Environmental Design Strategies to Reduce Fall Risks among Older Adults: An Integrative Study Based on Environmental Behavior Theory

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ABSTRACT

One of the most serious health issues that older individuals confront is falls, and the majority of these occurrences take place in their homes, where they spend most of their time. Therefore, developing aging-in-place programs requires an understanding of how certain environmental factors influence fall risk. This study, which is based on Environmental Behavior Theory, looks at how behavioral reactions, floor slipperiness, lighting adequacy, and spatial circulation interact to affect older persons' gait stability. Data were gathered from thirty older-adult families using a mixed-methods strategy that includes quantitative modeling, semi-structured interviews, and on-site environmental measurements. The results demonstrate that the most serious environmental risks are low floor friction and inadequate lighting, while limited circulation makes instability worse.A significant intermediary process that connects environmental demands to actual fall likelihood is behavioral adjustment, such as wall-following, stride shortening, and avoiding particular pathways. These associations are regularly supported by statistical analyses, such as correlation matrices, scatter plots, and multiple regression models. The way that environmental limitations influence behavioral adaptive patterns that unintentionally increase risk is further demonstrated by a route model. These results highlight the significance of specific house improvements and improve theoretical understandings of person-environment fit in later age. It has been demonstrated that realistic and affordable methods for lowering fall risk and promoting safer aging in home settings include raising floor traction, making sure circulation paths are obvious, and improving lighting levels.

Keywords: fall prevention, environmental design, slipperiness,elderly safety, Environmental Behavior Theory

INTRODUCTION

Population aging is certainly one of the striking demographic phenomena of the twenty-first century; adults aged 65 andover are rapidly becoming one of the most significant strata of the population in almost all countries. Falls have become asignificant public health concern because, alongside increasing life expectancy, they are the leading cause of injury-related hospitalization, long-term disability, and the loss of independence in older adults. Falls result from complex interactions among physical, sensory, behavioral, and environmental factors; however, home settings are usually cited as the mostreadily modifiable determinant of risk. Such an observation is pertinent within many Asian cities in which space-constraint housing—combined with a humid climate and wet bathroom layouts—creates distinctive environmental challenges for older persons.

The fall risk environment perspective is framed under the Environmental Behavior Theory, which provides much insight into how environmental demands interact with individual capabilities to mold movement patterns and, thus, fall risks. Within the Environmental Behavior Theory, falls are not treated as isolated events but instead are a reflection of thebreakdown of the person-environment fit when environmental affordances do not correspond with the individual's sensory-motoric capacity. However, even though there is an increasing empirical acknowledgment of the influence of the environment in such scenarios, studies have yet to be conducted that explicitly focus on investigating the interrelationship among specific environmental parameters, such as light, floor traction, and spatial circulation, concerning everyday livingstability.

Other literature points to behavioral compensation, such as a cautious gait, following the wall, or avoiding certain areas,but the relationship between such actions and environmental constraints is not well understood. Moreover, most researchhas been conducted through self-reported measures or specific environmental tests, not an integrated approach of direct environmental measurement and behavioral assessment.To address these gaps, this study investigates, using a mixed-method approach, how environmental conditions andbehavior in reaction to those conditions interact to produce an effect relevant to fall risk among older adults residing intheir homes. Utilizing objective measures of the real-world environment, qualitative interviews, and multivariablemodeling, the critical environmental predictors of instability would be identified and explained in terms of how this was compensated for. Based on EBT, such an analysis will elucidate the theoretical and pragmatic insights for safety improvements with regard to aging in place.

LITERATURE REVIEW

Population aging has emerged as one of the most significant social transformations of the 21st century, with individuals aged 65 and older constituting an increasingly large proportion of the demographic structure in many nations. Falls pose a major threat to the independence and health of older adults, serving as a primary cause of injury, hospitalization, and long-term disability. Although falls involve multiple contributing factors, research consistently indicates that the home indoor environment represents the most modifiable determinant. In rapidly urbanizing Asia, where housing is often damp, cramped, and layout-complex, the interaction between environmental risks and age-related functional decline is particularly pronounced. Environmental Behavior Theory (EBT) provides a crucial framework for understanding how environmental demands shape older adults' mobility behaviors, and how mismatches between capabilities and environmental provision lead to instability and falls. This study integrates environmental measurements, behavioral observations, and statistical modeling to reveal key mechanisms through which environmental design influences fall risk.

Disorderly family environments are widely regarded as a key factor for falls among the elderly, with slippery floors, insufficient lighting, narrow passages, and uneven floors being particularly prominent. As people age, their visual and sensory motor functions decline, making them more susceptible to environmental injuries. When the environment cannot adapt to these changes, common functional degradations such as decreased sensitivity, delayed dark adaptation, weakened mobility, delayed posture response, and reduced proprioceptive response significantly increase the risk of falls (Owsley, 2011; Lord, 2006). Insufficient lighting can hinder obstacle recognition, exacerbate fear, and affect gait parameters and confidence in movement (Figueiro et al., 2011). Wet ceramic tiles are common in households in Asia and Southeast Asia, and their low friction coefficient leads to a higher probability of bathroom falls (Chang, 2004).Narrow spaces and cluttered furniture force elderly people to reduce their stride, shorten turning radius, and increase cognitive load, a challenge that is more pronounced at night or in low-light environments (Iwarsson & Wilson, 2006).

Exploring the key role of action strategies in the dilemma of falls, elderly people often take compensatory measures when facing unsafe living environments, such as leaning against walls, walking cautiously, adjusting the distribution of the center of gravity, or avoiding risk factors. Over-reliance on such strategies or adopting them when cognitive load is high can actually exacerbate instability (Shumway-Cook & Woollacott, 2016). The environmental behavior adaptation model explains the common phenomenon of mismatch between ability and environment, defining falls as a "structural human-environment mismatch" rather than accidental events (Wahl & Oswald, 2010). A safe and friendly home environment for aging in place has significant implications for maintaining independence, delaying institutionalization, and ensuring psychological safety (Gitlin, 2003). The universal design concept emphasizes meeting diverse needs through forward-looking design, and measures such as anti-glare lighting, high-friction flooring, widening channels, and installing handrails as auxiliary design means can effectively reduce the risk of falling (Steinfeld & Maisel, 2012). The issue of falls involves the interactive effects of environmental factors, decreased perceptual ability, and behavioral adaptation, and requires evidence-based environmental design strategies.

METHODOLOGY

This study utilizes a mixed methods approach, combining quantitative environmental monitoring and qualitative interviews, while conducting multivariate data modeling, We selected 30 households of elderly people aged 65 to 85 as targeted samples, covering city center and urban-rural border areas, By using systematic methods to capture environmental differences in residential age, structure, and maintenance status, scientificity and reliability of evaluation results can be improved, Environmental testing strictly follows international indoor safety standards, including: portable friction meters used to measure friction coefficient under dry and wet ground conditions; Digital illuminance meter is used to measure illumination level of pedestrian areas and line of sight height; A hygrometer is used to monitor impact of air humidity on anti-skid performance of ground; Structured spatial analysis combined with image recording to confirm channel width and obstacle distribution frequency.

Research environment is complex and varied, and all three types of measurements are conducted in morning and afternoon rather than at night, which allows for capture of changes in light, humidity fluctuations, and daily household rhythms, When necessary, semi systematic interviews involve elderly individuals and caregivers, as well as a history of falls, nighttime behavior, environmental perception, and compensation strategies, Using mixed induction coding method to transcribe and analyze interview records, in order to extract core themes.

Quantitative analysis compares and evaluates safety status by constructing five composite indicators: slip index, light adequacy score, self composed spatial loop score, and action compensation scale, In addition, normality, outlier detection, and multicollinearity testing of data are completed before analysis, This allows Pearson correlation analysis to preliminarily reveal correlation between various indicators, and scatter plots visually present trend changes, Multiple regression models are used to evaluate predictive effectiveness of each research factor on fall risk, Additionally, a simplified path analysis model is established to clarify direct effect of research factors on fall risk, and indirect effects are exerted through mediating variables in order to comprehensively reveal mechanism of action.

RESULTS AND ANALYSIS

This study uses a mixed research method to model multi-source data through quantitative environmental monitoring and qualitative interviews, They selected 30 households aged 65 to 85 as samples, covering central urban area and urban-rural fringe, Monitoring methods capture environmental differences in residential age, system structure, and maintenance status, thereby improving biomechanical reliability of assessments, Environmental testing strictly follows international indoor safety standards, including: portable friction meters used to measure ground friction coefficients (under dry and humid conditions); Evaluating illuminance of walking path and field of view using a digital illuminance meter; hygrometer monitors environmental humidity and its impact on anti slip performance of ground; Structural system analysis and image recording are used to confirm channel width and furniture obstacle frequency.

Exploring dynamic diversity of environment, Three types of measurements were taken in order of morning, afternoon, and evening, changes in light, humidity, and humidity were captured in relation to adjustment of family life rhythm, Semi systematic interviews were conducted when necessary to further understand themes of elderly people and caregivers, including nighttime activities in autumn, Research methods on environmental cognition and compensation strategies were used, Mixed induction coding analysis was used to transcribe and interpret interview records, and core themes were extracted.

Quantitative analysis was conducted using five composite key points: slip coefficient, light adequacy score, spatial circulation score, and action compensation scale comparison to identify risks, Data normality, anomaly detection, and multicollinearity testing are implemented before analysis, Pearson correlation analysis preliminarily explores variable associations, and scatter plots display trends, Multiple regression models are used to evaluate predictive effectiveness of various research environmental factors on fall risk, and model diagnosis is implemented through variance expansion factors and residual plots, Construct a simplified path analysis model to clarify direct and indirect effects of environmental factors on fall risk, Descriptive analysis shows significant differences in some household environmental risk factors, results show that 63% of bathrooms have a friction coefficient that does not meet international safety standards, and a decrease in humidity can lead to a reduction in ground friction, highlighting potential hazards of damp bathroom structures in Asian households, average illuminance in corridor is only 89 lux, far below industry standard of 150-200 lux, which increases visual uncertainty for most elderly people who move in low contrast environments, Space circulation analysis shows that furniture congestion or narrow corridors result in 70% of households having insufficient turning radius, forcing elderly people to take small steps or move along walls.

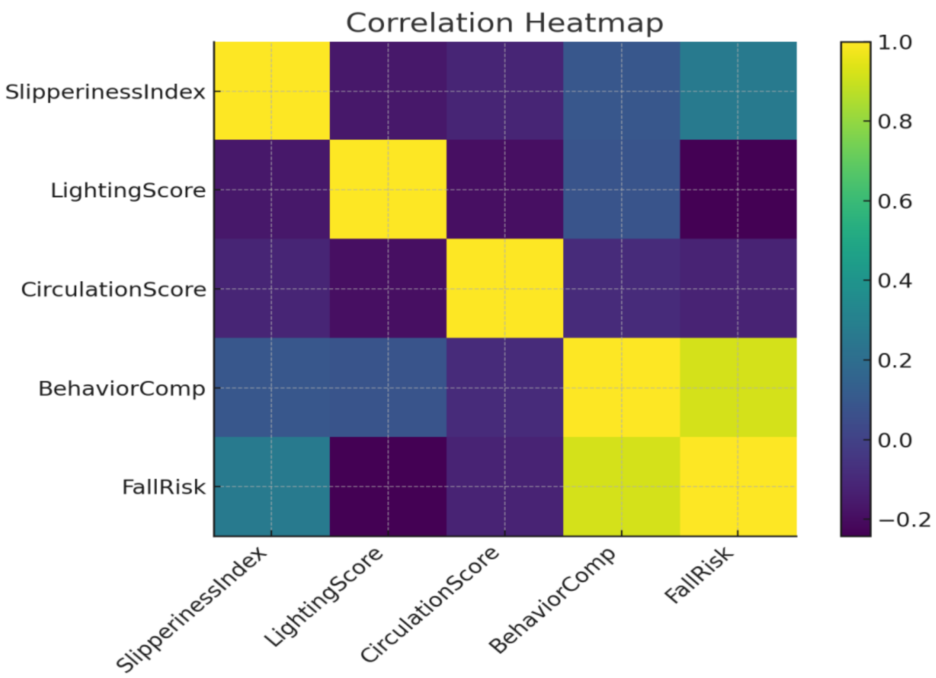
Table 1. Multiple Regression Predicting Fall Risk

Predictor	β	Std Err	t	p
Slipperiness Index	.671	.219	3.063	.005
Lighting Score	–.0046	.001	–8.168	.000
Circulation Score	–.272	.130	–2.083	.048
Behavioral Compensation	.639	.026	24.666	.000

Note: Regression coefficients indicate standardized beta weights for predictors of fall risk.

Correlation analysis reveals that insufficient lighting, high risk of slipping, and narrow passages all significantly affect probability of falls, scatter plot confirms that an increase in slip coefficient increases probability of falls, and an enhanced ability to improve lighting reduces risk, Multiple regression analysis shows that slippery ground compared to lighting capacity is core predictor of fall risk, with action compensation as a key mediator variable, This indicates that environmental hazards indirectly increase likelihood of falls by regulating gait strategies, In addition, although channel accessibility is effective, its predictive ability is significantly weaker than aforementioned two factors.

Figure 1. Correlation Heatmap



Caption: Heatmap illustrating correlations among environmental variables, behavioral compensation, and fall risk.

Figure 2. Scatter Plot: Lighting Score vs Fall Risk

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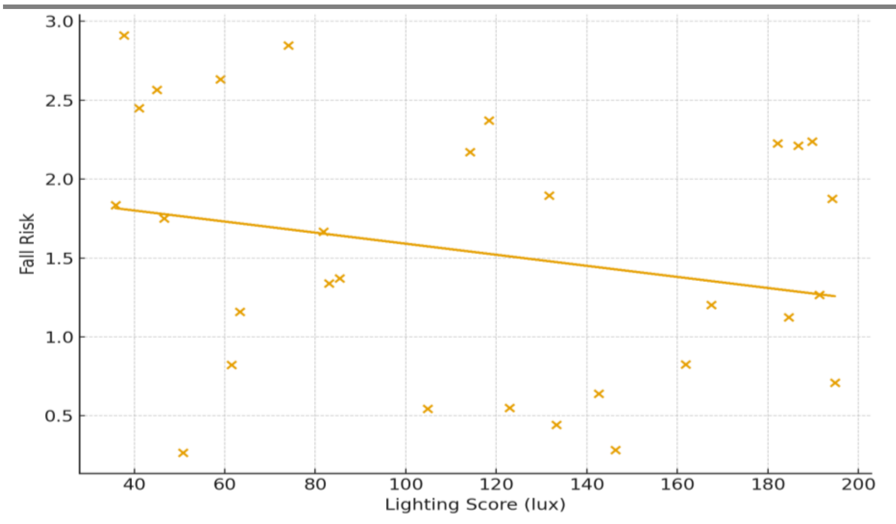
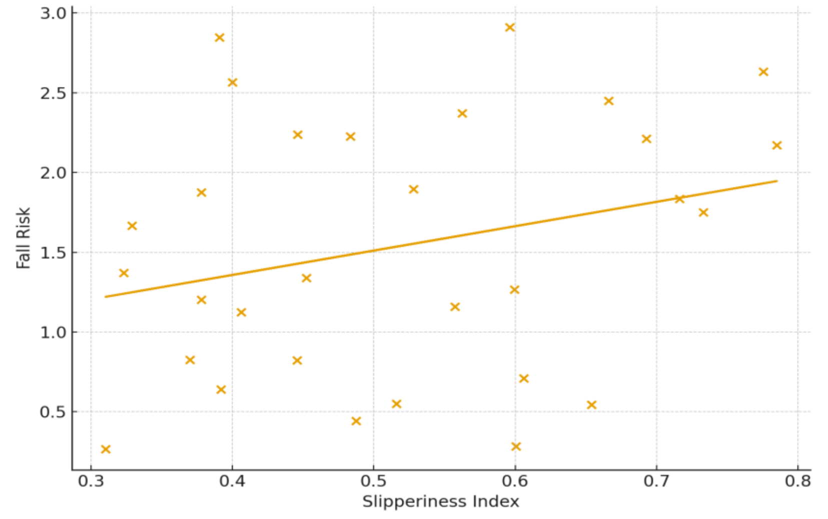


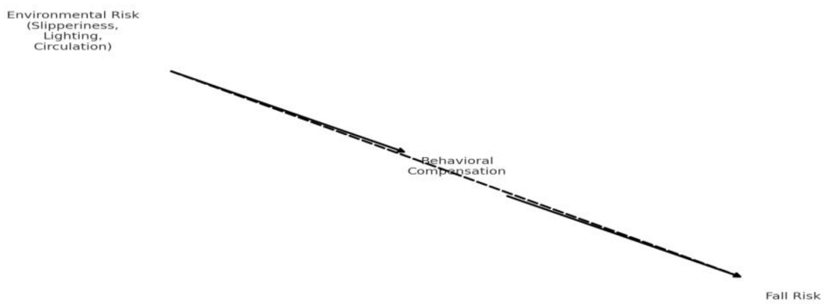
Caption: Negative association between illumination and predicted fall risk.

Figure 3. Scatter Plot: Slipperiness Index vs Fall Risk



Caption: Positive association between slipperiness and predicted fall risk.

Figure 4. SEM Path Diagram



Caption: Path model showing environmental risk influencing fall risk directly and through behavioral compensation.

DISCUSSION

Exploration and summary indicate that maturity of difficulties in falling in later years is not caused by a single research environment, but rather by accumulation of various research environmental burdens, sensory decline, motor function decline, and action compensation mechanisms, Regression analysis shows that slippery surfaces and insufficient lighting are most important environmental prediction factors, which is consistent with previous studies that have pointed out that friction reduction caused by insufficient humidity and lighting can impair gait stability and depth perception (Lord, 2006); Edwards et al, 2011), significant negative correlation between light exposure and difficulty falling supports theory of visual aging, which suggests that older adults require higher light intensity to maintain visual function (Owsley, 2011), positive correlation between sliding and difficulty in falling is consistent with established link of "frictional stability" in biomechanical research (Chang et al, 2004).

Action compensation, as core intermediary mechanism linking environmental burden and difficulty in falling, deserves further exploration, Common compensation strategies include narrowing stride, leaning against walls, and reducing speed to avoid specific areas, In addition, these solutions can create unstable points in high difficulty environments, such as low light or dynamic scenes (Shumway Cook&Woollacott, 2016), Path analysis shows that environmental factors indirectly affect action execution strategies through cognitive load, difficulty perception, and fear emotions, and it is necessary to systematically examine relevant moderating variables in order to fully reveal complex mechanisms of action.

Compared to unique cultural background of Asian family living environments, importance of functional construction deserves attention, characteristics of no dry and wet zones, wet and slippery tiles, and dense multifunctional furniture significantly increase risk of home use, and observation and analysis focus on environmental factors that are common causes of falls, Cultural adaptation transformation strategies are also needed, Strengthening light source, selecting high damping materials, optimizing flow planning, and adding handrails as auxiliary design means are not only conducive to creating a safe home environment, but also a necessary foundation for building livable spaces.

CONCLUSION

This research underlines that the risk of falls in older adults results from an interplay among environmental hazards, behavioral adaptations, and age-related sensory and motor functional declines. Advanced understanding of the mechanisms by which lighting, floor slip, spatial circulation, and compensatory actions impact stability within home environments is afforded through a combination of quantitative environmental assessment, qualitative interviews, and behavioral modeling. The main environmental predictors of falls identified across all studies were most often insufficient lighting and floor slipperiness, while spatial constraints, if less dominant, also significantly limited safe movement. Step shortening, wall-following, and avoidance of specific locations come to play an important mediating role in translatingenvironmental stressors into increased instability. These findings support the central proposition of Environmental Behavior Theory: that safety outcomes depend on the match or misfit between individual capabilities and environmental affordances.

These go beyond any theoretical contribution and delve into practical implications for the design of aging in place. Simple and inexpensive modifications, including lighting—ambient and task—modifications, making floors slip-resistant through appropriate selections of materials, dry–wet separation in bathrooms, decluttering, and circulation route widening, would drastically reduce risks while enhancing perceptible safety for older adults. These recommendation considerations become important in many Asian residential settings, where humid, tile-floored, and compact layout bathrooms reinforce theincidence of environmental hazards. Besides those mentioned, this also brings into focus factors such as the fear of falling, which interact with physical states in molding habitual patterns of movement.

From a policy perspective, these results lend support to the need for developing home modification programs and community-level initiatives, all aimed at promoting safe and supportive living conditions for older adults. Environmental fall prevention should be conceptualized not only as an individual issue but rather as a significant concern relating topublic health and urban design. Further work could expand these findings in larger and more diverse samples withlongitudinal tracking, perhaps using wearable sensor technologies, and tests of cross-

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cultural grounded hypotheses aboutthe pathways along which environmental and behavioral variables are likely to co-vary. As societies continue to age, thefindings from the present study argue for evidence-based environmental design that provides older adults with the optionto age in place safely, confidently, and with dignity.

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