widowed or separated	2331 (48.59)	2419 (50.39)	2175 (89.91)	244 (10.09)	
Job status					0.003
Job	629 (13.24)	583 (12.19)	546 (93.65)	37 (6.35)	
No job or retirement	4123 (86.76)	4198 (87.81)	3771 (89.83)	427 (10.17)	
Health					
Obesity					0.214
Normal (BMI<25)	1587 (33.92)	1662 (35.38)	1501 (90.31)	161 (9.69)	
Overweight(25≤BMI<30)	1762 (37.67)	1762 (37.51)	1606 (91.15)	156 (8.85)	
Obese (BMI≥30)	1329 (28.41)	1273 (27.1)	1136 (89.24)	137 (10.76)	
Self-reported health condition					<0.001
Excellent-very good	2109 (43.95)	2073 (43.2)	1944 (93.78)	129 (6.22)	
Good	1564 (32.59)	1601 (33.36)	1465 (91.51)	136 (8.49)	
Fair-poor	1126 (23.46)	1125 (23.44)	925 (82.22)	200 (17.78)	

Table 8 Continued

	Baseline	Follow-up			p-value (Between two groups)
	Total (n=4,802)	Total (n=4,802)	No falls (n=4,337)	Increased falls (n=465)	
History of falls in last year at 2011					<0.001
No	3757 (78.34)	-	3456 (91.99)	301 (8.01)	
Yes	1039 (21.66)	-	875 (84.22)	164 (15.78)	
Fear of falling in last month					<0.001
No	3612 (75.23)	3491 (72.71)	3248 (93.04)	243 (6.96)	
Yes	1189 (24.77)	1310 (27.29)	1088 (83.05)	222 (16.95)	
Depression (days)					<0.001
Not at all	3559 (74.19)	3552 (74.12)	3278 (92.29)	274 (7.71)	
Several days, more than half the days, nearly every day	1238 (25.81)	1240 (25.88)	1051 (84.76)	189 (15.24)	
Balance impairment in last month					<0.001
No	3651 (76.05)	3402 (70.9)	3210 (94.36)	192 (5.64)	
Yes	1150 (23.95)	1396 (29.1)	1125 (80.59)	271 (19.41)	
Mobility limitation within quarter mile in last month					<0.001
No	3613 (75.66)	3461 (72.47)	3219 (93.01)	242 (6.99)	
Yes	1162 (24.34)	1315 (27.53)	1096 (83.35)	219 (16.65)	
Difficulty with going outside in last month					<0.001
No	4129 (89.26)	4008 (87.99)	3703 (92.39)	305 (7.61)	
Yes	497 (10.74)	547 (12.01)	438 (80.07)	109 (19.93)	
Vision impairment					<0.001
No	4464 (92.96)	4441 (92.48)	4038 (90.93)	403 (9.07)	
Yes	338 (7.04)	361 (7.52)	299 (82.83)	62 (17.17)	
Arthritis					<0.001
No	2227 (46.44)	2015 (41.97)	1865 (92.56)	150 (7.44)	
Yes	2568 (53.56)	2786 (58.03)	2471 (88.69)	315 (11.31)	
Stroke					<0.001
No	4350 (90.64)	4289 (89.37)	3907 (91.09)	382 (8.91)	
Yes	449 (9.36)	510 (10.63)	428 (83.92)	82 (16.08)	
Dementia					<0.001
No	4709 (98.08)	4632 (96.5)	4202 (90.72)	430 (9.28)	
Yes	92 (1.92)	168 (3.5)	134 (79.76)	34 (20.24)	

Table 8 Continued

	Baseline	Follow-up			p-value (Between two groups)
	Total (n=4,802)	Total (n=4,802)	No falls (n=4,337)	Increased falls (n=465)	
Walking-related Behavior					
Use of walking aid to go outside in last month					<0.001
No	3744 (78)	3594 (74.84)	3338 (92.88)	256 (7.12)	
Yes	1056 (22)	1208 (25.16)	999 (82.7)	209 (17.3)	
Walking to get to places outside in last month					<0.001
No	2359 (49.17)	2394 (49.99)	2116 (88.39)	278 (11.61)	
Yes	2439 (50.83)	2395 (50.01)	2211 (92.32)	184 (7.68)	
Vigorous activity in last month					0.001
No	2915 (60.72)	2949 (61.45)	2629 (89.15)	320 (10.85)	
Yes	1886 (39.28)	1850 (38.55)	1705 (92.16)	145 (7.84)	
Frequency of going outside in last month					<0.001
0-4 days	609 (12.68)	731 (15.23)	626 (85.64)	105 (14.36)	
More than 5 days	4192 (87.32)	4069 (84.77)	3709 (91.15)	360 (8.85)	
Independent Variables (Time-variant)					
Change in litter/ broken glass, or trash, on sidewalks and streets around my home					0.001
Towards positive or positively stable	4252 (90.01)	-	3865 (90.9)	387 (9.1)	
Towards negative (no to yes)	258 (5.46)	-	220 (85.27)	38 (14.73)	
Negatively stable	214 (4.53)	-	183 (85.51)	31 (14.49)	
Change in graffiti on buildings and walls around my home					0.114
Towards positive or positively stable	4566 (96.66)	-	4131 (90.47)	435 (9.53)	
Towards negative (no to yes)	119 (2.52)	-	104 (87.39)	15 (12.61)	
Negatively stable	39 (0.83)	-	32 (82.05)	7 (17.95)	

Table 8 Continued

	Baseline	Follow-up			p-value (Between two groups)
	Total (n=4,802)	Total (n=4,802)	No falls (n=4,337)	Increased falls (n=465)	
Change in vacant or deserted houses or storefronts around my home					0.748
Towards positive or positively stable	4139 (87.62)	-	3739 (90.34)	400 (9.66)	
Towards negative (no to yes)	213 (4.51)	-	190 (89.2)	23 (10.8)	
Negatively stable	372 (7.87)	-	339 (91.13)	33 (8.87)	
Change in any broken or boarded up windows in front of my home					0.114
Towards positive or positively stable	4303 (91.34)	-	3897 (90.56)	406 (9.44)	
Towards negative (no to yes)	125 (2.65)	-	107 (85.6)	18 (14.4)	
Negatively stable	283 (6.01)	-	251 (88.69)	32 (11.31)	
Change in uneven walking surfaces or broken steps in the area leading to the home/ building					0.003
Towards positive or positively stable	4031 (85.58)	-	3665 (90.92)	366 (9.08)	
Towards negative (no to yes)	401 (8.51)	-	344 (85.79)	57 (14.21)	
Negatively stable	278 (5.9)	-	247 (88.85)	31 (11.15)	

Note: Significant difference between non-fallers and fallers, Note: **P<0.01, *0.01≤P<0.05

4.4.2. Neighborhood Environmental Factors Associated With Falls

Table 9 displays the likelihood of experiencing an increase in falls based on five neighborhood environmental barriers. Adjustments were made for baseline sociodemographic variables (sex, age, race, marital status, and job status), health variables (obesity, self-reported health condition, fear of falling, depression, balance impairment, mobility limitation, difficulty with traveling outside, vision impairment, arthritis, stroke, and dementia), and behavior variables (use of walking aids, walking to move to places, vigorous activity, and frequency of traveling outside). Two variables remained at significant risk of falling. In the longitudinal analysis, participants who became more negative in their perceptions of the neighborhood environment were more likely to experience an increased likelihood of falling. Our findings suggest that safe and well-maintained outdoor environments, especially sidewalks and steps, may help prevent falls among those who frequently travel outside. Such environments may encourage older adults to engage in health-promoting outdoor activities in the neighborhood. Compared to those who did not report increases in falling, those who reported increases in falling over the past year were more likely to be exposed to obstructions on sidewalks or streets around their homes (OR = 1.824, 95% CI = 1.166-2.854) and to uneven walking surfaces or broken steps over time (OR = 1.485, 95% CI = 1.058-2.086).

Table 9 Environmental Predictors of Incident Falls in Last Month at the 1-year Follow-up in Individuals without a History of Falls at Baseline: Unadjusted analysis and Partially Adjusted Analyses

Fall status at a follow-up	**Unadjusted Analysis**			**Adjusted Analysis [a]**		
	OR	**(95% CI)**	**p-value**	**OR**	**(95% CI)**	**p-value**
Environmental Obstruction						
Litter/ broken glass, or trash, on sidewalks and streets around my home (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.725**	1.204 - 2.472	0.003	1.388	0.893 - 2.159	0.145
Negatively stable	1.692*	1.14 - 2.511	0.009	1.824**	1.166 - 2.854	0.009
Neighborhood Disorder						
Graffiti on buildings and walls around my home (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.370	0.79 - 2.375	0.262	1.363	0.731 - 2.541	0.33
Negatively stable	2.077†	0.912 - 4.734	0.082	2.503†	0.995 - 6.296	0.051

Table 9 Continued

Fall status at a follow-up	Unadjusted Analysis			Adjusted Analysis [a]		
	OR	**(95% CI)**	**p-value**	**OR**	**(95% CI)**	**p-value**
Vacant or deserted houses or storefronts around my home (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.132	0.725 - 1.765	0.586	0.921	0.551 - 1.538	0.753
Negatively stable	0.910	0.627 - 1.32	0.619	0.839	0.541 - 1.299	0.43
Any broken or boarded up windows in front of my home (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.615†	0.97 - 2.688	0.065	1.449	0.808 - 2.596	0.213
Negatively stable	1.224	0.835 - 1.793	0.300	1.179	0.771 - 1.802	0.447
Problems in walking surface						
Uneven walking surfaces or broken steps in the area leading to the home/ building (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.659**	1.229 - 2.24	0.001	1.485*	1.058 - 2.086	0.022
Negatively stable	1.257	0.852 - 1.854	0.249	1.018	0.643 - 1.61	0.94

Note: **P<0.01, *0.01≤P<0.05, †0.05≤P <0.1
Adjusted for time-invariant and time-varying confounders: socio-demographic variables (sex, age, race, marital status, job status); health variables (obesity, self-reported health condition, fear of falling, depression, history of fall, balance impairment, mobility limitation, difficulty with going outside, vision impairment, arthritis, stroke, dementia); and behavior variables (use of walking aid, walking to get to places, vigorous activity, and frequency of going outside)

4.4.3. Neighborhood Environmental Factors Associated With Falls by Age Group

Table 10 summarizes results from partially adjusted analyses of neighborhood environmental factors and fall status by different age groups, testing the second hypothesis. The oldest-old (85+ years) age group appeared to face higher risks of falling compared to those of the youngest and middle-old age groups (65-84 years). For participants aged between 65 and 74 years, exposure to environmental obstruction (OR = 2.439, 95% CI = 1.258-4.727) was significantly associated with increased recent fall incidents. For participants aged between 75 and 84 years, walking surface problems (OR = 1.772, 95% CI = 1.056-2.974) were associated with increased fall incidents over time. For participants aged 85 years or older, broken windows near the home (OR = 3.64, 95% CI = 1.084-12.216) that create neighborhood disorder were associated with increased fall incidents over time.

Table 10 Environmental Predictors of Incident by Age Category

Fall status at a follow-up	Young-old (n=2,110)		Middle-old (n=1,951)		Oldest-old (n=742)	
	OR (95% CI)	**p-value**	**OR (95% CI)**	**p-value**	**OR (95% CI)**	**p-value**
Environmental Obstruction						
Litter/ broken glass, or trash, on sidewalks and streets around my home (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.661 (0.819 - 3.367)	0.160	1.215 (0.607 - 2.433)	0.583	1.231 (0.413 - 3.666)	0.709
Negatively stable	2.439* (1.258 - 4.727)	0.008	1.325 (0.638 - 2.752)	0.451	1.19 (0.249 - 5.684)	0.827
Neighborhood Disorder						
Graffiti on buildings and walls around my home (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.798 (0.684 - 4.725)	0.234	1.059 (0.358 - 3.133)	0.918	1.552 (0.385 - 6.261)	0.537
Negatively stable	3.823† (0.985 - 14.844)	0.053	1.309 (0.236 - 7.259)	0.758	2.541 (0.222 - 29.112)	0.453
Vacant or deserted houses or storefronts around my home (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.089 (0.47 - 2.526)	0.842	1.033 (0.482 - 2.213)	0.933	0.457 (0.101 - 2.062)	0.308
Negatively stable	0.634 (0.312 - 1.287)	0.207	1.211 (0.633 - 2.316)	0.563	0.362 (0.08 - 1.652)	0.190
Any broken or boarded up windows in front of my home (reference: Towards positive or positively stable)						
Towards negative (no to yes)	2.069 (0.846 - 5.063)	0.111	0.509 (0.147 - 1.763)	0.287	3.64* (1.084 - 12.216)	0.037
Negatively stable	1.651 (0.892 - 3.055)	0.110	1.03 (0.475 - 2.231)	0.941	0.919 (0.329 - 2.562)	0.871

Table 10 Continued

Fall status at a follow-up	Young-old (n=2,110)		Middle-old (n=1,951)		Oldest-old (n=742)	
	OR (95% CI)	**p-value**	**OR (95% CI)**	**p-value**	**OR (95% CI)**	**p-value**
Problems in walking surface						
Uneven walking surfaces or broken steps in the area leading to the home/ building (reference: Towards positive or positively stable)						
Towards negative (no to yes)	1.272 (0.735 - 2.199)	0.390	1.772* (1.056 - 2.974)	0.030	1.485 (0.602 - 3.66)	0.391
Negatively stable	0.901 (0.435 - 1.867)	0.780	0.891 (0.431 - 1.842)	0.756	1.461 (0.46 - 4.643)	0.520

Note: **P<0.01, *0.01≤P<0.05, †0.05≤P <0.1
Adjusted for time-invariant and time-varying confounders: socio-demographic variables (sex, continuous variable for age, race, marital status, job status); health variables (obesity, self-reported health condition, fear of falling, history of fall, depression, balance impairment, , mobility limitation, difficulty with going outside, vision impairment, arthritis, stroke, dementia); and behavior variables (use of walking aid, walking to get to places, vigorous activity, and frequency of going outside)

4.4.4. Multivariate Analysis of Risk Factors for Falls

Table 11 shows the adjusted odds ratios from the final multivariate model, which included the covariates and the four neighborhood factors that were significant ($p < 0.05$) in the previous and partially adjusted model. For the sociodemographic domain, non-Hispanic white participants (OR = 1.342, 95% CI = 1.027-1.754) were likely to report increased fall incidents over time. Several health factors were significantly associated with the risk of falling, including a fair/poor health condition (OR = 1.732, 95% CI = 1.263-2.374), a history of falling (OR = 1.402, 95% CI = 1.1-1.786), and balance impairment (OR = 2.328, 95% CI = 1.801-3.01). In terms of walking-related behavior, participants who walked to move to places outside (OR = 0.798, 95% CI = 0.638-0.997) were less likely to report increased fall incidents over time. Finally, a total of two environmental variables maintained their significance in this full model. Compared to those who did not report increased fall incidents, those who reported increased fall incidents during the past year were more likely to live in neighborhoods with obstructions on the sidewalks or streets in both 2011 and 2012 (OR = 1.894, 95% CI = 1.187-3.021) and with uneven walking surfaces or broken steps around their homes from 2011 to 2012 (OR = 1.422, 95% CI = 1.007-2.009).

Table 11 Final Multivariate Model: Falling Risk Factors

Fall in last month	**Total (n=4,802)**		
	OR	**(95% CI)**	**p-value**
Covariate			
Demographic			
Age (reference: 65-74)			
75-84	0.907	0.705 - 1.167	0.449
85+	1.081	0.766 - 1.527	0.657
Female, %	0.91	0.715 - 1.158	0.442
Non-Hispanic White	1.342*	1.027 - 1.754	0.031
Never married, or divorced, widowed or separated	0.916	0.722 - 1.162	0.469
No job or retirement	1.001	0.683 - 1.468	0.994
Health			
Obesity (Reference: Normal, BMI<25)			
Overweight(25≤BMI<30)	1.015	0.78 - 1.322	0.911
Obese (BMI≥30)	1.05	0.788 - 1.4	0.737
Self-reported health condition (Reference: Excellent-Good)			
Good	1.066	0.802 - 1.418	0.659
Fair-Poor	1.732**	1.263 - 2.374	0.001
Fear of falling in last month	1.272†	0.986 - 1.642	0.064
History of fall	1.402**	1.1 - 1.786	0.006
Depression	1.186	0.925 - 1.521	0.179
Balance impairment in last month	2.328**	1.801 - 3.01	<0.001
Mobility limitation within quarter mile in last month	1.006	0.73 - 1.385	0.973
Difficulty with going outside in last month	1.269	0.931 - 1.729	0.132
Vision impairment	1.147	0.78 - 1.686	0.485

Table 11 Continued

Fall in last month	Total (n=4,802)		
	OR	**(95% CI)**	**p-value**
Arthritis	1.032	0.811 - 1.314	0.798
Stroke	1.166	0.844 - 1.609	0.351
Dementia	1.436	0.84 - 2.457	0.186
Walking-related Behavior			
Use of walking aid to go outside in last month	1.337†	0.982 - 1.819	0.065
Walking to get to places outside in last month	0.884	0.702 - 1.114	0.297
Vigorous activity in last month	1.177	0.923 - 1.501	0.189
More than 1 days and Less than 5 days going outside in last month	1.298	0.924 - 1.824	0.132
Independent Variable			
Environmental Obstruction			
Litter/ broken glass, or trash, on sidewalks and streets around my home (reference: Towards positive or positively stable)			
Towards negative (no to yes)	1.280	0.811 - 2.02	0.288
Negatively stable	1.894**	1.187 - 3.021	0.007
Problems in walking surface			
Uneven walking surfaces or broken steps in the area leading to the home/ building (reference: Towards positive or positively stable)			
Towards negative (no to yes)	1.422*	1.007 - 2.009	0.046
Negatively stable	0.855	0.527 - 1.385	0.524

Note: **P<0.01, *0.01≤P<0.05, †0.05≤P <0.1; *N*=4,313; LR Chi2=241.85; *P*-value<0.001

4.5. Discussions

We examined the potential environmental risk factors of falling. Our findings from this study suggest an important interplay between outdoor environments and falling among older adults, indicating that certain environmental changes are associated with changes in fall status over time. After adjusting for individual factors, this prospective study found that the prevalence of outdoor environmental barriers, such as obstructions on the streets and problems related to walking surfaces, was independently associated with greater risk of fall incidents among community-dwelling older adults. Specifically, our study found a significant association between environmental obstructions and falling, thus indicating that continual exposure to environmental obstructions, including litter/trash on sidewalks near the home, serves as one of the most significant predictors of increased fall incidents among community-dwelling older adults. This finding is generally consistent with the findings of previous studies, showing that environmental obstructions on sidewalks and streets can cause imbalance and gait problems when an individual walks on the sidewalk (W. Li et al., 2006; Van Cauwenberg et al., 2012).

Our study also found that participants whose outdoor environments around their homes became more uneven or contained more broken steps after one year experienced an increased likelihood of falling. These findings are also consistent with those of previous studies, showing that unexpected change in level, such as uneven pavement or steps, serves as the most significant environmental influence on the risk of falling (Curl et al., 2016). Indeed, we found no evidence that older adults exposed to negative environmental conditions at ground level at both baseline and follow-up year faced any significant change in the risk of falling. This may be because older adults tend to adapt to their environments, enabling them to be cautious of consistent environmental risks, according to Lawton and Nahemow's ecological theory of aging (Lawton &

Nahemow, 1973). However, negative changes in level over time due to broken steps or uneven surfaces may increase the chance of an unexpected fall while walking.

In addition to exploring the association between neighborhood barriers and fall events over time, this study examined these relationships across different age groups (65-74 years, 75-84 years, and 85+ years) because these groups may require uniquely tailored strategies for fall prevention. Although the risk of falling increases with age, physical outdoor environmental barriers tend to be less recognized as influences on the risk of falling among the oldest age group, compared to the youngest and middle age groups. Perhaps the oldest group was less likely to walk outside and tended to stay at home because of declining health conditions (Smith, Borchelt, Maier, & Jopp, 2002). In contrast, the youngest and middle age groups tended to be more exposed to outdoor environments, which likely led to more outdoor fall events than for the oldest group (W. Li et al., 2006). Previous studies have also supported the notion that outdoor fallers are more likely to be younger, as these individuals tend to spend more time in outdoor environments (Chippendale, Gentile, James, & Melnic, 2017; Jennifer L Kelsey et al., 2010).

Although we were unable to distinguish between indoor and outdoor falls in this study, these findings provide insight into potential associations between neighborhood environments and fall events by location. Conceptually, outdoor environments might be more associated with outdoor falls because of walking, but indoor falls may also be influenced by negative outdoor design given that poor outdoor environmental conditions lead to reduced outdoor physical activity among older adults. When older adults tend to stay at home because of uneven pavement or unmanaged sidewalk conditions, they are more likely to be at risk of indoor falling.

The findings from this study, which identified the relationship between neighborhood environments and fall incidents, suggest the potential benefits of intervention through individual and community effort. Because mobility options decrease with age, older adults tend to engage in outdoor activities and walking in the neighborhood environments near their homes. Thus, cautious monitoring of these outdoor environments would help to prevent individual fall incidents. Also, urban planning and city works would play an important role in promoting safe neighborhoods and maintaining the quality of sidewalk and street surfaces, thus reducing fall incidents and promoting health and quality of life among older adults.

Our study possesses both limitations and strengths in terms of study design and data. First, the outdoor variables investigated were restricted to those collected in the NHATS survey, though we also used five outdoor environmental attributes based on interviewer observations. Future studies may benefit from including additional outdoor environmental variables that utilize both perceived and objective measurements. We also used self-reported recent fall data for incidents that occurred within a month of the survey period to mitigate participant recall bias and to match the environmental conditions observed at the stages of the interview. Further study would benefit from using optimized measurements to track falls and environmental changes more frequently, such as falls calendars or diaries and environmental audit tools (Hannan et al., 2010). We were also unable to separate outdoor falls from general falls in our data. To better understand the direct effects of outdoor environments on fall incidents, future studies are advised to include a separate questionnaire about the outdoor fall experience. A fourth limitation can be found in the potential bias of evaluations made by different interviewers of the same outdoor environments, although the items related to these environmental features (e.g., litter/trash on the streets or broken steps) were relatively straightforward. Finally, the study lacked geographical information, which may have led to inaccurate estimates, as outdoor activities may be highly influenced by offensive weather conditions (e.g., snow, rain, and heat waves). However, geographical locations with different weather conditions likely had only a small influence on our prospective study, as the participants were exposed to similar environmental conditions.

Our study also had several strengths. First, it included a large sample size, taken from a nationally representative sample of community-dwelling Medicare beneficiaries aged 65 years and older. Second, we accounted for a wide range of individual variables that explained increases in fall risk to better understand the association between changes in fall incidents and changes in outdoor environmental conditions over time. Third, to our knowledge, this was the first trial that used prospective evidence related to the effects of built environments on fall status. Thus, the current study provided strong understanding of whether poor neighborhood environments influence the risk of falling as well as insight for interventions that might reduce fall risk.

4.6. Implications for Practice and Policy

Walking is a popular form of meeting one's physical activity recommendations to maintain healthy aging. Given that walking is inherently related to fall incidents, it is important to support neighborhood conditions that would enable older adults to walk around their neighborhoods without concern about falling. The findings from our study suggest that safe and well-maintained outdoor environments may help prevent falls among older adults who actively engage in outdoor activities. Because living conditions and neighborhood environment quality have strong impacts on health according to the Social Determinants of Health, addressing the environmental risk factors of falling and keeping outdoor environments safe near community-dwelling older adults would be effective and efficient forms of intervention. Also, such environmental barriers are easily modifiable.

The findings of this study provide new insights into the risk factors of falling and fall prevention in relation to neighborhood environmental and policy interventions. Environmental interventions, including litter reduction and the repair of uneven walking surfaces, proves to be important for reducing fall incidents among older adults. Thus, policy and planning strategies to reduce fall-related hazardous environments would help public health experts, gerontologists, and urban planners to create safer neighborhoods, thus promoting and maintaining the health, mobility, and well-being of residents.

5. CONCLUSION

5.1. Summary of the Study

This dissertation research examines how neighborhood environments are linked to fall risks among older adults. The overarching goal of my dissertation is to understand the risk of falls in relation to neighborhood characteristics (e.g. socioeconomic conditions, street conditions, and safety). By employing multifaceted research approaches, my dissertation accomplished this goal by using three inter-related studies. The dissertation involves mixed research types (systematic review and analytical analysis), multiple research designs (cross-sectional and longitudinal studies), different datasets (national level: NHATS data and local level: EMS data), and two study levels (individual and neighborhood).

Through the systematic review, the first study (Section 2) examines the risk factors of indoor and outdoor falls in relation to health, behavior, and socio-economic status. Findings from this study show that the occurrence of indoor falls tends to be associated with being female and being frail, while outdoor falls are more common among males and those physically active. The second study (Section 3) explores the characteristics of neighborhood environments associated with fall injuries reported to emergency medical services (EMS). This study highlights the importance of stable and safe neighborhoods in reducing fall risks among older adults. The third study (Section 4) examines prospective associations of changes in environmental perceptions (e.g., street conditions, walking surfaces, and physical disorders) with changes in fall occurrence through a longitudinal study. The results show that safe and well-maintained outdoor environments help prevent falls among those older adults who actively engage in outdoor activities.

The overall findings of the dissertation provide new insights into the risk factors for falls and fall prevention in relation to neighborhood environmental and policy interventions. Although further research is needed to clarify our findings with adequate research designs separating indoor and outdoor falls and using larger samples, the two analytical studies at the individual and neighborhood level provide a rich understanding of the relationships between falls and neighborhood environments among older adults. The findings from this part of the studies suggest that multifaceted community interventions to create stable and safe neighborhoods could play a significant role in preventing fall-related injuries. Thus, environmental interventions to reduce the risk of falling should be considered by public health professionals, gerontologists, environmental psychologists, and urban planners interested in helping older adults reduce fall incidents while walking in their neighborhoods.

5.2. Contributions to the Literature

Historically, public health and urban planning have been interconnected, sharing common concerns about the spread of diseases in urban areas. Rapid urban population growth, beginning in the 19th century, has been one of the most inextricably wicked problems, producing several social issues such as inadequate housing, minimal sanitation, industrialization, and insufficient clean water supplies (Kenzer, 1999). To date, research on the relationships between urban planning and public health have been undertaken to identify specific human illnesses, including asthma, obesity, injuries, falls, cardiovascular disease, and mental illness caused by urban sprawl (Srinivasan, O'Fallon, & Dearry, 2003). Several proactive movements to promote a healthy environment in architecture and urban planning, such as smart growth, new urbanism, complete street, sustainable development, and several environmental policies and practical designs for health have been developed (Jackson, Dannenberg, & Frumkin, 2013).

Like other health agendas, my dissertation examining the relationships between falls and neighborhoods would provide new evidence of the importance of the neighborhood environment as preventive medicine. Given the fact that most studies have found that at least half of falls occur outdoors while most older adults tend to spend most of their time indoors (Robinson & Silvers, 2000), safe walking cannot be achieved only through public health. Rather, transportation and urban planners should consider street connectivity, neighborhood development patterns (grids or cul-de-sacs), and urbanity (urban or rural) as environmental determinants of falls and consider environmental strategies to modify physical conditions exacerbating falls among older adults.

Especially, the part of dissertation (Section 2) distinguishing indoor and outdoor fallers could cover a broad spectrum of the aging population (healthy vs. frail, low physical activity vs. high physical activity, poor walkable environments vs. good walkable environments). This is important as Satariano et al. (2012) suggested the necessity of expanding the study of diverse aging populations as a new direction for environmental research, practice, and policies (Satariano, Ory, & Lee, 2012). Neighborhoods or cities are not just a collective composition of streets, buildings, and open spaces; rather, neighborhoods and cities are dynamic social spaces linked to health conditions, workplaces, and social grounds (Barton & Tsourou, 2013). From the perspective of healthy urban planning, the dissertation on the environmental determinants related to falls would serve to connect promotion of active living, injury prevention, and built environments.

The dissertation research on the environmental determinants of falls (Section 3 and Section 4) is based on the stress-exposure disease framework. Gee and Payne-Sturges (2004) have focused on the intersection between community stress and personal stress. According to their conceptual framework, residential segregation by race/ethnicity is associated with allocation of community resources, neighborhood stressors, and structural factors, which may influence environmental hazards and pollutants and in turn contribute to individual health disparities (Gee & Payne-Sturges, 2004). For example, disadvantaged communities may encounter a higher exposure to environmental hazards, such as air pollution and traffic injuries, which exacerbates individual health problems such as cardiovascular disease (Cubbin, LeClere, & Smith, 2000). Likewise, an approach to understanding the relationships between community stress (built environmental barriers) and individual stress (falls) would assist urban planners in answering why a healthy community is necessary and how a healthy community works as preventive medicine.

The dissertation also contributes to a greater understanding of health disparities and environmental inequalities. Health disparities generally refer to variations in health status in different groups defined by race, ethnicity, socioeconomic status, or the geographic location where they live (Carter-Pokras & Baquet, 2002). Such health disparities have been a prevalent and persistent challenge in the aging population (Singh & Siahpush, 2006). For example, older adults who live in low-income neighborhoods have less opportunity to access medical care, healthy food, and other healthy physical and social activity places, while they may be exposed to higher crime and crash rates and lower quality housing compared to those who live in high-income areas. The study examining the contextual effects of neighborhoods on the distribution of falls shows disparities in falls in relation to environmental inequalities, including different neighborhood socioeconomic status.

5.3. Contributions to Practice and Policy

Falls are the most significant health problems among older adults in the United States and globally, and falls were, directly and indirectly, related to neighborhood features. Safe environments with well-maintained street conditions (Chippendale & Boltz, 2014) and good neighborhood qualities (Nicklett, Lohman, & Smith, 2017) could help prevent falls and encourage older adults to engage in outdoor activities. Such findings of the relationship between falls and neighborhood attributes could highlight the importance of developing design guidelines and policy interventions.

Firstly, tailored approaches are warranted for different location of where older adults experience falls. The result from the systematic review (Section 2) suggests that different interventions may be needed for indoor and outdoor fallers. For example, indoor fallers are more likely to be female and frail while outdoor fallers tend to be males and be physically active. Thus, older adults who spend most of their time indoor should keep their home safe and join an exercise program to cope with unexpected fall incidents (Sherrington et al., 2014). Given the empirical study on environmental change in fall status (Section 4), outdoor environmental barriers near participant’s home, such as broken sidewalks or litter on the sidewalks/streets were found to be closely associated with increased fall incidents. Thus, those who are actively engaged in outdoor activities, they need to keep their yard and outdoor environments around their home safe and well-maintained.

Also, fall preventions are needed to be understood not just by individual effort but by action-based interventions and environmental interventions. For example, the result of neighborhood-level fall incidents by using EMS data (Section 3) showed fall-centered areas with frequency of fall incidents. Given the evidence that fall incidents were clustered in certain neighborhoods in terms of different neighborhood characteristics (SES, residential stability, and socio-physical disorder), particular attention should be paid to fall-centered areas. For example, EMS providers can readily respond to a variety of emergency calls for help from those who are living in the fall-centered areas by providing adequate ambulance services. Also, high priority is warranted for environmental interventions to improve street condition by reducing litter and repairing uneven walking surfaces that directly influence the occurrence of fall incidents.

Finally, this study highlights the importance of fall preventions for older adults as one of the primary action items for policy interventions in promoting walking as well as walkable environments. Previous studies on the neighborhood environments in relation to health outcomes among older adults focused on traffic-crashes and injuries from crime as the determinants of walking among older adults (Nagel, Carlson, Bosworth, & Michael, 2008; Tucker-Seeley, Subramanian, Li, & Sorensen, 2009). However, maintenance of street conditions directly related to falls and policy interventions in encouraging stable neighborhoods and improving neighborhood quality are needed not only to reduce fall incidents but also to promote walking and walkable environment for older adults. The findings from this study on fall preventions through neighborhood environments ultimately help encourage older adults to remain healthy, independent, and age in place.

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APPENDIX A

Checklist for the methodological quality assessment

Criteria	Description	Score
Definition	**Was clear definition of both indoor and outdoor falls provided?**	
	No	0
	Yes	1
Study Design	**Cross-sectional study**	0
	Longitudinal study	1
Selection Bias	**Was it representative of the population?**	
	No	0
	Yes (e.g. probability sampling methods were used)	1
	Was a sample size large enough?	
	No (limited sample size, $N<400$)	0
	Yes (large sample size, $N \geq 400$)	1
Data Collection	**Was an adequate clinical assessment made with the usual techniques, such as questionnaires, interviews and/or clinical examinations?**	
	No	0
	Yes	1
Confounders	**Were relevant confounders (outdoor exposure) controlled?**	
	No	0
	Yes	1
	Were relevant confounders (other variables) controlled?	
	No (not well-controlled)	0
	Yes (well-controlled for demographic, health, behavioral, and socio-economic status)	1
Data Analysis	**Were the statistical methods appropriate for the study design?**	
	Bivariate analysis	0
	Multivariate analysis	1
Generalizability	**Was the outcome applicable to the elderly population in general practice?**	
	No	0
	Yes	1
Reproducibility	**Was the study reproduced by other investigators on the basis of the description of methods and outcomes?**	
	No	0
	Yes	1
Total		10

APPENDIX B

Quality assessment of the reviewed studies

Ref.	Definition	Study Design	Selection Bias		Data Collection	Confounders		Data analysis	Generalizability	Reproducibility	Total Score	Grade
			Sampling	Sample Size		Outdoor exposure	Other variables					
1	0	1	1	1	1	1	0	1	1	1	8	H
2	0	0	1	0	1	0	0	0	1	1	4	M
3	1	0	1	1	1	0	0	1	1	1	7	H
4	0	0	1	0	1	1	1	1	1	1	7	H
5	0	0	1	1	1	0	0	0	1	1	5	M
6	0	0	1	0	1	0	1	1	0	1	5	M
7	0	0	1	1	1	0	0	0	0	1	4	M
8	1	1	1	1	1	0	1	1	1	1	9	H
9	1	1	1	0	1	0	0	0	0	1	5	M
10	0	0	1	0	0	0	1	1	1	1	5	M
11	1	1	1	1	1	1	1	1	1	1	10	H
12	1	0	1	1	1	0	0	0	0	1	5	M
13	1	0	0	1	1	0	0	0	0	1	4	M
14	1	0	1	1	1	0	0	0	1	1	6	M

Note**:** High-quality: total scores of 7-10; Middle-quality: total scores of 4-6; Low-quality: total scores of 0-3;

References: 1= Loughlin et al (1994); 2= Bergland et al (1998); 3= Bath and Morgan (1999);4= Bergland et al (2003); 5= Pajala et al (2008); 6= Mänty et al (2009);7= Ranhoff et al (2010);8= Kelsey et al (2010);9= Bleijlevens et al (2010);10= Landy et al (2012);11= Li et al (2014); 12=Kim (2016); 13= Chippendale et al (2017); and 14= Nascimento et al. (2017)

APPENDIX C

Measurement of the Variables

Categories of risk factors	Descriptions
Biological/ Medical status	
Age	Years: Pajala et al 2008; Mänty et al 2009; Ranhoff et al 2010; Kelsey et al 2010; Chippendale et al 2017, <75 vs. 75+: Bath and Morgan 1999; 67-69, 70-74, 75-84, 85+: Bergland et al 1998; 65-69, 70-74, 75-79, 80+: Loughlin et al 1994, <80 vs. 80+: Bleijlevens et al 2010, 65-74, 75-84, 85+: Landy et al 2012; Kim 2016
Female	Male vs. Female: Bergland et al 1998; Bath and Morgan 1999; Ranhoff et al 2010; Kelsey et al 2010*; Bleijlevens et al 2010; Landy et al 2012; Kim 2016*; Chippendale et al 2017
White	Non-white vs. White: Kelsey et al 2010, White-non-Hispanic vs. Hispanic: Landy et al 2012*, White, Black, Asian, Other: Chippendale et al 2017*
obesity	Underweight/average vs. overweight/obese: Bath and Morgan 1999; Kelsey et al 2010, quartile: Bergland et al 2003; obesity (no vs. yes): Mänty et al 2009, > 20kg/m$^{2;}$ Ranhoff et al 2010*; (kg/m^2): Pajala et al 2008; Kelsey et al 2010; Chippendale et al 2017
History of falls	History of falls within 12 month (before the follow-up) Loughlin et al 1994; Bergland et al 2003; Pajala et al 2008; Mänty et al 2009; Ranhoff et al 2010. Number of falls: Kelsey et al 2010
Mobility-limitations	Difficulty walking 400 m: Loughlin et al 1994, difficulty walking 2km: Pajala et al 2008, disorder of joint with difficulty walking: T Chippendale et al 2017
Activity-limitations	Days of limited activity: Loughlin et al 1994; Being housebound (no vs. yes): Bath and Morgan 1999; Less than full score on IADL (no vs. yes): Bergland et al 2003, Pre-fracture ADL (Barthel Index): Ranhoff et al 2010, difficulty in climbing up one flight of stairs: Pajala et al. 2008, activities of daily living (No difficulty, a little or some difficulty, much difficulty or inability): Kelsey et al 2010, activity avoidance (≤almost never vs, ≥sometimes): Bleijlevens et al 2010
Performance-limitation (Time Up and Go)	Time Up and Go (good/ bad performance): Bergland et al 2003, TUG(seconds) Nascimento et al. 2017*
Fair Health status	Health index score (below median vs. above median): Bath and Morgan 1999, fair to poor self-ralted health: Kelsey et al 2010, perceived health (≥good vs. ≤ moderate): Bleijlevens et al (2010
Fear of fall	Pajala et al 2008; Mänty et al 2009, ≤almost never vs. <sometimes: Bleijlevens et al 2010
Depression	Feeling depression (no vs. yes): Bergland et al 2003
Hearing problem	No vs. yes: Bergland et al 2003; Mänty et al 2009; Ranhoff et al 2010
Vision Problem	No vs. yes: Bergland et al 2003; Ranhoff et al 2010, Visual loss (no vs. yes): Mänty et al 2009, poor vision (worse than 40/100): Kelsey et al 2010
Cognitive impairment	Less than full score on MMSE (no vs. yes): Bergland et al 2003; dizziness: Loughlin et al 1994; MMSE: Pajala et al 2008;Mänty et al 2009, cognitive function (IQCODE-SF): Ranhoff et al 2010, MMSE score 18-24 (%): Kelsey et al 2010, psychiatric disease: Kim 2016
Comorbidity	Suffering from more than 3 diseases (no vs. yes): Bergland et al 2003, number of chronic conditions: Pajala et al 2008;Mänty et al 2009, ASA score (n≥3): Ranhoff et al 2010
Balance	Amplitude of COP in the frontal plane: Bergland et al 2003, balance (velocity momement,

Impairment	mm^2/s): Pajala et al 2008; Mänty et al 2009, Berg balance scale score (≥51, 48-50, <48): Kelsey et al 2010
***Health* Behaviors**	
Gait speed	Non-ambulant/very slowly/ stroll at easy pace vs. normal/ fairly brisk/ fast: Bath and Morgan 1999*, comfortable walking speed (low vs. high): Bergland et al 2003; maximum walking speed (m/s): Pajala et al 2008; Mänty et al 2009; Li et al 2014, <0.68, 0.66-1.33, >1.33 (m/s): Kelsey et al 2010*
High physical activity	Physical activity (sedentary, moderately active, active): Pajala et al 2008, Bottom quartile of physical activity*: Kelsey et al 2010; Li et al 2014
Multi-medications	Number of prescribed drugs: Bath and Morgan 1999; Loughlin et al 1994; Mänty et al 2009; Kelsey et al 2010; Li et al 2014, Using more than 2 types of drugs (no vs. yes): Bergland et al 2003;
Alcohol consumption	Number of alcoholic drinks consumed in the past week: Loughlin et al 1994, se of alcohol (none, 1-3 drinks/month, 1-6 dirnks/wk) : Kelsey et al 2010; Li et al 2014
Utilitarian walk	Walking for purposeful activity: Bath and Morgan 1999 Utilitarian walk (no vs. yes): Li et al 2014
Recreation walk	Time spend walking for relaxation: Bath and Morgan 1999, recreation walk (no vs. yes): Li et al 2014
Outdoor exposure	Walking outdoors more often than 3 times a week (no vs. yes): Bergland et al 2003; outdoor walking activity (km/week): Mänty et al 2009, walk outside ≥3/wk: Li et al 2014
Socio*-economic *status	
Education	Years: Mänty et al 2009, ≤High school graduate, Some college or college graduate, ≥ Graduate studies: Kelsey et al 2010; Kim 2016, ≤primary school vs. > primary school: Bleijlevens et al 2010, year of schooling (non, 1-3, 4-7, 8+): Nascimento et al. 2017
Living situation	Living alone vs. living with a partner: Bleijlevens et al 2010; Landy et al 2012

Note: I/O=Indoor fallers versus outdoor fallers; I=Indoor fallers versus non-fallers; O= Outdoor fallers versus non-fallers; *=reversed coding