A MODEL FOR A HUMAN FACTORS BASED DESIGN GUIDELINES HANDBOOK FOR RESIDENTIAL LIVING ENVIRONMENTS FOR THE ELDERLY

by

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ABSTRACT

The elderly in America represent a significant and growing population. One relevant engineering aspect of an aging population is the suitability of residential environments for the independent-living elderly. Engineers, architects, and designers are increasingly involved in the design and assessment of residential living environments for elderly persons. These designs should consider the fundamental principles and techniques of human factors to make certain that residential settings enhance independence and overall quality of life for the independent-living elderly.

One way to help designers with this task is to develop a design guidelines handbook. However, to ensure designs are appropriate for the elderly, a prerequisite must be that guidelines are based on sound human factors principles.

Creating a design guidelines handbook based in science requires a significant amount of work, in terms of understanding the aging process, developing guidelines, and validating the applicability of the guidelines. Therefore, developing these guideline sets and compiling into a handbook is outside the scope of this thesis.

The role of this thesis is to bridge the gap between calling for the development and actually creating the handbook. Specifically, this thesis presents a model to categorize and analyze existing guidelines through use of a research matrix. The matrix provides a human factors based context to view existing work and highlights areas for additional research. This thesis also proposes the expansion of this matrix to be used as a framework for a future handbook.

In addition to the above research matrix, a guidelines development methodology is proposed. The methodology is a process that focuses on developing guidelines based on human factors principles.

After presenting the case for developing a guidelines handbook, and proposing a methodology to do so, a rationale to implement a handbook is described. This rationale concludes that the injury rates experienced by the elderly may, in some cases, be substantially reduced, by developing designs that accommodate the decreased functional abilities of the elderly. Developing human factors based guidelines and a handbook might ultimately help designers with this task.

CHAPTER 1

INTRODUCTION

An important research area for human factors engineers is the home environment for independent-living elderly. Since the mid-1970's, there have been calls for human factors engineers to develop a design guidelines handbook for constructing home environments for the independent elderly (Chapanis, 1974). To date, no such resource has been written. Although significant work remains before a completed handbook can be developed, such a resource would assist engineers, architects, designers, and homebuilders develop safer and more comfortable environments for the growing independent-living elderly population.

Engineers, architects, designers, and home builders are increasingly involved in designing and assessing residential living environments for elderly persons. Their designs need to consider fundamental principles and techniques of human factors acceptability for the independent-living elderly, including the following:

- Safety and ease of access to bathtubs and shower facilities
- Safety and access to storage facilities (too low, too high, etc.)
- Safety and access to utilities (electrical outlet, water, etc.)
- Sufficient lighting for general household, utility, task and other areas
- Flooring and walkway (trip hazards, visual contrast, etc.)
- Sensory input (visual, auditory, tactile, etc.)

These and many other fundamental considerations are important for home design and construction professionals to understand. Answering these considerations may enhance the quality of life for the independent-living elderly in terms of improved safety, reduced injuries, and increased comfort.

Independent-Living Elderly

It is well documented that the elderly represent a significant and growing demographic (U.S. Department of Health and Human Services, 2002). According to the 2000 Census, just over 35 million seniors (age 65+) live in the United States. This represents 12.4% of the total population (U.S. Census Bureau, 2001). More importantly, as shown in figures 1 and 2, the elderly are expected to grow significantly over the next 50 years, both in terms of population and percent of population.

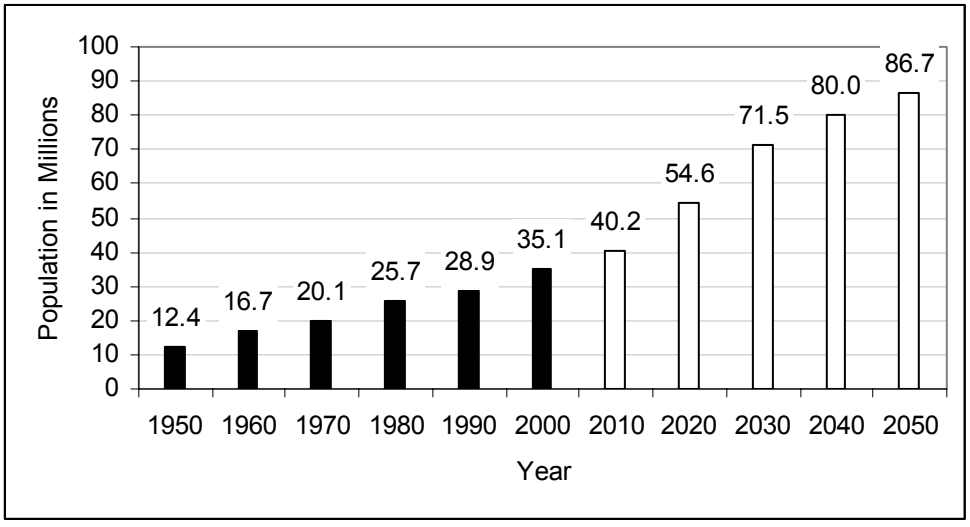

Figure 1. Population and projections of those 65+ years of age. Adapted from Pirkl (1994) and U.S. Census Bureau (2004a).

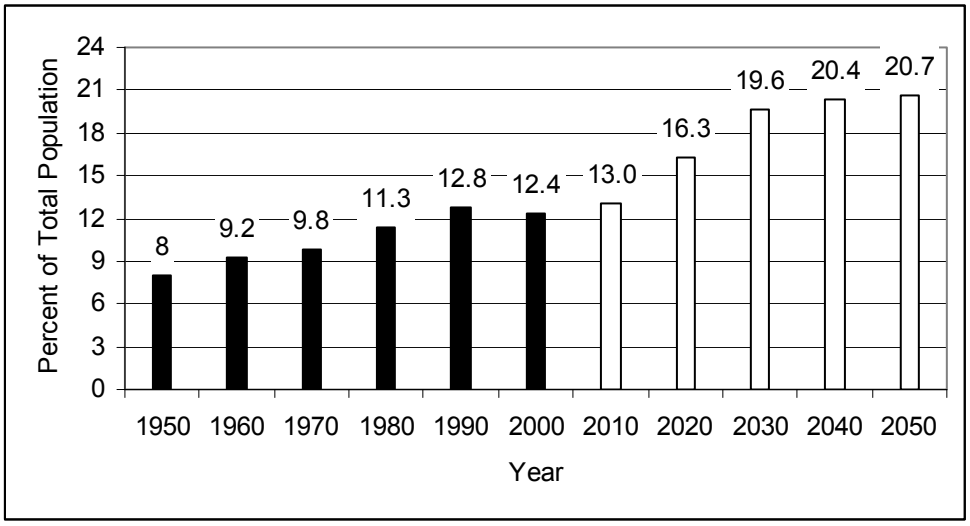

Figure 2. Elderly population as a percentage of total population. Adapted from Pirkl (1994) and U.S. Census Bureau (2004a).

Of these 35 million seniors who live in the United States, over 94% live in a residential household and less than 30% are physically disabled (U.S. Census Bureau, 2004b). Although many necessary guidelines exist for the handicapped population, it appears that the non-institutionalized, non-disabled elderly person has largely been forgotten.

Gitlin (2003, p. 629) points out that "there is a dearth of research on the dynamical processes of daily home life and a continued preference for, and proliferation of, research on older people in institutional facilities;" yet the much larger population of independent-living elderly is not nearly as well represented. Therefore, it may be worthwhile for human factors engineers to research the needs of this population in order to develop appropriate design guidelines for the home environment.

Thesis Overview

This thesis seeks to underscore the importance of the role that human factors engineers can play in the development of design guidelines related to residential living environments for the independent-living elderly. One way the thesis does this is by describing a new context in which to view existing guidelines, in a way that specifically emphasizes human factors contributions. This new context not only provides a framework to summarize existing literature, it also establishes the groundwork to develop a guidelines handbook and highlights specific areas that need additional research.

After reviewing the relevant literature and formalizing the thesis objectives, chapter four describes the approach used to analyze the current research related to residential homes for the independent living elderly. Specifically, chapter four introduces a matrix to categorize published guidelines and existing research into important architectural areas throughout a home.

Chapter five presents the results of populating the matrix with the existing research. In doing so, chapter five illustrates the lack of human factors research related to residential settings for the independent-living elderly.

The research findings are discussed in chapter six. Three potential design guideline handbook formats are also addressed. Depending on its specific end use, a design guidelines handbook could be categorized by functional limitation or disability (e.g., visual limitations, auditory limitations, physical limitations, cognitive limitations); grouped by tasks or daily living activities (cooking, bathing, cleaning); or organized by architectural area (kitchen, bathroom, bedroom).

In addition to presenting the three handbook formats, chapter six describes an original model that may be used to develop guidelines for the handbook. This model proposes six categories of guidelines, each promoting human factors principles as a basis for any design guideline.

Chapter seven presents a rationale for implementing a design guidelines handbook. The premise for this rationale is that high injury rates experienced by the elderly are caused by reduced functional abilities that come from aging. This chapter aims to establish targeted levels of at-home injury rates experienced by the elderly. The proposed methodology is first described, and then illustrated through three examples.

The final chapter summarizes the thesis, draws conclusions from the research, and discusses potential future areas of study.

In summary, this thesis is a stepping stone for developing a human factors-based design guidelines handbook that engineers, architects, designers, and homebuilders can use to help ensure residential housing designs enhance the independence and overall quality of life for the independent-living elderly.

CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this research is to develop a model for a human factors based guidelines handbook to assist in designing living environments for the elderly. Currently, no known single reference handbook exists that provides established human factors principles specific to the design of residential living environments for the elderly. The following presents a background of human factors related to the elderly and their living environments, and discusses existing design guidelines research.

Human Factors and the Elderly

Why is it important to study the elderly from a human factors perspective? First, the elderly represent a significant and growing demographic. According to the 2000 Census, almost 35 million seniors (age 65+) live in the United States, which represents 12.4% of the total population (U.S. Department of Commerce, U.S. Census Bureau, 2001). By 2030, the number of elderly persons will double and is expected to represent 20% of the population (U.S. Department of Health and Human Services, Administration on Aging, 2002). Clearly, the sheer size of this growing population alone warrants a fair study of the elderly and any related engineering and architectural design requirements.

Secondly, and just as important as population size, is the fact that the elderly represent a cohort with special issues including reduced mobility, agility, strength, and an

increased susceptibility to injury. As human factors engineers, we can use our skills to improve the quality of life for older people (Czaja, 1990b) in similar fashion as has been done for the industrial workforce in the past. Human factors, as defined by the Human Factors and Ergonomics Society (HFES) is "the knowledge concerning the characteristics of human beings that are applicable to the design of systems and devices of all kinds…and the use of such knowledge to achieve compatibility in the design of interactive systems of people, machines, and environments to ensure their effectiveness, safety, and ease of performance" (cited in Rogers, 1997, p.151). As Rogers, Meyer, Walker, and Fisk state, "we [human factors researchers] need to do more to ease the daily lives of older individuals" (1998, p.123). Likewise, Faletti agrees that human factors engineering has "direct conceptual and methodological relevance to the study of problems involving the older person and the physical environment" (1984, p.192)

Finally, we should study the elderly because we currently have insufficient data to make appropriate design recommendations for the elderly (Smith, 1990; Kelly and Kroemer, 1990; Czaja, 1990b; Kroemer, 1997). The elderly population is different than younger or middle-aged populations and we cannot assume or rely upon specifications and guidelines developed for the younger, "working" population. Therefore it is worthwhile to continue researching elderly needs from a human factors engineering perspective.

Human Factors and Elderly Living Environments

Alphonse Chapanis published one of the earliest known appeals to apply human factors to the design of residential living environments for the elderly (Parsons, 1981).

Chapanis acknowledged that while in the past human engineering was almost exclusively applied to military and industrial fields; human factors engineers have the methodology and tools to study and design elderly environments (1974). Chapanis called for a "large scale research effort" (1974) to study the needs and collect basic data on the elderly. Also in this work, Chapanis suggested the creation of a human engineering design guide for the elderly.

Nearly a decade later, in direct response to living environments, Parsons stated that "when users vary greatly in competence, it becomes difficult to provide design guidelines that should apply throughout a residential facility" (1981, p.41) however, Parsons sought to develop a framework to study elderly living arrangements using the bedroom as an example (Parsons, 1981). He went on to express that to design residential environments for the elderly, we must understand how constructed environments affect elderly persons and then we can systematically apply this understanding to all areas within residences (1981).

The Parsons article was published in the 1981 *Human Factors* special issue on aging. Although there was much research on the topic in the 1980's (Czaja, 1990b), *Human Factors* did not release another special issue on Aging until 1990. That year, the National Research Council published a report detailing research needs for aging populations (Czaja, 1990a). This research focused on many aspects of elderly life, including home activities and the need for a design guidebook specifically for the elderly (Czaja, 1990a).

Human Factors Handbooks

Two design guideline handbooks for use in residential housing for the elderly are Roger and Fisk's *Handbook of Human Factors and the Older Adult* (1997) and Woodson's *Human Factors Design Guidebook* (1981). Kroemer (1997) also suggests that, Denno et al's *Human Factors Design Guidelines for the Elderly and People with Disabilities* (1992), the American Association of Retired Persons *Life-Span Design of Residential Environments for an Aging Population* (1993), and Prikl's *Transgenerational Design* (1994) are early attempts at developing human factors based design guideline handbooks. These handbooks are briefly described below.

In 1997, a handbook related to human factors and the elderly was published (Rogers and Fisk, 1997). The handbook contained fundamental characteristics associated with aging including anthropometrics (Kroemer, 1997) and a series of chapters on applying human factors. A chapter was included that described technologies available for use in home-related tasks (Czaja, 1997) and another chapter discussed using robotic technologies for cooking (Engelhardt and Goughler, 1997). Although this handbook included some research into residential living environments for the elderly, it was not a systematic investigation of this topic nor did it provide a more complete set of design guidelines.

Woodson's (1981) design guidelines handbook is extremely comprehensive in scope and serves many purposes. However, in terms of designing for the elderly, Woodson's handbook is not entirely acceptable to be used extensively. One problem is that this handbook does not specifically address the elderly for many of the residential

design issues (admittedly, that is probably not this book's purpose). Another issue is that few guidelines cite specific research as a validation of the guideline. Therefore, while Woodson's handbook is a fascinating general reference, it may not be an acceptable design guidebook to accommodate the design needs of the independent-living elderly.

One design guidelines handbook that had promise was Denno et al's (1992) draft. This guidebook explicitly considered human factors research and began developing guidelines for controls, visual and auditory displays, and panel layouts used by the elderly and disabled. Despite a good start, this draft only addressed a few design issues, while leaving many issues to be addressed later.

American Association of Retired Persons (1993) compilation, although described as a guidelines handbook by Kroemer (1997), was actually a proceedings for a conference on designing residential environments for the elderly. Papers within this volume covered architecture, technology, and senior housing. While these articles captured significant issues in designing elderly housing, no human factors based design guidelines were established or reported.

The final handbook (Pirkl, 1994) discusses "transgenerational design." Although there is an in-depth discussion on the aging process and functional limitations that need to be addressed with design, this book focuses mainly on consumer products that are currently available or in the research and design stage.

Architecture Handbooks

The architecture field has published numerous articles and books on housing for the elderly. However, many of these architectural publications focus on barrier free

environments and designing institutional settings (Zeisel, Epp, and Demos, 1977; Jordan, 1978; Koncelik, 1982; Blitch, 1983, Macsai, 1983; Marans et al., 1983; Regnier and Byerts, 1983; American Institute of Architects, 1985; Steinfeld, 1987).

Harrigan (1987) stressed the need for architects to consider human factors in design. However, his work presented a research methodology imploring human factors rather than any discussion of applicable guidelines.

In *Human Dimension & Interior Spaces* (Panero and Zelnick, 1979), the authors describe "a more anthropometrically based approach to preliminary design" (p.123). While the concepts presented are relevant, not enough anthropometric data were available on the elderly at that time to develop any tangible guidelines.

One of the most complete handbooks found was one issued by the government of Canada (National Advisory Council on Aging, 1988). After describing characteristics associated with aging, this book presented numerous guidelines for residential housing for the independent-living elderly in the form of a workbook. Checklists were developed for each architectural area within a home, which provides a simple reference for designers.

Although there appears to be a fair treatment of housing for the elderly in the field of architecture, two limitations found in these publications are that 1) almost no guidelines reference any research as a means to validate the guidelines and 2) many of the handbooks discussing elderly housing focus on those that are disabled. There is certainly a special need to design for disabled persons, however, establishing heights based on wheelchair users can be vastly different than heights required for the

ambulatory elderly. While designing for wheelchair access may "accommodate" the elderly, it is interesting to wonder if there are negative ramifications associated with doing so (e.g., could increasing the level of discomfort, speed the rate of functional decline in the elderly?).

Summary

Developing a single reference handbook may help engineers, architects, designers, and homebuilders ensure residential housing designs best meet the needs of the independent living elderly. Housing for the elderly has been considered by both human factors engineers and architects and some guidelines based on published research have been developed. However, it appears that no complete set of guidelines that have been based in or validated by research exists. Therefore, summarizing the current literature and proposing a framework for a handbook of design guidelines seems to be an important step in creating a single reference handbook.

CHAPTER 3

RESEARCH OBJECTIVES

From the literature, it is apparent that design guidelines for elderly living environments are appropriate. Much research has been completed in the field yet much work remains. Despite the increase in studying elderly environments from a human factors perspective, there are still calls for much more specific research (Kroemer, 1997). This master's thesis attempts to address this call for research with the focus on living environments. The four primary objectives of the thesis are described below.

I. Objective 1: To analyze the current research related to residential homes for the independent living elderly. The analysis will show relevant human factors engineering and architecturally related research with respect to areas in residential living environments for the elderly. The analysis was intended to be more than just a compilation of research; it was used as a mechanism to assess the current literature and identify areas of needed research.

   Understanding what literature exists is the foundation of this research and therefore may be the most significant contribution to the field. Objective 1 is treated in the Research Approach, Results, and Discussion chapters.

II. Objective 2: To develop a potential framework for a human factors design guidelines handbook specific to residential living environments for the elderly. Many researchers have discussed the need for these design guidelines (Chapanis,

1974; Czaja, 1990b; Kroemer, 1997) but it appears that no known handbook based in human factors research is available. The research required to formulate such a handbook is far from trivial but it is hoped that defining a possible framework may guide further research in this area. Objective 2 is addressed in the Discussions chapter.

III. Objective 3: Subsequent to Objectives 1 and 2, the purpose of Objective 3 is to recommend areas for future research. Specifically, the recommendations will focus on developing design guidelines for residential living environments for the elderly based on sound human factors principles. The recommendations will stem from gaps in the literature expressed by the outcome of Objective 1 and will be implied in the Results chapter and treated in the Conclusions chapter.

IV. Objective 4: To develop a methodology for establishing a targeted level of injury rates for unintentional injuries experienced by the elderly in residential settings. This methodology will be illustrated through three examples. Targeted injury rates will be calculated for injuries involving bathtubs/showers, stairs/steps, and floors/flooring materials. These three injury classifications were chosen because they contribute to the three highest injury rates (Czaja, 1993) and injury costs (Lawrence et al., 2000) experienced by the elderly at home.

Objective 4 is a logical progression of developing guidelines based on sound human factors principles. That is, if we recognize that the elderly age

group generally gets injured more often than younger age groups due to a decreased ability to adjust to standard designs (Keiser, 1978), and creating human factors based guidelines can improve standard designs, then it seems appropriate to quantify a target level of injury rates for the elderly related to home environments. Objective 4 is treated in a separate chapter titled Rationale for Implementation.

CHAPTER 4

RESEARCH APPROACH

This chapter outlines the approach used to analyze the current research related to residential homes for the independent living elderly (Objective 1). The first step was to systematically break down a home into architectural system components. For this research, architectural subcomponents refer to the physical and non-physical entities, and the spatial environment in a home. Physical entities include objects such as flooring, walls, stairways, etc., while heating, lighting, and ventilation are considered non-physical entities. Examples of spatial environment are layout and room dimensions.

The second step involved designating categories to appropriately capture existing literature. The two obvious categories are the design guideline/recommendation and the source of the guideline (citation). Since this thesis attempts to focus on human factors and researched-based guidelines, the other data collected were the research objective, a description of the research (including number/age of subjects and a description of the research methods used to develop the guideline) and a categorization of the functional limitation on which the research was based (i.e. physical, sensory/perception, and/or cognitive).

Documenting the categories of functional limitation was considered important because existing research might address only one or two of the categories when all three categories are relevant to developing a design guideline. For example, when designing controls used to operate a cook-top range, one physical consideration is the torque required to turn a rotary control, one sensory consideration is the size of lettering used to

label the controls, and one cognitive consideration is the arrangement of the controls in relation to the burners (i.e., which control actuates which burner). Functional limitations were categorized by these three types because numerous impairments can be sub-classified under these main functional limitations (Denno et al., 1992).

The final step was to populate the fields within the matrix with information from relevant human factors engineering and architectural publications. Table 1 presents the matrix template used in this research.

Table 1. Template for matrix of research corresponding to architectural system components.

Architectural System Component	Citation	Design Guideline/ Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
INTERIOR							
Kitchen							
Cabinet/ Storage Systems							
Cooking Technologies							
Counter							
Floor Surface							
Layout							
Lighting/Illumination							
Oven/Range							
Refrigerator							
Room Dimensions							
Room Transition							
Sink/Faucets							
Ventilation							
Bathroom							
Bath/Shower							
Bathroom Technologies							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Sink/Faucets							
Storage							
Toilet							
Ventilation							

Table 1. Template for matrix of research corresponding to architectural system components (continued).

Architectural System Component	Citation	Design Guideline/ Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
INTERIOR							
Bedroom							
Bedroom Technologies							
Closet/Storage							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Ventilation							
Living Room							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							
Dining Room							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							
Office							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							
Common Features/Misc.							
Doors/Doorways							
Electrical Receptacles							
Emergency Escape							
Entrance							
Flooring (General)							
Hallways							
Heating (General)							
Heating (General)							
Ingress/Egress							
Lighting/Illumination (General)							
Light Switches							
Other Misc. Storage							
Ramps (Interior)							
Room Dimensions (General)							
Smoke Alarms/ Smoke Detector							
Stairways (Interior)							

Table 1. Template for matrix of research corresponding to architectural system components (continued).

Architectural System Component	Citation	Design Guideline/ Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
INTERIOR							
Thermostats							
Ventilation (General)							
Walls (General)							
Windows							
EXTERIOR							
Driveway/Parking							
Electrical Receptacles (Exterior)							
Entrance							
Garage							
Hose Connection							
Lawn/Yard							
Lighting/Illumination							
Ramps (Exterior)							
Walkways							

Limitations and Delimitations

There are two primary limitations to this research approach. First, it is possible that areas not considered important are included in the matrix. Second, it is also possible that important architectural areas were left out of the matrix.

The first limitation is addressed by recognizing that adding extra areas within the matrix is conservative, therefore it is better to include extra information than leave out information that should be included. The second limitation is addressed by acknowledging that this was the first known attempt at compiling design guideline research related to living environments for the elderly. Consequently, as research continues, this matrix can be updated as needed.

The main delimitation is that only architectural subcomponents (as defined above) were considered, that is, no consumer product design guidelines were investigated (except refrigerator and oven/range). A secondary delimitation is that research

considered only public documents. Although some architecture and homebuilding companies may have developed in-house design handbooks, this research did not attempt to locate such sources.

CHAPTER 5

RESULTS

This chapter presents the populated research matrix discussed in Research Approach. Two tables are displayed for each architectural area (Kitchen, Bathroom, etc.). The first table is a quick reference to illustrate which guidelines are associated with research and which functional limitation is addressed by the research. Note that subcomponents are repeated when associated with more than one guideline. The second table is used to present guidelines and recommendations found within the research.

Kitchen

Table 2 represents the guidelines related to the kitchen. Only four out of the twenty sets of guidelines are supported directly with research. Of those four, Kirvesoja et al. analyzed kitchen cabinetry/shelving heights and countertop height used by the elderly in Finland (2000), Englehardt and Goughler investigated the applicability of using robotic technologies in meal preparation (1997), and Koppa et al. performed a laboratory study to define guidelines that would aid in the design of refrigerators (1989).

Table 3 is a list of kitchen guidelines and recommendations found in the current literature. To minimize bending, some recommend keeping storage shelves 12” or higher above the floor (Kirvesoja et al., 2000; Pinto et al., 2000), while the U.S. Department of Housing and Urban Development (HUD) recommends 9” (HUD, 1996). Likewise, Kirvesoja et al. (2000) and Pinto et al. (2000) recommend the top storage shelf be no higher than 63” while HUD (1996) recommends not exceeding 54”.

A common countertop height recommendation is 36” (Woodson, 1981; National Advisory Council on Aging, 1988; Kirvesoja et al., 2000); however, HUD (1996) suggests installing counters at various heights or using adjustable countertops to accommodate elderly users of different heights.

Notable missing guidelines/recommendations include kitchen layout, the transition between kitchens and other adjoining rooms (i.e. floors, walls), and ventilation requirements specific to the kitchen.

Table 2. Representation of guidelines and research in the Kitchen.

Architectural System Component	Citation	Design Guideline	Research Objective	Research Description	Functional Disabilities: Physical	Functional Disabilities: Sensory	Functional Disabilities: Cognitive
INTERIOR							
Kitchen							
Cabinet/ Storage Systems	■	■	■	■	■		
Cabinet/ Storage Systems	■	■					
Cabinet/ Storage Systems	■	■					
Cabinet/ Storage Systems	■	■					
Cabinet/ Storage Systems	■	■					
Cooking Technologies	■	■	■	■	■	■	
Counter	■	■	■	■	■		
Counter	■	■					
Counter	■	■					
Counter	■	■					
Floor Surface	■	■					
Floor Surface	■	■					
Layout							
Lighting/Illumination	■	■					
Oven/Range	■	■					
Oven/Range	■	■					
Oven/Range	■	■					
Refrigerator	■	■					
Refrigerator	■	■	■	■			
Room Dimensions	■	■					
Room Transition							
Sink/Faucets	■	■					
Ventilation							

Table 3. Guidelines and guideline sources for the Kitchen.

Architectural System Component	Citation	Design Guideline/Recommendation
INTERIOR		
Kitchen		
Cabinet/ Storage Systems	Kirvesoja, H., Vayrynen, S., & Haikio, A. (2000)	Height for storage shelves: 12-63" (300-1600mm) for Finnish elderly.
Cabinet/ Storage Systems	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Recommendations: - Shelf height 63" (1600mm) - Cupboard height between 12" (300mm) and 55" (1400mm)
Cabinet/ Storage Systems	HUD (1996)	Recommendations: - Storage shelf height 9-54" - Locate bottom shelf of upper cabinet at 48" - Utilize drawers that fully pull out
Cabinet/ Storage Systems	National Advisory Council on Aging: Government of Canada (1988)	Wall cupboards 14" above counters Provide D-type handles on cupboards and drawers
Cabinet/ Storage Systems	Woodson, W.E. (1981)	Wall cupboards 15" above counters
Cooking Technologies	Englehardt, K.G. & Goughler, D.H. (1997)	No explicit guideline, however, authors strongly suggest that designers match the needs and abilities of older adults with the design and capabilities of technologies
Counter	Kirvesoja, H., Vayrynen, S., & Haikio, A. (2000)	Counter height = 33.5" (850mm) for Finnish elderly Note: Authors found 800-900mm acceptable.
Counter	HUD (1996)	Recommendations: - Mount counters at more than one height - Utilize adjustable countertops - Provide visual contrast at counter edge
Counter	National Advisory Council on Aging: Government of Canada (1988)	Counter or table height ≤ 3'
Counter	Woodson, W.E. (1981)	Counter height = 36"
Floor Surface	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Non-skid flooring
Floor Surface	HUD (1996)	Non-skid flooring
Layout		
Lighting/Illumination	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Provide direct lighting on work surfaces
Oven/Range	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Oven: Place on top of counter (to avoid back strain) Range: Provide raised edge to protect against spills
Oven/Range	HUD (1996)	Recommendations: - Front mounted controls - Staggered burners - Consider flush (or low) burners - Consider separating oven from range and provide knee space below range (wheelchair access)
Oven/Range	National Advisory Council on Aging: Government of Canada (1988)	Provide 1' wide counter surface on either side of range (at same height)
Refrigerator	HUD (1996)	Recommendations: - Side-by-side model refrigerator/freezer -Allow doors to open 180° - Include pull-out shelves - Include water/ice dispenser (for those with limited hand dexterity)

Table 3. Guidelines and guideline sources for the Kitchen (continued).

Architectural System Component	Citation	Design Guideline/Recommendation
INTERIOR		
Kitchen		
Refrigerator	Koppa, R.J., Jurmain, M.M., & Congleton, J.J. (1989)	Recommended standard features: - Adjustable height shelves - Three shelves - Top freezer - Two produce bins - Temperature control located at height of 45-49" Recommended design options: - Detachable lazy susans - Pull-out shelves - Easily openable doors, with auto-close functionality - Bins should glide smoothly
Room Dimensions	International Conference of Building Officials (1997b)	Ceiling height ≥ 7' Floor area: None Wall dimension: None (503.1-503.3)
Room Transition		
Sink/Faucets	HUD (1996)	Recommendations: - Use lever style handles - Select model with high temperature stop - Sink depth ≤ 6.5" - Consider adding a removable front and bottom cabinet below sink to accommodate future wheelchair access
Ventilation		

Bathroom

As shown in table 4 thirteen sets of guidelines/recommendations were found that relate to bathrooms, while two of the sets were directly linked with research. Meindl and Freivalds (1992) sought to determine the optimal shape and location of faucet handles (for use in bathtubs and showers) and Bordett et al. (1988) investigated the torque required to shut off water at a faucet. In the same study, Bordett et al. quantified which of seven different handle styles the elderly could generate enough torque to meet or surpass the shut off requirement. Table 4 also shows that guidelines are missing for bathroom technologies, room layout, transitions from the bathroom to other rooms, and storage needs.

The guideline sets and recommendations found for bathrooms are presented in table 5. Using lever-style handles in bathtubs, showers, and sink faucets is a common recommendation (Bordett et al., 1988; Meindl and Freivalds, 1992; HUD, 1996). Another consistent recommendation for bathtubs/showers is to install hand-held shower heads (National Advisory Council on Aging, 1988; HUD, 1996).

Although there is little information on flooring, HUD recommends non-skid flooring (1996); however, no further details are provided. Regarding lighting, the International Building Code (IBC) requires "appropriate artificial light" or greater than 3 square feet of window glazing (International Code Council, 2003). Both the IBC (International Code Council, 2003) and the Uniform Building Code (UBC) (International Conference of Building Officials, 1997b) specify ventilation requirements. The UBC suggests natural ventilation, although mechanical ventilation can be substituted for natural ventilation.

Regarding the toilet, the UBC (International Conference of Building Officials, 1997b) and HUD (1996) specify the amount of clear space around the toilet and HUD (1996) and the National Advisory Council on Aging (1988) suggest building in supports for grab bars but recommend waiting to install grab bars until necessary.

Table 4. Representation of guidelines and research in the Bathroom.

Architectural System Component	Citation	Design Guideline	Research Objective	Research Description	Functional Disabilities: Physical	Functional Disabilities: Sensory	Functional Disabilities: Cognitive
INTERIOR							
Bathroom							
Bath/Shower	■	■					
Bath/Shower	■	■	■	■	■		
Bath/Shower	■	■					
Bathroom Technologies							
Floor Surface	■	■					
Layout							
Lighting/Illumination	■	■					
Room Dimensions	■	■					
Room Transition							
Sink/Faucets	■	■					
Sink/Faucets	■	■	■	■	■		
Storage							
Toilet	■	■					
Toilet	■	■					
Toilet	■	■					
Ventilation	■	■					
Ventilation	■	■					

Table 5. Guidelines and guideline sources for the Bathroom.

Architectural System Component	Citation		Design Guideline/Recommendation
INTERIOR			
Bathroom			
Bath/Shower	HUD	(1996)	Recommendations: - Lever style handles - Include removable seat - Include reinforcements for future grab bars - Provide hand-held shower head
Bath/Shower	Meindl, B.A. & Freivalds, A.	(1992)	1. Use lever handles where possible. 2. Use one handle for hot and one handle for cold and mark appropriately. 3. Install two sets of faucet handles located at 21" and 42" (above tub floor) if possible, otherwise, set height at 32". (Note: recommendations for retirement facilities)
Bath/Shower	National Advisory Council on Aging: Government of Canada	(1988)	Recommendations: - Locate grab bar (horizontal) 30" above floor - Install vertical grab bar - Slip-resistant bathtub floor - Hand-held shower head with adjustable positioning
Bathroom Technologies			
Floor Surface	HUD	(1996)	Non-skid flooring
Layout			
Lighting/Illumination	International Code Council	(2003)	Natural light ("aggregate glazing" per code) ≥ 3sq.ft. Note: Except when "appropriate" ventilation and artificial light is provided (no illumination level specified). (R303.3)
Room Dimensions	International Conference of Building Officials	(1997b)	Ceiling height ≥ 7' Floor area: None Wall dimension: None (503.1-503.3)
Room Transition			
Sink/Faucets	HUD	(1996)	Recommendations: - Sink height 30-34" Note: There is no "ideal" height (pg.49) - Lever style handles - Provide high temp stop
Sink/Faucets	Bordett, H.M., Koppa, R.J., & Congleton, J.J.	(1988)	Cover metal edges with compressible material than can also act as a nonslip surface when operated with wet hands. Lever style handles allow greater exertion of torque. Round all edges to prevent discomfort and/or injuries.
Storage			
Toilet	International Conference of Building Officials	(1997b)	Clear space requirements: Width ≥ 30" Space in front ≥ 24" (503.3)
Toilet	HUD	(1996)	Recommendations: - Locate 18" from side wall - Provide reinforcement for future placement of grab bars - Install offset flange to allow future movement of toilet (by up to 3")
Toilet	National Advisory Council on Aging: Government of Canada	(1988)	Top of toilet seat = 18" above floor - Delay installation of grab bar until resident moves in (and locate accordingly)
Ventilation	International Code Council	(2003)	Mechanical ventilation ≥ 50cfm for intermittent ventilation Mechanical ventilation ≥ 20cfm for continuous ventilation (R303.3)
Ventilation	International Conference of Building Officials	(1997b)	Natural ventilation ≥ 5% of floor area with 1.5sq.ft. minimum In lieu of natural ventilation, Mechanical ventilation ≥ 5 air changes/hour (504.3)

Bedroom

Table 6 shows that none of the nine sets of guidelines and recommendations for the bedroom were based directly on research. Guidelines not found in this research were related to bedroom technologies (if they exist), floor surface, layout, room transition, lighting, and ventilation. However, general guidelines that may be applicable to lighting and ventilation within a bedroom (or other rooms) are provided in building codes (International Conference of Building Officials, 1997b; International Code Council, 2003) and therefore are listed in the common areas subcategory.

The only published sets of guidelines/recommendations for the bedroom were guidelines/recommendations for closets/storage spaces and room dimensions. Guidelines for closet spaces focused on closet dimensions (Green et al., 1975; USGPO, 1977) and hanging rods or shelf height (Green et al., 1975; USGPO, 1977; National Advisory Council on Aging, 1988; HUD, 1996). Existing guidelines specify that hanging rods be mounted approximately 4 to 4 ½' high although HUD (1996) suggests using adjustable brackets so individuals can set desired height.

Room dimensions range from 90-280+ square feet, depending on use (Beyer and Nierstrasz, 1967; Grandjean, 1973; Green et al., 1975; USGPO, 1977; Woodson, 1981). One interesting note is that several of the guidelines were from the late 1960's to the early 1980's with no guidelines found after 1981. These guidelines are listed in table 7.

Table 6. Representation of guidelines and research in the Bedroom.

Architectural System Component	Citation	Design Guideline	Research Objective	Research Description	Functional Disabilities: Physical	Functional Disabilities: Sensory	Functional Disabilities: Cognitive
INTERIOR							
Bedroom							
Bedroom Technologies							
Closet/Storage							
Closet/Storage							
Closet/Storage							
Closet/Storage							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Dimensions							
Room Dimensions							
Room Dimensions							
Room Dimensions							
Room Transition							
Ventilation							

Table 7. Guidelines and guideline sources for the Bedroom.

Architectural System Component	Citation		Design Guideline/Recommendation
INTERIOR			
Bedroom			
Bedroom Technologies			
Closet/Storage	HUD	(1996)	Recommendations: - Use adjustable shelves and hanging rods - Loop handles on doors - Properly illuminate closet - Closets deeper than 18" should have door opening of 32" - Shelf height 9-54"
Closet/Storage	National Advisory Council on Aging: Government of Canada	(1988)	Recommendations: - Provide at least 4' between bed and closet (5' preferred) - Hanging rods ≤ 56" high
Closet/Storage	USGPO	(1977)	2'X3' closet Hanging rods adjustable to 48" high
Closet/Storage	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L.	(1975)	26"X82" closet Hanging rods=55" high
Floor Surface			
Layout			
Lighting/Illumination			
Room Dimensions	Woodson, W.E.	(1981)	Size: 90-120 sq.ft. for single adult Size: 192-288 sq.ft. for married couple
Room Dimensions	USGPO	(1977)	Size ≥ 120sq.ft. Size ≥ 180 sq.ft (for combined living room-bedroom) Ceiling height ≥ 7'6"
Room Dimensions	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L.	(1975)	Size ≥ 135 sq.ft. Ceiling height ≥ 8' (7'4" in for perimeter portions)
Room Dimensions	Grandjean, E.	(1973)	Size ≥ 150 sq.ft. (although 170+ sq.ft. recommended)
Room Dimensions	Beyer, G.H. & Nierstrasz, F.H.J.	(1967)	Size ≥ 130 sq.ft.
Room Transition			
Ventilation			

Living Room, Dining Room, Office

Tables 8 and 9 show the architectural areas within the living room, dining room, and office. Except for the general requirements listed in building codes (International Conference of Building Officials, 1997b; International Code Council, 2003) for lighting, ventilation, and room dimensions, no guidelines or research was located for the living room, dining room, or office.

Table 8. Representation of guidelines and research in the Living room, Dining room, and Office.

Architectural System Component	Citation	Design Guideline	Research Objective	Research Description	Functional Disabilities: Physical	Sensory	Cognitive
INTERIOR							
Living Room							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							
Dining Room							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							
Office							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							

Table 9. Guidelines and guideline sources for the Living room, Dining room, and Office.

Architectural System Component	Citation	Design Guideline/Recommendation
INTERIOR		
Living Room		
Floor Surface		
Layout		
Lighting/Illumination		
Room Dimensions		
Room Transition		
Storage		
Ventilation		
Dining Room		
Floor Surface		
Layout		
Lighting/Illumination		
Room Dimensions		
Room Transition		
Storage		
Ventilation		
Office		
Floor Surface		
Layout		
Lighting/Illumination		
Room Dimensions		
Room Transition		
Storage		
Ventilation		

Common Features

A list showing guidelines for the common features of a home is presented in table 10. Of the ten guideline sets based directly on research, stairways had four, smoke alarms and flooring two each, and lighting and thermostats one each.

The stairway research consisted of an investigation of stairway accidents caused by short tread depths (Roys, 2001), a laboratory study to assess how changes in visual conditions affect stair descent (Christina et al., 2000), and two separate studies by Maki et al. that considered optimal handrail heights for three different stairway slopes (1984, 1985).

Of the smoke alarm research, Huey et al. (1994), through a field study, evaluated current smoke detector alarm signals with respect to hearing limitations of the elderly.

Meanwhile, Lerner and Huey (1991) sought to improve the design of smoke alarms with the help of elderly homeowners by conducting a series of focus group sessions.

The two flooring studies considered the effect carpet has on an elderly person's balance. Redfern et al. (1997) conducted a study in which eight elderly subjects stood on seven different floor types (low to high pile, various pad types, etc.) while balance was measured using an Equitest Posturography Platform. Dickenson et al. (2001) also measured balance of elderly subjects with an Equitest Posturography Platform. In that study, subjects stood on firm and compliant floor surfaces.

Table 11 displays guidelines for the common areas of a home. Architectural components that are listed as "general" (i.e. flooring, heating, lighting, ventilation, etc.) are not room specific and therefore are listed under this section rather than sections on individual rooms.

Table 10. Representation of guidelines and research in Common Areas.

Architectural System Component	Citation	Design Guideline	Research Objective	Research Description	Functional Disabilities: Physical	Functional Disabilities: Sensory	Functional Disabilities: Cognitive
INTERIOR							
Common Features/Misc.							
Doors/Doorways	■	■					
Doors/Doorways	■	■					
Doors/Doorways	■	■					
Doors/Doorways	■	■					
Doors/Doorways	■	■					
Doors/Doorways	■	■					
Electrical Receptacles	■	■					
Electrical Receptacles	■	■					
Electrical Receptacles	■	■					
Electrical Receptacles	■	■					
Electrical Receptacles	■	■					
Electrical Receptacles	■	■					
Emergency Escape	■	■					
Emergency Escape	■	■					
Entrance	■	■					
Flooring (General)	■	■	■	■	■	■	
Flooring (General)	■	■					
Flooring (General)	■	■	■	■	■	■	
Flooring (General)	■	■					
Flooring (General)	■	■					
Flooring (General)	■	■					
Hallways	■	■					
Heating (General)	■	■					
Heating (General)	■	■					

Table 10. Representation of guidelines and research in Common Areas (continued).

Architectural System Component	Citation	Design Guideline	Research Objective	Research Description	Functional Disabilities: Physical	Functional Disabilities: Sensory	Functional Disabilities: Cognitive
INTERIOR							
Common Features/Misc.							
Ingress/Egress	■	■					
Lighting/Illumination (General)	■	■					
Lighting/Illumination (General)	■	■	■	■		■	
Lighting/Illumination (General)	■	■					
Lighting/Illumination (General)	■	■					
Lighting/Illumination (General)	■	■					
Light Switches	■	■					
Light Switches	■	■					
Light Switches	■	■					
Light Switches	■	■					
Other Misc. Storage	■	■					
Ramps (Interior)	■	■					
Ramps (Interior)	■	■					
Room Dimensions (General)	■	■					
Room Dimensions (General)	■	■					
Smoke Alarms/ Smoke Detector	■	■					
Smoke Alarms/ Smoke Detector	■	■					
Smoke Alarms/ Smoke Detector	■	■	■	■		■	
Smoke Alarms/ Smoke Detector	■	■	■	■	■	■	■
Smoke Alarms/ Smoke Detector	■	■					
Smoke Alarms/ Smoke Detector	■	■					

Table 10. Representation of guidelines and research in Common Areas (continued).

Architectural System Component	Citation	Design Guideline	Research Objective	Research Description	Functional Disabilities: Physical	Functional Disabilities: Sensory	Functional Disabilities: Cognitive
INTERIOR							
Common Features/Misc.							
Stairways (Interior)	■	■					
Stairways (Interior)	■	■					
Stairways (Interior)	■	■					
Stairways (Interior)	■	■					
Stairways (Interior)	■	■	■	■	■		
Stairways (Interior)	■	■	■	■		■	
Stairways (Interior)	■	■					
Stairways (Interior)	■	■					
Stairways (Interior)	■	■	■	■	■		
Stairways (Interior)	■	■	■	■	■		
Stairways (Interior)	■	■					
Thermostats	■	■					
Thermostats	■	■	■	■	■	■	
Ventilation (General)	■	■					
Ventilation (General)	■	■					
Walls (General)	■	■					
Walls (General)	■	■					
Windows	■	■					
Windows	■	■					

Table 11. Guidelines and guideline sources for Common Areas.

Architectural System Component	Citation		Design Guideline/Recommendation
INTERIOR			
Common Features/Misc.			
Doors/Doorways	Pinto, M.R., De Medici, S., Zlotnicki, A., Bianchi, A., Van Sant, C., & Napoli, C.	(1997)	Recommendations: - Doors made of opaque materials - Handles obvious and of different color to the door - Use lighting to increase color contrast between door and surroundings
Doors/Doorways	HUD	(1996)	Recommendations: - Doorway opening ≥ 32" - Lever or loop style door handles - Install swing away door hinge in narrow doorways - Easily operable locking mechanism - Include secondary "peep" hole at lower level (for shorter or seated people) - Provide auxiliary door handle to facilitate closing Level of force to open door: - 8 lbs (exterior) - 5 lbs (interior)
Doors/Doorways	National Advisory Council on Aging: Government of Canada	(1988)	Recommendations: - Minimum 32" clear doorway opening (30" if access is straight on) - Door handle height 30-36" - Lever style door handles - Threshold height ≤ 5/8" Door closure pressure: - ≤ 34N (newtons) for exterior doors - ≤ 22N for interior doors - ≤ 10N (interior doors operated by frail elderly)
Doors/Doorways	Woodson, W.E.	(1981)	Recommendations: -Width = 36" -Height = 80" -Threshold height = 0.5" -Lever-style handle preferred
Doors/Doorways	Koncelik, J.A.	(1976)	Recommendations: - Lever type handle - Handle height 40" - Provide illumination at keyhole - Curve lock insert inward (to direct key to opening) - Also, Keys should have long shank and large gripping surfaces
Doors/Doorways	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L.	(1975)	Recommendations: - 34" clear opening with no threshold - Lever type handle - Handle height 4'6" - Pressure to open door ≤ 5 lbs
Electrical Receptacles	HUD	(1996)	Height 15-48"
Electrical Receptacles	National Advisory Council on Aging: Government of Canada	(1988)	Height 18-21"
Electrical Receptacles	Koncelik, J.A.	(1976)	Height 16-20"
Electrical Receptacles	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L.	(1975)	Height 24"
Electrical Receptacles	Central Mortgage	(1972)	Height ≥ 21"
Electrical Receptacles	Musson, N. & Heusinkveld, H.	(1963)	Height 18-24"

Table 11. Guidelines and guideline sources for Common Areas (continued).

Architectural System Component	Citation	Design Guideline/Recommendation
INTERIOR		
Common Features/Misc.		
Emergency Escape	International Code Council (2003)	Openable area of rescue window ≥ 5.7 sq.ft. Window dimensions: Minimum height=24" Minimum width=20" (R310.1)
Emergency Escape	International Conference of Building Officials (1997a)	Openable area of rescue window ≥ 5.7 sq.ft. Window dimensions: Minimum height=24" Minimum width=20" (310.4)
Entrance	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Recommendations: - Door threshold < 1" (25mm) - Non-skid flooring - Grab-bars near door - Reduce difference in illumination between inside and outside - Light-switches close to door - Passages free from furniture and equipment - Box to hold keys near door - Adjustable coat-hanger
Flooring (General)	Dickinson, J.I., Shroyer, J.I., Elias, J.W., Hutton, J.T., & Gentry, G.M. (2001)	Architects, interior designers, and health care providers can specify similar carpet as used in study. Carpet: 36-oz., 1/8" gauge, 100% nylon, 1/2 cut pile Pad: Rebonded, polyurethane, 6 lb density, 7/16" thick Note: This is the most common carpet specified for residential use (Dickinson et al. 2001).
Flooring (General)	Pinto, M.R., De Medici, S., Zlotnicki, A., Bianchi, A., Van Sant, C., & Napoli, C. (1997)	Recommendations: - Inset doormat, use shallow pile - Doorstep height < .75/1" - Height and width of floor component joints < .75"
Flooring (General)	Redfern, M.S., Moore, P.L. & Yarsky, C.M. (1997)	No specific guideline, however, the reported results suggest that while more "compliant" floors are comfortable and may reduce the potential for hip fractures, they destabilize balance and therefore increase the risk of falls.
Flooring (General)	HUD (1996)	Recommendations: - Select firm carpet, with 0.5" maximum pile height - Carpet edge transition heights should be ≤ 0.5" - All hard surfaces should be non-skid - Eliminate changes in height between floor transitions
Flooring (General)	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Non-glare floor surfaces - Slip-resistant floor surfaces - Carper securely attached, pile height ≤ 0.5" with firm under pad or no under pad
Flooring (General)	Beyer, G.H. & Nierstrasz, F.H.J. (1967)	Non-skid flooring
Hallways	International Conference of Building Officials (1997b)	Ceiling height ≥ 7' Floor area: None Wall dimension: None
Heating (General)	International Code Council (2003)	Heating system to maintain room temperature ≥ 68°F at 3' above floor in all habitable rooms (where winter design temperatures ≤ 60° F) (R303.8)
Heating (General)	International Conference of Building Officials (1997b)	Heating system to maintain room temperature ≥ 70°F at 3' above floor in all habitable rooms (701.1)

Table 11. Guidelines and guideline sources for Common Areas (continued).

Architectural System Component	Citation		Design Guideline/Recommendation
INTERIOR			
Common Features/Misc.			
Ingress/Egress	International Code Council	(2003)	Hallway: Minimum width = 3' Exit Door: Minimum width = 3' Minimum Height = 6'8" (R311)
Lighting/Illumination (General)	International Code Council	(2003)	Natural light ("aggregate glazing" per code) ≥ 8% of floor area in habitable rooms Note: Except when "appropriate" ventilation and artificial light is provided (average illumination level ≥ 0.6 foot-candle [6.46 lux] over the floor at height = 30"). (R303.1)
Lighting/Illumination (General)	Charness, N. & Dijkstra, K.	(1999)	No specific guideline, however, the reported results suggest that lighting levels in homes are typically below IESNA recommendations.
Lighting/Illumination (General)	Pinto, M.R., De Medici, S., Zlotnicki, A., Bianchi, A., Van Sant, C., & Napoli, C.	(1997)	Recommendations: -Lighting at floor ≥ 300 lux - Lighting of work surfaces 500-800 lux - Design for absence of glare and shadows - Reduce the different level of illumination between inside and outside - Use uniform lighting between corridors and rooms - Correctly locate direct light
Lighting/Illumination (General)	International Conference of Building Officials	(1997b)	Natural light ≥10% of floor area with 10sq.ft. minimum Note: For guest rooms and habitable rooms (504.2)
Lighting/Illumination (General)	National Advisory Council on Aging: Government of Canada	(1988)	Recommendations: - Lighting ≥ 50 lux - Lighting is even and well-diffused to eliminate spottiness or shadows - Provide supplementary task lighting where necessary
Light Switches	HUD	(1996)	Recommendations: - Height 36-48" - Use rocker, toggle, or touch sensitive switches - Use remote controlled switches to turn on and off consumer products (e.g. lamps), if applicable
Light Switches	National Advisory Council on Aging: Government of Canada	(1988)	Height 33-43"
Light Switches	Koncelik, J.A.	(1976)	Height 35"
Light Switches	Central Mortgage	(1972)	Height 3'-4'8"
Other Misc. Storage	National Advisory Council on Aging: Government of Canada	(1988)	Storage shelving within in range of 8-56" high
Ramps (Interior)	International Code Council	(2003)	Slope ≤ 12.5% (Note: Slopes ≥ 8.33% require handrail) (R311.6)
Ramps (Interior)	National Advisory Council on Aging: Government of Canada	(1988)	See exterior ramps (National Advisory Council, 1988)
Room Dimensions (General)	International Code Council	(2003)	Ceiling height ≥ 7' Floor area: 1 room ≥ 120sq.ft. with other rooms ≥ 70 sq.ft. Wall dimension: ≥ 7' in all horizontal directions Note: For all habitable rooms (R304)

Table 11. Guidelines and guideline sources for Common Areas (continued).

Architectural System Component	Citation	Design Guideline/Recommendation
INTERIOR		
Common Features/Misc.		
Room Dimensions (General)	International Conference of Building Officials (1997b)	Ceiling height ≥ 7'6" Floor area: 1 room ≥ 120sq.ft. with other rooms ≥ 70 sq.ft. Wall dimension: ≥ 7' in all horizontal directions (503.1-503.3)
Smoke Alarms/ Smoke Detector	International Code Council (2003)	Location: Install in following locations: 1. Each sleeping room 2. Outside each sleeping area within the vicinity of bedrooms 3. On each additional story of dwelling (Note: Designated for new construction) (R313.1)
Smoke Alarms/ Smoke Detector	International Conference of Building Officials (1997a)	Location: Install detector in each sleeping room and at a point centrally located in corridor or area giving access to each separate sleeping area. Install detector on each story including basement (where applicable). Sound: "Detector shall sound an alarm audible in all sleeping areas of the dwelling unit in which they are located" (pg. 1-28) (310.9.1)
Smoke Alarms/ Smoke Detector	Huey, R.W., Buckley, D.S. & Lerner, N.D. (1994)	Include lower frequency audible sounds in alarm (primary peak at 500 Hz); Include fast modulation rate (instead of continuous sound). Note: Currently, several smoke detector audible signals in 4000 Hz frequency (pg. 147).
Smoke Alarms/ Smoke Detector	Lerner, N.D. & Huey, R.W. (1991)	Recommendations: - Controls and batteries should be accessible without climbing and operable by those with limited hand strength or dexterity - Installation should be easy and inexpensive - Trouble indicator should be understandable. - Include positive indicator when functioning properly - System should be self-testing - Include alarm-cancel feature - Audible signal should be detectable by the normal range of older adults - Distribute alarms throughout the home - Provide clear guidance for selecting and locating smoke detectors - System should include aids to egress - Product should be battery powered or include battery backup - Consider aesthetics
Smoke Alarms/ Smoke Detector	Beyer, G.H. & Nierstrasz, F.H.J. (1967)	Alarms should be low pitched
Smoke Alarms/ Smoke Detector	Musson, N. & Heusinkveld, H. (1963)	Alarms should have both low and high pitch
Stairways (Interior)	International Code Council (2003)	Illumination: All interior/exterior stairways require illumination on landing and treads. Interior tread and landing illumination level ≥ 1 foot-candles (11 lux) (R303)

Table 11. Guidelines and guideline sources for Common Areas (continued).

Architectural System Component	Citation	Design Guideline/Recommendation
INTERIOR		
Common Features/Misc.		
Stairways (Interior)	International Code Council (2003)	Dimensions: Width ≥ 36" (above handrail) Width ≥ 31.5" (below handrails with 1 rail) Width ≥ 27" (below handrails with 2 rails) (Note: Does not include spiral or other "special" staircases) Headroom ≥ 6'8" Riser height ≤ 7.75" Tread depth ≥ 10" Walking surface slope ≤ 2% (R311.5)
Stairways (Interior)	International Code Council (2003)	Handrails: Required for continuous run of treads or flight with 4 or more risers Handrail height between 34"-38" Grip size (Type 1): 1.25" ≤ Outside Diameter ≤ 2" (R311.6)
Stairways (Interior)	Roys, M. S. (2001)	Stair Tread depth: Minimum of 9.6" (245mm) for Residential area Note: Minimum tread depth for "Semi-public" area should be 270mm (10.6") and for public area, 300mm (11.8")
Stairways (Interior)	Christina, K.A., Okita, N., Owens, D.A., & Cavanagh, P.R. (2000)	No explicit guidelines
Stairways (Interior)	International Conference of Building Officials (1997a)	General Dimensions: Step width ≥ 36" 4" ≤ Step Rise ≤ 7" Step Run ≥ 11" Note- Private steps with fewer than 10 occupants: Max rise = 8" Min run = 9" Headroom ≥ 6'8" Handrails: 34" ≤ Height ≤ 38" Outside Dimension (on circular grip): 1.25"-2.0" Note: Private stairways do not need handrails (1003.3.3)
Stairways (Interior)	HUD (1996)	Recommendations: - Stair surface should provide adequate traction - Provide color contrast between riser and tread - Round all nosings - Handrail height 30-38" - Place handrails on both sides of stairs - Handrail should be round or oval shaped and 1.25-2" in diameter - Handrails should be 1.5" from wall - Handrails should extend 1' at top and bottom of stairway

Table 11. Guidelines and guideline sources for Common Areas (continued).

Architectural System Component	Citation		Design Guideline/Recommendation
INTERIOR			
Common Features/Misc.			
Stairways (Interior)	National Advisory Council on Aging: Government of Canada	(1988)	Recommendations: - Conform to NBC Sec 3.4 - Lighting ≥ 50 lux - Handrails 32-36" high - Handrails extend 1' beyond top and bottom of stairs - Riser height 6-7" - Tread width 10.5-14" - Bevel stair nosings - Mark edges with color contrast - Avoid winding stairs
Stairways (Interior)	Maki, B.E., Bartlett, S.A., & Fernie, G.R.	(1985)	For 41 deg. slope stairway: - Acceptable height for elderly 35.5-40" (.91-1.02m) Recommended height based on comfort 36" For 49 deg. slope stairway: - Acceptable height for elderly 35.5" (.91m) Recommended height based on comfort 36"
Stairways (Interior)	Maki, B.E., Bartlett, S.A., & Fernie, G.R.	(1984)	For 33 deg. Slope stairway: - Acceptable height for elderly 34-40" (.86-1.02m) Recommended height based on comfort 35.5"
Stairways (Interior)	Woodson, W.E.	(1981)	Tread depth = 11" with nosing 1-1.5" Riser height = 6.5" Handrail height = 34"
Thermostats	HUD	(1996)	Recommendations: - Mounting height ≤ 48" - Provide easy to use controls
Thermostats	Metz, S., Isle, B., Denno, S., &Odom, J.	(1992)	Non-conclusive guideline, however, subjects preferred thermostat with large numbers and large outer ring (to set temp.) over standard Honeywell thermostat (model T87F).
Ventilation (General)	International Code Council	(2003)	Natural ventilation ≥ 4% of floor area Note: For guest rooms and habitable rooms In lieu of natural ventilation, Mechanical ventilation ≥ 0.35 air changes/hour in room or whole-house ventilation ≥ 15 cfm of outside air per occupant (R303.1)
Ventilation (General)	International Conference of Building Officials	(1997b)	Natural ventilation ≥ 5% of floor area with 5sq.ft. minimum Note: For guest rooms and habitable rooms In lieu of natural ventilation, Mechanical ventilation ≥ 2 air changes/hour with 20% of air supply from outside (504.3)
Walls (General)	Pinto, M.R., De Medici, S., Zlotnicki, A., Bianchi, A., Van Sant, C., & Napoli, C.	(1997)	Non-glare surfaces: glare index limit < 10
Walls (General)	National Advisory Council on Aging: Government of Canada	(1988)	Recommendations: - Non-glare wall finishes - Minimum sound reflection
Windows	HUD	(1996)	Recommendations: - Avoid single- or double-hung windows where possible - Utilize large, easy to use hand cranks on casement windows - Ensure all locking mechanisms are accessible
Windows	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L.	(1975)	Windows should be easily operated and not too high

Exterior

Table 12 shows that eleven sets of guidelines were found for the exterior areas of a home environment and that none were based directly on research. The three most documented guidelines were for the entrance, ramps, and driveway/parking area.

Table 13 lists published guidelines for the exterior. Eight of the eleven sets of guidelines were published by the National Advisory Council on Aging (1988). The National Advisory Council on Aging addressed parking, exterior electrical receptacles, a home's entrance, the location of a water hose connection, lighting, ramps, and walkways. The other three sets of guidelines came from Woodson (1981) and HUD (1996).

Table 12. Representation of guidelines and research for Exterior.

Architectural System Component	Citation	Design Guideline	Research Objective	Research Description	Functional Disabilities: Physical	Functional Disabilities: Sensory	Functional Disabilities: Cognitive
EXTERIOR							
Driveway/Parking							
Driveway/Parking							
Electrical Receptacles (Exterior)							
Entrance							
Entrance							
Entrance							
Garage							
Hose Connection							
Lawn/Yard							
Lighting/Illumination							
Ramps (Exterior)							
Ramps (Exterior)							
Walkways							

Table 13. Guidelines and guideline sources for Exterior.

Architectural System Component	Citation	Design Guideline/Recommendation
EXTERIOR		
Driveway/Parking	HUD (1996)	Provide an access aisle
Driveway/Parking	National Advisory Council on Aging: Government of Canada (1988)	- Shelter parking from rain, snow, and ice - Grades ≤ 1:20 Avoid changes in level (steps) where possible
Electrical Receptacles (Exterior)	National Advisory Council on Aging: Government of Canada (1988)	18-21" above ground (for wheelchair accessibility)
Entrance	International Conference of Building Officials (1997a)	Means of egress illumination: ≥ 1 foot-candle (10.76 lux) at floor level Note: Not required in private residences (Group R-Division 3) (1003.2.9)
Entrance	HUD (1996)	Recommendations: - Door threshold ≤ 0.5" - "good overall lighting" for security - Provide package shelf near door (latch side) - Provide easy to see, lighted doorbell - Construct/raise porch to be level with interior floor surfaces - Provide focused lighting at door handle and lockset
Entrance	National Advisory Council on Aging: Government of Canada (1988)	Shelter entrance from the elements
Garage		
Hose Connection	National Advisory Council on Aging: Government of Canada (1988)	2-4' above ground (accessible from a paved area-for wheelchair access)
Lawn/Yard		
Lighting/Illumination	National Advisory Council on Aging: Government of Canada (1988)	Exterior lighting "adequate"
Ramps (Exterior)	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Color contrast at changes in level - Lighting ≥ 50 lux at floor level and 300 lux at top and bottom of ramp - Slope ≤ 1:20 (unless impractical, never > 1:12) - Slip-resistant surface - Rise ≤ 30" (at 1:12 slope) - Length ≤ 30' (slope > 1:20) - Width ≥ 3' (for 1 wheelchair) - Width ≥ 5'4" (for 2 whlchrs) - Cross slope ≤ 1:50 - Handrails for ramps > 1:16 (and conform to building code) - Handrails extend 1' beyond top and bottom of ramp
Ramps (Exterior)	Woodson, W.E. (1981)	Slope: Recommend ≤ 5%; 8% maximum Length: ≤ 30'
Walkways	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Surfaces firm, even and slip-resistant - Pathways 5' wide - Site grades (used by pedestrians) ≤ 1:20 - Site grades in pedestrian routes ≤ 1:12 - Lighting ≥ 50 lux - Lighting ≥ 300 lux on all changes in level

CHAPTER 6

DISCUSSION

Research Matrix

The utility in developing a research matrix for this thesis was to provide a new context to view and analyze existing guidelines specific to residential housing for the independent-living elderly. Looking through the results reveals that a total of sixteen human factors based studies were found that directly related to developing guidelines for residential settings for the elderly. It is surprising that such little research was found, considering that Chapanis (1974) first suggested the creation of a guidelines handbook in the early 1970's.

In addition to the lack of guidelines supported directly by human factors based research, another aspect of the findings is that only one study (Lerner and Huey, 1991) addresses all three functional limitations. While not all guidelines are affected by each functional limitation, many are, and therefore, all newly developed guidelines should acknowledge the presence of functional limitations.

One limitation with documenting guidelines from architectural or government publications, (i.e. those guidelines found outside of human factors research journals or conference proceedings) is that a guideline may be based in research even though no direct study was referenced. Noting the inconsistencies between many guidelines and the overall lack of human factors research, it is fairly likely that many of the guidelines from architectural and government publications may just not be based on human factors

principles. These guidelines may still be valuable, however, they should also be challenged with scientific methods and empirically validated or researched and improved upon.

Proposed Framework for Design Guidelines Handbook

One reason to develop a human factors based design guidelines handbook is to help ensure that residential housing designs provide a maximum enhancement possible for independence and overall quality of life for the independent-living elderly. Therefore, the actual guidelines in a design handbook are more valuable than the actual format. Likewise, the proper format for a handbook might depend on who uses it and for what purpose. For instance, a human factors specialist or a researcher in the medical field may prefer that guidelines be categorized by functional limitation or disability (e.g., visual limitations, auditory limitations, physical limitations, cognitive limitations), or grouped by activities of daily living (cooking, bathing, cleaning); whereas an architect or homebuilder may prefer guidelines organized by architectural area (kitchen, bedroom, bathroom).

Since the inherent value of a handbook is not in the format, but in the content; it seems appropriate to continue developing guidelines, and then format those guidelines in any or all ways as needed. However, in order to begin the process of developing a guidelines handbook, the research matrix described earlier can suffice as a starting point. One benefit of using this matrix is the fact that it already highlights which areas have guidelines, and where research exists or is needed. In summary, the proposed research matrix may help focus future human factors studies and provide a format for a handbook

that engineers, architects, and homebuilders can use to ensure the suitable design of residential environments.

Guidelines Development Model

One interesting realization to stem from this research is that different end-uses might warrant establishing different formats for a design guidelines handbook; therefore, an important contribution to creating a design guidelines handbook is to suggest a methodology to develop, evaluate, and categorize human factors researched-based guidelines.

To supplement this research, an original methodology is proposed to help ensure design guidelines are directly based on human factors principles. Figure 3 represents this proposed model and makes use of six guideline categories.

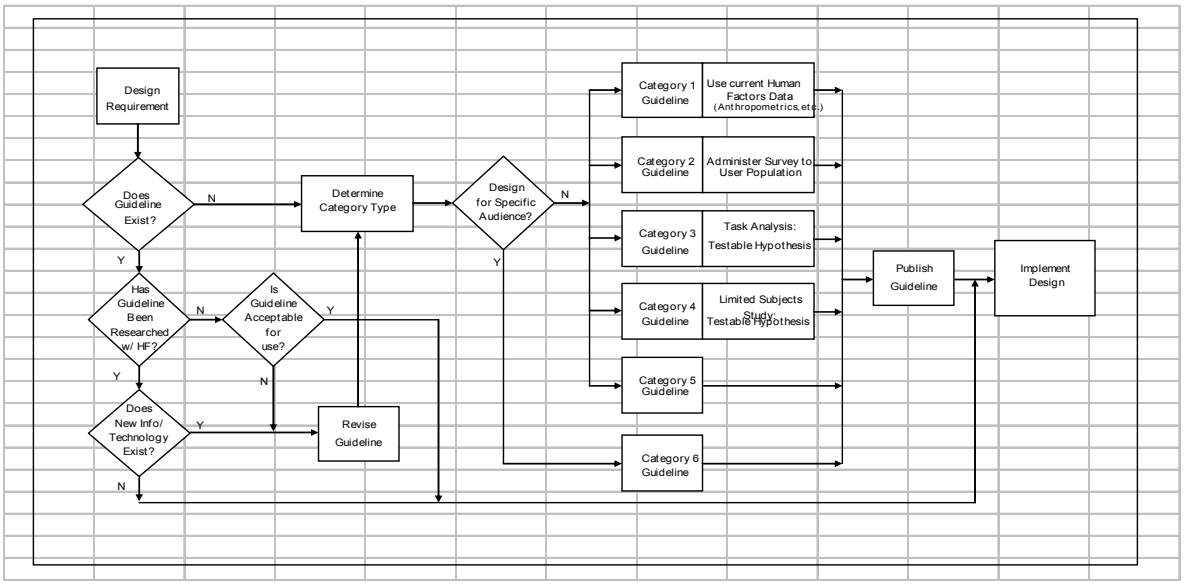

Figure 3. Proposed Model for Developing Guidelines for the Elderly in Residential Environments.

Guideline Category Definitions

The six proposed guideline categories are defined below. Six categories of guideline sets are proposed because, with such a diverse population, it is not likely one guideline set will suffice.

- Category 1 refers to preliminary guidelines based on known, collected data relating to anthropometry, biomechanics, sensory acuity, motor-skills, and cognitive ability. Category 1 is "preliminary" due to current insufficient human factors data regarding the elderly.
- Category 2 considers design preferences of the user population. A tangible, yet relatively economic means of involving the user population in the design process is through administered surveys and focus groups.
- Category 3 involves conducting a task analysis to ensure designers understand the person-environment transactions in residential living environments for the elderly.
- Category 4 is a limited human-subject study formulated around a testable set of hypotheses. Category 4 is limited by the number and background (age, race, ethnicity, etc.) of the subjects.
- Category 5 requires widespread collection of data from populations not included in existing data. Category 5 is an expansion of Category 4 and involves a greater number of subjects while considering a larger representation of the elderly population.
- Category 6 guidelines are for a specific person or persons.

Categories 5 and 6 are similar in that they represent guidelines using the highest level of engineering design. They differ in that Category 5 represents general guidelines for diverse populations by considering persons of differing backgrounds, age, and functional limitation as well as race, ethnicity, and socioeconomic status (Gitlin, 2003). Because of the inherent diversity within the elderly population and because the elderly population tends to move less frequently than other populations (U.S. Census Bureau, 2003), it seems appropriate for designers to consider designing for specific users (even as few as one or two persons). If a designer specifies designs for new construction or the remodeling of an existing living space for one particular household resident rather than designing based on data related to a diverse population, they should consider the anthropometrics, biomechanics, and functional limitations of the designed-for resident. Therefore, Category 6 guidelines require that needs of the intended audience are met vis-à-vis appropriate studies from a human factors perspective. These "engineered" guidelines may help ensure that elderly persons are best able to live independently.

Description of Proposed Guidelines Development Model

The six proposed categories are meant to promote new directives in studying home environments for the independent-living elderly. Figure 3 represents a proposed model for applying these categories to research after a design need has been identified.

The first step is to determine if a guideline exists. If so, the next step is to determine if the guideline has been previously researched and published in human factors literature. If no guideline exists, the researcher determines the extent of research that will be conducted. This decision is based on the desired cost/benefit ratio of the guideline.

Guideline Category 1 will typically have the lowest research cost while Category 6 the highest. Therefore, design solutions with higher potential benefits are more likely to justify higher cost research activities.

Considering again the question of whether or not the guideline has been researched from a human factors perspective, if it has, it is important to determine if new technology or new information about the elderly age group exists that would render the old research as sub-optimal. This is important because as new technology is developed and as more is learned about the aging process, it will be imperative that new research is conducted that incorporates the new technology and information. A key characteristic of this model is that research and design guidelines be continuously updated as knowledge increases. For example, kitchen countertops are typically installed 36" above the floor; however, this may or may not be an appropriate height for an elderly person. Therefore, even though countertop height is a well documented guideline, revisions might still be appropriate. As shown in the model, if no new technology or information exists, a researcher can skip to implementation.

If a guideline is not human factors research based, then a decision must be made if a guideline is deemed acceptable for use. Intuitively, some guidelines may not need to be researched; however, many guidelines may still need revision, even if a published guideline is commonly used.

When developing human factors based guidelines, a decision must be made whether to design for a general audience or a specific audience. Often, designers try to accommodate the 5^{th} or 95^{th} percentile with design solutions (Sanders and McCormick,

1993); however, because the elderly tend to stay in one home for longer periods of time (U.S. Census Bureau, 2003), it may be appropriate to design for the individual or individuals living in a household. For example, if a tall husband and short wife (hypothetically) live in a household such that a 36" countertop height does not satisfactorily accommodate either, it may be appropriate to install adjustable height countertops or to install kitchen countertops in various sections at different heights, specifically accommodating the elderly residents, as has been previously done (Luscombe, 2003). This is another key characteristic in the proposed guidelines development model.

After conducting research to develop a guideline, the third key characteristic of this model is to publish both the guideline and research. Publishing the research will allow other researchers and designers to understand the important assumptions behind a guideline that may help determine whether or not a guideline is appropriate or acceptable for use.

To summarize, the primary function of the proposed methodology is its iterative requirement. Guidelines should never be considered an end-goal (Sanders & McCormick, 1993) but rather a transition between knowledge states. That is, as new information becomes available and as technology advances, all guidelines need to be challenged and continuously updated and improved. The foundation of developing guidelines based on human factors principles is to constantly reassess the assumptions (e.g. available knowledge, current technology) underlying each guideline.

Although this model will not be fully validated within the scope of this project, the model's utility will be demonstrated through the following exemplars. The first exemplar demonstrates a design need to satisfy physical limitations, specifically those anthropometric-related. The second exemplar illustrates a design requirement to satisfy sensory limitations. The third exemplar illustrates a design need related to both physical and sensory limitations while the last exemplar attempts to address a cognitive functional limitation.

The four exemplars below are discussed to demonstrate the potential usefulness of the model and guideline categories, and to more fully explain the process and decision steps. The first example will begin with a countertop height as the design requirement. Stepping through the model, a design guideline does exist and has been researched for the elderly in Finland (Kirvesoja, Vayrynen, and Haikio, 2000); however, no research was found for elderly U.S. citizens. The next question is whether or not the guideline is acceptable for use. This design height is so common that it must be acceptable for use, however it may not always be the best choice. Therefore, this is a guideline that can be revised. The next step is to determine which type of research to conduct. In order to develop a rough-cut guideline quickly, current known anthropometric data for the elderly can be used (Kroemer, 1997). This will be a Category 1 guideline. Since the known anthropometric data on elderly in the U.S. is relatively incomplete (Kroemer, 1997), after publishing the research and new guideline, it may be worthwhile to revisit the design guideline. Stepping through the model again, a researcher could choose to perform a more detailed study, for instance a study to meet a Category 5 guideline. To do this

requires a nation-wide collection of anthropometric data from the elderly. This collection must include a representation of the U.S. elderly population including the various races, ethnicities, etc. to ensure the guideline will accommodate the widest range possible. In lieu of a nation-wide study, the designer could choose to collect anthropometric data on the household residents only and then design specifically for them. This category 6 guideline would work well if the residents intended to remain in the residence for a long period of time. Regardless of research classification, after conducting the research and developing a guideline, the final step is to publish both the guideline and research.

A second example pertains to developing guidelines for smoke alarms. Guidelines do exist and have been researched (Lerner and Huey, 1991; Huey, Buckley, and Lerner, 1994). From this research, it was determined that the alarm signal sound in standard smoke alarms is in a high frequency range and that the elderly tend to lose hearing in that frequency range (Lerner and Huey, 1991). This research can be classified as Category 1 since the researchers used existing auditory system information. In later research, Huey, Buckley, and Lerner (1994) used focus groups with elderly subjects to assist in redesigning smoke alarms that were both more audible and more user friendly (when testing and changing batteries) than standard smoke alarms. The guidelines from this type of research are classified as Category 2, as explained in the category definitions.

A third exemplar involves developing guidelines for designing stairways. Since stairway use changes as a person's body dimensions change, that is riser height, tread depth, and handrail height are affected by stature (Maki, Bartlett, and Fernie, 1984: 1985), and since improper contrast between steps and the floor can lead to falls (HUD,

1996), a possible research solution in developing better stairway guidelines might be setting up a task analysis and breaking down stairway use in to basic components to determine where hand placement on handrails is best, where to place and how much contrast to use between steps and floors, and to detail foot placement and motion in relation to risers and treads. This detailed task analysis (Category 3) allows human factors researchers to compare the demands of a task with the capabilities of the person involved, which ultimately can help lead to design solutions to improve the interactions between the person and the activity (Czaja, 1990a). Therefore, this type of research is important both in terms of this model and in developing human factors based guidelines.

One final example which is used to explain a Category 4 guideline is the potential use of signage in homes of independent-living persons with dementia. Just as signage is commonly used in institutional settings (Scialfa, Laberge, and Ho, 2004); signage may also play a role in allowing persons with dementia to live independently longer. Since no guidelines were found that discuss signage use for the independent-living elderly person with dementia, it may be appropriate to design a limited human-subjects study involving persons with dementia to determine if signage can increase the length of independence.

Summary

Based on earlier results and these discussions, it seems reasonable to conclude that there exist several potential benefits from developing guidelines for residential housing for the independent-living elderly. One significant benefit might come from reducing injury rates among the elderly. Therefore, the next chapter describes a rationale

for developing and implementing a design guidelines handbook by focusing on the potential to reduce injury rates experienced by elderly persons.

CHAPTER 7

RATIONALE FOR IMPLEMENTATION

Czaja points out that there is a substantial amount of literature relating to the importance of safety issues with which the elderly contend (1993). Specifically, some of the safety issues are the types and causes of injuries that occur within the elderly population.

Despite the available literature, it appears that no efforts have attempted to propose target levels of injury rates for the elderly. Some researchers (Miller and Waehrer, 1998; Lawrence et al., 2000) have sought to quantify costs associated with injuries. Establishing injury costs will help narrow the research focus, but costs won't reveal an "ideal" level of injuries.

The purpose of this chapter is to describe a proposed methodology for establishing injury rate targets for injuries occurring at home for the elderly. Intuitively, we know that elderly persons are injured more often than younger persons and injuries are generally more severe. This proposed methodology utilizes statistics to verify intuition, which then allows conclusions to be made relating to injury rates of different age groups.

The proposed methodology utilizes injury data from the U.S. Consumer Product Safety Commission's (CSPC) National Electronic Injury Surveillance System (NEISS). Injury rate targets are established for injuries involving bathtubs/showers, stairs/steps, and floors/flooring materials. Only injuries occurring in a home environment are considered.

Discussion of Metrics

Prior to discussing injury rates experienced by the elderly, it seems prudent to explore other potential metrics for evaluating the efficacy of design guidelines for residential living environments. By starting with a simple question, "how do we know the design is working?," it seems probable that answering this question might lead to several possible ways to evaluate the effectiveness of designs and design guidelines.

Three ways to suggest a design may work are 1) the new design provides a safer environment, as defined by a reduction in injuries or deaths, 2) a design promotes independence, allowing elderly persons to live independently in a residential home (as opposed to an institutional setting) for longer periods of life, and 3) a design provides a more comfortable living environment, or rather, reduces discomfort that may be associated with aging and various interactions with the environment (i.e. cleaning, bathing, sleeping). While there may be more means of evaluating designs, these three are sufficient to help develop one potential metric for design evaluation. The following two paragraphs will discuss possible metrics.

Measurements to evaluate if an environment is safe include tracking injuries directly associated with living environments, tracking mortality rates, studying how injuries occur at home, conducting assessments of living environments for hazards (slipping, tripping, etc.), and documenting and tracking the cost of injuries over time. Data to track injuries can come from the NEISS (as done in this thesis), from government or private-party surveys (National Safety Council, 2003), or possibly from other medical facilities (doctor's offices, urgent care centers, etc.).

Means of assessing independence include monitoring functional abilities of subjects (Mann et al., 1999) and soliciting input from elderly subjects via surveys or focus groups. Means of assessing comfort levels may include input from surveys or focus groups, monitoring functional abilities over time (Mann et al., 1999), or assessing discomfort of elderly subjects as has been similarly done in industrial settings (Marley and Kumar, 1996).

Although there exists several potential metrics for evaluating effective designs (and hence guidelines), this research investigated only injury rates between different age groups as a rationale for developing guidelines specifically for designing residential environments for the elderly. The four reasons for utilizing injury rates were 1) injury rates are a common measurement in industrial settings and therefore may be applicable to residential settings, 2) injury data were available through the NEISS for the elderly, 3) safety is an important concern when studying the elderly (Czaja, 1993), and 4) it was hoped that targeted levels of injury rates could be established by tracking NEISS injury data over time. One unique outcome from establishing "ideal" levels of injuries is that more significant improvements in safety may be obtainable. That is, rather than arbitrarily specifying a desired injury rate reduction, hypothetically 5 or 10% as an example, maybe injury rates can be reduced by 70 or 90% when compared with other age groups, as is discussed further in this chapter.

Only injury data from NEISS is used as a metric to evaluate human factors-based designs in this research; therefore it is important to express that this is a preliminary investigation of one possible metric and certainly not the only indicator of effective

design. Assuming injuries will decrease over time as human factors design solutions are implemented, injury rate data collected through the NEISS should show corresponding reductions. One consideration is that not every injury experienced in a residential setting will be directly related to human factors. For example, an injury from a fall resulting from taking medication may not be prevented through better design. However, just as administrative and/or engineering controls and personal protective equipment (PPE) are used in industry to minimize hazards, improved design in residential settings may mitigate seemingly unrelated injuries as well.

In summary, although just a pilot study, collecting injury data through the NEISS may serve as an effective metric to evaluate new designs over time. Therefore, this research is limited to using NEISS injury data as a means of evaluating potential design solutions and consequently is discussed in more detail below.

Overview of NEISS

The NEISS is an injury surveillance system maintained by the U.S. Consumer Product Safety Commission. The primary function of the NEISS is to report injury data collected from hospital emergency departments in the United States. The NEISS uses a probability sample of hospital emergency departments to develop nation-wide estimates for injuries treated in all hospital emergency rooms (Schroeder and Ault, 2001). The first NEISS was implemented in 1971 and from 1971 to 1999, only consumer product-related injuries were reported. Beginning with the year 2000, data is now collected for virtually all injuries (i.e. not just those injuries related to consumer products).

Out of approximately 5,400 hospitals in the United States, the NEISS collects injury data from a sample of 100 hospitals that are spread throughout the country (U.S. Consumer Product Safety Commission, 2000; Schroeder and Ault, 2001). Figure 4 shows the locations of the hospitals that participate in the NEISS. Injury estimates are calculated by multiplying actual incidences occurring each month at each hospital by a hospital-specific weighting factor, and then summing the scores across all hospitals (Schroeder and Ault, 2001).

Figure 4. NEISS sample hospital locations. (U.S. Consumer Product Safety Commission, 2000).

The NEISS has been in existence since 1971 and has provided numerous government agencies with injury trends over time (U.S. Consumer Product Safety Commission, 2000). Aside from government agencies, researchers have used the NEISS to investigate a wide variety of injuries. Researchers have used the NEISS to collect sports and recreational injury data related to bicycling (Schulman, Sacks, and

Provenzano, 2002), ice-hockey (Hostetler, Xiang, and Smith, 2004), in-line skating (Beirness, Foss, and Desmond, 2001), Lacrosse (Diamond and Gale, 2001), paintball (Conn, Annest, and Gilchrist, 2004) downhill skiing (Xiang, Stallones, and Smith, 2004), weight training (Jones, Christensen, and Young, 2000), and even recreational injuries occurring among the elderly (Gerson and Stevens, 2004).

Other research using the NEISS to collect injury data has included research on injuries related to occupational injuries (Miller and Waehrer, 1998; Chen and Layne, 1999; Chen and Hendricks, 2001; Jackson, 2001) and unintentional injuries occurring to women (Mack, 2004) and the elderly (Stevens and Sogolow, 2005).

Methodology

The following proposed methodology consists of four parts. The first part is to start with the assumption that injury rates can be reduced. Although actually reducing injuries is not trivial, injury rates aren't likely to decrease without the realization that most injuries are caused by some factor (or combination of factors). Disregarding the causal nature of injuries might lead to underestimating possible reductions in injury rates.

The second step requires data collection. For this research, data was collected using the NEISS online database. Data was collected for injuries involving bathtubs/showers, stairs/steps, and floors/flooring materials. The data was segmented into three age groups, ages 15-44, ages 45-64, and ages 65 and older.

The next step involved statistically comparing the injury rates of three age groups using the Mann-Whitney U test, which is an alternate to the two-sample t test (Johnson, 2000). If the injury rate sample data show that each age group is significantly different at

a given alpha level, then a reasonable assumption is that the average injury rates for each age group can also be considered different.

The last step of the proposed methodology utilizes the fundamental ergonomic model as a foundation to postulate that injury rates of the elderly age group can be reduced to similar injury rates of younger age groups. The reasoning behind this assumption is that elderly adults are less able to adapt to the environment than younger adults (Keiser, 1978).

One premise of the fundamental ergonomic model is to use engineering and administrative controls to allow humans to perform tasks when, otherwise, their accommodation level would not permit them to perform a task (Fernandez and Marley, 1998). By creating design guidelines based on human factors principles, the guidelines must provide the engineering and administrative controls that supersede an elderly person's reduced ability to adapt to certain environments.

If the proposed methodology holds true, average, at-home injury rates for younger age groups can and should be used as a target level for average, at-home injury rates for the elderly.

Data Collection

Falls are the most frequent unintentional injury that occur among the elderly within the home environment (Czaja, 1993) and the most common source of falls are on stairways, floors, and bathtubs (Sterns, Barrett, & Alexander, 1985). Furthermore, Lawrence et al. report that, among the elderly, floors, stairs, and bathtubs result in the highest injury costs related to home structures (2000). Therefore, for this research, data

is limited to unintentional injuries occurring within the home, specifically injuries related to stairways, floors, and bathtubs.

Data was collected using the US Consumer Product Safety Commission's NEISS database. As shown in figure 5, data are available through the NEISS Query Builder for injuries occurring between 1991 and 2003. The online database allows researchers to query data by selecting a desired date range, injury type (via product code), sex, age, body part, diagnosis, disposition, location, or any combination of those given parameters.

For this research, data were collected for each year between 1991 and 2003 for injuries involving bathtubs or showers (NEISS product code 611), stairs or steps (product code 1842), and floors and flooring materials (product code 1807). All injuries occurred within a home environment and injuries were categorized into three adult age groups (15-44, 45-64, 65+). No distinction was made between males and females.

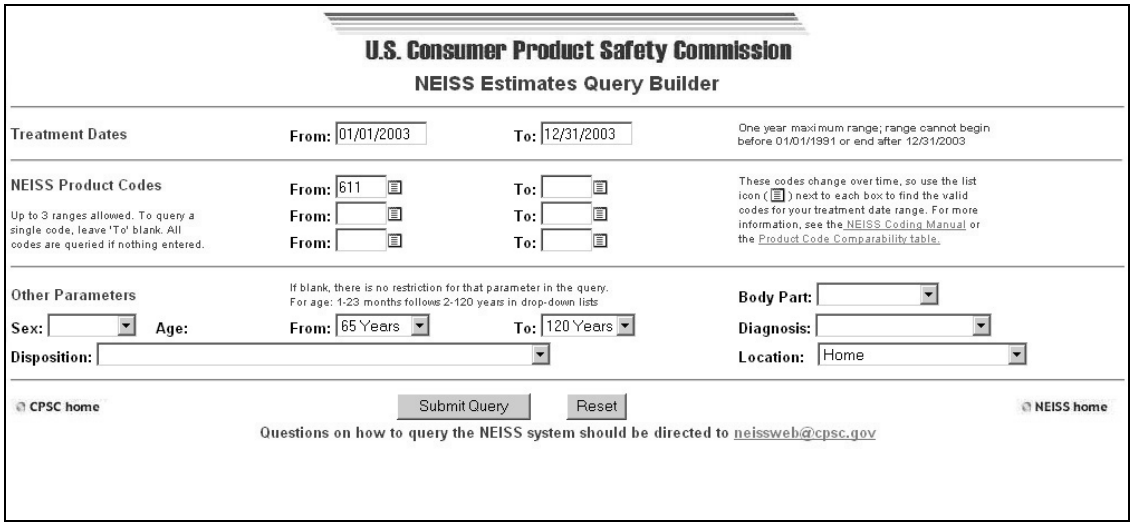

Figure 5. NEISS online query builder.

Figure 6 displays a NEISS query result for a single query, while table 14 presents NEISS injury estimates for the three injury categories and three adult populations. See appendix B for detailed records of query results, including the sample count, coefficient of variation, confidence interval, and adjusted estimate (for results prior to 1997).

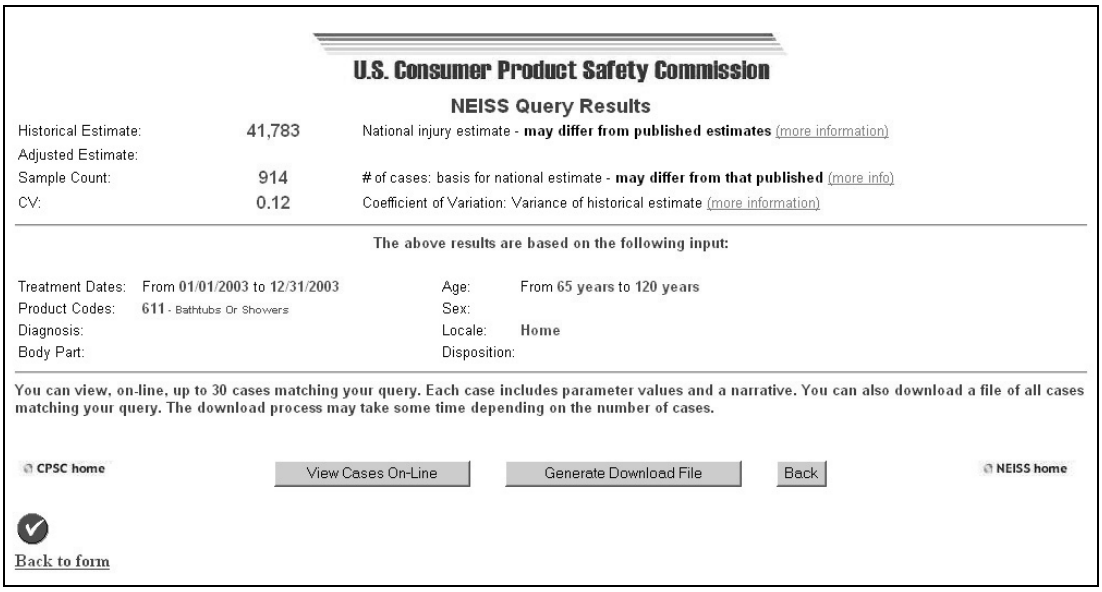

Figure 6. NEISS online query results.

Injury estimates for each age group were then converted into injury rates to allow for comparisons between age groups. Population was determined based on U.S. Census estimates for each year and each age group. The WISQARS (2004) online database was the mechanism chosen to extract the annual U.S. Census Bureau estimates.

Table 14. NEISS estimates (in numbers of injuries) by injury category and age groups for the years 1991-2003.

	Bathtubs or Showers (611)		
Year	Ages 15-44	Ages 45-64	Ages 65+
2003	65,260	38,075	41,783
2002	64,113	33,469	37,325
2001	60,794	30,019	32,077
2000	54,445	27,441	34,989
1999	52,915	23,379	32,656
1998	48,438	22,083	31,167
1997	37,505	16,000	26,130
1996	35,586	16,938	24,821
1995	33,603	13,468	23,635
1994	39,781	17,653	23,888
1993	33,146	14,940	21,694
1992	32,476	14,266	21,703
1991	32,691	14,624	20,245
Year	Stairs or Steps (1842)		
2003	332,634	148,016	105,625
2002	328,729	136,219	97,611
2001	307,200	118,557	95,153
2000	291,170	115,762	89,574
1999	265,184	105,064	95,919
1998	255,537	95,017	87,115
1997	216,184	83,518	75,302
1996	219,713	79,560	85,663
1995	228,498	82,080	83,160
1994	268,987	87,740	90,336
1993	260,051	88,415	87,171
1992	259,003	83,671	82,323
1991	254,326	80,960	83,062
Year	Floors or Flooring Materials (1807)		
2003	117,666	94,280	239,799
2002	113,108	77,802	228,506
2001	115,174	74,614	218,268
2000	119,239	83,780	266,500
1999	110,315	82,889	268,016
1998	104,524	73,837	260,603
1997	87,879	57,499	209,773
1996	86,302	56,530	211,150
1995	96,147	55,875	213,608
1994	90,991	53,791	195,565
1993	86,054	47,842	179,561
1992	79,408	47,909	162,013
1991	69,186	40,178	139,101

Statistical Analysis

The premise for comparing the elderly age group with other adult age groups is to verify that injury rates for the elderly age group can be considered significantly different than those of younger age groups. If there is a statistically significant difference, then it can be assumed that the average rates of injury for the three age groups are also significantly different (Johnson, 2000).

To test for differences between the three injury classifications and age groups, the Mann-Whitney U test was performed on each age group pair within each injury classification. The primary reason for using the Mann-Whitney U test is its "distributionless" property. The Mann-Whitney U test is a nonparametric method for testing significance (Johnson, 2000), therefore, it is not necessary to make assumptions regarding the distribution of the data (i.e. normal, etc.).

After stating the null hypothesis and selecting a level of significance, the eight-step procedure for the Mann-Whitney U test in this research was as follows:

1. Select two age groups to compare
2. Pool and rank-order samples
3. Calculate the ordered, ranked sums (W_i)
4. Calculate the U statistic
5. Calculate mean and variance of U statistic
6. Calculate the standard normal random variable Z
7. Compare Z with z_α
8. Reject null hypothesis if $Z < - z_\alpha$ or $Z > z_\alpha$

The null hypothesis for each Mann-Whitney U test is that the two compared samples come from identical populations, while the alternative hypothesis is that population 2 is stochastically larger than population 1.

The level of significance for all tests is 0.01; therefore, to reject the null hypothesis:

$$Z < -2.575 \text{ or } Z > 2.575$$

Where $2.575 = \pm z_{\alpha}$ (from Appendix B-Table 3 in Johnson, 2000).

The following equations are used to calculate the U statistic (Johnson, 2000):

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$$U = \min\{U_1, U_2\}$$

Where W_1 = rank ordered sum of sample set 1

W_2 = rank ordered sum of sample set 2

n_1 = number of observations in sample set 1

n_2 = number of observations in sample set 1

The following equations are used to calculate the mean and variance of the U statistic:

$$\mu_U = \frac{n_1 n_2}{2}$$

$$\sigma_U^2 = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

Finally, Z is calculated as:

$$Z = \frac{U - \mu_U}{\sigma_U}$$

See appendix B for detailed calculations.

Results

The null hypothesis is rejected for all but one comparison, that between the age groups 15-44 years of age and 45-64 years of age (bathtubs/showers classification). Table 15 presents a summary of results from the Mann-Whitney U test. In every comparison between the elderly age group and a younger age group, the null hypothesis is rejected. Therefore, the elderly age group can be assumed to be significantly different than the younger age groups at an alpha level of 0.01.

The implication that the elderly age group is different from the younger age groups suggests that the mean injury rates between the age groups can be compared. A summary of injury rates for the three classifications and three age groups is presented in table 16 and figures 7-9. Based on the average injury rates, for bathtubs/showers, the injury rate for the younger age groups is approximately 55% less than for the elderly age group. For stairs/steps, injury rates for the 15-44 age group is 16% less than the elderly age group, while injury rates for the 45-64 age group is 33% less. For floors/flooring materials, injury rates for the youngest age group is 87% less and injury rates for the 45-64 age group is 81% less than the elderly age group.

These examples suggest that by designing new environments that appropriately accommodate the needs of the elderly, within their population or individual capabilities, may lead to significant reductions in injury rates.

Table 15. Summary of rejection decision from Mann-Whitney U test.

1. *Null Hypothesis:* Populations are identical
2. *Level of Significance:* $\alpha = 0.01$
3. *Criterion:* Reject the null hypothesis if $Z < -2.575$ or $Z > 2.575$

	Comparison	Z	z_α	Decision
Bathtubs or Showers (611)	Age Group 1 vs. Age Group 2	-0.333	-2.575	Do Not Reject
	Age Group 1 vs. Age Group 3	-3.410	-2.575	Reject
	Age Group 2 vs. Age Group 3	-4.333	-2.575	Reject
Stairs or Steps (1842)	Age Group 1 vs. Age Group 2	-3.615	-2.575	Reject
	Age Group 1 vs. Age Group 3	-3.410	-2.575	Reject
	Age Group 2 vs. Age Group 3	-4.333	-2.575	Reject
Floors or Flooring Materials (1807)	Age Group 1 vs. Age Group 2	-4.333	-2.575	Reject
	Age Group 1 vs. Age Group 3	-4.333	-2.575	Reject
	Age Group 2 vs. Age Group 3	-4.333	-2.575	Reject

Age Group 1 = 15-44 years of age
Age Group 2 = 45-64 years of age
Age Group 3 = 65+ years of age

Table 16. Summary of injury rates (per 100,000 persons) by injury classification and age group.

	Bathtubs or Showers (611)- Injury Rates per 100,000		
Year	Ages 15-44	Ages 45-64	Ages 65+
1991	27.5	31.2	63.6
1992	27.2	29.4	67.1
1993	27.6	29.9	65.9
1994	33.0	34.4	71.7
1995	27.7	25.5	70.0
1996	29.1	31.1	72.7
1997	30.5	28.4	76.0
1998	39.2	37.9	90.0
1999	42.7	38.7	93.8
2000	43.8	44.3	100.0
2001	48.7	46.5	90.8
2002	51.2	50.3	104.8
2003	52.0	55.4	116.3
Average	36.9	37.2	83.3
Year	Stairs or Steps (1842)- Injury Rates per 100,000		
1991	213.6	172.7	261.1
1992	216.9	172.4	254.4
1993	216.7	177.2	264.9
1994	222.9	171.0	271.0
1995	188.2	155.5	246.3
1996	179.9	146.3	250.9
1997	175.9	148.4	218.9
1998	206.9	163.1	251.6
1999	214.0	174.1	275.6
2000	234.4	186.9	256.0
2001	246.2	183.8	269.3
2002	262.7	204.5	274.1
2003	265.2	215.4	294.1
Average	218.7	174.7	260.6
Year	Floors or Flooring Materials (1807)- Injury Rates per 100,000		
1991	58.1	96.5	437.3
1992	66.5	113.4	500.7
1993	71.7	112.6	545.7
1994	75.4	125.9	586.7
1995	79.2	130.0	632.6
1996	70.6	127.6	618.4
1997	71.5	102.2	609.8
1998	84.6	126.8	752.8
1999	89.0	137.3	770.2
2000	96.0	135.2	761.6
2001	92.3	115.7	617.7
2002	90.4	116.8	641.7
2003	93.8	137.2	667.6
Average	79.9	121.3	626.4

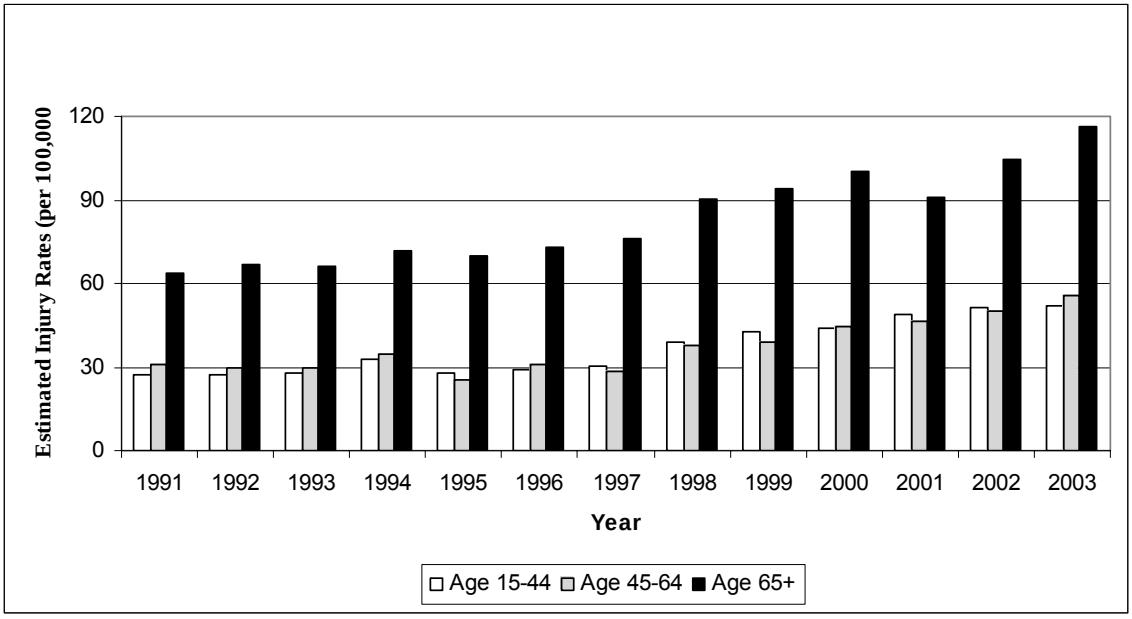

Figure 7. Estimated injury rates for bathtubs and showers (by age group).

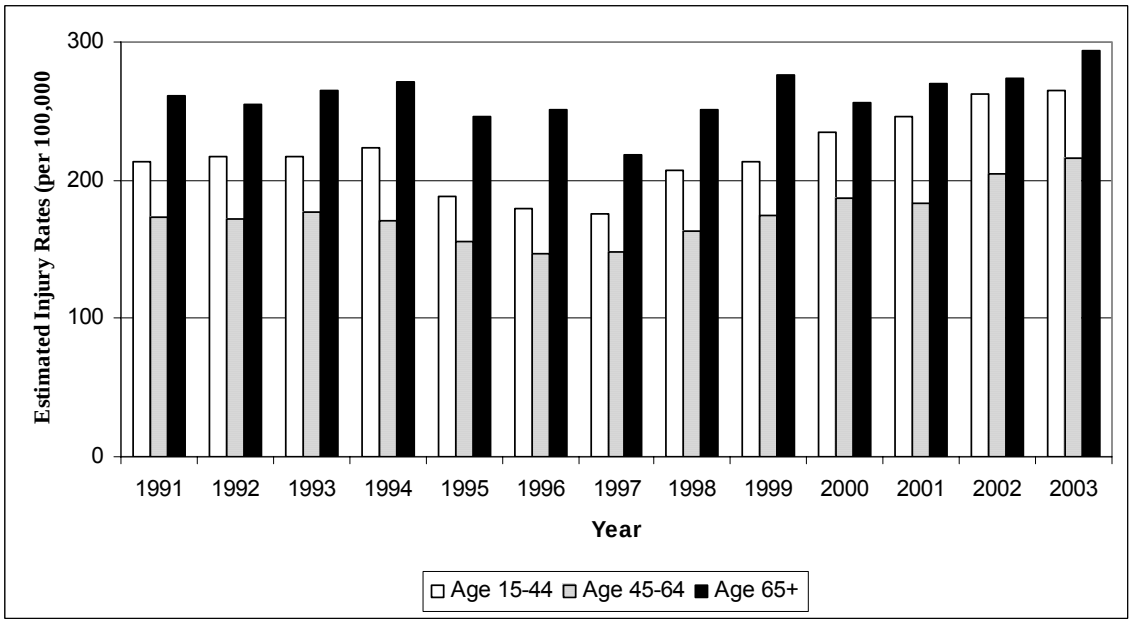

Figure 8. Estimated injury rates for stairs or steps (by age group).

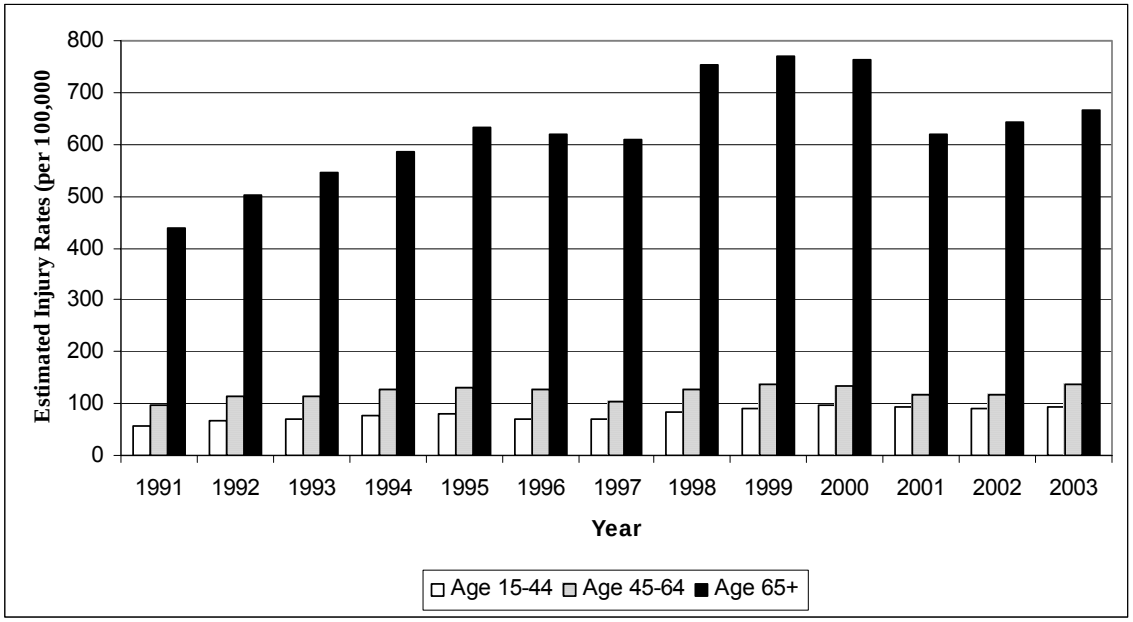

Figure 9. Estimated injury rates for floors or flooring materials (by age group).

Limitations

Three primary limitations of the NEISS are that 1) data is likely to be skewed toward higher, at-home injury rates among the elderly, 2) the NEISS is based on a nation-wide sample of hospitals and therefore is only an estimation, and 3) injury data is only collected from emergency department visits at a hospital.

At-home injury rates will likely be higher for the elderly age group because after retirement, it is reasonable to assume that the elderly, in general, will spend more time at home than younger, working-age persons. Despite this limitation, injury rates might still be reduced to those experienced by younger age groups. The reason for this is because the development of appropriate guidelines must factor in an increased likelihood of injury and therefore these guidelines must be that much more suitable.

Consider an analogous example from industry; that of injury rates between construction work and office work. Obviously, construction work results in more serious injuries than office work, but that doesn't imply that the construction industry is free to adopt some "acceptable" level of deaths or injuries. Rather, construction must work that much harder to minimize injuries. Similarly, at-home injuries for the elderly shouldn't be seen as a "given," these higher injury rates simply need to be designed out through use of suitable guidelines.

CHAPTER 8

CONCLUSIONS AND FUTURE WORK

In *Transgenerational Design*, Jim Pirkl (1994, p. 114) wrote,

”Contrary to popular opinion, 95 to 96 percent of the older population do not depend on institutional support. Most are not blind, deaf, or in need of a wheelchair or other specialized adaptive devices. And despite their functional limitations, most live in the same kinds of spaces, use the same kind of products, and express the same desire for independence as younger people. But remaining independent means retaining control over the micro- as well as the macroenvironment. Control means choice-the opportunity to modify the environment to accommodate one or more functional limitations.”

This thesis attempts to assist in the overarching need to accommodate the diminished functional abilities the elderly have, by encouraging human factors based modifications to the environment, specifically, the residential home.

The following pictograph (figure 10), represents visually, the role this thesis provides in the human factors literature.

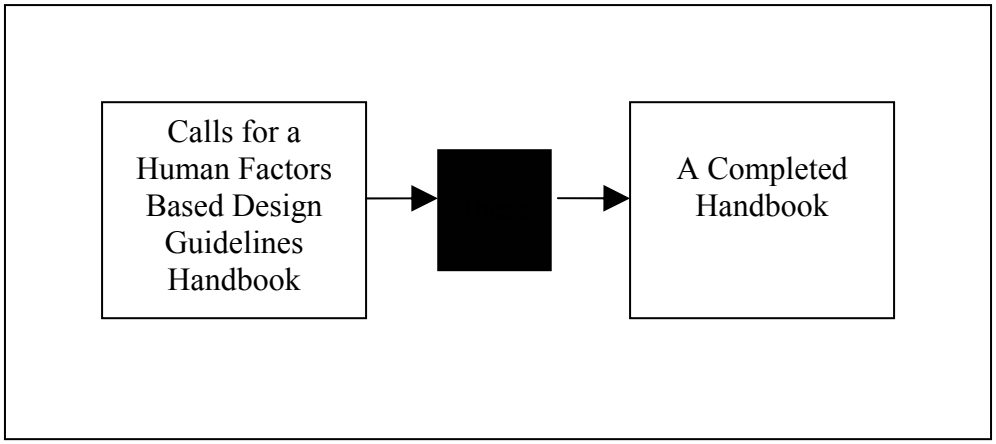

Figure 10. Visual representation of thesis.

Currently, there are calls for developing a human factors design guidelines handbook for residential homes for the elderly (Chapanis, 1974; Czaja, 1990a; Kroemer, 1997). At this time however, a “black box” separates those calls and the actual

completion of a design guidelines handbook. This thesis attempts to clarify the black box by describing a process for developing the handbook.

Specifically, this thesis describes a new context in which to categorize and analyze existing research. A matrix was developed and populated with existing guidelines, and when a guideline was based on research, a description of that research was provided. The research description included the research objectives, a discussion of the type of study, methods, and subjects involved, and which functional limitation (physical, sensory, cognitive) the research addressed.

After populating the research matrix, this thesis discussed how the matrix could also be used as one possible format for a design guidelines handbook that could be used by architects and designers. Two other formats were discussed as well.

Realizing that the actual guidelines were more important than the handbook format, a proposed model to develop guidelines based on human factors was described. This proposed model suggested the adoption of six categories of guidelines to aid in focusing research.

Finally, a rationale for developing and implementing a design guidelines handbook was presented. The basis for this rationale is that functional abilities decrease as we age, and that decrease in ability makes it more difficult to adapt to the environment as compared to younger persons. By overcoming those decreased abilities with improved designs (developed through human factors based studies), it is likely that injury rates experienced by the elderly can decrease to the injury rates that occur in younger age groups.

Although the final outcome of this research was not a handbook of design guidelines for residential housing for the elderly, it is hoped that this thesis may provide focus for continued human factors research and someday, such a handbook.

Future Work

Although the future work related to independent-living elderly is almost limitless, this section describes tangible next steps, directly resulting from this thesis. Because at-home injury rates and injury costs are the highest for unintentional injuries involving floors, stairs or steps, and bathtubs/showers, respectively (Czaja, 1993; Lawrence et al., 2000), it seems appropriate to focus human factors efforts on guidelines that impact those areas. As tables 2 to 13 and Appendix A show, only two studies have been published that related to guidelines for flooring. Those studies only addressed a few flooring types and none investigated whether or not flooring in specific rooms (kitchen, bathroom, bedroom) affect the ability to live independently. Therefore, human factors engineers should design experiments to specify guidelines for flooring, stairs/steps, and bathtubs/showers.

Another future work consideration is to test the proposed design guidelines development model. Conceptually, the model seems to be a feasible method for developing guidelines. The next steps are to empirically validate the model by following the process through for a series of guidelines.

Another area of future work might be to use the National Electronic Injury Surveillance System (NEISS) to generate target levels of injury rates for more injuries than were illustrated in this research. It might be appropriate to adopt a similar method to establish death rates as well.

One last area might be to combine the work presented in this thesis with the work of Mann et al. (1999). The preliminary results of Mann et al's study suggest that home environmental interventions (e.g. adding ramps, lowering cabinets, and other home modifications considered in this research) and assistive technology devices (e.g. walkers, bathtub bench, etc.) might increase the independence for elderly persons by slowing function decline (i.e. certain aspects of aging). Findings from that study also suggest that health care costs can be reduced by implementing environmental interventions and assistive technologies.

Since this thesis specifically addressed at-home environmental interventions, it is recommended that as future guidelines are developed and implemented as designs, experiments similar to that performed by Mann et al. be used as another measure to assesses the value of those new designs.

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APPENDICES

APPENDIX A

COMPLETED RESEARCH MATRIX

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
INTERIOR							
Kitchen							
Cabinet/ Storage Systems	Kirvesoja, H., Vayrynen, S., & Haikio, A. (2000)	Height for storage shelves: 12-63" (300-1600mm) for Finnish elderly.	To compare the subjective evaluations of heights for kitchen counters and kitchen shelving (low and high shelf) with an expert's opinion and height recommendations based on anthropometric data. Note: Study also investigated chair height which is not included here.	Laboratory Study: N= 55 (mean age 74.4); 31 females, 19 males 41 healthy subjects (normal muskuloskeletal system), 14 required a cane to move around Using a mock-up simulator with two sets of heights, subjects performed the following task: - Grab kettle from low shelf, carry to faucet, fill with water, carry to cooker, grab 3 cups (one from each shelf in cupboard), rinse cups, place back on shelf. - Heights of mock-up 1: -lower shelf=6.5" (165mm) -counter=31.5" (800mm) -Upper shelf heights=49.2" (1250mm), 59" (1500mm), 68.5" (1740mm) -Heights of mock-up 2: -lower shelf=10.4" (265mm) -counter=35.4" (900mm) -Upper shelf heights=53.1" (1350mm), 63" (1600mm), 72.4" (1840mm) After performing task, subjects rated heights. These evaluations were then compared with an expert's opinion (the expert watched video footage of tasks) and recommendations based on anthropometric data.	Anthropometric Data: Stature, elbow height		
Cabinet/ Storage Systems	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Recommendations: - Shelf height 63" (1600mm) - Cupboard height between 12" (300mm) and 55" (1400mm)					
Cabinet/ Storage Systems	HUD (1996)	Recommendations: - Storage shelf height 9-54" - Locate bottom shelf of upper cabinet at 48" - Utilize drawers that fully pu out					
Cabinet/ Storage Systems	National Advisory Council on Aging: Government of Canada (1988)	Wall cupboards 14" above counters Provide D-type handles on cupboards and drawers					
Cabinet/ Storage Systems	Woodson, W.E. (1981)	Wall cupboards 15" above counters					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Cooking Technologies	Englehardt, K.G. & Goughler, D.H. (1997)	No explicit guideline, however, authors strongly suggest that designers match the needs and abilities of older adults with the design and capabilities of technologies	To investigate the utility of micro-processor-based technologies that reduce caregiver burden and promote care-receiver independence in meal preparation tasks	Task Analysis: N=7 caregiver/care-receiver teams - Teams prepared a standard meal that was nutritionally balanced - The meal included the following tasks: lean steak wrapped in cellophane; whole potatoes packaged in heavy paper with a cord closure; a packaged frozen vegetable; fruit in a flip-top can; juice in a half gallon container, rolls in a plastic bag, knotted shut; and butter in a paper wrapper. - The videotaped sessions were conducted in the participants' kitchens - Videotapes were evaluated by nurses, geriatricians, roboticists, administrators, caregivers, and physical therapists - Videotapes assessed at 3 increasingly detailed levels of activity: 1) functions (e.g. gathering, preparing, tending); 2) tasks (e.g., opening package, reaching); and 3) finite movements (e.g., grasping, finger flexion, shoulder flexion)	General physical capabilities	Vision, hearing	
Counter	Kirvesoja, H., Vayrynen, S., & Haikio, A. (2000)	Counter height = 33.5" (850mm) for Finnish elderly Note: Authors found 800-900mm acceptable.	See Cabinet/Storage Systems section	See Cabinet/Storage Systems section	Anthropometric Data: Stature, elbow height		
Counter	HUD (1996)	Recommendations: - Mount counters at more than one height - Utilize adjustable countertops - Provide visual contrast at counter edge					
Counter	National Advisory Council on Aging: Government of Canada (1988)	Counter or table height≤ 3'					
Counter	Woodson, W.E. (1981)	Counter height = 36"					
Floor Surface	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Non-skid flooring					
Floor Surface	HUD (1996)	Non-skid flooring					
Layout							
Lighting/Illumination	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Provide direct lighting on work surfaces					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Oven/Range	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Oven: Place on top of counter (to avoid back strain) Range: Provide raised edge to protect against spills					
Oven/Range	HUD (1996)	Recommendations: - Front mounted controls - Staggered burners - Consider flush (or low) burners - Consider separating oven from range and provide knee space below range (wheelchair access)					
Oven/Range	National Advisory Council on Aging: Government of Canada (1988)	Provide 1' wide counter surface on either side of range (at same height)					
Refrigerator	HUD (1996)	Recommendations: - Side-by-side model refrigerator/freezer -Allow doors to open 180° - Include pull-out shelves - Include water/ice dispenser (for those with limited hand dexterity)					
Refrigerator	Koppa, R.J., Jurmain, M.M., & Congleton, J.J. (1989)	Recommended standard features: - Adjustable height shelves - Three shelves - Top freezer - Two produce bins - Temperature control located at height of 45-49" Recommended design options: - Detachable lazy susans - Pull-out shelves - Easily openable doors, with auto-close functionality - Bins should glide smoothly	To determine a set of design guidelines for independent living elderly people.	Laboratory Study: N=25 participated in 2 phases of study. Phase 1: N=22, (16 ambulatory women-age 65+, 6 wheelchair users-aged 27 to 78). Administered questionnaire designed to identify problem area with the refrigerator. Phase 2: N=12 (mean age=72.6), Note: no wheelchair users in this phase. Phase 2 consisted of 3 parts, 1) Simulation of refrigerator tasks using five shelf-types (ordinary-control- shelf, pull-out shelf, lazy susan shelf, pull-out/lazy susan combination shelf, and pull-out and pop-up/down type shelf), 2) Opinion questionnaire about the shelves, 3)User-designed portion in which each participant configured the inside of the refrigerator			

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Room Dimensions	International Conference of Building Officials (1997b)	Ceiling height≥ 7' Floor area: None Wall dimension: None (503.1-503.3)					
Room Transition							
Sink/Faucets	HUD (1996)	Recommendations: - Use lever style handles - Select model with high temperature stop - Sink depth≤ 6.5" - Consider adding a removable front and bottom cabinet below sink to accommodate future wheelchair access					
Ventilation							
Bathroom							
Bath/Shower	HUD (1996)	Recommendations: - Lever style handles - Include removable seat - Include reinforcements for future grab bars - Provide hand-held shower head					
Bath/Shower	Meindl, B.A. & Freivalds, A. (1992)	1. Use lever handles where possible. 2. Use one handle for hot and one handle for cold and mark appropriately. 3. Install two sets of faucet handles located at 21" and 42" (above tub floor) if possible, otherwise, set height at 32". (Note: recommendations for retirement facilities)	To determine location and shape of bathroom faucet fixtures to meet the specific needs and desires of the elderly.	Laboratory Study: N=15 (mean age =79.9) Study comprised of 13 females and 2 males. Subjects manipulated 3 sets of faucet handles (star, acrylic, lever) in 2 position (21" & 42") and 2 angles (90 & 45). 3 trials per subject.	Based on torque generated from handle design and faucet location (height/angle).		
Bath/Shower	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Locate grab bar (horizontal) 30" above floor - Install vertical grab bar - Slip-resistant bathtub floor - Hand-held shower head with adjustable positioning					
Bathroom Technologies							
Floor Surface	HUD (1996)	Non-skid flooring					
Layout							

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Lighting/Illumination	International Code Council (2003)	Natural light ("aggregate glazing" per code)≥ 3sq.ft. Note: Except when "appropriate" ventilation and artificial light is provided (no illumination level specified). (R303.3)					
Room Dimensions	International Conference of Building Officials (1997b)	Ceiling height≥ 7' Floor area: None Wall dimension: None (503.1-503.3)					
Room Transition							
Sink/Faucets	HUD (1996)	Recommendations: - Sink height 30-34" Note: There is no "ideal" height (pg.49) - Lever style handles - Provide high temp stop					
Sink/Faucets	Bordett, H.M., Koppa, R.J., & Congleton, J.J. (1988)	Cover metal edges with compressible material than ca also act as a nonslip surface when operated with wet hands. Lever style handles allow greater exertion of torque. Round all edges to prevent discomfort and/or injuries.	To determine if there is a difference between paddle-type and common knob faucets and to determine if torque generated by subjects would be enough to shut off actual faucet valves	Laboratory Study: N=23 (females ages 65-90); 2 in wheelchairs, 21 able to stand however, 11 chose to sit and 12 were standing during study Study: Applied torque was measured on 7 handles (tripoint, lever&lip, cross, small paddle, lever, multipoint, large paddle) for 4 conditions (right-hand clockwise (cw), right-hand counterclockwise (ccw), left-hand cw, left-hand ccw) with static-type torque meter. All handles were placed at 3'1" (.95m) above floor.	Physical- grip strength		
Storage							
Toilet	International Conference of Building Officials (1997b)	Clear space requirements: Width≥ 30" Space in front≥ 24" (503.3)					
Toilet	HUD (1996)	Recommendations: - Locate 18" from side wall - Provide reinforcement for future placement of grab bars - Install offset flange to allow future movement of toilet (by up to 3")					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Toilet	National Advisory Council on Aging: Government of Canada (1988)	Top of toilet seat = 18" above floor - Delay installation of grab ba until resident moves in (and locate accordingly)					
Ventilation	International Code Council (2003)	Mechanical ventilation≥ 50cfm for intermittent ventilation Mechanical ventilation ≥ 20cfm for continuous ventilation (R303.3)					
Ventilation	International Conference of Building Officials (1997b)	Natural ventilation≥ 5% of floor area with 1.5sq.ft. minimum In lieu of natural ventilation, Mechanical ventilation≥ 5 air changes/hour (504.3)					
Bedroom							
Bedroom Technologies							
Closet/Storage	HUD (1996)	Recommendations: - Use adjustable shelves and hanging rods - Loop handles on doors - Properly illuminate closet - Closets deeper than 18" should have door opening of 32" - Shelf height 9-54"					
Closet/Storage	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Provide at least 4' between bed and closet (5' preferred) - Hanging rods≤ 56" high					
Closet/Storage	USGPO (1977)	2'X3' closet Hanging rods adjustable to 48" high					
Closet/Storage	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L. (1975)	26"X82" closet Hanging rods=55" high					
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions	Woodson, W.E. (1981)	Size: 90-120 sq.ft. for single adult Size: 192-288 sq.ft. for married couple					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Room Dimensions	USGPO (1977)	Size≥ 120sq.ft. Size≥ 180 sq.ft (for combined living room-bedroom) Ceiling height≥ 7'6"					
Room Dimensions	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L. (1975)	Size≥ 135 sq.ft. Ceiling height≥ 8' (7'4" in for perimeter portions)					
Room Dimensions	Grandjean, E. (1973)	Size≥ 150 sq.ft. (although 170+ sq.ft. recommended)					
Room Dimensions	Beyer, G.H. & Nierstrasz, F.H.J. (1967)	Size≥ 130 sq.ft.					
Room Transition							
Ventilation							
Living Room							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							
Dining Room							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							
Office							
Floor Surface							
Layout							
Lighting/Illumination							
Room Dimensions							
Room Transition							
Storage							
Ventilation							
Common Features/Misc.							
Doors/Doorways	Pinto, M.R., De Medici, S., Zlotnicki, A., Bianchi, A., Van Sant, C., & Napoli, C. (1997)	Recommendations: - Doors made of opaque materials - Handles obvious and of different color to the door - Use lighting to increase colo contrast between door and surroundings					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Doors/Doorways	HUD (1996)	Recommendations: - Doorway opening ≥ 32" - Lever or loop style door handles - Install swing away door hinge in narrow doorways - Easily operable locking mechanism - Include secondary "peep" hole at lower level (for shorter or seated people) - Provide auxiliary door handle to facilitate closing Level of force to open door: - 8 lbs (exterior) - 5 lbs (interior)					
Doors/Doorways	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Minimum 32" clear doorway opening (30" if access is straight on) - Door handle height 30-36" - Lever style door handles - Threshold height ≤ 5/8" Door closure pressure: - ≤ 34N (newtons) for exterior doors - ≤ 22N for interior doors - ≤ 10N (interior doors operated by frail elderly)					
Doors/Doorways	Woodson, W.E. (1981)	Recommendations: -Width = 36" -Height = 80" -Threshold height = 0.5" -Lever-style handle preferred					
Doors/Doorways	Koncelik, J.A. (1976)	Recommendations: - Lever type handle - Handle height 40" - Provide illumination at keyhole - Curve lock insert inward (to direct key to opening) - Also, Keys should have long shank and large gripping surfaces					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Doors/Doorways	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L. (1975)	Recommendations: - 34" clear opening with no threshold - Lever type handle - Handle height 4'6" - Pressure to open door≤ 5 lbs					
Electrical Receptacles	HUD (1996)	Height 15-48"					
Electrical Receptacles	National Advisory Council on Aging: Government of Canada (1988)	Height 18-21"					
Electrical Receptacles	Koncelik, J.A. (1976)	Height 16-20"					
Electrical Receptacles	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L. (1975)	Height 24"					
Electrical Receptacles	Central Mortgage (1972)	Height≥ 21"					
Electrical Receptacles	Musson, N. & Heusinkveld, H. (1963)	Height 18-24"					
Emergency Escape	International Code Council (2003)	Openable area of rescue window ≥ 5.7 sq.ft. Window dimensions: Minimum height=24" Minimum width=20" (R310.1)					
Emergency Escape	International Conference of Building Officials (1997a)	Openable area of rescue window ≥ 5.7 sq.ft. Window dimensions: Minimum height=24" Minimum width=20" (310.4)					
Entrance	Pinto, M.R., De Medici, S., Van Sant, C., Bianchi, A., Zlotnicki, A., & Napoli, C. (2000)	Recommendations: - Door threshold < 1" (25mm) - Non-skid flooring - Grab-bars near door - Reduce difference in illumination between inside and outside - Light-switches close to door - Passages free from furniture and equipment - Box to hold keys near door - Adjustable coat-hanger					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Flooring (General)	Dickinson, J.I., Shroyer, J.I., Elias, J.W., Hutton, J.T., & Gentry, G.M. (2001)	Architects, interior designers, and health care providers can specify similar carpet as used in study. Carpet: 36-oz., 1/8" gauge, 100% nylon, 1/2 cut pile Pad: Rebonded, polyurethane, 6 lb density, 7/16" thick Note: This is the most common carpet specified for residential use (Dickinson et al. 2001).	"To determine the effect of selected residential carpet and pad on the balance of healthy, community-dwelling older adults" pg.281. Specifically, this research questioned 1) if carpet increased postural sway in older adults, 2) if carpet caused a change in hip vs. ankle balance strategy, and 3) if carpet affected visual and somatosensory cues.	Laboratory Study: N=25 (mean age=73.25) Group comprised of 7 men and 18 women. Using a Neurocom computerized Equitest Posturography balance machine, researchers teste 3 independent variables: Two floor surfaces (firm vs. compliant surface). Four sensory conditions (eyes open, stationary forceplate; eyes closed, stationary forceplate; eyes open, moving forceplate; eyes closed, moving forceplate). Three trials.	Postural balance	Visual and somatosensory cues	
Flooring (General)	Pinto, M.R., De Medici, S., Zlotnicki, A., Bianchi, A., Van Sant, C., & Napoli, C. (1997)	Recommendations: - Inset doormat, use shallow pile - Doorstep height < .75/1" - Height and width of floor component joints < .75"					
Flooring (General)	Redfern, M.S., Moore, P.L. & Yarsky, C.M. (1997)	No specific guideline, however, the reported results suggest that while more "compliant" floors are comfortable and may reduce the potential for hip fractures, they destabilize balance and therefore increase the risk of falls.	1. To study the effect of flooring on standing balance of older adults. 2. To study the interactions with visual cues used in postural control.	Laboratory study: N=8 in young group (mean age=23.8) N=8 in elderly group (mean age=76). Each group consisted of 5 healthy women and 3 healthy men. Using Equitest Posturography Platform, subjects stood (sans shoes) on 7 simulated floor surfaces (low to high piles and differing pad types + hardwood floor) and 3 visual conditions (eyes open with fixed visual scene, eyes closed, eyes open with moving scene).	Balance	Visual effects on posture	

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Flooring (General)	HUD (1996)	Recommendations: - Select firm carpet, with 0.5" maximum pile height - Carpet edge transition heights should be ≤ 0.5" - All hard surfaces should be non-skid - Eliminate changes in height between floor transitions					
Flooring (General)	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Non-glare floor surfaces - Slip-resistant floor surfaces - Carper securely attached, pile height ≤ 0.5" with firm under pad or no under pad					
Flooring (General)	Beyer, G.H. & Nierstrasz, F.H.J. (1967)	Non-skid flooring					
Hallways	International Conference of Building Officials (1997b)	Ceiling height ≥ 7' Floor area: None Wall dimension: None					
Heating (General)	International Code Council (2003)	Heating system to maintain room temperature ≥ 68°F at 3' above floor in all habitable rooms (where winter design temperatures ≤ 60° F) (R303.8)					
Heating (General)	International Conference of Building Officials (1997b)	Heating system to maintain room temperature ≥ 70°F at 3' above floor in all habitable rooms (701.1)					
Ingress/Egress	International Code Council (2003)	Hallway: Minimum width = 3' Exit Door: Minimum width = 3' Minimum Height = 6'8" (R311)					
Lighting/Illumination (General)	International Code Council (2003)	Natural light ("aggregate glazing" per code) ≥ 8% of floor area in habitable rooms Note: Except when "appropriate" ventilation and artificial light is provided (average illumination level ≥ 0.6 foot-candle [6.46 lux] over the floor at height = 30"). (R303.1)					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Lighting/Illumination (General)	Charness, N. & Dijkstra, K. (1999)	No specific guideline, however, the reported results suggest that lighting levels in homes are typically below IESNA recommendations.	1. To determine the typical luminance levels in the "buil environment" (pg. 173). 2. To assess if ambient light levels in homes change with age. 3. To determine if changing light levels improves legibility performance of older adults (compared with younger adults). 4. To determine the barriers that prohibit improving lighting levels in buildings.	Field study: N=34 in elderly group (mean age=69.3, SD=6.64). Group comprised of 21 women and 13 men. Study related to the home environment consisted of 5 tasks (newspaper reading task, phone book reading task, newspaper task, proofreading task, and phone book task). Lighting levels were documented and compared with IESNA recommendations.		Vision	
Lighting/Illumination (General)	Pinto, M.R., De Medici, S., Zlotnicki, A., Bianchi, A., Van Sant, C., & Napoli, C. (1997)	Recommendations: -Lighting at floor≥ 300 lux - Lighting of work surfaces 500-800 lux - Design for absence of glare and shadows - Reduce the different level of illumination between inside and outside - Use uniform lighting between corridors and rooms - Correctly locate direct light					
Lighting/Illumination (General)	International Conference of Building Officials (1997b)	Natural light≥10% of floor area with 10sq.ft. minimum Note: For guest rooms and habitable rooms (504.2)					
Lighting/Illumination (General)	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Lighting≥ 50 lux - Lighting is even and well-diffused to eliminate spottiness or shadows - Provide supplementary task lighting where necessary					
Light Switches	HUD (1996)	Recommendations: - Height 36-48" - Use rocker, toggle, or touch sensitive switches - Use remote controlled switches to turn on and off consumer products (e.g. lamps), if applicable					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Light Switches	National Advisory Council on Aging: Government of Canada (1988)	Height 33-43"					
Light Switches	Koncelik, J.A. (1976)	Height 35"					
Light Switches	Central Mortgage (1972)	Height 3'-4'8"					
Other Misc. Storage	National Advisory Council on Aging: Government of Canada (1988)	Storage shelving within in range of 8-56" high					
Ramps (Interior)	International Code Council (2003)	Slope ≤ 12.5% (Note: Slopes≥ 8.33% require handrail) (R311.6)					
Ramps (Interior)	National Advisory Council on Aging: Government of Canada (1988)	See exterior ramps (National Advisory Council, 1988)					
Room Dimensions (General)	International Code Council (2003)	Ceiling height≥ 7' Floor area: 1 room≥ 120sq.ft. with other rooms ≥ 70 sq.ft. Wall dimension≥ 7' in all horizontal directions Note: For all habitable rooms (R304)					
Room Dimensions (General)	International Conference of Building Officials (1997b)	Ceiling height≥ 7'6" Floor area: 1 room≥ 120sq.ft. with other rooms ≥ 70 sq.ft. Wall dimension≥ 7' in all horizontal directions (503.1-503.3)					
Smoke Alarms/ Smoke Detector	International Code Council (2003)	Location: Install in following locations: 1. Each sleeping room 2. Outside each sleeping area within the vicinity of bedrooms 3. On each additional story of dwelling (Note: Designated for new construction) (R313.1)					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Smoke Alarms/ Smoke Detector	International Conference of Building Officials (1997a)	Location: Install detector in each sleeping room and at a point centrally located in corridor o area giving access to each separate sleeping area. Instal detector on each story including basement (where applicable). Sound: "Detector shall sound an alarm audible in all sleepin areas of the dwelling unit in which they are located" (pg. 1 28) (310.9.1)					
Smoke Alarms/ Smoke Detector	Huey, R.W., Buckley, D.S. & Lerner, N.D. (1994)	Include lower frequency audible sounds in alarm (primary peak at 500 Hz); Include fast modulation rate (instead of continuous sound). Note: Currently, several smoke detector audible signal in 4000 Hz frequency (pg. 147).	Establish a preferred smoke detector alarm signal based on the hearing requirements of the elderly.	Field study: N=37 (age 65+) - 8 listening conditions (2 alarm locations, 4 listener scenarios); 14 alarm sounds (varied frequencies fast vs. continuous pulse); Sound generated with function generator at frequencies between 500 and 4000 Hz.		Hearing: (elderly tend to lose hearing in high frequency range)	
Smoke Alarms/ Smoke Detector	Lerner, N.D. & Huey, R.W. (1991)	Recommendations: - Controls and batteries should be accessible without climbing and operable by those with limited hand strength or dexterity - Installation should be easy and inexpensive - Trouble indicator should be understandable. - Include positive indicator when functioning properly - System should be self-testing - Include alarm-cancel feature - Audible signal should be detectabl by the normal range of older adults - Distribute alarms throughout the home - Provide clear guidance for selectin and locating smoke detectors - System should include aids to egress - Product should be battery powered or include battery backup - Consider aesthetics	To examine residential fire safety problems of older people, present information from focus group panels of older homeowners, and discuss recommendations for improved smoke detector designs.	Focus Group: N=23 (mean age=74) Three focus group sessions were held to discuss the following: - Fire safety attitudes and practice - Knowledge of smoke detector products and features - Response to new product features and concepts Following the focus group discussions, participants filled out a brief questionnaire.	Physical ability to maintain smoke detectors	Hearing and visual concerns	Understanding of features and how to install and maintain smoke detectors
Smoke Alarms/ Smoke Detector	Beyer, G.H. & Nierstrasz, F.H.J. (1967)	Alarms should be low pitched					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Smoke Alarms/ Smoke Detector	Musson, N. & Heusinkveld, H. (1963)	Alarms should have both low and high pitch					
Stairways (Interior)	International Code Council (2003)	Illumination: All interior/exterior stairways require illumination on landing and treads. Interior tread and landing illumination level≥ 1 foot-candles (11 lux) (R303)					
Stairways (Interior)	International Code Council (2003)	Dimensions: Width≥ 36" (above handrail) Width≥ 31.5" (below handrails with 1 rail) Width≥ 27" (below handrails with 2 rails) (Note: Does not include spiral or other "special" staircases) Headroom≥ 6'8" Riser height≤ 7.75" Tread depth≥ 10" Walking surface slope≤ 2% (R311.5)					
Stairways (Interior)	International Code Council (2003)	Handrails: Required for continuous run of treads or flight with 4 or more risers Handrail height between 34"-38" Grip size (Type 1): 1.25" ≤ Outside Diameter≤ 2" (R311.6)					
Stairways (Interior)	Roys, M. S. (2001)	Stair Tread depth: Minimum of 9.6" (245mm) for Residential area Note: Minimum tread depth for "Semi-public" area should be 270mm (10.6") and for public area, 300mm (11.8")	To investigate stair accidents caused by shorter tread depths, and discuss ways to prevent these injuries.	Author considered existing anthropometric data (foot length) to recommend a 25mm increase in tread depth. This is based on larger foot sizes in current population and factors in a 30mm allowance for shoes.	Anthropometric Data: Foot length		

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Stairways (Interior)	Christina, K.A., Okita, N., (2000) Owens, D.A., & Cavanagh, P.R.	No explicit guidelines	To investigate means for safely negotiating stairs in altered visual conditions and to determine frictional demands of stair descent under optimal and non-optimal visual conditions. Note: Study included both younger and older populations.	Laboratory Study: N=12; mean age 24±3.3yrs for younger subjects N=10; mean age 73.7±1.9yrs for older subjects - Subjects completed 5 stair descents for each of 4 visual and lighting conditions. (1. normal vision/300 lux illuminance; 2. normal vision/3 lux illuminance; 3.bifocals/300 lux; 4. bifocals/3 lux). - Descent occurred on 7-step staircase (rise≈7" (18cm), tread depth≈11" (28cm) - Ground reaction force data collected with 2 force plates (Type 9286, Kistler Instruments Corp.) installed on the 2nd and 4th steps.		Visual (normal vision vs. bifocals; different illumination levels)	
Stairways (Interior)	International Conference of Building Officials (1997a)	General Dimensions: Step width ≥ 36" 4" ≤ Step Rise ≤ 7" Step Run ≥ 11" Note- Private steps with fewer than 10 occupants: Max rise = 8" Min run = 9" Headroom ≥ 6'8" Handrails: 34" ≤ Height ≤ 38" Outside Dimension (on circular grip): 1.25"-2.0" Note: Private stairways do not need handrails (1003.3.3)					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Stairways (Interior)	HUD (1996)	Recommendations: - Stair surface should provide adequate traction - Provide color contrast between riser and tread - Round all nosings - Handrail height 30-38" - Place handrails on both sides of stairs - Handrail should be round or oval shaped and 1.25-2" in diameter - Handrails should be 1.5" from wall - Handrails should extend 1' at top and bottom of stairway					
Stairways (Interior)	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Conform to NBC Sec 3.4 - Lighting≥ 50 lux - Handrails 32-36" high - Handrails extend 1' beyond top and bottom of stairs - Riser height 6-7" - Tread width 10.5-14" - Bevel stair nosings - Mark edges with color contrast - Avoid winding stairs					
Stairways (Interior)	Maki, B.E., Bartlett, S.A., & Fernie, G.R. (1985)	For 41 deg. slope stairway: - Acceptable height for elderly 35.5-40" (.91-1.02m) Recommended height based on comfort 36" For 49 deg. slope stairway: - Acceptable height for elderly 35.5" (.91m) Recommended height based on comfort 36"	To determine an optimal handrail height for stairways with a 41 and 49 deg slope based on subjects ability to generate stabilizing forces and moments at given handrail heights	Laboratory Study: N=20 (for elderly participants) 8 males, 12 females; age=59+ Description: - Same research as (1984) study using stairway slopes of 41 & 49 deg	Physical-strength		

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Stairways (Interior)	HUD (1996)	Recommendations: - Stair surface should provide adequate traction - Provide color contrast between riser and tread - Round all nosings - Handrail height 30-38" - Place handrails on both sides of stairs - Handrail should be round or oval shaped and 1.25-2" in diameter - Handrails should be 1.5" from wall - Handrails should extend 1' at top and bottom of stairway					
Stairways (Interior)	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Conform to NBC Sec 3.4 - Lighting≥ 50 lux - Handrails 32-36" high - Handrails extend 1' beyond top and bottom of stairs - Riser height 6-7" - Tread width 10.5-14" - Bevel stair nosings - Mark edges with color contrast - Avoid winding stairs					
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Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Thermostats	Metz, S., Isle, B., Denno, S., &Odom, J. (1992)	Non-conclusive guideline, however, subjects preferred thermostat with large numbers and large outer ring (to set temp.) over standard Honeywell thermostat (model T87F).	To test new thermostat designs and determine which design is easier to use and read by elderly persons (and other populations). Note: One requirement was that new design must be adaptable to current Honeywell thermostat (model T87F).	Laboratory study: N=34 in elderly group (mean age=68.9). Note: Study included a disabled group, but results not considered in this research. Subjects tested 2 new thermostat designs: 1. Temp. adjustment via knurled outer ring; large numbers for display 2. Temp. adjustment with lever handle; large number for display. Subjects performed designated tasks with each design and state preference (and reasoning). Researchers observed subjects and noted relative success and behavioral strategies during task performance.	Physical (force required to adjusting dial)	Visual display	
Ventilation (General)	International Code Council (2003)	Natural ventilation≥ 4% of floor area Note: For guest rooms and habitable rooms In lieu of natural ventilation, Mechanical ventilation≥ 0.35 air changes/hour in room or whole-house ventilation≥ 15 cfm of outside air per occupant (R303.1)					
Ventilation (General)	International Conference of Building Officials (1997b)	Natural ventilation≥ 5% of floor area with 5sq.ft. minimum Note: For guest rooms and habitable rooms In lieu of natural ventilation, Mechanical ventilation≥ 2 air changes/hour with 20% of air supply from outside (504.3)					
Walls (General)	Pinto, M.R., De Medici, S., Zlotnicki, A., Bianchi, A., Van Sant, C., & Napoli, C. (1997)	Non-glare surfaces: glare index limit < 10					

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Walls (General)	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Non-glare wall finishes - Minimum sound reflection					
Windows	HUD (1996)	Recommendations: - Avoid single- or double-hung windows where possible - Utilize large, easy to use hand cranks on casement windows - Ensure all locking mechanisms are accessible					
Windows	Green, I., Fedewa, B.E., Jackson, W.M., Johnston, C.A., & Deardorff, H.L. (1975)	Windows should be easily operated and not too high					
EXTERIOR							
Driveway/Parking	HUD (1996)	Provide an access aisle					
Driveway/Parking	National Advisory Council on Aging: Government of Canada (1988)	- Shelter parking from rain, snow, and ice - Grades≤ 1:20 Avoid changes in level (steps) where possible					
Electrical Receptacles (Exterior)	National Advisory Council on Aging: Government of Canada (1988)	18-21" above ground (for wheelchair accessibility)					
Entrance	International Conference of Building Officials (1997a)	Means of egress illumination: ≥ 1 foot-candle (10.76 lux) at floor level Note: Not required in private residences (Group R-Division 3) (1003.2.9)					
Entrance	HUD (1996)	Recommendations: - Door threshold≤ 0.5" - "good overall lighting" for security - Provide package shelf near door (latch side) - Provide easy to see, lighted doorbell - Construct/raise porch to be level with interior floor surfaces - Provide focused lighting at door handle and lockset					
Entrance	National Advisory Council on Aging: Government of Canada (1988)	Shelter entrance from the elements					
Garage							

Architectural System Component	Citation	Design Guideline/Recommendation	Research Objective	Research Description	Categories of Disabilities		
					Physical	Sensory	Cognitive
Hose Connection	National Advisory Council on Aging: Government of Canada (1988)	2-4' above ground (accessible from a paved area-for wheelchair access)					
Lawn/Yard							
Lighting/Illumination	National Advisory Council on Aging: Government of Canada (1988)	Exterior lighting "adequate"					
Ramps (Exterior)	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Color contrast at changes in level - Lighting≥ 50 lux at floor level and 300 lux at top and bottom of ramp - Slope≤ 1:20 (unless impractical, never > 1:12) - Slip-resistant surface - Rise≤ 30" (at 1:12 slope) - Length≤ 30' (slope > 1:20) - Width≥ 3' (for 1 wheelchair) - Width≥ 5'4" (for 2 whlchrs) - Cross slope≤ 1:50 - Handrails for ramps > 1:16 (and conform to building code) - Handrails extend 1' beyond top and bottom of ramp					
Ramps (Exterior)	Woodson, W.E. (1981)	Slope: Recommend ≤ 5%; 8% maximum Length: ≤ 30'					
Walkways	National Advisory Council on Aging: Government of Canada (1988)	Recommendations: - Surfaces firm, even and slip-resistant - Pathways 5' wide - Site grades (used by pedestrians)≤ 1:20 - Site grades in pedestrian routes≤ 1:12 - Lighting≥ 50 lux - Lighting ≥ 300 lux on all changes in level					

APPENDIX B

UNINTENTIONAL INJURY CALCULATIONS

Summary of Injuries in the Home by Age Group

	Bathtubs or Showers (611) Rates per 100,000			Stairs or Steps (1842) Rates per 100,000			Floors or Flooring Materials (1807) Rates per 100,000		
Year	**15-44**	**45-64**	**65+**	**15-44**	**45-64**	**65+**	**15-44**	**45-64**	**65+**
1991	27.5	31.2	63.6	213.6	172.7	261.1	58.1	96.5	437.3
1992	27.2	29.4	67.1	216.9	172.4	254.4	66.5	113.4	500.7
1993	27.6	29.9	65.9	216.7	177.2	264.9	71.7	112.6	545.7
1994	33.0	34.4	71.7	222.9	171.0	271.0	75.4	125.9	586.7
1995	27.7	25.5	70.0	188.2	155.5	246.3	79.2	130.0	632.6
1996	29.1	31.1	72.7	179.9	146.3	250.9	70.6	127.6	618.4
1997	30.5	28.4	76.0	175.9	148.4	218.9	71.5	102.2	609.8
1998	39.2	37.9	90.0	206.9	163.1	251.6	84.6	126.8	752.8
1999	42.7	38.7	93.8	214.0	174.1	275.6	89.0	137.3	770.2
2000	43.8	44.3	100.0	234.4	186.9	256.0	96.0	135.2	761.6
2001	48.7	46.5	90.8	246.2	183.8	269.3	92.3	115.7	617.7
2002	51.2	50.3	104.8	262.7	204.5	274.1	90.4	116.8	641.7
2003	52.0	55.4	116.3	265.2	215.4	294.1	93.8	137.2	667.6
Average	**36.9**	**37.2**	**83.3**	**218.7**	**174.7**	**260.6**	**79.9**	**121.3**	**626.4**

Age Group= 15-44

			Bathtubs orShowers (611)					Stairs or Steps (1842)					Floors or Flooring Materials (1807)				
	Year	Pop. Est.	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV
1	2003	125,449,355	52.0	65,260		1,668	0.10	265.2	332,634		8,298	0.10	93.8	117,666		3,244	0.15
2	2002	125,139,593	51.2	64,113		1,731	0.10	262.7	328,729		8,682	0.10	90.4	113,108		3,512	0.15
3	2001	124,772,272	48.7	60,794		1,517	0.11	246.2	307,200		7,424	0.10	92.3	115,174		3,318	0.14
4	2000	124,224,142	43.8	54,445		1,313	0.10	234.4	291,170		6,472	0.10	96.0	119,239		2,770	0.13
5	1999	123,931,115	42.7	52,915		1,222	0.09	214.0	265,184		5,838	0.09	89.0	110,315		2,482	0.11
6	1998	123,511,704	39.2	48,438		1,052	0.10	206.9	255,537		5,310	0.10	84.6	104,524		2,273	0.11
7	1997	122,881,145	30.5	37,505		750	0.11	175.9	216,184		4,070	0.11	71.5	87,879		1,731	0.12
8	1996	122,157,376	29.1		35,586	915	0.10	179.9		219,713	5,934	0.10	70.6		86,302	2,451	0.15
9	1995	121,437,105	27.7		33,603	876	0.10	188.2		228,498	5,775	0.10	79.2		96,147	2,525	0.15
10	1994	120,680,294	33.0		39,781	960	0.09	222.9		268,987	6,840	0.09	75.4		90,991	2,361	0.14
11	1993	120,027,724	27.6		33,146	810	0.10	216.7		260,051	6,131	0.10	71.7		86,054	2,103	0.15
12	1992	119,407,549	27.2		32,476	756	0.10	216.9		259,003	5,665	0.11	66.5		79,408	1,834	0.17
13	1991	119,058,173	27.5		32,691	759	0.09	213.6		254,326	5,571	0.10	58.1		69,186	1,509	0.17

Note: Prior to 1997, use adjusted estimate to compare with data later than 1997- per NEISS

Age Group= 45-64

			Bathtubs or Showers (611)					Stairs or Steps (1842)					Floors or Flooring Materials (1807)				
	Year	Pop. Est.	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV
1	2003	68,704,335	55.4	38,075		930	0.10	215.4	148,016		3,617	0.10	137.2	94,280		2,376	0.13
2	2002	66,597,136	50.3	33,469		881	0.10	204.5	136,219		3,545	0.09	116.8	77,802		2,239	0.12
3	2001	64,500,373	46.5	30,019		718	0.11	183.8	118,557		2,855	0.09	115.7	74,614		1,997	0.13
4	2000	61,952,636	44.3	27,441		632	0.10	186.9	115,762		2,450	0.10	135.2	83,780		1,821	0.14
5	1999	60,355,849	38.7	23,379		542	0.09	174.1	105,064		2,199	0.10	137.3	82,889		1,794	0.14
6	1998	58,242,814	37.9	22,083		458	0.10	163.1	95,017		1,888	0.10	126.8	73,837		1,555	0.13
7	1997	56,276,821	28.4	16,000		307	0.11	148.4	83,518		1,498	0.10	102.2	57,499		1,114	0.13
8	1996	54,389,952	31.1		16,938	410	0.11	146.3		79,560	2,150	0.10	127.6		56,530	1,502	0.16
9	1995	52,800,265	25.5		13,468	333	0.11	155.5		82,080	2,115	0.10	130.0		55,875	1,435	0.16
10	1994	51,311,901	34.4		17,653	402	0.12	171.0		87,740	2,269	0.10	125.9		53,791	1,317	0.17
11	1993	49,892,424	29.9		14,940	339	0.11	177.2		88,415	2,126	0.10	112.6		47,842	1,141	0.16
12	1992	48,545,779	29.4		14,266	307	0.12	172.4		83,671	1,896	0.11	113.4		47,909	990	0.22
13	1991	46,866,013	31.2		14,624	311	0.11	172.7		80,960	1,704	0.11	96.5		40,178	843	0.21

Note: Prior to 1997, use adjusted estimate to compare with data later than 1997- per NEISS

Age Group= 65+

			Bathtubs or Showers (611)					Stairs or Steps (1842)					Floors or Flooring Materials (1807)				
	Year	Pop. Est.	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV	Rates per 100,000	Historical Estimate	Adjusted Estimate	Sample Count	CV
1	2003	35,919,183	116.3	41,783		914	0.12	294.1	105,625		2,367	0.10	667.6	239,799		5,571	0.13
2	2002	35,607,547	104.8	37,325		898	0.13	274.1	97,611		2,451	0.09	641.7	228,506		5,618	0.13
3	2001	35,337,728	90.8	32,077		716	0.12	269.3	95,153		2,115	0.09	617.7	218,268		5,014	0.14
4	2000	34,991,753	100.0	34,989		733	0.13	256.0	89,574		1,831	0.09	761.6	266,500		5,428	0.16
5	1999	34,797,847	93.8	32,656		672	0.13	275.6	95,919		1,901	0.10	770.2	268,016		5,587	0.15
6	1998	34,619,166	90.0	31,167		636	0.11	251.6	87,115		1,712	0.11	752.8	260,603		5,274	0.14
7	1997	34,401,565	76.0	26,130		485	0.12	218.9	75,302		1,328	0.11	609.8	209,773		3,731	0.18
8	1996	34,143,052	72.7		24,821	563	0.15	250.9		85,663	2,172	0.12	618.4		211,150	4,962	0.22
9	1995	33,769,307	70.0		23,635	549	0.12	246.3		83,160	2,050	0.10	632.6		213,608	4,916	0.19
10	1994	33,330,804	71.7		23,888	530	0.13	271.0		90,336	2,251	0.10	586.7		195,565	4,313	0.18
11	1993	32,901,813	65.9		21,694	478	0.13	264.9		87,171	2,025	0.12	545.7		179,561	3,694	0.22
12	1992	32,355,995	67.1		21,703	423	0.13	254.4		82,323	1,783	0.12	500.7		162,013	3,112	0.24
13	1991	31,811,625	63.6		20,245	385	0.14	261.1		83,062	1,664	0.13	437.3		139,101	2,539	0.22

Note: Prior to 1997, use adjusted estimate to compare with data later than 1997- per NEISS

Raw Data- for Floors/Flooring

n_i	Group	Inj rate	Group	Inj rate
1	1	58.1	2	96.5
2	1	66.5	2	113.4
3	1	71.7	2	112.6
4	1	75.4	2	125.9
5	1	79.2	2	130.0
6	1	70.6	2	127.6
7	1	71.5	2	102.2
8	1	84.6	2	126.8
9	1	89.0	2	137.3
10	1	96.0	2	135.2
11	1	92.3	2	115.7
12	1	90.4	2	116.8
13	1	93.8	2	137.2

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	1	58.1
2	1	66.5
3	1	70.6
4	1	71.5
5	1	71.7
6	1	75.4
7	1	79.2
8	1	84.6
9	1	89.0
10	1	90.4
11	1	92.3
12	1	93.8
13	1	96.0
14	2	96.5
15	2	102.2
16	2	112.6
17	2	113.4
18	2	115.7
19	2	116.8
20	2	125.9
21	2	126.8
22	2	127.6
23	2	130.0
24	2	135.2
25	2	137.2
26	2	137.3

Ordered Ranks

Group 1	Group 2
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
	14
	15
	16
	17
	18
	19
	20
	21
	22
	23
	24
	25
	26
SUM= 91	260
=W1	=W2

$n_1 = 13$
$n_2 = 13$

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$U_1 =$ 0
$U_2 =$ 169

$U = \min\{U1, U_2\} =$ 0

$$\mu_{U_1} = \frac{n_1 n_2}{2} \qquad \sigma^2_{U_1} = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

$\mu_{U_1} =$ 84.5

$\sigma^2_{U_1} =$ 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

$Z =$ -4.333

For $\alpha = 0.01$, $Z = +\text{-}\ 2.575$

Therefore, reject because: $Z < -z_\alpha$

Raw Data- for Floors/Flooring

ni	Group	Inj rate	Group	Inj rate
1	1	58.1	3	437.3
2	1	66.5	3	500.7
3	1	71.7	3	545.7
4	1	75.4	3	586.7
5	1	79.2	3	632.6
6	1	70.6	3	618.4
7	1	71.5	3	609.8
8	1	84.6	3	752.8
9	1	89.0	3	770.2
10	1	96.0	3	761.6
11	1	92.3	3	617.7
12	1	90.4	3	641.7
13	1	93.8	3	667.6

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	1	58.1
2	1	66.5
3	1	70.6
4	1	71.5
5	1	71.7
6	1	75.4
7	1	79.2
8	1	84.6
9	1	89.0
10	1	90.4
11	1	92.3
12	1	93.8
13	1	96.0
14	3	437.3
15	3	500.7
16	3	545.7
17	3	586.7
18	3	609.8
19	3	617.7
20	3	618.4
21	3	632.6
22	3	641.7
23	3	667.6
24	3	752.8
25	3	761.6
26	3	770.2

Ordered Ranks

	Group 1	Group 2
	1	
	2	
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		20
		21
		22
		23
		24
		25
		26
SUM=	91	260
	=W1	=W2

$n_1 = 13$
$n_2 = 13$

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$U_1 =$ 0
$U_2 =$ 169

$U = \min\{U1, U_2\} =$ 0

$$\mu_{U_1} = \frac{n_1 n_2}{2} \qquad \sigma^2_{U_1} = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

$\mu_{U_1} =$ 84.5

$\sigma^2_{U_1} =$ 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

$Z =$ -4.333

For $\alpha = 0.01$, $Z = +- 2.575$

Therefore, reject because: $Z < -z_\alpha$

Raw Data- for Floors/Flooring

ni	Group	Inj rate	Group	Inj rate
1	2	96.5	3	437.3
2	2	113.4	3	500.7
3	2	112.6	3	545.7
4	2	125.9	3	586.7
5	2	130.0	3	632.6
6	2	127.6	3	618.4
7	2	102.2	3	609.8
8	2	126.8	3	752.8
9	2	137.3	3	770.2
10	2	135.2	3	761.6
11	2	115.7	3	617.7
12	2	116.8	3	641.7
13	2	137.2	3	667.6

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	2	96.5
2	2	102.2
3	2	112.6
4	2	113.4
5	2	115.7
6	2	116.8
7	2	125.9
8	2	126.8
9	2	127.6
10	2	130.0
11	2	135.2
12	2	137.2
13	2	137.3
14	3	437.3
15	3	500.7
16	3	545.7
17	3	586.7
18	3	609.8
19	3	617.7
20	3	618.4
21	3	632.6
22	3	641.7
23	3	667.6
24	3	752.8
25	3	761.6
26	3	770.2

Ordered Ranks

	Group 1	Group 2
	1	
	2	
	3	
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		17
		18
		19
		20
		21
		22
		23
		24
		25
		26
SUM=	91	260
	=W1	=W2

$n_1 = 13$
$n_2 = 13$

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$U_1 =$ 0
$U_2 =$ 169

$U = \min\{U1, U_2\} =$ 0

$$\mu_{U_1} = \frac{n_1 n_2}{2} \qquad \sigma^2_{U_1} = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

$\mu_{U_1} =$ 84.5

$\sigma^2_{U_1} =$ 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

$Z =$ -4.333

For $\alpha = 0.01$, $Z = +- 2.575$

Therefore, reject because: $Z < -z_\alpha$

Raw Data- for Stair or Steps

n_i	Group	Inj rate	Group	Inj rate
1	1	213.6	2	172.7
2	1	216.9	2	172.4
3	1	216.7	2	177.2
4	1	222.9	2	171.0
5	1	188.2	2	155.5
6	1	179.9	2	146.3
7	1	175.9	2	148.4
8	1	206.9	2	163.1
9	1	214.0	2	174.1
10	1	234.4	2	186.9
11	1	246.2	2	183.8
12	1	262.7	2	204.5
13	1	265.2	2	215.4

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	2	146.3
2	2	148.4
3	2	155.5
4	2	163.1
5	2	171.0
6	2	172.4
7	2	172.7
8	2	174.1
9	1	175.9
10	2	177.2
11	1	179.9
12	2	183.8
13	2	186.9
14	1	188.2
15	2	204.5
16	1	206.9
17	1	213.6
18	1	214.0
19	2	215.4
20	1	216.7
21	1	216.9
22	1	222.9
23	1	234.4
24	1	246.2
25	1	262.7
26	1	265.2

Ordered Ranks

Group 1	Group 2
	1
	2
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SUM= 246	105
=W1	=W2

$n_1 = 13$
$n_2 = 13$

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$U_1 =$ 155
$U_2 =$ 14

$U = \min\{U1, U_2\} =$ 14

$$\mu_{U_1} = \frac{n_1 n_2}{2} \qquad \sigma^2_{U_1} = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

$\mu_{U_1} =$ 84.5

$\sigma^2_{U_1} =$ 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

$Z =$ -3.615

For $\alpha = 0.01$, $Z = +- 2.575$

Therefore, reject because: $Z < -z_\alpha$

Raw Data- for Stair or Steps

n_i	Group	Inj rate	Group	Inj rate
1	1	213.6	3	261.1
2	1	216.9	3	254.4
3	1	216.7	3	264.9
4	1	222.9	3	271.0
5	1	188.2	3	246.3
6	1	179.9	3	250.9
7	1	175.9	3	218.9
8	1	206.9	3	251.6
9	1	214.0	3	275.6
10	1	234.4	3	256.0
11	1	246.2	3	269.3
12	1	262.7	3	274.1
13	1	265.2	3	294.1

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	1	175.9
2	1	179.9
3	1	188.2
4	1	206.9
5	1	213.6
6	1	214.0
7	1	216.7
8	1	216.9
9	3	218.9
10	1	222.9
11	1	234.4
12	1	246.2
13	3	246.3
14	3	250.9
15	3	251.6
16	3	254.4
17	3	256.0
18	3	261.1
19	1	262.7
20	3	264.9
21	1	265.2
22	3	269.3
23	3	271.0
24	3	274.1
25	3	275.6
26	3	294.1

Ordered Ranks

Group 1	Group 2
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19	
	20
21	
	22
	23
	24
	25
	26
SUM= 109	242
=W_1	=W_2

---

n_1 = 13
n_2 = 13

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

U_1 = 18
U_2 = 151

U = min{U1,U_2}= 18

$$\mu_{U_1} = \frac{n_1 n_2}{2} \qquad \sigma^2_{U_1} = \frac{n_1 n_2 (n_1+n_2+1)}{12}$$

μ_{U_1} = 84.5

$\sigma^2_{U_1}$ = 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

Z = -3.410

For α = 0.01, Z = +- 2.575

Therefore, reject because: $Z < -z_\alpha$

Raw Data- for Stair or Steps

ni	Group	Inj rate	Group	Inj rate
1	2	172.7	3	261.1
2	2	172.4	3	254.4
3	2	177.2	3	264.9
4	2	171.0	3	271.0
5	2	155.5	3	246.3
6	2	146.3	3	250.9
7	2	148.4	3	218.9
8	2	163.1	3	251.6
9	2	174.1	3	275.6
10	2	186.9	3	256.0
11	2	183.8	3	269.3
12	2	204.5	3	274.1
13	2	215.4	3	294.1

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	2	146.3
2	2	148.4
3	2	155.5
4	2	163.1
5	2	171.0
6	2	172.4
7	2	172.7
8	2	174.1
9	2	177.2
10	2	183.8
11	2	186.9
12	2	204.5
13	2	215.4
14	3	218.9
15	3	246.3
16	3	250.9
17	3	251.6
18	3	254.4
19	3	256.0
20	3	261.1
21	3	264.9
22	3	269.3
23	3	271.0
24	3	274.1
25	3	275.6
26	3	294.1

Ordered Ranks

	Group 1	Group 2
	1	
	2	
	3	
	4	
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	8	
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		17
		18
		19
		20
		21
		22
		23
		24
		25
		26
SUM=	91	260
	=W1	=W2

$n_1 = 13$
$n_2 = 13$

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$U_1 =$ 0
$U_2 =$ 169

$U = \min\{U1, U_2\} =$ 0

$$\mu_{U_1} = \frac{n_1 n_2}{2}$$

$$\sigma^2_{U_1} = \frac{n_1 n_2 (n_1+n_2+1)}{12}$$

$\mu_{U_1} =$ 84.5

$\sigma^2_{U_1} =$ 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

$Z =$ -4.333

For $\alpha = 0.01$, $Z = +\text{-}\ 2.575$

Therefore, reject because: $Z < -z_\alpha$

Raw Data- for Bathtub/Shower

ni	Group	Inj rate	Group	Inj rate
1	1	27.5	2	31.2
2	1	27.2	2	29.4
3	1	27.6	2	29.9
4	1	33.0	2	34.4
5	1	27.7	2	25.5
6	1	29.1	2	31.1
7	1	30.5	2	28.4
8	1	39.2	2	37.9
9	1	42.7	2	38.7
10	1	43.8	2	44.3
11	1	48.7	2	46.5
12	1	51.2	2	50.3
13	1	52.0	2	55.4

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	2	25.5
2	1	27.2
3	1	27.5
4	1	27.6
5	1	27.7
6	2	28.4
7	1	29.1
8	2	29.4
9	2	29.9
10	1	30.5
11	2	31.1
12	2	31.2
13	1	33.0
14	2	34.4
15	2	37.9
16	2	38.7
17	1	39.2
18	1	42.7
19	1	43.8
20	2	44.3
21	2	46.5
22	1	48.7
23	2	50.3
24	1	51.2
25	1	52.0
26	2	55.4

Ordered Ranks

Group 1	Group 2
	1
2	
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	23
24	
25	
	26
SUM= 169	182
=W1	=W2

$n_1 = 13$
$n_2 = 13$

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$U_1 =$ 78
$U_2 =$ 91

$U = \min\{U1, U_2\} =$ 78

$$\mu_{U_1} = \frac{n_1 n_2}{2} \qquad \sigma^2_{U_1} = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

$\mu_{U_1} =$ 84.5

$\sigma^2_{U_1} =$ 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

$Z =$ -0.333

For $\alpha = 0.01$, $Z = +- 2.575$

Therefore, do not reject because: $Z > -z_\alpha$

Raw Data- for Bathtub/Shower

ni	Group	Inj rate	Group	Inj rate
1	1	27.5	3	63.6
2	1	27.2	3	67.1
3	1	27.6	3	65.9
4	1	33.0	3	71.7
5	1	27.7	3	70.0
6	1	29.1	3	72.7
7	1	30.5	3	76.0
8	1	39.2	3	90.0
9	1	42.7	3	93.8
10	1	43.8	3	100.0
11	1	48.7	3	90.8
12	1	51.2	3	104.8
13	1	52.0	3	116.3

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	1	27.2
2	1	27.5
3	1	27.6
4	1	27.7
5	1	29.1
6	1	30.5
7	1	33.0
8	1	39.2
9	1	42.7
10	1	43.8
11	1	48.7
12	1	51.2
13	1	52.0
14	3	63.6
15	3	65.9
16	3	67.1
17	3	70.0
18	3	71.7
19	3	72.7
20	3	76.0
21	3	90.0
22	3	90.8
23	3	93.8
24	3	100.0
25	3	104.8
26	3	116.3

Ordered Ranks

Group 1	Group 2
1	
2	
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12	
	13
	14
	15
	16
	17
	18
19	
	20
21	
	22
	23
	24
	25
	26
SUM= 109	242
=W1	=W2

$n_1 = 13$
$n_2 = 13$

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$U_1 =$ 18
$U_2 =$ 151

$U = \min\{U1, U_2\} =$ 18

$$\mu_{U_1} = \frac{n_1 n_2}{2} \qquad \sigma^2_{U_1} = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

$\mu_{U_1} =$ 84.5

$\sigma^2_{U_1} =$ 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

$Z =$ -3.410

For $\alpha = 0.01$, $Z = +- 2.575$

Therefore, reject because: $Z < -z_\alpha$

Raw Data- for Bathtub/Shower

ni	Group	Inj rate	Group	Inj rate
1	2	31.2	3	63.6
2	2	29.4	3	67.1
3	2	29.9	3	65.9
4	2	34.4	3	71.7
5	2	25.5	3	70.0
6	2	31.1	3	72.7
7	2	28.4	3	76.0
8	2	37.9	3	90.0
9	2	38.7	3	93.8
10	2	44.3	3	100.0
11	2	46.5	3	90.8
12	2	50.3	3	104.8
13	2	55.4	3	116.3

Group 1 = Age group 15-44
Group 2 = Age group 45-64
Group 3 = Age group 65+

Ranked Data

N	Group	Inj rate
1	2	25.5
2	2	28.4
3	2	29.4
4	2	29.9
5	2	31.1
6	2	31.2
7	2	34.4
8	2	37.9
9	2	38.7
10	2	44.3
11	2	46.5
12	2	50.3
13	2	55.4
14	3	63.6
15	3	65.9
16	3	67.1
17	3	70.0
18	3	71.7
19	3	72.7
20	3	76.0
21	3	90.0
22	3	90.8
23	3	93.8
24	3	100.0
25	3	104.8
26	3	116.3

Ordered Ranks

	Group 1	Group 2
	1	
	2	
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		16
		17
		18
		19
		20
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		22
		23
		24
		25
		26
SUM=	91	260
	=W1	=W2

$n_1 = 13$
$n_2 = 13$

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

Therefore,

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

$U_1 =$ 0
$U_2 =$ 169

$U = \min\{U1, U_2\} =$ 0

$$\mu_{U_1} = \frac{n_1 n_2}{2} \qquad \sigma^2_{U_1} = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

$\mu_{U_1} =$ 84.5

$\sigma^2_{U_1} =$ 380.25

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

$Z =$ -4.333

For $\alpha = 0.01$, $Z = +- 2.575$

Therefore, reject because: $Z < -z_\alpha$