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OBM Geriatrics

Review

Design Guidelines to Reduce Extrinsic Fall Risks in the Built Environment

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Academic Editor: Ray Marks

Special Issue: Mobility and Aging: Falls Prevention Among the Elderly

OBM Geriatrics
2019, volume 3, issue 4
doi:10.21926/obm.geriatr.1904095

Received: August 28, 2019
Accepted: December 09, 2019
Published: December 16, 2019

Abstract

As people age, environments supporting changing needs can potentially impact their quality of life. Aging often leads to a decrease in the ability of people to interpret sensory cues within their environment. Using Pastalan's Empathic Model as a framework, a list of guidelines for the physical environment was established to address the extrinsic risk factors affecting falls. Attention to these items may not prevent all falls but will mitigate some of the external risks that cause falls for older adults.

It is the goal of the authors that these guidelines be utilized as a design tool by families, design professionals, and healthcare providers for assessing sensory cues that can enhance aging adults' ability to maneuver within the built environment. Enhanced knowledge can serve to increase the safety, comfort, and ability of residents to maneuver the environment on their own.

Keywords
Interior design; aging, falls; sensory cues; physical environment; built environment; elderly; interior space; fall risks

1. Aging Trends in the U.S.

As a society, the number of people aging in the U.S. is increasing exponentially. For example, the number of Americans age 65 and older grew from 40.3 million in 2010 to 52 million in 2018 and is expected to increase to 98.2 million by 2060. People age 65-and-older will represent 23 percent of the total population, with nearly one in four U.S. residents predicted to be above age 65 [1]. The number of people age 85+ is expected to increase by approximately 129%, from 6.4 million in 2016 to 14.6 million in 2040 to 19.7 million in 2060 [2, 3]. In fact, the fastest growing group by proportion is older adults 100+. To illustrate their changing demographics, in 1950, there were 2,300 centurions. In 2016, there were 81,896 Americans age 100 or older, [3] with a projected number of 601,000 living in 2050 [4].

The recent trends in the number of people living into old age in many ways has left our society unprepared for addressing the unique needs of this population, e.g., fixed retirement incomes; loss of purpose and friends/family; declining health, sensory abilities, and mobility, which increases stress and impacts their ability to adapt to these changes [5].

2. Risk Factors for Falling

Unintentional injuries remain one of the top 10 causes of death for older adults age 65+ years, with falls being the leading cause of these injuries [6-10]. In the U.S., approximately three-quarters of deaths due to falls occur in the population age 65 or older, with the rate and complications from falls rising steadily with age [11]. Therefore, accidental falls are increasingly becoming a concern due to their prevalence and to the high costs related to care [12].

Fall research is sometimes contradictory relative to gender, although it appears that the fall outcomes tend to be more acute for women. For example, Heilman [13] indicates that men fall more frequently than women, and Stalenhoelf, Diederiks, Knottnerus, Witte, and Crebolder [14] report that women have a significantly higher incidence of unintentional falls until the older ages, but that the gender differences disappear among the oldest old and centurions. Stevens [9] estimates unintentional fall injury rates to be 40%-60% higher for women compared to men. Fuzhong et al., [15] reported that women aged 85+ years have the highest death rate resulting from a fall, exceeding 180 deaths per 100,000. From all of these studies, the one conclusion that all sources agree upon is that fall rates increase with age.

Fall risk factors listed in NANDA-I include age 65 years or older, fall history, living alone, lower limb prosthesis and use of assistive devises. The pharmacologic agents are use of alcohol and drugs. The physiological factors are acute illness, blood sugar changes, anemia, arthritis, foot problems, decreased lower extremity strength, diarrhea, difficulty with gait, faintness when extending the neck, faintness when turning the neck, hearing difficulties, impaired balance and physical mobility, incontinence, neoplasm, neuropathy, orthostatic hypotension, postoperative conditions, proprioceptive deficits, insomnia, urinary urgency, vascular disease, and visual difficulties. Cognitive risk factors relate to changes in cognitive function. The environmental risk factors include a cluttered environment, exposure to conditions of weather-related insecurities, (e.g., wet floor, ice), dimly-lit room, no anti-slip material in bath and/or shower, unfamiliar room, restraints, and use of throw/scatter rugs [16].

Other resources categorize fall risk factors into two categories: intrinsic and extrinsic. Age, gender (74% female vs. 26% male), gait abnormalities, age-related cognitive decline [8, 17-19] vision, incontinence, seizures/strokes, cardiac abnormalities, nutritional deficiencies, depression [20-22] and/or chronic diseases such as arthritis and Parkinson's disease [23] were identified as additional significant intrinsic risk factors for falling. Other intrinsic risk factors affecting falls include race (white); incidence of previous falls; or use of medications such as blood pressure pills, heart medication, sleeping pills, and antidepressants, all of which can cause confusion, dizziness, disorientation, and slowed reflexes. Muscle weakness is also common among the older population, which generally stems from inactivity and disease, rather than being a normative aging effect [11, 17, 24, 25]. Lack of finances may also be a contributing factor to overall fear of falling since the consequence of potential injury, combined with a lack of income or health insurance, may result in economic devastation [26]. Difficulty with these normal activities of daily living, at least in part, explains why aging adults identify a decrease in quality of life and problems interacting with the built environment and others around them [27].

Extrinsic risk factors such as going outside when it is slippery; taking a walk for exercise; reaching for something overhead [11, 15]; wet or slippery floors; use of throw rugs; inappropriate footwear; poor lighting; confusing floor patterns/color use; use of extension cords in foot traffic areas; poor placement of equipment/furnishings; and stairs, steps, or beds at inappropriate heights [20, 23, 25, 28-32] also contribute to increased fall risks.

Two-thirds of the U.S. population over the age of 65 experience two or more sensory losses, which is an important component of well-being. Olfactory loss is correlated with cognitive loss; vision is associated with depression, poor quality of life, cognitive decline, and mortality; hearing loss is connected with slower gait speed, poor cognition, and mortality; and smell is linked to nutritional compromise and in-patient mortality. Patients who experience multiple sensory impairments are at higher risk for experiencing neurodegeneration, complications from falls, burns, food poisoning, smoke inhalation, etc. [27]. In fact, Al-Aama, [33], reported that the risk of falling grows as the number of risk factors increases, and each year the risk of falling doubles with each additional risk factor.

The work of Barstow and Vogtle looked at the occupational performance and home safety perspectives of aging adults with declining vision. Their work focused on the person–environment interaction with five categories of home safety emerging from the analysis: (1) lighting, (2) contrast, (3) visual distractions, (4) glare, and (5) compensation strategies [34]. Comparisons across categories revealed that study participants had specific concerns about home safety that were not thoroughly addressed in the selected assessments. Their work provides rationale for this study. The need is to identify specific safety features that are concerns of aging adults, especially those with low vision, but that are not included in standard design assessments, often due to the idea that it is more important to meet code requirements rather than to include more broad-based solutions that include people's perspectives of good design.

The work of Delcamp-Carda, Torres-Barchino, and Serra-Lluch [35] is noteworthy in their connection of the impact of color and light to older adults' perception of their environments, and to the need to design spaces that minimize older adults' spatial difficulties. They performed a multidisciplinary literature review of scientific-based articles relating to color, the built environment, and aging where they noted the importance of adapting the physical environment to meet the needs of residents living in care homes. Residents were affected by a range of impairments as a result of the aging process, including sensory decline. In fact, one of the most common issues affecting elders is a decline in visual sensitivity, which can impact their ability to interact within the built environment. For example, as aging occurs, there is an increase in eye lens density that causes the partial loss of light that falls on the cornea toward the retina, which decreases the total transmission of visible light. Outcomes of this include 1) a yellowing of the lens that alters color perception, 2) absorption of short wavelengths that impacts perception of colors in the blue and green range, 3) environmental light and a scattering effect that impacts visual acuity, 4) pupil size that becomes smaller and less flexible with age so that the eye admits less light, which makes it more difficult to see in darkened environments, 5) changes in sensory perception, which alters the sense of well-being, 6) slower response time and visual processing abilities, and 7) objects that are not well defined because they are less easily distinguished. For example, if a door should not commonly be used by residents, it could be painted the same color as the adjacent wall to help conceal its presence. In general, older adults need more time to recognize objects and response speed for gray and blue stimuli, which is significantly slower than for yellows, oranges, and reds. Another consequence of the yellowing of the lens is the need to avoid some color combinations. For example, white and yellow are perceived similarly while green-blue, dark blue-black, and brown-purple become the most confusing color combinations. Aging adults can distinguish small details in red and yellow but less in green, blue, and purple. In addition, they need greater contrast levels in the built environment such as furniture contrasting from floors and walls, and door trims or light switches being distinguishable from walls. Clear hues are easier to see than complex colors, and high levels of saturation and lightness differences are needed. In senior residences, it is important to create distinct zones through color contrasts and to use color combinations of reds, yellows, and oranges or great contrasts in the lightness of the colors if using blues and greens. Use of lighter colors is recommended for smaller spaces as they provide an enhanced sense of spaciousness and improved lighting conditions. Color is a resource for recollection of memories, objects, and images and can facilitate wayfinding within the built environment. Application of this evidence-based research can affect aging adults' visual perception and impact their ability to carry out daily tasks [35].

Other studies have been unable to show a significant link between extrinsic risk factors and fall rates [36-38]. Despite the inconsistent findings, aging adults who experience multiple risk factors are likely to benefit when the number of risk factors is reduced. Shoemaker [20] identified strategies for reducing falls due to intrinsic factors which included clear reminders to assisted living facility staff members of which residents were prone to falling; providing shoe orthotics to increase balance/stability and reduce pain/stress [39]; developing fall management committees to manage risks; ensuring staff understand the proper use of assistive devices; ensuring eyeglasses/contacts were clean and hearing aids were operational and worn correctly; ensuring residents used the restroom regularly; encouraging at-risk residents to wear a responder pendant to alert staff quickly if there was a problem; and offering resident exercise programs [20, 25]. Strategies for reducing falls due to external factors in the environment included training staff on the danger of wet floors, eliminating the use of extension cords where someone might trip, providing adequate light levels (without glare), positioning furniture/equipment to promote safe movement, and providing safe footwear [20]. Attention to these items may not prevent all falls but will mitigate some causes of intrinsic and extrinsic falls.

Cameron, Dyer, Panagoda, Murray, Hill, Cumming, and Kerse's [25] literature review of over 95 controlled trials identified fall risk factors by the elderly. They found that risks (and interventions) were attributed to various factors such as exercise, use of Vitamin D and other medications, and low vision. An important aspect of this review was that there were few findings discussing the relationship of risk factors to the physical environment, demonstrating the need to study the physical environment and human characteristics, i.e., low vision, limited walkability, etc. Much research has explored other factors.

The work of Clemson, Mackenzie, Ballinger, Close, and Cumming [40] is similar in that their research conducted a meta-analysis of multi-factorial issues to look at environmental features preventing falls. Despite this self-description of their work, their findings provided little evidence of physical environmental characteristics or interventions to aid in fall prevention, again demonstrating the need to add to the body of knowledge in this area.

Cheng, Tan, Ning, Li, Gao, Wu, Schwebel, Chu, Yin, and Hu [41] acknowledged that falls are a worldwide threat to aging adults and conducted a meta-analysis of studies over time to determine the most effective interventions for fall prevention in community-dwelling adults aged 60 and over. One important contribution of their work was the recommended combination of exercise and hazard assessment and modification, but there was no mention of what the hazards were, nor the modifications.

Additional work stated that a fall may have a singular cause or may result from multiple causes, and for older adults who fall more than once, there may be diverse causes for each incident [42]. In general, the more risk factors that a person has, the greater their chance of falling [32]. The U.S. Public Health Service estimates that falls are potentially preventable two-thirds of the time. Studies by Clemson et al. [43], Letts et al. [44], and Rubenstein [11] indicate that identifying and eliminating environmental hazards i.e., extrinsic risk factors in homes and institutions, may prevent many falls that are caused by the negative interactions between the environment and aging adults. In other words, when something that may cause a fall within the environment is identified, then it should be fixed or eliminated as soon as possible. This is essential since older adults may have increasing difficulty recovering from a fall, making fall prevention more critical [45]. Previous interventions have often focused on multiple solutions: exercise; medication use; medication review; surgery, e.g., cataracts, pacemakers and podiatric surgeries, etc.; management of urinary incontinence; fluid or nutrition therapy, psychological intervention; environment/assistive technology aids, e.g., mobility aids, eye glasses, hearing aids, etc.; social environment, e.g., staff ratio, staff and caregiver training, homecare services, etc.; and knowledge/educational interventions [32]. An awareness of this specialized population segment, knowledge of older adults' declining sensory abilities and increased fall risks, combined with the need to include interventions to the physical environment that minimize fall risks is beneficial to caregivers, designers/architects, and healthcare providers as they seek design solutions that are based on informed decision making.

3. Fall Issues: Contributing Factors and Consequences

The majority of people who fall do not suffer major consequences, but unintentional falls can result in serious injuries, such as fractures. Serious injury occurs approximately 4%-6% of the time with approximately 25% of those resulting in hip fractures, which can lead to reduced independence or even death. The mortality rate from falls among persons aged ≥65 years increased 31% between 2007 and 2016, with an increase in 30 states and the District of Columbia, and among both genders. The fastest-growing rate was among persons aged ≥85 years (3.9% per year) [46]. To emphasize this point, in a study of 311 residents living in nursing homes, 207 residents fell. Of those who fell, ~36% died within a year compared to nearly 14% of the 94 who did not fall. Although it is not possible to attribute all falls in elderly to dizziness and balance problems, these problems are more prevalent (9.1%) for older adults than for young adults (1.9%) [47]. For those older adults who are admitted to a hospital and suffer a hip fracture following a fall, approximately 25%-36% of older adults will die within six months from the injury and 50% one year from the injury [11, 48, 49]. Of those who survive, more than half are admitted to a nursing home, with nearly half of these older adults still residing within the nursing home one year later. Survivors of hip fractures often experience a decrease in their overall quality of life and experience a 10 to 15% decrease in life expectancy [26].

It is estimated that one in three older adults living in the traditional community [7, 50, 51] and 60% of people living in nursing homes [26, 32, 52] fall each year. Typically, two-thirds of those individuals will fall again within six months [26, 52]. The rates increase for those who are older than 75 [53, 54] or 80 [14]. This is due in part to the slower reflexes and cognitive decline of older individuals, making it more difficult to quickly regain balance [51]. For those who do have an unintentional fall, wrist fractures are most prevalent in individuals ages 65-75, and hip fractures are more common in individuals who are older than 75 [11]. The fall rates for older adults over the age of 80 may be as high as 40% and approaching 100% for institutionalized elderly adults [6, 14]. Marks [55] reported that 43% of older adults had fallen at least once in the last five years, with 39% of those individuals falling within the last year. Of those who reported falling in the last year, 25% had fallen more than one time.

Falls were the most common cause of non-fatal injuries and of hospital admissions for traumatic injuries, accounting for 5.3% of all hospitalizations in individuals aged 65+ years. In addition, there were 2.2 million non-fatal fall injuries treated in hospital emergency rooms [7], up from 1.8 million in 2005. The overall cost of injuries resulting from falls is high [6, 9, 11] and are one of the leading causes of liability claims for assisted living facilities [20].

Another consequence to individuals who fall is the frequent inability to get up, which can itself be dangerous. This occurs as often as 50% of the time, although the percentage is not clear because some older adults are resistant to reporting due to embarrassment and due to forgetfulness [14]. When older adults are unable to get up and are found lying for extended periods of time, they become subject to the risk of dehydration, pressure sores, pneumonia, and fear of future falls and are often associated with increasing physical frailty in individuals' age 80+, year, which includes declining strength, poor balance, arthritis, and dependency for Assistance of Daily Living (ADL) [20, 56].

Between 40-73% of older adults who have previously fallen, and 20-46% of those who have not, acknowledge a fear of falling [42, 51]. This can become its own health concern for older adults because of the potential for self-restriction of activities that often lead to a variety of adverse health consequences such as loss of mobility and strength, poor life satisfaction, increasing depression, declining social and physical functions, increased institutionalization, and decreased quality of life [9, 11, 56, 57]. With over 52 million of the population over 65 years old [1] and falls estimated at one-third for older adults living in the traditional community and 60% or higher for people living in nursing homes, our society has a large population at risk for serious injury.

4. Empathic Model

Few articles related solutions to extrinsic factors within the built environment. Pastalan et al. recognized the reality of older adults' sensory deterioration and the impact of the physical environment on those declines [58]. His framework proposed the organization of elements within the environment to create a better fit between environmental characteristics and the needs of aging adults [5]. Pastalan's et al. [58] work is seminal, in that it is perhaps the first behavioral research technique to focus on bridging the gap between research and practice, e.g., the designer/architect's need for anecdotal experiences linking the physical environment to human responses and abilities vs. the rigors needed for the science of research [5, 41, 59]. This established an important framework for use by interior designers and architects. This study is building on one component of Pastalan's framework, empathic modeling.

Empathic modeling, as applied in the research, allows researchers to simultaneously be experimenters and research subjects by replicating the normative aging process through modification of each of their bodily senses, e.g., vision, hearing, touch, taste, and smell, to simulate typical aging for a person in their late seventies to early eighties. Pastalan's Empathic Model is particularly relevant to the elderly population and fall risk factors because it focuses on people's declining abilities in their living and working spaces. Repetitive use of this model over time has provided verifiability of environmental solutions needed for scientific credibility [5]. From that work, three spatial principles supporting human behavior emerged for the physical environment: organized space as orientation, organized space as mastery, and organized space as stimulus.

Organized space as orientation organizes space for its predictive value, requires space to have a singular and clear use, and uses landmarks and focal points to cue spaces [5]. Organized space as mastery involves two important dimensions. The first relates to the need for people to claim their own personal space. The second relates to older adults' ability to master decreasing spatial scale and with fewer people. For example, as people age, their world shrinks over time which affects the design of buildings to compensate for the aging adults' decreased ability to master relationships with larger numbers of people and in less complex spaces [5]. The third principle, and most relevant to fall risks, involves organized space as stimulus. This is the concept of aging adults receiving multiple cues about the environment through stimulation of their diverse senses. This is relevant since senses that have been reduced to a point where a message cannot get through, or can get through only weakly, may cause a person to respond to a given situation inappropriately. An example to clarify this concept includes providing multiple messages about a mechanical space within an assisted living facility that should not provide access to the residents or to the public. The door could have a lock (physical cue). However, the door could be painted a special color and also have a sign that clarifies non-entry (visual cues). The door knob/lever could have a texture that is different than other door hardware; the floor surface in front of the door could be a different texture than the adjacent flooring to cue that there was something different about this location (tactile cues); and an alarm could sound if the door was opened (auditory cue). This way, if a person had a hearing impairment, they would receive a visual or tactile cue. If the person had vision loss, the audible alarm could be heard or the tactile cues felt, and if both vision and hearing had declined, the person could feel the message of non-entry through the change in texture. Redundant cueing helps to compensate for sensory loss by way of organizing an environmental message to be received through more than one sense [5].

Research outcomes from Pastalan's et al. [58] work demonstrate that the environment can provide older adults with multiple messages about how they are to maneuver within it, and that if only one cue provides a message about the environment, the way to function effectively and safely within that space may be missed due to older adults' sensory acuity decline [59]. Knowledge that certain characteristics can be clarified/enhanced within the physical environment and can aid older adults in their increased awareness of their surroundings by embedding more than one sensory cue within the design solution is thought-provoking due to the potential for fall reduction for aging adults. Therefore, the effects of the physical environment may be particularly important in homecare settings where integrating appropriate sensory cues into the built environment may serve as one measure of fall prevention among the elderly.

To develop the Empathic Model, Pastalan's researchers modified each sense to replicate the normative aging process by use of simple devices that simulated loss. To modify their visual sense, under the supervision of an optometrist, they used a coating on glasses to modify vision. The visual loss simulated the problem of light scatter or glare. Supervision of hearing loss was administered by a speech and hearing specialist who oversaw the use of individually made ear plugs. A coating of a liquid fixative was placed on each finger to impact researchers' touch and use of cotton wadding in the anterior nasal passages was used to simulate olfactory loss [58].

Although it is clear that each older adult is impacted by different rates of physical decline, Pastalan's et al. [58] findings showed that vision was the sense most impacted, and that visual acuity was greatly impacted by: glare from uncontrolled light sources and shiny finishes; disappearing boundaries such as dark surfaces placed adjacent to a window emitting an uncontrolled light source; and moving boundaries such as small-scale striped patterns, large flooring prints, and adjacent complimentary colors.

The ability to hear was impacted by background noises such as appliances, sound reflectance from hard surfaces, and high frequency tones. Tactile responses were difficult to discern if subtle textures and temperature were used, and anything requiring tight pinching and grasping, such as knobs, were hard to turn. Decreasing smell (olfactory) created a decreased interest in eating that could affect long-term nutrition and health; the sense of smell was also conversely related to the number of medications being administered. The more medications that a person was taking, the more likely their smell was affected. Therefore, given the impact of aging on sensory decline, it is important to design to reduce extrinsic fall risks, especially those related to sensory loss, and to include multiple sensory cues.

5. Characteristics to Incorporate into the Physical Environment in Response to Extrinsic Fall Risks

As Delcampo-Carda, Barchino, and Serra-Lluch [35], and Pastalan's et al. [58] work acknowledge, the physical environment can be a difficult space for older adults to navigate, especially if it has not been designed to accommodate changing sensory needs. The following recommendations outline characteristics that architects, designers, and caregivers should be mindful of when creating spaces for older adults, especially those with a higher risk of falling. The literature review identified the findings of previous research, with the recommendations from each study now assimilated into one location. These recommendations are grouped by senses: Vision, Auditory, and Tactile and then by category: Vision: Finishes/Accessories; Lighting/Electrical, Alarms/Signals; Corridors/Hallways; Signage/Text /Artwork; Contrast Application; Stairwells; Miscellaneous. Auditory: Alarms/Signals; Miscellaneous. Tactile: Miscellaneous, Restrooms. Olfactory: Miscellaneous (as shown in Table 1). Cues relative to vision were predominant in the literature review and outnumbered all other sensory cues combined. As shown in Table 1, the sensory findings of Pastalan's et al. [58] framework are clarified as a reminder of the purpose for the inclusion of each category. Additionally, several images are included that provide examples of some of these cues (see Figure 1, Figure 2 and Figure 3).

Table 1 Design guidelines to reduce extrinsic fall risks in the built environment.

Sense: Vision		
Findings by Pastalan, Mantz, and Merrill [58] and Delcampo-Carda, Barchino and Lluch [41] showed that visual acuity was most impacted by glare from uncontrolled light sources and shiny finishes; disappearing boundaries such as dark surfaces placed adjacent to a window that emitted an uncontrolled light source; or moving boundaries such as small-scale striped patterns, large flooring prints, and adjacent complimentary colors. Vision seemed to be the sense that most impacted an older adult's ability to maneuver in the built environment. Melton, Horvat, and Ray [8] indicated that poor vision includes visual acuity, visual field, contrast sensitivity, and depth perception. Five categories of home safety emerged from the qualitative study by Barstow, Bennett, and Vogtle [34] and included lighting, contrast, visual distractions, glare, and compensation strategies.		
Category	Purpose	Guideline
Finishes/Accessories	Reduce glare [26, 28, 35].	Use matte finishes, e.g., furniture, finish, and appliance selections on walls, floors and ceilings (Figure 1).
		Minimize placement of dark surfaces adjacent to a window that emits uncontrolled light source.
		Select non-glare window glazing, e.g., tinted.
	Minimize tripping [20, 23, 26, 30].	Minimize use of area rugs and runners that sit on top of the floor surface. Inset rugs and

		runners are satisfactory if they are flush or secure to the floor.
		Reduce the height between floor materials to <1/4”.
		Omit trailing wires when using portable light fixtures or technology.
	Minimize vibrating boundaries [26].	Minimize use of small-scale striped patterns and large-scale flooring prints.
		Avoid placing complimentary colors next to one another.
	Maintain a clear, planar definition and balance when walking [20, 23, 30, 31].	Minimize use of graphic images or patterns on flooring surfaces.
		Clearly define floors from the walls, such as through value changes, texture differences and patterns.
Lighting/Electrical	Increase light levels [16, 20, 23, 26, 30].	Locate receptacles adjacent to furniture groupings so that floor or table lamps can be next to the seating.
	Provide transition lighting for recovery by the eye [26, 35].	Provide transitional lighting where extreme contrasts in light levels might exist to aid in safe movement from the exterior to the interior, e.g., parking lots, walkways leading to entrance doors.
	Minimize glare [28, 35, 60].	Cover exposed bulbs on ambient, accent, task and portable lighting.
		Select window treatments that allow adjustment of natural light.
	Provide light upon room entry to increase safety and ability to discern spatial qualities [29, 34, 35].	Locate light switches so that a person does not need to enter a dark room, e.g., adjacent to door entrances.
		Locate light switches at each end of any corridor.
		Provide portable lighting that can be operated by thermal touch or open hands to eliminate the need for tight grasping and pinching.
	Provide adaptable lighting levels [26, 35].	Provide flexible lighting options, such as dimmer switches, to provide diverse light levels.
		Provide flexible lighting options so that light levels can be increased by up to six times in task areas, e.g., kitchen cutting area.

	Control color and light quality [28, 35].	Specify full spectrum bulbs that introduce the longer wavelength light to introduce warm hues into the space, e.g., reds, oranges, and yellows.
	Ensure adequate lighting levels [11, 15, 26, 35, 60].	Locate receptacles a minimum of every 12’.
		Specify wall receptacles at 15”-18”H (instead of 12”H) to maximize forward reach access.
		Provide bedside light access.
	Ensure adequate lighting levels and encourage sustainability [17].	Provide lighting sensors related to light or movement.
Alarms/Signals	Communicate important information for visual impairment [17].	Include alarms with visual cues, such as blinking lights.
		Select elevators that communicate the floor level.
Corridors/Hallways	Minimize tripping hazards and maintain balance [20, 31, 39, 60].	Incorporate handrails along a minimum of one corridor wall.
		Omit the placement of equipment on at least one wall to create clear walkways.
		Provide clear circulation paths and uninterrupted visual cues to reduce disorientation by promoting clear wayfinding.
		Eliminate clutter throughout the environment.
Signage/Text/Artwork	Provide clear wayfinding and promote balance, which could be compromised by turning too quickly [5, 20, 24, 35, 39, 48].	Incorporate pictograms into permanent signage.
		Use signage to promote clear directions.
		Ensure that signage between 27” AFF and 80” AFF extends no more than 4” into the environment.
		Clearly note emergency exits.
		Provide contrast between signage letters and backgrounds.
		Use saturated, clear, hues or primary colors to aid in coding.
		Use color, signage, photographs and/or memorabilia as orientation tools (Figure 2).
		Use landmarks and focal points to cue spaces.

		Incorporate braille on permanent signage.
Contrast Application	Provide clear wayfinding and promote balance that could be compromised if turning to located places too quickly [35, 51].	Use artwork, and/or memorabilia that contrasts with the wall to assist with wayfinding.
		Locate grab bars adjacent to waterclosets (toilets) and within showers.
	Define the visibility of planes or contrast sensitivity [28, 35, 60].	Select hardware color and/or texture that contrasts with the door.
		Contrast wall base with the wall (Figure 3).
		Locate handrails in corridors that contrast with the wall.
		Contrast all restroom fixtures, e.g., sinks, waterclosets, bathtubs/showers with adjacent finishes on floors and walls.
		Contrast window trim with the walls.
		Locate restroom grab bars by waterclosets and in showers/tubs that contrast with walls.
		Clearly note the leading edge of steps (where the rise and run meet).
		Minimize and repair uneven surfaces.
		Define floors from the walls, such as through value changes, texture differences, and patterns (Figure 3).
		Define furniture from the floor, such as through value changes, texture differences, and patterns.
		Contrast switch plates from the wall surface.
		Place windows to minimize glare.
		Select a color palette that is sensitive to warmer tones, color combinations, and texture/pattern usage.
	Define the visibility of planes or contrast sensitivity [31, 35].	Specify a consistent flooring color use in public corridors and adjacent spaces.
Stairwells	Promote balance [20, 23, 29, 60].	Provide appropriate stair handrails indoors and outdoors.
		Plan stairway handrails to extend at least 12” beyond the top and bottom step.
		Provide a consistent stair rise and run.

		Provide closed stair risers.
		Define stair edges (Figure 3).
		Provide headroom clearance of at least 7' high.
	Minimize trip hazards [20, 23, 29, 30, 60].	Plan interior doors to swing over a landing rather than over stair steps.
		Eliminate use of extension cords.
		Train staff on the danger of wet floors.
		Position furniture/equipment to promote safe movement.
		Provide safe footwear.
	Provide light upon entry to stairwell [29].	Place light switches at the top and bottom of stairs.
Miscellaneous	Increase socialization opportunities to reduce depression [21, 22].	Provide common areas with furniture groupings to create opportunities for social engagement.
		Plan space to have a singular and clear use.
	Organize space for mastery [5].	Provide opportunities for residents to claim their own space.
		Scale space to master decreasing spatial scale and with fewer people.
	Organize space with multiple sensory cues [5, 58, 59].	Provide redundant cues of the same environmental message within the environment.
	Maximize safety [16, 60].	Reduce clutter within an environment.
		Minimize exposure to at-risk weather-related conditions.
		Plan a watercloset close to the bedroom.
Sense: Auditory		
Pastalan, Mantz, and Merrill's [58] findings showed that auditory losses were impacted by background noises such as appliances, sound reflectance from hard surfaces, and high frequency tones.		
Category	**Purpose**	**Guideline**
Alarms/Signals	Communicate an emergency for full vision impairment, blurred vision, or an inability to orient correctly [48].	Include auditory alarm signals.
		Specify elevators that communicate the floor level.

Miscellaneous	Aid in socialization opportunities [21, 22].	Minimize background noises such as appliances, sound reflectance from hard surfaces, and high frequency tones.
Sense: Tactile		
Pastalan, Mantz, and Merrill's [58] findings showed that tactile responses were difficult to discern if subtle textures and temperature were used. In addition, knobs were hard to turn.		
Category	Purpose	Guideline
Miscellaneous	Promote stability and balance [16, 26].	Provide seating with arms.
		Provide seating with firm cushions.
		Select seat heights that are approximately 18" AFF or higher.
		Provide handrails that can be gripped, e.g., smaller diameter and recessed finger grips.
		Provide anti-slip flooring materials in bath and/or shower.
		Omit use of throw/scatter rugs.
	Provide stable furnishings [26].	Provide chairs with four stationery legs, or stationery back legs and casters only on front legs.
	Minimize injury from falls [26].	Select furniture edges that are rounded (Figure 2).
	Promote easy access [58].	Provide levered hardware.
Restrooms	Promote safety [27].	Set the temperature of hot water heaters low enough so that skin is not scalded or burned.
	Promote stability and balance [16, 26, 60].	Provide grab bars in the toilet and bathroom areas.
		Include a non-slip mat in the shower.
		Provide an adequate coefficient of friction when selecting flooring to minimize slippery flooring.
Sense: Olfactory		
Category	Purpose	Guideline
Miscellaneous	Increase the ability to smell [11, 17].	Be aware of the number of medications, with oversite by a physician.

Figure 1 Matte finishes are used on floor and wall finishes. Source: photograph taken by authors.

Figure 2 Corridor accent wall is used to assist in wayfinding. Furniture edges are rounded. Seat grouping promotes social interaction. Source: photograph taken by the authors.

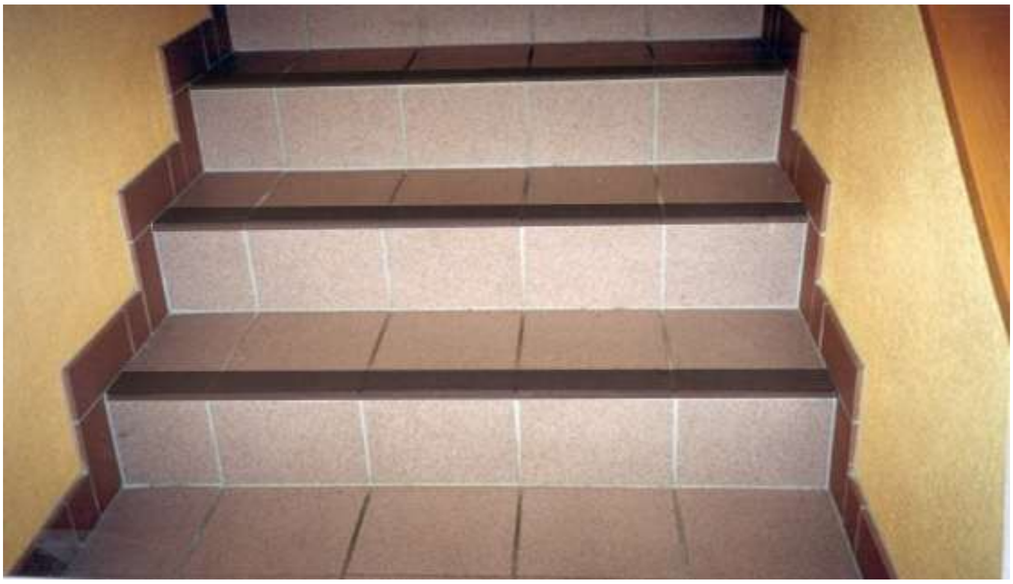

Figure 3 Wall base contrasts with wall and stair treads are distinct. Source: photograph taken by the authors.

6. Discussion

This review identified numerous causes of falls, which originate from many disciplinary backgrounds, e.g., occupational therapists, nurses, doctors, physiotherapists, public health officers and architects. There is merit in integrating interdisciplinary solutions from multiple viewpoints and varied backgrounds in future work. Systematic reviews such as from Gillespie et al. [39], Cheng et al. [41] and Clemson et al. [40, 43] found that home hazards management and intervention were one of the best approaches for preventing falls among older people in the community. Hopewell [32] found that exercise was one of the most effective and well-established interventions for both single interventions and multiple component interventions, while a study by Frick et al. [49] stated that home modifications were the most cost-effective approach for fall prevention, even compared with exercise. Although the research differs in the most effective way to integrate preventative practices, acknowledging that the physical environment is one element that contributes to fall risks is a step forward. Identifying design characteristics that can be added, or eliminated, from the built environment can help balance the physical demands with each person's ability to respond when participating in functional activities [35, 42]. Most important to this study is the contribution of science-based research that supports the physical observations and recommendations by Pastalan, et al [5, 58, 59]. The combination of this integrated approach provides designers/architects with a clear set of design characteristics needed to mitigate fall risks, so that these factors can be at the forefront when designing or renovating facilities for older adults. That factor alone, combined with the use of Pastalan's work as a framework, means that this different approach to studying fall issues contributes in a new way to the existing body of knowledge.

Extrinsic factors that identify fall prevention strategies can assist in creating safer physical environments for aging adults that promote increased function and well-being. The resulting design guidelines can be used to develop new designs for interior spaces, resulting in enhanced quality of life [35]. If even one item assists in reducing falls, then it will have served as an effective partner for aging individuals, but also to those who are caregiving.

These findings are of consequence due to the rapid growth of aging population levels within the U.S and the consequences resulting from falls. As a result, family members, designers/architects, healthcare professionals, policy makers, consumers, and researchers will collectively be called upon to creatively address these dynamic issues at individual, societal, and global levels [32]. Attention to these items may not prevent all falls but will mitigate some of the external risks that cause falls. By developing an understanding of declining senses in aging adults, design solutions can positively support the health and well-being of the people who reside and visit within residential and commercial environments. Although the reasons that older adults fall are diverse, the impact of the physical environment is still an area requiring additional study. Future research may establish other characteristics to increase or mitigate fall risks, include more study into the biological effects of sensory decline, or even provide a comparison of which characteristics have the greatest impact on fall risks. Enhanced knowledge in these areas can serve to increase the safety, comfort, and ability of residents, impacting overall quality of life [61].

When financial resources are tight, knowledge of characteristics that address the extrinsic fall risk factors can assist in prioritizing cost effective budgetary issues within both residential and commercial settings. This will benefit residents, family members, staff members, assisted living facility (ALF) directors, and society as a whole through reduced health expenses, increased quality of care, and higher quality of life. Although it is rarely possible to prevent the cause of all falls, improving even one environmental quality may result in a disproportionate increase in quality of life for older adults who have reduced physical health, sensory processes, cognition, and interpersonal relationships [12, 62]. The goal of each caregiver and designer should be nothing less.

Author Contributions

JW-N conducted the research and drafted the paper. EB contributed to the literature review and revisions to the paper. DG was involved in revisions to the paper. All authors critically reviewed the manuscript and approved the final version.

Funding

This research was funded in part by the Steelcase Corporation and the American Academy of Healthcare Interior Designers, Inc., the Interior Design Educators Council Foundation, Carol Price Shanis Graduate Scholarship, and the John and Ann Jensen Scholarship/Mt. Pleasant Community Foundation.

Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the American Academy of Healthcare Interior Designers, Inc. or Steelcase Healthcare.

Competing Interests

The authors have declared that no competing interests exist.

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