Effects of Detectable Warnings on Individuals with Mobility Impairments

Helen Lee
Western Michigan University

Follow this and additional works at: https://scholarworks.wmich.edu/dissertations

Part of the Disability and Equity in Education Commons

Recommended Citation
Lee, Helen, "Effects of Detectable Warnings on Individuals with Mobility Impairments" (2007).
Dissertations. 889.
https://scholarworks.wmich.edu/dissertations/889
EFFECTS OF DETECTABLE WARNINGS ON INDIVIDUALS WITH MOBILITY IMPAIRMENTS

by

Helen Lee

A Thesis, Project, or Dissertation [select which]
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Education
Department of Special Education and Literacy Studies
Dr. George Haus, Advisor

Western Michigan University
Kalamazoo, Michigan
April 2007
EFFECTS OF DETECTABLE WARNINGS ON INDIVIDUALS WITH MOBILITY IMPAIRMENTS

Helen Lee, Ed. D.
Western Michigan University, 2007

The Americans with Disabilities Act (ADA) mandates that environmental and architectural barriers, such as curbs, be removed to enable individuals with disabilities to travel about in the community with increased mobility. While installation of ramps benefit individuals with mobility impairments, the absence of curbs results in the loss of information used by individuals with visual impairments for street detection. As a result, truncated domes detectable warning surfaces were developed to alert visually impaired travelers of potential hazards and vehicular pathways. Research to date is limited and inconclusive regarding the impact of detectable warning surfaces on individuals with mobility impairments. Further, no research has been conducted using the most recent ADA accessibility guidelines for truncated domes detectable warning. Twenty-one individuals who use wheelchairs for travel in the built environment were recruited to negotiate ramps installed with detectable warnings in a controlled setting. Participants’ perception of safety and ease of negotiating ramps with and
without detectable warnings were collected on a Likert-type instrument. Additionally, two raters evaluated videotapes of more than half of the participants' performances. MANOVA findings indicate that detectable warning surfaces did not compromise the safety of the participants or adversely affect their ability to traverse the ramps that had been installed with the warning surfaces. In fact, results of this study suggest that truncated domes detectable warnings may be beneficial for individuals who are wheelchair users.
INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.
# TABLE OF CONTENTS

LIST OF TABLES........................................................................................................ vi

LIST OF FIGURES....................................................................................................... vii

STATEMENT OF THE PROBLEM.................................................................................. 1

INTRODUCTION........................................................................................................ 8

Definition of Disability............................................................................................ 8

Legislation and Environmental Barriers................................................................. 10

Mobility Impairments in the United States............................................................ 15

Built Environment and Accessibility...................................................................... 16

  Individuals with Mobility Limitations............................................................... 16

  Ramps................................................................................................................... 20

  Ramp Research.................................................................................................... 23

Universal Design...................................................................................................... 26

  Curb Ramps and Universal Design................................................................. 28

Pedestrians with Visual Impairments..................................................................... 29

  The Modern Intersections................................................................................... 34

Detectable Warning Surfaces................................................................................ 36

  Design Standards............................................................................................... 38

  Early Research on Tactile Surfaces................................................................. 39

  Tactile Surface Research in the 1990s.............................................................. 42
Table of Contents--Continued

Truncated Domes Detectable Warnings ................................................. 44
Detectable Warnings and Travelers with Ambulatory Impairments................................. 47
Detectable Warnings Research and Individuals with Mobility Impairments ........................ 50
New Design Guidelines ...................................................................... 56
PURPOSE AND RESEARCH QUESTIONS ..................................................... 59
RESEARCH METHODOLOGY ..................................................................... 60
Test Site Installation ................................................................................ 60
Materials ....................................................................................................... 61
Participants .................................................................................................. 62
Measures for Subjective Responses ......................................................... 64
Measures for Objective Responses .......................................................... 65
Procedure ..................................................................................................... 66
RESULTS ............................................................................................................. 69
Section One ................................................................................................ 69
Participant Data Analysis ................................................................... 69
MANOVA for Participant Data.............................................................. 70
Univariate Analysis for Participant Data ........................................... 73
Participants Preference for Ramp Treatment .....................................73
Research Question One: Difference in Negotiability of Ramps ..........74
Table of Contents—Continued

Research Question Two: Safety Concerns ................................. 78
Section Two ........................................................................ 78
Rater Data Analysis ............................................................... 78
Inter-rater Agreement ............................................................. 79
MANOVA Analysis of Rater Data .............................................. 80
Univariate Analysis of Rater Data .............................................. 81
Research Question One: Difference in Observed Negotiability of Ramps ............................................ 82
Research Question Two: Observed Safety ............................. 83

DISCUSSION ............................................................................. 84
Subjective and Objective Data Comparison .............................. 84
Current Findings and Previous Research .................................. 86
Limitations of the Study ......................................................... 87
Future Research ................................................................. 89

REFERENCES .............................................................................. 93

APPENDICES

A. Recruitment Flyer .............................................................. 107
B. Screening Script ............................................................... 109
C. Participant Attributes ......................................................... 112
D. Participant Data Form ......................................................... 114
E. Rater Data Form ............................................................... 116

iv

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
F. Approved Letter From the Human Subjects
   Institutional Review Board Approval........................................ 118
LIST OF TABLES

1. Environmental barriers which impede mobility in urban areas, in rank order ........................................... 21
2. The principles of Universal Design .............................................................................................................. 28
3. Descriptive statistics for upward ramp travel .............................................................................................. 71
4. Descriptive statistics for downward ramp travel .......................................................................................... 72
5. Total for participants ranking of ramp by preference ...................................................................................... 74
6. Descriptive statistics by raters for upward travel .......................................................................................... 75
7. Descriptive statistics by raters for downward ramp travel ............................................................................. 76
LIST OF FIGURES

1. ADAAG specifications for truncated domes size, inter-dome spacing, and pattern for alignment .............................................. 5
2. Curb ramp layout designs ............................................................................ 33
3. Truncated dome detectable warning applied to curb ramp .......................................................... 51
4. Detectable warning surface applied to bottom 2 ft. of ramp .......................................................... 57
5. Diagram of ramp layout constructed at test site .............................................. 60
6. Mean traction for manual chair users .......................................................... 77
7. Mean traction for power chair users .......................................................... 77
8. Factors ramp X direction interaction for the measure “effort” ........................... 81
STATEMENT OF THE PROBLEM

Medical advances, technological innovations, and more favorable attitudes will likely result in increased numbers of persons with mobility impairments who will travel about in the community and public roadways. The Architectural Barriers Act and the Rehabilitation Act of 1973 are key legislation ensuring access to public facilities and public right-of-ways by all persons, including those who have disabilities. Physical barriers that prevent individuals with disabilities access to public facilities are prohibited by law. The Americans with Disabilities Act (ADA) extended accessibility compliance to private industries and prohibits discriminatory practice toward individuals with disabilities. Due to these legislative pieces, environmental and architectural barriers are being removed to enable individuals with disabilities to move about in the community with increased mobility. The curb ramp is perhaps the most common example of accessible design.

The change from the perception of disability as a physical anomaly that prohibits individuals from participating in daily activities toward a definition that limitations experienced by individuals are imposed by social and environmental barriers has also contributed to the redesigning of our built environment. The paradigm shifts the responsibility of accommodation from individual to community. The basic concept of “universal design” is that the built environment should accommodate a wide spectrum of potential users (Stratton, 2001). The
design of buildings, sidewalks, roadways, and vehicles can greatly impact the 
mobility of individuals and their ability to access community services and events. 
Universal design can be cost effective and benefit individuals across age and 
abilities. Ramps, for example, were designed for individuals who use 
wheelchairs but are beneficial for people with shopping carts, parents with 
strollers, bicyclists, and workers with utility carts.

While installation of ramps benefit individuals with mobility impairments, 
the absence of curbs results in the loss of information used by individuals with 
visual impairments for street detection (Barlow & Bentzen, 1994; Hauger, 
Safewright, Rigby & McAuley, 1996). Consequently, pedestrians with visual 
impairments experience difficulty in locating the boundary between the sidewalk 
and road; particularly when the slope of the ramp is gradual. Detectable 
warnings were developed to alert visually impaired travelers of potential hazards 
and vehicular pathways. A detectable warning is “A standardized surface feature 
built in or applied to walking surfaces or other elements to warn people who are 
blind or visually impaired of specified hazards.” (Final Report Public Rights-of-
Way Access Advisory Committee, 2001, p.5). The only surface that has 
repeatedly been demonstrated to be detectable to most pedestrians with visual 
impairments is the truncated dome detectable warning surface. The vast 
majority of research in detectable warning surfaces, as one can expect, focused 
on its effects on individuals with visual impairments. Research to date is limited 
and findings are inconclusive regarding the impact of detectable warnings on the 
safe travel of individuals with mobility impairments.
Detectable warning surfaces have been used in Japan since the 1960's and in the United Kingdom since the 1980's to alert pedestrians with visual impairments of hazards or upcoming a vehicular way (Bentzen, 2000; Bentzen, Barlow, & Tabor, 2000). Detectable warning surfaces are commonly found in other countries such as Australia, New Zealand, Germany, France and Italy. The earliest product produced in the U.S. was designed after the surfaces that had been in use in Japan since the 1960s (Bentzen et al., 2000; McGean, 1991). The terms "detectable warning" and "truncated dome detectable warnings" are used to describe the domed pattern of the walking surface as specified in ADA accessibility guidelines (ADAAG 4.29.2.).

Investigation in the use of detectable warning surfaces began in the United States in the 1980's. Research initially focused on identifying surface materials and textures for walking surfaces that would be highly detectable to travelers with visual impairments. The United States Access Board published the ADA Accessibility Guidelines (ADAAG) in 1991, which were then adopted by the Department of Justice (DOJ) as the ADA Standard for Accessible Design. These standards are enforceable by law. The Access Board (U.S. Department of Transportation, 2006), having commissioned a number of studies, states that the truncated dome is the most reliable surface for detection by cane and underfoot. The Access Board goes on to state that, based on research findings, other designs such as grooves, striations, and exposed aggregate should not be considered for use because of their similarity to other surface textures in the built environment. The current standards for the dimensions and pattern of detectable
warnings are based on research conducted in the late 1980s and subsequently required by the ADA to be installed at all transit stations (Peck & Bentzen, 1987; Mitchell, 1987; Weule, 1986).

Truncated domes detectable warning surfaces have been found to be the most highly detectable surface for pedestrians who are blind or visually impaired (Bentzen, Nolin, Easton, Desmarais, & Mitchell, 1994; Hauger, Rigby, Safewright, & Mcauley, 1996). ADAAG originally required truncated domes detectable warnings on the full surface of curb-ramps, excluding the flares. It was also acceptable, according to the original ADAAG guidelines, for the truncated domes to be arranged in either a diagonal or parallel configuration aligned to direction of travel (ADAAG 4.29.2). Figure 1 shows overhead views of truncated domes in each array. The drawing to the left illustrates the domes arranged diagonal to the direction of travel. In second drawing to the right, the same array has been rotated 45 degrees so that the domes are parallel with or perpendicular to the direction of travel. The spacing between any two adjacent domes, center-to-center is 2.35" (60 mm). The ADA guidelines also specify that the domes have a base of 0.9" (23 mm) and a height of 0.2" (5mm) and must visually contrast with adjoining surfaces.

Truncated domes are more commonly installed using the diagonal configuration (Bentzen, Barlow, & Tabor, 2000). Research relating to detectable warnings and their impact on persons with mobility impairments were conducted using this original criterion (Bentzen, et al., 1994; Hauger, et al., 1996).
However, to minimize potential problems for people who use wheelchairs and other ambulatory devices and to provide consistent information for travelers with visual impairments, Bentzen & Barlow (1995) recommended that truncated domes be installed along the bottom 24-inch depth of curb ramps instead of the whole ramp surface. The researchers stated this would allow sufficient information to travelers with visual impairments and reduce the amount of textured surface that must be negotiated by individuals using ambulatory aids. The Public Rights-of-Way Access Advisory Committee (PROWAAC, 2001) and the American Council of the Blind (ACB, 2004) has endorsed this recommendation. It is also consistent with the ADAAG requirement for the use of truncated domes detectable warning at transit platforms (Bentzen, Barlow, & Tabor, 2000). PROWAAC (2001) suggested the following accommodation for persons with mobility impairments: (a) domes of detectable warning surfaces are to be aligned in the direction of the ramp slope, and (b) detectable warnings need only cover 24 inches of the ramp following the curb line. The committee also

Figure 1. ADAAG specifications for truncated domes size, inter-dome spacing, and pattern for alignment.
recommended that the requirements for dome size and spacing be more flexible. The new guidelines allow a range for base diameter measurements of 0.9 inches minimum to 1.4 inches maximum with dome height of 0.2 inches. Inter-dome spacing (center-to-center) can vary from 1.6 inches minimum to a maximum spacing of 2.4 inches. These new standards have not been tested; no empirical evidence has been collected on the effects of these guidelines on the negotiability of ramps by persons with mobility impairments.

Existing literature suggest that truncated domes detectable warnings did not have adverse impact on wheelchair negotiability on ramps. Bentzen, et al. (1994) examined a comparison of various types of truncated dome surfaces on test ramps by individuals using various mobility aids. It was not conclusive whether dome spacing or alignment pattern specifically impacted on the performance individuals who negotiated the ramps using wheelchairs. Hauger et al. (1996) conducted research in the actual environment. Findings from this research indicated that the majority of the 30 participants with mobility impairments did not report negative effects in negotiating the ramps with detectable warnings. Despite the findings, 26% of the participants preferred curb ramps without detectable warnings. Both of these studies involved the use of detectable warning surfaces installed under the old guidelines; the whole ramp area was covered with truncated domes. The most recent ADAAG guidelines recommend truncated domes be aligned in a square array and limited to the bottom 2 feet of the curb ramp. It also provides more flexibility for inter-dome spacing and dome diameter (Access Board, 2004). This research will add
additional data to the existing body of knowledge regarding the effects of detectable warnings on pedestrians who have mobility impairments. Data from this study will also be important since no data exists for the effects of detectable warnings on this target population when installed under the new ADAAG guidelines.
INTRODUCTION

In recent years, the built environment has been the focus within the disability movement (Hahn, 2002). The "built environment" refers to the established ways that our architectural dwellings (e.g., dimensions of our furnishings, doorways, and closets) are designed as well as the passage space to and from places in the external environment (Philip, 1983). One current perspective on disability considers individual limitations are posed by the design of the built environment and the interaction of individuals within it. The disability movement during the last two decades has been the catalyst for legislative changes resulting in efforts to change the built environment to better accommodate individuals with disabilities. This section will present current perspectives on disability definitions, environmental barriers to individuals with mobility limitations, legislation that has resulted in the removal of barriers in the built environment and the impact these changes have on individuals with mobility limitations. Issues relating specifically to public-right-of-ways and individuals with mobility limitations will be examined through existing research literature.

Definition of Disability

Disability concerns were originally the domain of the health sciences having a clinical orientation. The medical and rehabilitation based perspectives focused on disability as an individual limitation that prevented the individual from performing activities of daily living (Scotch, 2002). Resulting interventions were focused on improving the individual's function by facilitating the individuals' ability
to accommodate to the impairment and adapt to the environment. The World Health Organization (WHO) published an international classification system that utilized the medical/functional concepts associated with impairment (WHO, 1980). The initial version of the International Classification of Impairment, Disability, and Handicap (ICIDH) organized disabilities into three categories. “Impairment” refers to “any loss or abnormality” of physiological or psychological function, “disability” refers to the limitations in performing activities, and “handicap” is the disadvantage imposed by the disability preventing one from assuming a “normal” role in his/her community.

This model was met unfavorably by individuals with disabilities and advocacy groups. The medical model did not take into account social and environmental factors that contributed to the limitations experienced by individuals and seemed to focus on the impairment rather than the whole individual. Also, changes in how disability is conceptualized in western cultures occurred at least ten years prior to the development of the ICIDH. The focus had shifted from the individual’s impairment as an anomaly that interfered with activities of living to the individual’s interaction with the environment.

This new perspective, referred to as the “minority group” or “socio-political” model, posed the notion that external factors contributed to the limitations experienced by individuals with disabilities (Barnes, 2003; Scotch, 2002). The environment was no longer considered static, but changeable to accommodate individuals. This new paradigm provided momentum toward the independent living and disability rights movements of the 1970s and 1980s. Taking a civil
rights approach, the opportunity to lead an independent life and access community resources is considered a fundamental human right. Environmental barriers preventing individuals with disabilities from attaining full participation in their communities are in violation of these rights (Unger, 1997). Examination of environmental factors imposing functional limitations on individuals began to shape public policies, increased public tolerance toward diversity, and is transforming the urban landscape (Blanck, 2000; Hahn, 2002).

This new paradigm is reflected in WHO’s latest effort to redefine disability. The International Classification of Functioning (ICF), formerly known as ICIDH2 (WHO, 2002) attempts to reconcile the traditional individual based medical model and the socio-political model of disability. The constructs “impairment”, “disability” and “handicap” are referred to in the ICF as “body function and structure”, “activity”, and “participation”. Importantly, the new headings for the classification system acknowledge the inter-relationship of individuals and their social and physical environments in defining disabilities. Service providers and professionals who plan and design our environment are reexamining their roles and basic values regarding how disabilities have been viewed in the past and the necessity to engage in the disability rights movement (Zola, 2005).

Legislation and Environmental Barriers

Historically, people with disabilities were often excluded from community settings and generally not expected to participate in community living or activities (Barnes, 1997). The increased visibility of persons with disabilities in the
community can be attributed to medical advances, more favorable public attitudes, and technological innovations. Medical advances have improved the chances of survival from trauma while improved health care has contributed to longer lifespan. Public attitude toward disabilities has changed through education and media portrayal of characters with disabilities (Kolucki, 2006). The view of disability in western cultures has changed whereby disabilities are now viewed as a universal characteristic of humans. Disability is considered an experience that could affect any given individual in a population (Bickenbach, Chatterji, Badley, & Usteun, 1999).

Technological innovations have improved the mobility of individuals with functional limitations through improved wheelchair designs, accessible mass transit vehicles and barrier-free designs of public spaces. Inclusion of individuals with disabilities into the mainstream of social and economic life has been a major issue for policy makers since the 1960's. Disability issues are no longer considered central to the individual and his/her impairment (Barnes & Mercer, 2003). The core basis of the “minority group” model is the recognition that all aspects of the external world are shaped by public policy and that policies reflect pervasive cultural values and attitudes. Our human environment, including architecture and public-right-of ways, is a product of these public policies (Hahn, 2002).

The earliest piece of legislation concerning the built environment appeared in 1965 when Congress authorized the formation of the United States Commission on Architectural Barriers to study the extent of architectural barriers
with follow-up recommendations for eliminating such obstructions in future construction. The final report resulted in the passage of the Architectural Barriers Act (ABA) in 1968. The intent of this legislation was to ensure that buildings constructed with federal dollars would be accessible to individuals with disabilities. The Department of Health, Education, and Welfare and the American National Standards Institute (ANSI) also adopted this legislation for new and remodeled buildings. ANSI, a non-governmental organization, sets a variety of industry standards, including barrier free design requirements. The organization is an association of individuals with disabilities, rehabilitation professionals, design professionals, builders and manufacturers. Its accessibility standards are generally accepted by the private sector and recommended for use in state and local building codes. The Uniform Federal Accessibility Standards (UFAS) follows the ANSI format and attempts to maintain uniformity between the federal requirements and those commonly followed by state and local governments (Access Board, 2006a). Examples of facilities covered under this law include post offices, social service offices, and national parks. Public institutions such as schools, public housing, and mass transit systems are also covered under the ABA.

The Architectural and Transportation Barriers Compliance Board (ATBCB) was created under the Rehabilitation Act of 1973 to monitor federally funded construction projects for compliance with the accessibility standards. The ATBCB, now called the Access Board, is empowered to investigate, hold public hearings and issue orders for compliance with accessibility standards and, if
necessary, withhold funds for construction. It is also significant to note that barrier removal was no longer specific to architectural structures. Street, sidewalk, and shared-use path construction that are funded wholly or in part with federal funds were also subject to the Architectural Barriers Act of 1968 and the Rehabilitation Act of 1973. The Access Board maintains and updates the guidelines for barrier free design. These standards are used to enforce the law under the Department of Transportation (DOT) and the Department of Justice (DOJ).

Congress added tax incentives for businesses in the private sectors with the Tax Reform Act in 1978. This piece of legislation granted tax deductions for private business owners who were willing to eliminate barriers to individuals with disabilities. Efforts to improve the accessibility of public sidewalks and roadways for pedestrians and non-motorists continued with passage of the Transportation Equity Act for the 21st Century (TEA-21) (United States Department of Transportation, 1998). Section 1202 of TEA-21 requires that the safety of bicyclists and pedestrians, including pedestrians with disabilities, be considered during the development of comprehensive transportation plans by state and local planning organization. This section also encompasses pedestrian walkways in conjunction with all new construction and reconstruction of transportation facilities. Similar to the Tax Relief Act, the TEA-21 is not a mandate. Its provisions are merely authorizations for federal matching funds.

The evolution of disability rights has resulted in unprecedented level of opportunities and services for over 50 million Americans with disabilities. The
impact of the disability rights movement on public policy was evident when the American with Disabilities Act (ADA) was signed into law in 1990. The ADA is considered by some to be the most comprehensive federal civil rights law prohibiting discrimination against individuals with disabilities in all aspects of their lives (Baldwin, 2000; Blanck, 2000). The ADA (1990) was landmark in that private sectors in the community were now held accountable for compliance with accessibility guidelines. The U.S. Access Board published the Americans with Disability Act Accessibility Guidelines (ADAAG) in 1991. These guidelines were adopted by the DOJ as the ADA Standards for Accessible Design and are enforceable by law. ADAAG differs from ANSI because it contains scoping requirements and exceeds minimum requirement standards. ADAAG provide specifications as to the number of and under what circumstances accessibility features must be incorporated. The mandates under this law extend to state and local governments as well as private industries in the public sectors regardless of funding source. Under Title III of the ADA, new or remodeled architectural constructions, pedestrian facilities, and public-right-of-ways are required to be designed in a manner that addresses accessibility for all segments of the population. A renewed emphasis was placed on architectural and environmental design. This trend has evolved into a philosophical framework with established criteria influencing designers, architects, engineers, and community planning professionals. This new philosophy, Universal Design, will be addressed later in this paper.
Mobility Impairment in the United States

Although no single data source directly assesses the prevalence of mobility impairments in the United States, several statistical sources can be used to define disability in terms of activity or functional limitations. The U.S Bureau of Census collects information through the periodic Survey of Income and Program Participation (SIPP) and defines disabilities in terms of sensory and physical activities. According to the U.S. Census Bureau (2002) 52.6 million Americans, nearly 20 percent of our population, have a disability. Of these, 25 million individuals over 15 years of age reported ambulatory disabilities, defined as having difficulty walking, climbing stairs, or use of ambulatory aid. The National Center for Health Statistics (NCHS) collects data through examination of vital and medical records. The NCHS also collects information through periodic surveys such as the Assistive Devices Supplement to the National Health Interview Survey (NHIS). The NHIS provides, perhaps, the most accurate estimate for the prevalence of mobility impairment in the U.S. population (Jones & Stanford, 1996). The Supplement inquires whether individuals used various assistive devices (i.e., canes, wheelchairs, etc.) and if home modifications were made to accommodate impairments such as mobility. The data makes it possible to determine which respondents experience mobility related impairments. The last conducted survey showed that use of assistive devices has increased significantly over the past decade (NCHS, 1997). Significantly, findings indicate more people used assistive devices to compensate for mobility impairments than any other type of general impairments. It was estimated that as many as 8.6
million individuals used mobility devices for mobility. Of these were a reported 2.2 million individuals over the age of 15 who used wheelchairs (McNeil, 1997). The data also reveal that the number of individuals using wheelchairs has doubled from 1991 to 1997. Due to decreasing mortality rates for a variety of disabling illnesses and the population trend for aging, the increase in the number of individuals with mobility impairments is likely. It can be expected that the number of individuals using wheelchairs or assistive walking devices will continue to increase over the next 20 years (Cooper & Cooper, 2003; Jones & Stanford, 1996).

Built Environment and Accessibility

Individuals with Mobility Limitations

Physical barriers can limit access by individuals with disabilities to public buildings, sidewalks, and transportation systems. Assistive mobility devices such as wheelchairs alleviate the impact of mobility limitations for many individuals and enable them to negotiate the built environment and participate in community affairs. Although mobility device users comprise only a small part of the population with disabilities, they have played a major role in the disability rights movement (LaPlante, 2003, Woods & Watson, 2002). Mobility devices are visible signs of disabilities and have, in themselves, become the symbols of disability. The stylized wheelchair and user icon denotes when a facility is "handicapped accessible". It is also associated with the familiar blue and white signage and accompanying blue lines that reserve parking spaces for individuals.
with mobility related disabilities. Woods & Watson (2003) assert that development of the modern wheelchair was slowed because socio-political conditions "needed to be in place before those innovations became meaningful" (p. 178). The shift in the disability paradigm may have provided impetus for changes in the areas of wheelchair technologies and rehabilitation practices. Wheelchairs in the early 1900's were referred to as "invalid chairs". These chairs were very cumbersome and typically required that the individual in the chair be pushed from behind by an attendant. The wheelchair "passenger" was viewed a victim of unfortunate events and, having lost mobility, found it necessary to rely on another for his or her ambulatory needs (Woods & Watson, 2002). By the late 1970s, new wheelchair technologies offered individuals with mobility impairments greater freedom in navigating their surroundings. Improvements in the design of the manual wheelchair and the increased availability of powered chairs have made it possible for users to exercise personal control over their movement within the built environment. The resulting image of the wheelchair user is transformed from one of dependence to one of able-ness and self-reliance. The International Standards Organization (ISO) for wheelchair standards was in place by the early 1990s. Federal funding opportunities through agencies such as National Institute on Disability and Rehabilitation Research NIDRR, the Access Board, and the U.S. Department of Education have contributed toward the research and development of assistive technologies, including wheeled mobility aids and rehabilitation practices. The field of anthropometry refers to the study of the dimensions and abilities of the human body (human factors) within the built
environment. In the last decade, much activity has been undertaken in anthropometric research of individuals with disabilities. One purpose of these studies is to better understand how the design of the built environment affects the functioning of individuals (Access Board, 1997; Rehabilitation Engineering Research Center, 2001). The anthropometry of wheeled mobility includes human factors such as reaching abilities, maneuvering, and other aspects of space as experienced from the mobility device (Center for Inclusive Design and Environmental Access, 2006). The increased availability of wheelchairs with improved propulsion technologies has afforded more than two million individuals in the United States greater mobility and independence.

All wheelchairs are not alike. Wheelchairs come in an array of designs and can be manual or powered. Manual chairs can be designed for specific environments, individual needs, or specialized for such use as wheelchair sporting events. The wheel diameter, axle length, suspension and vertical axis of the wheels (camber) can affect a chair’s maneuverability, rolling resistance, stability, and performance (Trudel, Kirby, & Bell, 1995). Variations in the design and performance of manual chairs affect both the comfort and efficiency of the user depending on his or hers specific mobility needs (Cooper & Cooper, 2004). Powered mobility aids can be designed for indoor or outdoor use and classified as rear wheel drive, mid wheel drive, or front wheel drive. The drive systems are determined by the location of the drive wheel location and define the handling characteristics of any powered chair. Chairs designed with a mid wheel drive system allow for increased maneuverability in tight spaces but can be
problematic when negotiating a curb cut where the front and rear casters can get caught leaving less traction on the middle drive wheels. Similarly, front drive systems offer the user good stability and maneuvers well in tight spaces but may be difficult to drive in a straight line on uneven surfaces. Efficiency in the use of mobility devices is dependent upon the users’ skills as well as the accessibility of the environments that will be negotiated.

The most obvious type of barrier for individuals ambulating by wheelchair is when any object or feature in the environment restricts the movement of the individual and their chair. Examples of barriers encountered by persons in wheelchairs include alternate building access located away from main entrances, counter heights that have been designed for standing adults, narrow doors, and location of fixtures or control buttons that are positioned out of reach. Physical barriers experienced by this population in the outdoor environment include curbs, uneven or rough surfaces, narrow paths, and steep gradients (Crum & Foote, 1996; Unger, 1999). These barriers, when encountered by individuals using wheeled mobility devices result in an expenditure of more energy through direct encounter, or indirectly when the barriers cause individuals to double back and take an alternate route. Additionally, uneven surfaces can cause wheeled mobility devices to become unstable compromising the safety of the traveler. Matthews & Vujakovic (1995) administered a survey to individuals who ambulated by wheelchair asking them to identify the most common environmental barriers encountered in their community. A summary of their findings is presented in Table 1. It is interesting to note that the survey
participants considered the most problematic barriers related to elevation changes and surface textures. Although no similar research has been conducted since, new research activities concerning barriers encountered in the community by wheelchair users are currently underway through NIDRR funding (RERC, 2006).

Ramps

Both ADAAG and UFAS provide specific information on dimension, materials and details for new construction and alterations in the built environment. In 1994, the U.S. Access Board published four additional sections of ADAAG, including the public-right-of-way guidelines. Title II of the ADA specifies that new and altered streets with sidewalks must contain curb ramps and that existing pedestrian routes should be retrofitted with curb ramps (Access Board, 1999). A ramp is defined as a walking surface with a slope greater than and including 1:20 (5 percent). The 1:20 ratio indicates an increase in elevation or rise of one inch for every 20 inches of running slope defined as parallel to the direction of travel. Although the intended beneficiaries of this accessibility design were wheelchair users, individuals pushing shopping carts, strollers, utility carts, and those riding bicycles or skateboards represent another segment of the population who benefit from this environmental feature. In the only comparison study to date, Couch (1992) investigated the preference of shoppers in an urban shopping mall in negotiating elevation changes; stairs versus ramps. The researcher found, after 3,354 observations, 65.5 percent of the shoppers chose
to use the ramps rather than stairs when entering and leaving a department store. Mothers with strollers and young children represented the majority of the users, followed by individuals with disabilities (temporary or permanent), elderly individuals, and workman using utility carts. Couch argues that provision of

Table 1:
*Environmental barriers which impede mobility in urban areas, in rank order.*

<table>
<thead>
<tr>
<th>RANK</th>
<th>BARRIER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High curbs and/or lack of dropped curbs</td>
</tr>
<tr>
<td>2</td>
<td>Steep gradients or ramps</td>
</tr>
<tr>
<td>3</td>
<td>Uneven paving slabs</td>
</tr>
<tr>
<td>4</td>
<td>Rough or cobbled surfaces</td>
</tr>
<tr>
<td>5</td>
<td>Slippery surfaces</td>
</tr>
<tr>
<td>6</td>
<td>Narrow pavements</td>
</tr>
<tr>
<td>7</td>
<td>Street furniture poorly placed, restricting access</td>
</tr>
<tr>
<td>8</td>
<td>Congested pavements</td>
</tr>
<tr>
<td>9</td>
<td>Steps without adjacent ramp</td>
</tr>
<tr>
<td>10</td>
<td>Dropped curbs on roads not adjacent to each other</td>
</tr>
<tr>
<td>11</td>
<td>Difficult camber on pavement</td>
</tr>
<tr>
<td>12</td>
<td>Deep gutters along roadside, impeding crossing</td>
</tr>
<tr>
<td>13</td>
<td>Busy roads</td>
</tr>
<tr>
<td>14</td>
<td>Lack of resting places on slopes and ramps</td>
</tr>
<tr>
<td>15</td>
<td>Handrails not provided on ramps</td>
</tr>
<tr>
<td>16</td>
<td>Insufficient designated road-crossing places</td>
</tr>
<tr>
<td>17</td>
<td>Drains near to dropped curbs</td>
</tr>
<tr>
<td>18</td>
<td>Cars parked adjacent to dropped curbs</td>
</tr>
<tr>
<td>19</td>
<td>Raised manhole covers at road-crossing points</td>
</tr>
<tr>
<td>20</td>
<td>Poor pathway maintenance leading to problems of fouling by dogs and litter</td>
</tr>
</tbody>
</table>

Note: categories 1-8 were mentioned by more than 50% of respondents

ramps not only address accessibility issues, but can result in greater customer satisfaction of businesses providing such access.

The curb ramp is perhaps one of the most common examples of accessible design and may be the most important design consideration for individuals who utilize wheelchairs (University of North Carolina Highway Safety Research Center, 1999). A curb ramp is a feature in the built environment connecting the curb with a landing area to address a change from street level. This provides street and sidewalk access to pedestrians who utilize wheelchairs or other ambulatory devices (Kirschbaum, Axelsson, Longmuir, Mispagel, Stein, & Yamada, 2001). Feature characteristics of curb ramps include ramp grade, cross slope, ramp length and width. ADAAG permits a maximum curb ramp slope of 8.33 percent or a maximum rise of one inch per 12 inch of running slope (1:12). The length of the curb ramp is determined by the difference in elevation between the street and the sidewalk. The greater the difference, the longer the ramp needs to be in order to meet the recommended grade specification. A standard curb height of 6 inches results in an overall ramp length of 6 feet. Sidewalks and roadways are designed in such a way to provide drainage when water is present (i.e. rainfall). A “cross slope” refers to the tilt of the surface in directions other than the line of travel. The ADA and associated ADAAG clearly specify that cross slopes should not exceed 2 percent (1:48) at all points along an accessible route. Curb ramps typically have both a running slope and a cross-slope. The recommended width for curb ramp and landing areas is 48 inches to allow for adequate space needed for travel by individuals using wheelchairs and other
ambulatory devices. The landing is a level area allowing users to maneuver on and off the curb ramp and onto the path of travel within pedestrian zone.

Ramp Research

Studies dating from the late 1980s and 1990s focused on wheelchair design and/or the development of methodologies to quantify energy expenditure by wheelchair users under various conditions (Asato, Cooper, & Robertson, 1993; Brubaker, 1986; Capozzo, Felici, Figura, Marchetti, & Ricci, 1991a; Richter, Smith, Chizinsky, Chesney, & Axelson, 1998). Research on the effects of slope dimensions on wheelchair stability and energy expenditure provided basis for the current accessibility guidelines. Recommended gradients varied in the research literature. This was likely due to the wide variety of impairments represented, wide age range and abilities (Sanford, 1996). Despite the differences among the researchers considering the optimal ramp dimensions, there was overall consensus among the researchers on the major codes and standards. In general, individuals with mobility limitations expend significantly more energy when negotiating steep grades in comparison to gradual inclines (Canale, Felici, Marchetti, & Ricci, 1991b; Chesney & Axelson, 1996; Sanford, Arch, Story & Jones, 1996). Perhaps the most recent and comprehensive research concerning ramp standards, Sanford (1996) evaluated 171 participants selected to match the general population of mobility device users. Participant performance was measured on a 30 foot slopes with grades ranging from 1:14 to 1:8. Sanford concluded that although most of the participants were able to negotiate slopes
steeper than the current 1:12 standard, no changes were recommended. The research noted several limitations. Sanford stated that the participants might not have been representative of the general population since only individuals who were in good health were allowed to participant. Secondly, the participants that experienced the most difficulty, women over the age of 65, represent the largest numbers of individuals using ambulatory aids. Lastly, research was conducted indoors using a 30-foot aluminum ramp. Outdoor factors, such as inclement weather conditions, cement or asphalt surface conditions, and cross slopes could affect performance outcomes.

The Access Board (1998) considers “excessive” cross slopes the greatest barrier to individuals with mobility impairment. The Access Board literature also cautions that loss of balance or slippage on cross slopes would project the individual toward the street. Chesney and Axelson (1996) and Kockelman, Heard, Kweon and Rioux (2002) found that cross slopes of 2 degree required 30 percent more effort by individuals with mobility impairments than for a level surface. Kockelman et al. (2002) argue that the current ADA cross slope maximum design standard of 2 percent too conservative and found that individuals with mobility impairments are able to negotiate cross slopes greater than 6 percent. The researchers did note when the running slope is 5 percent or more, the maximum cross slope should be limited to 5 percent. They also suggested that evaluation of cross slopes must be evaluated with other factors such as the length of the sidewalk section and user characteristics. The researchers found increases in cross slope, primary slope, and distance traveled...
exacerbated the discomfort experienced by the participants. Of the 67 participants representing a diverse range of mobility limitations, including blindness, wheelchair users and those using canes and crutches perceived the most difficulty with cross sloping. These findings are consistent with those of Sanford’s study whose data identified wheelchair users as the group most significantly affected by slope gradients.

Although no research specifically addressing the effects of curb ramps on individuals with ambulatory impairments has been conducted to date, inferences may be drawn from previous research. While much of the research concerning ramp slopes examined the participant’s ability to traverse distances of 30 feet or more, simulating sidewalks or building entrances, findings verify energy expenditure is greater with steeper slopes. Running slopes combined with cross slopes also increases physical effort. Canale et al. (1991) observed 140 wheelchair users negotiate two different ramp inclines. The research findings suggest a maximum incline of 15 percent for a 1 meter (3.28 feet) running slope and a 10 percent maximum slope for a running slope of 3 meters (9.84 feet). The researchers did not include the cross slope variable. A curb ramp based on ADAAG standards for a 6-inch elevation, a standard curb height, would result in an 8.33 percent incline for a 6 feet running slope. When one factors in the 2 percent cross slope requirement, ADAAG standards seem to closely fit those suggested by Canale et al.
Universal Design

The ability to receive education, find housing, attend religious institutions, shop, and secure employment is made possible by our built environment. For nearly 200 years, our built environment consisting of schools, shopping and business districts, restaurants, theaters, public transit systems and public pathways have all been designed with able-bodied persons in mind (Peterson, 1998; Schriner & Scotch, 2001; Unger, 1999). Disability results when the environment in which the individual must function is designed to accommodate only a limited range of human characteristics. Failure to consider the diverse needs of all persons in community planning results in increased costs from retrofitting existing environments for “special needs users” and by fostering dependence on governmental services (Mace, 1998; Zola, 2005). Universal design advocates argue that inaccessible environments result from the unintentional lack of attention to the needs of individuals with disabilities.

Universal design is a term that was coined by architect Ron Mace in 1990. The concept of universal design proposes that careful planning of the environment and product design can address the needs of all individuals regardless of abilities (Mace, 1998). The focus is, therefore, no longer on individual limitations. Instead, it is considered a process that reflects consumer market issues. The new paradigm invites engineers, architects, product designers as well as other service providers to address the notion of an environment that is accessible to all without specialized design that may be stigmatizing or expensive. The universal design principles do not target the
needs of individuals with disabilities, but attempts to accommodate the needs of the greatest number of people (Stratton, 2001). Application of these seven principles (see Table 2) will likely benefit most individuals who share the same environment, including those with disabilities. In general when products, systems, or environments are made more accessible to persons with limitations, they are usually easier for non-disabled persons. Benefits that may be realized through these design principles include improved performance and efficiency, enhanced comfort, fewer errors, and minimal fatigue.

Equal access to built environments underscores the global commitment toward equalizing opportunities for individuals with disabilities (Metts, 2000). Adhering to universal design principles provides the type of environment that welcomes all individuals, including those with special needs, into the mainstream of a society designed with consideration to functional aesthetics, ingenuity, and commonality of purpose. This approach exceeds the minimum requirements of accessibility laws. Eliminating barriers through inclusive designing generate direct costs to society through the reductions of dollars spent by entitlement programs and through the increased productivity and economic contribution to society (Mace, 1998; Zola, 2005). Evidence that universal design principles are having impact on the design of the built environment can be seen in our urban landscape and through the availability of numerous publications, and informational websites.

The Center for Universal Design was created in 1989 under a grant from the National Institute on Disability and Rehabilitation Research (NIDRR). The center operates the Rehabilitation Engineering Research Center (RERC) on Universal
Design and the Built Environment with the purpose of improving the accessibility and usability of the built environment (The Center for Universal Design, 2006; National Center for the Dissemination of Disability Research, 2004).

Table 2.
*The principles of Universal Design.*

<table>
<thead>
<tr>
<th>Principle One</th>
<th>Equitable Use</th>
<th>The design is useful and marketable to people with diverse abilities; does not disadvantage, segregate, or stigmatize any group of users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principle Two</td>
<td>Flexibility in Use</td>
<td>Design accommodates a wide range of individual preferences and accommodates a wide range of abilities.</td>
</tr>
<tr>
<td>Principle Three</td>
<td>Simple &amp; Intuitive</td>
<td>Design is easy to understand regardless of the user's experience, knowledge, language skills, or current concentration level.</td>
</tr>
<tr>
<td>Principle Four</td>
<td>Perceptible Info</td>
<td>Design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.</td>
</tr>
<tr>
<td>Principle Five</td>
<td>Tolerance for Error</td>
<td>Design minimizes hazards and the adverse consequences of accidental or unintended actions.</td>
</tr>
<tr>
<td>Principle Six</td>
<td>Low Physical Effort</td>
<td>Design can be used efficiently and comfortably and with minimum fatigue.</td>
</tr>
<tr>
<td>Principle Seven</td>
<td>Size and Space</td>
<td>Appropriate size &amp; space provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.</td>
</tr>
</tbody>
</table>


*Curb Ramps as Universal Design*

Evidence exists that barriers are being removed (Access Board, 2000).

The 1994 Harris Poll survey of persons with disabilities found that 75% of the
respondents reported that access to public facilities such as theaters, restaurants, stores, and museums have improved since the passage of the ADA. Despite these signs of progress, barriers still exist that impede the full participation of individuals with disabilities within their communities (Kaye, 1998). Accessibility features that benefit a segment of the population may not be as beneficial for other members in the population. Development of the early ANSI standards for environmental modifications focused on building access and maneuvering spaces for wheelchair users (Bentzen, 1997). Accessible routes were created to link destinations in the built environment by replacing curbs and stairs with ramps. Although ramps enable wheelchair users to access sidewalks and buildings, removal of curbs and stairs has inadvertently eliminated a vital part of the environmental feature used by pedestrians who are blind or have visual impairment. For instance, curbs provide individuals with visual impairments tactual information that assists them in determining that they have arrived at a street crossing (Access Board, 1999; Bentzen, 1997).

**Pedestrians with Visual Impairments**

Consistencies in environmental features provide information for orientation by individuals with visual impairment. For example, streets often run at a ninety-degree angle to each other. Parking meters are often arranged in a linear pattern paralleling both street and sidewalk. Meters are typically installed between the walkway and street. Street, curbs, and sidewalks have a
predictable relationship to each other providing the pedestrian with information for establishing and maintaining spatial orientation (Long & Hill, 1997).

Traditional techniques for non-visual travel involve the utilization of these environmental features to facilitate a line of travel to intended destinations. Maintaining orientation is essential for successful street crossing. Travelers who have visual impairment are taught to utilize sounds from vehicles that are parallel to their pathway as confirmation that they are properly aligned to the pedestrian crosswalk. The primary tasks involved in street crossing at traffic controlled intersections include detecting the street and locating the crosswalk, aligning the body to establish a heading toward the opposite corner, determining the appropriate time to cross, and walking in a straight path to the opposite corner (Guth & Rieser, 1997).

Curb ramps can be problematic for persons with vision impairment. Traditionally, individuals with visual impairment were taught to utilize the curb for determining the transition point between sidewalk and street (Bentzen, 2000; Hill & Ponder, 1976; LaGrow & Weessies, 1994). With the removal of curbs at pedestrian crosswalks, pedestrians who have visual impairment must rely on the availability of other environmental cues for identifying the point at which the sidewalk ends and the road begins. Research by Barlow and Bentzen (1994) identified the predominant cues used by pedestrians with visual impairments to establish whether they have arrived at a vehicular way. Cane or underfoot detection of the ramp slope and presence of traffic in the perpendicular street (street to be crossed) were frequently cited by the pedestrians. These cues,
however, are not always reliable since sidewalks and streets are sometimes level (referred to as blended curbs) or have very little slope. Traffic patterns often vary at different times of the day and days of the week. In the case of more complex intersections, large traffic volume and numerous turning lanes may be disorienting to the traveler who is visually impaired (Bentzen, Barlow, & Bond, 2005). Additional cues that were utilized by the research participants were the upward camber of the street as it extends away from the sidewalk-to-street transition, the curb encountered on each side of the ramp, the textural differences between the ramp and the street, the presence of other pedestrians, and the use of building lines to approximate the distance to the upcoming street crossing (Barlow & Bentzen, 1994). Again, these cues are not always present in the environment and reliance on some of these strategies may compromise the traveler's safety. Using strategies such as exploration of the intersection for locating the curb at the side of the ramp or stepping into the roadway to detect the upward gradient change of the street places the traveler in a vulnerable position.

Curb ramps are especially difficult to detect when the slope is gradual because of the subtle transition between the sidewalk and the street. Bentzen & Barlow (1995) conducted a study in which eighty persons with visual impairments were asked to travel in unfamiliar routes in their respective communities. All of the participants were considered to be experienced travelers and utilized the long cane as their primary travel aid. Ten participants were observed in each of the eight designated research sites across the United States. Each route included
ten street approaches having curb ramps or blended curbs. Of the 557 observations of the participants descending curb ramps, 39% of the approaches resulted in the participants stepping into the street. In 27% of the observations, the participants failed to locate the street and stopped prematurely thinking they had arrived at the roadway. Also significant was the fact that in half of the occurrences in which the participants had stepped into the road, traffic was present in the perpendicular street. This is of particular importance since this supports the case that presence of traffic does not assure that all non-visual travelers have enough information to determine that a vehicular way has been reached. The research findings suggest that curb ramps can have adverse impact on the safety of individuals with visual impairments, especially when ramps have a slope of 1:12 or less as required by ADAAG.

Hauger, Rigby, Safewright, and McAuley (1996) replicated Bentzen & Barlow's research in the detectability of curb ramps by persons with visual impairments. As in the earlier study, the participants were considered experienced independent travelers and utilized the long cane as their primary travel tool. Twenty-five individuals were asked to negotiate an unfamiliar route that included twelve intersections with curb ramps having slopes that varied between 1:20 and 1:10. Findings support the argument that gradual slopes are more difficult to detect and contributed to the participants' failure to identify when they had arrived at the street. Participants unintentionally entered the roadway in thirty-five of thirty-eight observations. The most frequent cues used for curb detection, as reported by the participants, were detection of the curb edge.
adjacent to the curb ramp, the slope of the ramp, and traffic sounds. These findings are consistent with those of Barlow & Bentzen's (1994) prior study of cues used by travelers with visual impairments for locating street crossings. Hauger et al. also found that the orientation of the slope to the roadway affected the participants' ability to accurately align for a street crossing. Alignment refers to the process of establishing a heading toward the opposite corner from one's present position. The researchers found that the participants also were more likely to veer outside of the crosswalk when traveling down a diagonal ramp layout (Figure 2).

Figure 2. Curb ramp layout designs. Source: U.S. Dept. of Transportation (2004).

Diagonal or apex curb ramps, having slopes that orient toward the middle of the intersection, were associated with unsuccessful crossings. Perpendicular or parallel curb ramps that were positioned within the crosswalk lines contributed to more successful crossings. Hauger et al. explained that diagonal curb ramps, in the absence of other cues, caused pedestrians with visual impairments to misalign for crossing the perpendicular street. Using the running slope as a cue does not always result in a successful crossing since running slopes are not
always oriented in the same direction as the crosswalk. This is especially true in the case of apex curb ramps or in offset street corners. Misalignment, when positioning for a street crossing, places the pedestrian at risk since he or she is more likely to veer out of the designated pedestrian crossing zone. Parallel curb ramps, designed to align in the same direction of the crosswalk, are considered an optimal layout design for intersections when considering pedestrians who are visually impaired (U.S. Department of Transportation, 2004).

The Modern Intersections

As urban areas continue to expand, distances between businesses, schools and other institutions have increased. The design of the urban landscape has evolved over the years to better accommodate automobile traffic. New automobile technologies have produced faster and quieter motor vehicles (Franck & Barlow, 1999). Automated traffic signals and wider roadways have been developed to allow for increased traffic volume and maximum traffic flow. Little thought had been given to pedestrian needs. The traditional straightforward sidewalk-to-street alignment has been replaced by offset intersection designs, free lanes for turning traffic and right-turn-on-red for motored vehicles. Computerized traffic signals have replaced fixed-time traffic controls making it more difficult for pedestrians to anticipate light changes. Offset intersection designs make it difficult for some pedestrians to align for street crossings. In the case of intersection designs such as "roundabouts", traffic never stops. The modern intersection has become increasingly complex requiring pedestrians to
rely on speed and vision to negotiate intersections (Zeeger, Huang, Harkey, & Burden, 1999).

According to the 2003 statistics by the DOT, an estimated 75,000 pedestrians were killed or injured by motor vehicles in the United States. Over 35% of these accidents occurred while pedestrians were crossing at intersections. Section 3.5 of Accessible Rights-Of-Way: A Design Guide (Access Board, 1999) states:

"Pedestrians who have vision and mobility impairments and cognitive disabilities are increasingly at a disadvantage when they leave the sidewalk to cross the street. The lack of useful information at intersections for blind pedestrians and those who have low vision is a particular impediment to independent travel".

Studies by Bentzen and Barlow (1995) and Hauger et al. (1996) demonstrated the importance of physical and auditory cues such as curbs, ramps with detectable slopes, and traffic sounds for this population.

Changes in the features of the built environment such as the elimination of curbs and in the development of quieter automobiles have posed new mobility related issues for pedestrians with visual impairments. Quieter engine noise makes it more difficult to aurally detect the presence of oncoming traffic in very low traffic situations such as in residential neighborhoods or in situations when traffic is scarce. The opposite is true in environments with high traffic volume. The increased noise and resulting increase in ambient sounds can mask the
directional flow of traffic and the sounds of automobiles starting and stopping at the intersection (Bentzen, Barlow, & Tabor, 2000). In the case of offset intersection designs, participants in a recent study by Bentzen, Barlow, & Bond (2005) inadvertently walked into the center of high traffic intersections. In over three hundred observations for street crossings, 50% of the participants, after having determined that they were aligned with the crosswalk, ended up crossing outside of the crosswalk area.

Detectable Warnings Surfaces

The U.S. Access Board (2003) defines detectable warnings as “a distinctive surface pattern of domes detectable by cane or underfoot...used to alert people with vision impairments of their approach to streets and hazardous drop-offs”. Implementation of ADA regulations for an accessible built environment provided the impetus for research and development in detectable warning surfaces and, at the same time, became a highly controversial provision. It would become the topic of much debate among transportation authorities and national advocacy groups for individuals with disabilities for the next 15 years. Research findings support the effectiveness of detectable warning surfaces in alerting pedestrians with visual impairments of upcoming drop-offs and vehicular ways (Hauger, Rigby, Safewright, & McAuley, 1996; Peck & Bentzen, 1987). The language and requirements for detectable warning surfaces in federal guidelines have undergone a number of revisions since tactile warnings were first addressed by ANSI in 1980. In 1991, ADAAG 4.29 was adopted as the U.S.
standard and truncated domes detectable warnings were required on curb ramps and vehicular ways. However, issues raised from public feedback during the rule-making process resulted in a number of suspensions since its introduction (Access Board, 2005).

Transportation officials and civil engineers have expressed concerns relating to the installation and maintenance of detectable warning products while several national advocacy groups have debated whether the warnings are needed on ramps at vehicular ways. The American Council of the Blind (2004), a consumer organization and the American Association for Education and Rehabilitation of the Blind and Visually Impaired, a professional organization, support the installation of detectable warnings at intersections. Another consumer group, The National Federation of the Blind (NFB), argues against installation of the warning products. Opinions differ within the NFB organization; one faction believes that detectable warnings should be installed on ramps with a grade of 1:15 or less while other members feel that the warning surfaces are discriminatory and unnecessary. The NFB holds the belief that individuals who have visual impairment can negotiate most environments if they have been properly trained and are competent travelers (Elliott, 1996, Freeman, 2003). The Paralyzed Veterans Administration expressed concern about the adverse impact of detectable warning surfaces on individuals who ambulate through the community by wheelchairs or other ambulatory aids (Bentzen et al., 2000; O'Leary, Lockwood, & Taylor, 1995).
The original ADAAG standard for detectable warnings, with the exception of transit platforms, was suspended in 1994 and in 1998. The suspension was lifted in 2001 and truncated domes detectable warnings were once again required on curb ramps and vehicular ways. However, due to continuing controversies, the Access Board elected to omit this provision in the most recent version of the ADAAG. The ADAAG was revised and published in 2004 and amended in 2005. The Access Board is currently revisiting the issue in a separate rulemaking on accessible public rights-of-way and has stated the need for additional research on detectable warnings to assist in its rulemaking.

Although detectable warnings are not currently mandated under federal guidelines, the Federal Highway Administration (FHWA) encourages the use of “best practices” as described in the Public Rights-of-Way Access Advisory Committee (PROWAAC) draft guidelines (Federal Highway Administration, 2004; Public Rights-of-Way Access Advisory Committee, 2001). The current recommendation standards for tactile surfaces on curb ramps and vehicular ways will be examined through literature on the development of truncated domes detectable warning surfaces. Research in the application of detectable warning surfaces in the built environment and its effects on individuals with mobility limitations will also be discussed.

Design Standards

The benefits of universal design have been recognized by agencies and industries responsible for the policies and design of the built environment
In response to the ABA’s early efforts to address accessibility for individuals with visual impairments, the original ANSI standard A117 (1980) required a 36 (915 mm) inch wide strip of detectable warnings (referred to at the time as tactile warnings) installed at the top of stairways and where walkways joined vehicular ways. The original language relating to the texture for tactile warnings (ANSI A117.1-1980 4.29.2) lacked specifications for design characteristics, width and height of the raised features for the warning surfaces. The original guidelines for tactile warnings on walking surfaces stated: “Tactile warning textures on walking surfaces shall consist of exposed aggregate, concrete, rubber, or plastic cushioned surfaces, raised strips or grooves. Textures shall contrast with that of the surrounding surface…” ANSI also specified that grooved surfaces were to be used in interior environments only and that tactile warnings were to be standardized within buildings and facilities.

The next version of ANSI A117.1 was published in 1986 and nearly identical in specifications for surface treatments but the language in the later version now referred to tactile warnings textures as “detectable warnings”. The 1986 version extended the application of detectable warning surfaces to the full width and depth of curb ramps and blended curbs at intersections.

**Early Research on Tactile Surfaces**

Investigation in the use of detectable warning surfaces began in the United States in the 1980’s and continued into the mid 1990’s. Research initially focused on the identification of various surface materials and textures for walking
surfaces that would be highly detectable to travelers with visual impairments. The tactile surfaces were to be installed on public right-of-ways to alert individuals with visual impairments of potential upcoming hazards such as vehicular ways and drop-offs at transit platforms. Most of these studies were commissioned by federal agencies such as the U.S. Department of Housing and Urban Development, Federal Transit Administration, Federal Highway Administration, and the Access Board. Results from these studies provided the basis for the early ANSI standards for tactile warning surfaces.

The earliest studies evaluated the effects of surface resiliency and sound-on-cane contact on the detectability of various materials by the participants with visual impairments (Aiello & Steinfeld, 1980; Templer & Wineman, 1980; Templer, Wineman & Zimring, 1982). Results from these studies showed that resilient materials such as rubber matting, tennis court surfacing and thermoplastic were highly detectable when compared to brushed concrete and paving bricks. Aiello and Steinfeld compared ribbed rubber matting and an abrasive material applied in strips and solid squares of varying thickness. The participants detected the rubber matting in 100% of the approaches. Templer & Wineman evaluated eleven different surfaces and measured each material for detectability and its effect on stopping distance by individuals with visual impairments. Kushionkote, a material for surfacing tennis courts, and strips of thermoplastic, arranged in a linear pattern spaced six inches apart perpendicular to the participants approach, were rated by the participants as most detectable. It was also recommended by the researchers that the treatment surface be an
area of at least 48 X 48 inches to allow for response or reactions time individuals needed for stopping upon cane detections. A follow-up study by Templer et al. (1982) examined the properties of sound, texture, and resiliency of different materials when compared to the baseline material of brushed concrete. The researchers concluded that the sound from cane-to-surface contact proved to be the most significant predictor of detectability among the surfaces in a laboratory environment. The tests were based on comparing auditory feedback from materials such as plywood and steel to the concrete surface. Although “sound” contrasted highly to the adjacent materials, findings may have been confounded because the surfaces also differed in resiliency. Auditory feedback was also more evident in cane-to-surface contact than from foot-to-surface contact.

The high level of ambient noise in a natural setting such as transit stations or busy intersections could mask the sound cues that were found to be effective in a controlled laboratory environment. These earlier studies relied on the fabrication of the various surfaces specifically for the discrimination tasks involved in the research and were not commercially produced. Comparisons were made between experimental surfaces and brushed concrete. The surfaces found highly detectable by the participants were detectable only when compared to a concrete surface; findings cannot be generalized to surfaces other than concrete. Later research involved the use of commercially produced materials and compared the products with surfaces more commonly found in the built environment. Findings from the later studies (Peck & Bentzen, 1987; Bentzen, Nolin, Easton, Desmarais & Mitchell, 1994; Tauchi, Kizuka, Sakamoto, Sueda, &
Tanka, 1998) were more specific regarding materials, texture, layout and dimensions. The results led to a more precise definition of detectable warnings that were lacking in the 1980 and 1986 versions of the ANSI standards.

In 1991, the Access Board included in its ADAAG publication the scoping and technical specifications for truncated dome detectable warnings (ADAAG 4.29.2). The warning surfaces were to be installed on transit platforms that drop-off at the edges, at reflecting pools, at hazardous vehicular ways, and on the full width and depth of curb ramps. The new definition replaced the ambiguous guidelines in the ANSI's standards (1980, 1986) concerning the required warning surface characteristics. The departure from the various surface textures, including exposed aggregate surfaces, created conflicting views among the various interest groups mentioned earlier in this section. As a result, the requirement for detectable warning surfaces at curb ramps and vehicular ways was suspended in early 1994 pending review of additional research data.

**Tactile Surface Research in the 1990s**

Subsequent research by O'Leary, Lockwood and Taylor (1995) reinforced the argument that surface treatments such as grooved concrete and exposed aggregate surfaces were not highly detectable to pedestrians with visual impairments and were easily mistaken for other common surface treatments for pedestrian right-of-ways. The outdoor installation consisted of two exposed aggregate and five domed surfaces. The results for the forty-seven participants confirmed previous findings that truncated domes were more highly detectable
than other surface treatments. Bentzen et al. (1994) evaluated thirteen truncated domes detectable warning products in a laboratory setting. The commercial products differed in dome dimensions, spacing and materials. Each of the warning products were evaluated against brushed concrete, concrete with exposed aggregate, wooden decking, and rubber tiles. The researchers concluded that the truncated domed surface designs were highly detectable with a 95% detection rate by the twenty-four participants with visual impairments. They also noted that the domed surface texture might have been more difficult to detect when adjacent to exposed coarse aggregate surfaces. These and earlier findings have been incorporated into the language found in the Access Board’s guidelines for accessible public right-of-ways. Despite these findings, the DOJ again suspended the requirement of detectable warnings at vehicular ways until 2001 stating that more data was needed.

The continuing debate fueled by roadway officials concerned with the performance of the products in inclement weather conditions, conflict among the blindness organizations about the necessity of the warning surfaces, and concerns relating to the safety and comfort of those who ambulate with mobility aids have contributed to the on-going suspension of the 1991 ADAAG mandate. Despite a number of studies on detectable warnings that have been carried out since 1991, the DOJ and the Access Board (2006b) continue to solicit additional research to assist in the rulemaking process. The federal agencies have requested still more information on the impact of tactile surfaces at hazardous vehicular ways on individuals with disabilities. The following section will present
research relevant to the development of the current standards for the design and application of truncated domes detectable warning surfaces on curb ramps at vehicular ways. The remainder of this document will also address the impact these warning surfaces on individuals with ambulatory impairments.

Truncated Domes Detectable Warnings

Safety issues at transit platforms were raised as the result of reported falls and accidents with a higher percentage involving individuals with visual impairments (U.S. Department of Transportation, 1997). In a course set by earlier studies, Peck and Bentzen (1987) continued in the exploration of tactile flooring materials that would prove reliable for long cane and underfoot detection. Specifically, the researchers were commissioned by the DOT to identify a tactile warning surface that would have practical application for transit platforms. Comparisons were made of textured surfaces from commercially produced materials. Twenty-three individuals with visual impairments were recruited to participate in the evaluation of steel, rubber, Kushionkote, and “corduroy” surfaces in a laboratory setting. The prototype corduroy surface differed from the ribbed surfaces of the earlier studies having raised ridges that were rounded over, instead of flat, creating a dome-like cross-section. Anticipating that the ambient noise level in the actual transit environments could mask the sound cues from surface contact, the researchers controlled for the sound variable by continuous play of a recording from a Boston transit station at 80 db.
The effectiveness of the tactile surfaces was measured by "stopping
distance" and the "number of cane and/or foot contacts" the participants made
with the each experimental surface. Participants were also asked to rank order
each surface by "ease of detection". Analysis of objective and subjective data
indicated that the corduroy textured surface had the highest detectability rating
when adjacent to materials typically installed at transit platforms such as
concrete, wood, and rubber tile. Peck and Bentzen found that 24 inches of tactile
warning surface, measured from the desired stopping point, provided adequate
stopping distance for more than 90% of the research participants.

Peck and Bentzen carried out the second phase of their research in
collaboration with San Francisco's Bay Area Rapid Transit Authority (BART). For
the field study, the researchers focused on the comparison of three surfaces; a
PVC corduroy pattern, an epoxy corduroy pattern, and the new Pathfinder
warning tile. The newly available product differed from the textured surfaces
used in previous studies in that it was designed with a series of raised domes
truncated at the top. Four BART stations were retrofitted with either corduroy or
domed warning products. Thirty participants with visual impairments traveled
with the aid of the long cane or dog guide and all participants participated in trials
using a human guide. Stopping distance was measured from the participants’
lead foot to the edge of the platform. Data was collected for over 474
observations.

Both corduroy and domed surfaces were found to be highly detectable by
the research participants in cane-to-surface contact and underfoot detection.
The researchers found the 24-inch width of warning surface, measured from the platform edge, provided sufficient notice for most of the participants (91%) of the upcoming drop-off but suggested a wider warning strip of 30-36 inches. Although the prototype corduroy and domed warning tile were found to be equally detectable and were recommended for installation at transit stations, Peck and Bentzen recommended that the commercially produced Pathfinder be used as the standard for tactile warnings since the linear pattern of "corduroy" surface is similar to surfaces used in other countries for directional information (Bentzen et al., 2000).

Research by Peck and Bentzen was replicated at the Metro-Dade transit agency in Miami with similar results (Mitchell, 1988). Data collection following the installation of the Pathfinder warning tiles in the BART stations showed a decrease in the number of falls among individuals with visual impairments as well as in the general population. Transit officials also reported that commuters in general stood farther from the platform's edge in stations with detectable warning surfaces (McGean, 1991). Following the research results, detectable warning surfaces were installed in a number of commuter train stations across the country. Of significance, findings from these studies helped form the basis for the ADA guidelines and specifications for detectable warning surfaces (Spiller & Muller, 1992, Bentzen et al., 2000). Truncated domes detectable warnings are currently mandated on transit station platform edges with drop-offs.

The novel Pathfinder tile provided a model from which manufacturers began production of tactile warning products for commercial applications in the
built environment. Perhaps the most recent and extensive research examining the optimal dimensions for truncated domes detectable warnings was carried out in Japan in 1997-1998 in a laboratory setting (Tauchi et al., 1998). The researchers examined twenty-one different surface textures; nine were domed products of varying dimensions and spacing. The intent was to establish a standard for tactile patterns by determining the surface treatment that proved most reliably detectable by the sixty participants. The truncated domed surface pattern that was found to have the highest degree of detectability is similar in design and dimensional characteristics to those of the Pathfinder product used in Peck and Bentzen's study.

Detectable Warnings and Travelers with Ambulatory Impairments

Since the initiation of the disability rights movement, architects and engineers have recognized that designing an environment that serves the diversity of needs and abilities of a population is a challenging endeavor. Goldsmith, an architect, (1976) remarked, “the heterogeneity of the disabled population bedevils architectural answers. What may be convenient for one set of disabled people can be anathema to another, and what for the majority is exorable can be indispensable for the few.” The solution for creating a universally accessible environment continues to be one of work in progress. Installation of ramps seemingly provided a feature that was useful for individuals with ambulatory impairments and for non-disabled persons as well (Couch, 1992). Issues caused by removal of drop-curbs in the built environment were
presented in previous sections. Paradoxically, steeper slopes are more easily
detected by non-visual travelers but create difficulty by demanding an increase of
energy expenditure for travelers in wheelchairs (Chesney & Axelson, 1996;
Sanford, Arch, Story & Jones, 1996). Curb ramps have necessitated the
development of tactile warning surfaces to assist individuals with visual
impairment in safe travel. As mentioned earlier, the requirement of truncated
domes detectable warning surfaces have raised concerns among various
stakeholders, including individuals with ambulatory impairments. Few studies
have been conducted on the effects of truncated domed surfaces on individuals
using ambulatory aids.

Although the population of primary interest was of individuals with visual
impairments, Peck and Bentzen (1987) were perhaps the first to consider the
impact of detectable warning surfaces on individuals with ambulatory limitations.
Twenty-four participants with mobility impairments were recruited to negotiate the
BART transit platforms that had been fitted with the experimental corduroy and
domed warning surfaces. Of the participants with mobility limitations, fourteen
individuals utilized powered or manual wheelchairs. The remainder reported
having gait problems, using no aid, or used ambulatory devices such as canes or
walkers.

Objective measures were collected on each participant’s ability to
complete a series of six maneuvers on each of the experimental surfaces. All of
the participants reportedly completed each task on the tactile surfaces.
Subjective responses were collected from the participants on whether the
installations affected their ease of travel in the station. None of the participants anticipated that his/her ability to travel on BART would be seriously impaired. An interesting finding was the fact that nine of the participants volunteered that one or both of the surface treatments would be helpful in negotiating the transit platforms; eight of the nine representing the sub-group who were non-wheelchair users. Several individuals who used wheelchairs reported difficulty with directional control of their chairs when traveling on the domed surface and suggested that orienting the domes in a line parallel to the direction of travel could alleviate this problem. It was anticipated that this alignment would allow the wheels of the wheelchairs to contact the space between the domes.

O'Leary et al. (1995) were commissioned by the Virginia DOT to determine whether truncated domes detectable warnings were indeed necessary for non-visual travelers. State DOT officials were concerned with the pragmatics of the installation and maintenance of warnings surfaces to meet ADA guidelines for public right-of-ways. The officials also wanted to ensure that truncated domes detectable warning surfaces were, in fact, the most optimal design for detection by pedestrians with visual impairments. The findings did support that exposed aggregate concrete was not easily distinguishable for the majority of the 47 participants and that truncated domes were more highly detectable. A small sample of six individuals with ambulatory impairments provided subjective information after performing a series of maneuvers on the treatment surfaces. All of the individuals reported preference for the exposed aggregate surface over the tactile warnings due to maneuvering difficulties on the domed surface treatments.
The six participants used either powered or manual wheelchairs, support devices or human aid. The sample was clearly too small to draw any significant conclusions, however, all six of the participants reported that the tactile warning surfaces compromised their safety.

*Detectable Warnings Research and Individuals with Mobility Impairments*

Studies, conducted in the mid-1990s addressed, in part, concerns raised by the Access Board following the 1994 suspension of the warning surfaces on curb ramps and at vehicular ways. Although detectable warning research surrounded the usefulness of the tactile surfaces for pedestrians with visual impairments, it was important that the warning surfaces did not pose a barrier to other pedestrians. Only three studies have been conducted to date concerning the effects that detectable warnings on curb ramps have on individuals with ambulatory impairments. The studies included participants who ambulated by powered or manual chairs, support devices such as crutches, walkers, and canes, and those who reported gait difficulties but did not use any aids. The domed surfaces in two of the studies adhered to the ADAAG recommendations that the detectable warning surfaces be applied on the full length and width of the ramps (Figure 3) (Bentzen et al. 1994; Hauger et al. 1996). The third study was more exploratory in nature and examined the impact of various tactile surface layouts, deviating from ADAAG guidelines, on individuals with mobility impairments (Hughes, 1995).
Figure 3. Truncated dome detectable warning applied to curb ramp. Source: Bentzen, Barlow, & Tabor, (2000).

Bentzen et al. (1994) conducted perhaps the most controlled and thorough study on the impact of ramps with detectable warning surfaces on the safety of individuals with ambulatory impairments. The researchers constructed a test site consisting of nine experimental surfaces and one brushed concrete ramp for comparison. Nine different commercially produced truncated domed surfaces of various materials and dimensions were used for the experimental ramps. The ramps were constructed to the maximum allowable slope of 1:12 to simulate the "worst case scenario" that the participants were likely to encounter in the real environment. Measures were taken of the 40 participants traversing each experimental ramp. The participants all reported having ambulatory limitations and represented users of manual (n=5) and powered chairs (n=10), support devices (n=18) and no aids (n=7). Each participant performed maneuvers involving stopping, starting, and reversing direction as they ascended each ramp. Subjective data was collected of each participant's perception of the negotiability and safety of each ramp in comparison to the brushed concrete ramp.
“Negotiability” was defined as the effort to travel over the surface in terms of starting, stopping, and turning on the surface material. “Safety” was defined in terms of whether the participant perceived as though they would fall, slip or tip over. Each surface was rated by the participants on a 5-point scale for ease of negotiability and safety relative to the concrete ramp. The participants also ranked each ramp in the order of preference. Objective data was gathered through videotaped analysis of each trial. Three raters, one a registered Physical Therapist, evaluated each participant’s performance noting the following behaviors: (a) effort required; (b) stability; (c) slippage, and (d) wheels or support device becoming trapped between domes. The raters evaluated whether each participant’s performance was the “same” or “worse” in comparison to each of their performance on the control ramp.

Bentzen et al. were primarily concerned with how the surface characteristics of the various detectable warning products impacted on the safety and negotiability of the ramps by individuals with mobility impairments. Overall, none of the 40 participants were considered to be at serious risk in negotiating the tactile surfaces. The raters were in agreement for 89% of the 2,268 rated behaviors. Users of powered wheelchairs demonstrated little difficulty on any of the surfaces while those who were proficient in use of their manual chairs also negotiated all surfaces with few difficulties. It was also noted that the size of the front wheels of the mobility aids contributed to the difficulties characterized by a few of the participants. Devices or chairs with smaller, narrow wheels appeared to catch between the domes of several surfaces. The researchers observed that
the participants who experienced the most difficulty negotiating the surfaces were also limited in their ability to travel independently in the actual environment.

Of significance, one surface stood out from the group and posed strong evidence that dome configuration and alignment may impact on the negotiability and safety of travelers using wheeled mobility devices. The surface most preferred by these participants was also identified as causing the least difficulty for any group by the raters, particularly for those using wheeled devices. The surface was characterized by square alignment of the truncated domes and had the widest inter-dome spacing with relatively small domes. It was the only surface having this combination of characteristics. Two other surfaces that were ranked higher in preference by the participants and observed to cause fewer difficulties also shared the characteristic of smaller domes than were found in the other tactile surfaces. However, the other truncated domes detectable warning surfaces were designed with the domes staggered or diagonally aligned pattern. The preference for a square orientation of the domed warning surface in this study supports the feedback of individuals in a previous study concerning dome alignment (Peck & Bentzen, 1987). It is important to note that research findings, conducted in the same laboratory, concluded that dome alignment did not affect the detectability of detectable warning surfaces by individuals with visually impairments (Bentzen et al., 1994).

Hauger et al. (1996) conducted field research using routes that included a matched set of ramps at each intersection; one with truncated dome detectable warning surfaces and one without. The detectable warning surfaces, all identical
black polymeric material, were previously installed by the city of Greensboro, North Carolina. Thirty individuals having ambulatory limitations were asked to cross each pair of curb ramps and to compare the matched ramps using the criteria of effort, stability, traction, and safety. Similar to previous studies, participants used an array of mobility devices although no mention was made in the literature specifying the numbers of each type of devices that were represented. Hauger et al. did not design provisions for objective data collection for their research involving individuals with ambulatory impairments although the use of videotaping was utilized in their larger research project involving pedestrians with visual impairments. The researchers elected, instead, to rely on subjective responses using the criteria similar to those used by Bentzen et al. (1994) and from follow-up interviews with the participants.

Interestingly, the researchers found that the participants, using the four criteria, generally preferred the ramps with detectable warnings. Seventy-three percent of the individuals reported that their preference for the surfaces were related to having greater traction, 62% felt they were safer, 55% reported that they were more stable, and 44% stated that they required less effort when traversing ramps with detectable warning surfaces. Despite the fact that the majority of the participants preferred ramps with detectable warning surfaces, 19% of the participants reported feeling safer and 23% reported expending less energy when negotiating the curb ramps without detectable warnings. This group was represented by a large number of individuals who ambulated with support devices such as canes and braces. Follow-up interview with the
participants revealed that the participants with balance issues found the detectable warning surfaces most problematic.

A smaller scale study by Hughes (1995) departs from the ADAAG standard evaluating the effects of texturing only portions of the curb ramp in an experimental setting. The purpose of the research was to determine whether it was possible to apply the tactile warning surfaces in a pattern that would increase ease of use by participants using wheelchairs without compromising its effectiveness for individuals with visual impairments. A test site was installed with eight ramps with various tactile surface treatments that also differed in surface coverage. Five of the ramps were treated with truncated domes detectable warning products; two having 12 inch strips across the width of the top of the ramp, two having the domed surface applied in a strip from top to bottom of ramp in anticipation that the wheelchairs can straddle the surfaces without contacting the actual warning materials, and the last having a three foot width of detectable warning surface running the length of the ramp. All ramps had gradients measuring 1:12. Nine participants, four wheelchair users and five using support aids, traversed each of the eight ramps. After completion of each ramp traversal, participants were asked to provide their perception of the following five criteria: (a) directional control, (b) effort required, (c) discomfort, (d) concern for tipping and (e) ability to maneuver while on the ramp. Participants were asked to respond to the criteria using a three-point scale representing “little or no problem”, “somewhat of a problem”, and “a major problem”. None of the nine participants reported having significant difficulties or safety issues in
negotiating the ramps. Findings suggested that limiting application of truncated domes to only a portion of the ramp could alleviate some of the discomfort expressed by individuals with ambulatory impairments. However, Hughes cautioned that doing so might cause orientation issues for travelers who are visually impaired resulting in the inability to align properly for street crossings. The researcher concluded that detectable warning surfaces should cover the full surface of the curb ramp to ensure detection by non-visual travelers.

New Design Guidelines

The Access Board chartered The Public-Rights-of Way Access Advisory Committee (PROWAAC) in 1999 to recommend modifications to ADAAG's accessibility provisions relating to sidewalks and streets. The committee's 33 members represented government agencies, standards-setting bodies, transportation and traffic industries, public works departments, design professionals, civil engineers, and disability organizations. The committee's report, "Building a True Community" (2001) provides guidelines specific to public rights-of-way under the ADA and the ABA. PROWAAC recommended a change to the ADAAG provision that detectable warnings be applied to the entire surface of curb ramps. The committee suggested that detectable warnings be 24 inches in the direction of travel covering the width of the curb ramp (Figure 4). Additionally, the committee recommended placement of the detectable warnings at the bottom of the curb ramp so that the edge nearest the curb is set back six to eight inches from the curb line. The new design guidelines were developed in
response to research conducted since the publication of ADAAG in 1991. PROWAAC’s suggested guidelines also reflect comments received from individuals, organizations and industries during the public comment period of the rulemaking process (Access Board, 2003).

Both the Access Board and the FWHA encourage the use of the new design over the original ADAAG guidelines (Federal Highway Administration, 2002). A publication by Kirschbaum et al. (2001), disseminated by the U.S. DOT, is a "best practice design guide" for designing accessible sidewalks and trails. The publication recommends that a 24-inch strip of detectable warnings be located at the base of curb ramps. The American Council of the Blind and American Association for Education and Rehabilitation of the Blind and Visually Impaired have also endorsed 24-inch layout design for detectable warnings on curb ramps (American Council of the Blind, 2004).

Limiting application of the detectable warnings to 24 inches, instead of full ramp coverage, and in a square array was in consideration of minimizing discomfort for individuals using wheelchairs for community travel (Bentzen et al.,

Figure 4. Detectable warning surface applied to bottom 2 ft. of ramp.
2000; PROWAAC, 2001). Research findings suggest that a 24-inch deep warning surface sufficient for alerting pedestrians with visual impairment of potential upcoming hazards and that alignment was not critical for detectability underfoot or by cane (Peck & Bentzen, 1987; Bentzen et al., 1994; Hauger et al., 1996). Few studies have been carried out examining the impact of truncated domes detectable warning surfaces on curb ramps on individuals using wheelchairs. The research has been limited to detectable warnings installed under the original ADAAG guidelines for full ramp coverage and no specifics regarding alignment of the domes. Truncated domes are more commonly installed using the diagonal configuration (Bentzen, Barlow, & Tabor, 2000). The new design guidelines for detectable warnings were intended to minimize impact on individuals using wheelchairs and other mobility aids. However, the new detectable warnings guidelines have not been tested.
PURPOSE AND RESEARCH QUESTIONS

It is important to examine technologies that have been developed for individuals with disabilities to determine whether universal design principles are truly adhered to (Center for Universal Design, 2003). It is equally prudent to provide empirical evidence to support public policies regarding accessibility in the built environment. The installation of curb ramps in the built environment created travel issues for individuals with visual impairments. As a result, truncated domes detectable warnings were developed to alert individuals with visual impairments of potential hazards and upcoming vehicular ways. Research findings support the use of truncated domes to assist in the safe travel of pedestrians with visual impairments; however, no studies have been carried out examining how the new design criteria affects individuals with mobility impairments.

The purpose of this study is to evaluate truncated domes detectable warnings installed in accordance to the revised design guidelines and its effects on the safety and negotiability of ramps by individuals who use wheelchairs. Specific questions that will be examined are (a) are there differences in the negotiability of concrete ramps with truncated domes having square alignment, diagonal alignment, and without truncated domes as compared by persons with mobility impairments? (b) what are the perceived and observed effects of each ramp condition on the safety of each research participant?
RESEARCH METHODOLOGY

Test Site Installation

A local construction firm, CP Diversified Construction, donated an undeveloped section of an industrial park in Kalamazoo for the test site. The outdoor test site is located away from main roadways and traffic activity in a cul-de-sac. The construction firm prepped the site and a local cement contractor who worked with CP Diversified in a number of development projects poured the concrete ramps according to needed specifications using ADAAG guidelines.

Each ramp measured four feet in width and six feet long (Figure 5). Transition of the poured slab to the existing road was smoothed to alleviate any problems due to abrupt surface changes causing the wheelchair to become

![Diagram of ramp layout constructed at test site.](image)

*Figure 5.* Diagram of ramp layout constructed at test site.
unstable. The ramps were poured with an incline of one inch rise per linear foot (1:12); two having truncated domes installed at the lower 24 inches along the curb-line and one control ramp without truncated domes. The 1:12 rise for the ramp was used because this is the maximum allowed under ADAAG guidelines and the steepest incline that the individuals will likely encounter in the real environment. Using the steepest allowable slope with truncated domes simulated the "worst case scenario" for individuals with mobility impairments when traveling in the built environment. One ramp was installed with truncated domes aligned in the direction of travel (running slope of the ramp) in a square configuration. A second ramp was installed with truncated domes aligned at a 45-degree angle. A brushed concrete ramp without truncated domes was used as a control ramp for comparison. The top of the ramp, a level area measuring five feet by twelve feet, allowed the participants to maneuver and turn around during the trials. The ramps were poured against an existing asphalt road. The ramps were installed in a field and did not include sidewalks.

Materials

The concrete ramps were poured as a single slab and designed so the ramps adjoined one another. The resulting concrete “pad” measured 11 feet by 12 feet and was finished with a “brushed” texture complying with ADAAG requirements for a non-slip surface treatment. The truncated domes detectable warning surface was applied per the manufacturer’s specifications once the concrete slab was “cured” and prepped.
Truncated domes manufactured by Cotel Industries were installed on site by the researcher. The polyurethane product by Cotel was selected because it meets ADA product specifications for detectable warning surfaces (Access Board, 2004). The domes had a base diameter of 0.9", dome height of 0.2", and inter-dome spacing of 2.35". It was surface applied after the concrete has been poured. This was more cost effective since the installation did not require the presence of a trained technician, additional installation procedures or expensive equipment. The decision to use the Cotel product was based on practicality as well as the criteria required by the ADA; no relationship exists between the company and this researcher except as supplier and consumer.

Participants

Participants were recruited through five public service organizations serving the needs of individuals with physical impairments in Kalamazoo and Calhoun counties. The following agencies were contacted: Disability Resource Center, Kalamazoo Metro Transit, Disabled American Veterans, Western Michigan University Disabled Student Resources and Services, and Kalamazoo Valley Community College Disabled Student Resources. These area service providers assisted by disseminating research information to potential participants. Recruitment flyers were also posted at the offices of each service provider and/or mailed out to their consumers (Appendix A). Interested participants contacted the project coordinator directly or provided a contact number with the agencies requesting the researcher to contact them. Each
participant received $25.00 for participation in the single session. Transportation was provided to individuals living outside public transportation service areas.

Potential participants were required to be at least 18 years of age having physical disabilities that require use of manual wheelchair, powered chair, or scooter. Physical mobility limitations may relate but not limited to cerebral palsy, multiple sclerosis, spinal cord injury, spina bifida, stroke, circulatory, amputation, etc. An additional selection criterion required that the individual traveled independently in the outdoor built environment. Information about specific physical attributes was collected following the completion of the consent process at the test site and before the trials began.

Individuals who were interested in participating in this study were screened through use of a script during initial contact with the researcher (see Appendix B). Research participants were selected if they used wheeled mobility aids as their primary mode of travel in the community, traveled independently, and if they did not have any limiting medical condition that posed a health risk by participation in the study, i.e., exposure to certain weather conditions or lack of stamina for repeated traversal of the ramps in the study. The project received approval through the Western Michigan University Human Subjects Institutional Review Board.

Of the twenty-six individuals who were contacted about the research, two individuals declined and three failed to show up for data collection. Attempts to reschedule with the three potential participants were unsuccessful. Twenty-one individuals, ten males and eleven females, participated in the study. Ages
ranged from 18 to 68 years of age with a mean age of 38 (\(md=39\)). Ten participants utilized manual wheelchairs for the study while the remainder of the eleven participants used powered wheelchairs. All participants were able to complete the research activity. Among the disabilities reported by the participants were cerebral palsy, diabetes, spinal cord injury, and orthopedic related conditions (See Appendix C).

Measures for Subjective Responses

After traversing each of the three ramps subjective measures were collected from the participants on their perceptions of the safety and negotiability. Testing and evaluation for this study included (a) testing of truncated domes applied using the current recommendations by the Public-Rights-of-Way Access Advisory Committee Report (PROWAAC, 2001) and subsequent guidelines specified by Americans with Disabilities Act Accessibility Guidelines (ADAAG), and (b) data collection regarding the safety and negotiability for individuals who ambulate using wheelchairs over the truncated domes applied to concrete ramps under two conditions.

Since no instrument existed prior to Bentzen's (1994) research, the instrument used in this study was based on the scheme designed by Bentzen for both objective and subjective measures of each ramp condition. The instrument differed from Bentzen's scheme in that it used a seven-point scale instead of five. Also, in this study, participants rated each condition in comparison to "a level sidewalk" rather than the control ramp. Using Bentzen's terms, the
measurements for negotiability were expressed as "effort", "traction" and "comfort". Participants were asked to utilize a seven-point scale, ranging from 1 to 7, for safety, effort, traction, and comfort. A score of 1 = "much better than a level sidewalk" and a score of 7 = "much worse than a level sidewalk" (See Appendix D). A research assistant recorded subjective responses from the participants after each trial during a one minute timed rest period. Observations were separated for traversal of each ramp going "up" and "down". Each trial was videotaped from four angles for later viewing and analysis by two independent raters. Cameras were positioned on tripods at street level, top of the ramp, and at opposite sides of the ramps.

Measures for Objective Responses

Objective measures were obtained by having two independent raters view videotapes of the trials for the first thirteen participants. Scoring sheets were designed noting specific behaviors of each research participant during each trial over each condition. Based on the instrument developed by Bentzen, the behaviors noted were propulsion effort, wheel entrapment, traction, and stability (Appendix E). One rater was a registered Physical Therapy Assistant and the second, a certified Orientation & Mobility Specialist with a specialty in Travel Instruction. Both raters had extensive working experience with individuals with mobility impairments.

Each rater had the task of reviewing videotapes of each trial from four different vantage points; front, rear, left and right of each participant. For each
trial, the raters first viewed the participant’s performance on the control ramp as a comparison from which to rate the behaviors of the same participant traveling in the same direction on the experimental ramps. Both raters elected to run three videotapes simultaneously; one video monitor was used for the participant’s performance on the control ramp and the other two monitors showed two of the four camera angles. Once the raters had recorded the data for the two views, the videotapes with the remaining views for that particular trial were played back for review and analysis. Practice videos were made and used to train the raters. The raters practiced until they had reached an agreement of at least 90%. The raters, in fact, reached 93% agreement over 192 observations for the “practice participant.” Each rater worked independently once the actual trial tapes were reviewed.

**Procedure**

Participants were tested individually to ensure that no interaction or discussion took place between participants at the time of data collection. Although each person received a cue identifying the ramp they were to traverse next and when to begin ascent or descent, none were provided with instruction in how to approach each ramp. All of the participants began at street level from a distance of 10 feet from the bottom of the ramp they were assigned to traverse. The distance provided each participant a “running start” to establish momentum needed to ascend for the first trial. This seemed logical since it was expected that if persons in wheelchairs were traveling up a ramp at street level that they
would be doing so in the process of crossing a roadway and not approaching from a "standstill". It was also decided to have all participants start at street level to alleviate the need for half of the participants to traverse to the top of the ramp to begin their first trial had the researcher elected a random assignment for the direction variable (up or down). This would have necessitated that the participants who were to begin at the top of the ramp to travel an extra distance uphill possibly adding to their overall level of fatigue at the study's end or required that the researcher transport each participant to the top of the ramp.

Ramp sequence was established for each participant through random assignment. Ramp, direction, and trial number were recorded on separate pieces of paper that were placed into two separate canisters. The ramps were identified as Ramp A, Ramp B, and Ramp C. Two canisters were used to control for the direction variable since it was important to ensure that the participant would travel down the next ramp when they were at the top and vice versa. Assignments were then randomly drawn for each participant. In all, the participants traversed each ramp three times in each direction for a total of 18 trials. This study consisted of a total of 378 trials. Participants were given a one-minute rest period between trials. The actual trials and data collection took approximately one hour to complete. Videotapes of each participant negotiating each ramp were recorded from four camera angles for subsequent analysis.

Following each trial, the research participants rated each surface on a 7-point rating scale for effort, safety, traction, and comfort. Each participant was shown the rating scale and associated values after each trial during the one-
minute rest period during which data was collected. A rating of "4" approximated a "level sidewalk" and ratings less than "4" represented increased ease of travel or safety while ratings greater than "4" indicated increased effort to negotiate or less safe than a level sidewalk. After completion of all trials, each participant ranked each ramp in the order of preference. Participants were also provided an opportunity for additional comments.

Rater data was collected on an instrument similar to the one used for collecting participant data. A seven-point scale was utilized for objective measures with "1" = better than control ramp and "7" = worse than control ramp. The videotaped trials were analyzed by two independent raters for observed behaviors such as wheel slippage, entrapment, instability of the individual and wheelchair, and propulsion effort. The raters evaluated 13 (62%) of the participants for their performance on each treatment ramp relative to their performance on the brushed concrete ramp. Objective analysis was not conducted on all participants because the research occurred in two different time frames. The raters were used for the first participant group (n=13). Additional participants were recruited and data collected two months later. The raters were not available to review the data from the second set of participants. Objective measures were collected for 1,872 (n=13 X 18 trials X 2 raters X 4 camera angles) observations.
RESULTS

Section One

Participant Data Analysis

Treatment of ordinal data as interval data is common in the social sciences. Literature supports the appropriateness of multivariate analyses for ordinal variables due to the flexibility and power gained from these methods and that the benefits outweigh the small biases that may result (Kim, 1978; Labovitz, 1967, 1971; Winship & Mare, 1984). A multivariate repeated measure analysis was conducted to determine the effects of three ramp conditions on four measures of safety and negotiability as perceived by the 21 research participants. Participant responses were collected on a seven-point Likert type rating scale. A rating of “4” was equivalent to a “same as a level sidewalk”. Response ratings of less than “4” were more favorable while ratings greater than “4” indicated that the respondent considered the condition less favorable in comparison to a level sidewalk (Appendix D).

Participants were randomly assigned to negotiate each ramp three times in each direction (up and down) for a total of 18 trials. All twenty-one of the research participants were able to complete the required trials without difficulty. Between-subject analysis was performed for wheelchair type (aid); manual chair users (n=10) and power chair users (n=11). Within-subject factors were analyzed for direction of travel and three different ramp conditions (truncated domes square, truncated domes diagonal, and no domes). This section will
present findings from the analysis of the three independent variables “direction”, “aid”, and “ramp” treatment and their effects on the four dependent variables “effort”, “safety”, “traction”, and “comfort”.

**MANOVA for Participant Data**

An examination of mean differences across trials was not found to be significant suggesting that practice or fatigue effects did not influence outcome measures. Thus, trial was not included as a dependent measure in any of the analyses. Because the sphericity assumption was not met, Pillai’s Trace and Greenhouse-Geisser statistics were used. The Pillai’s Trace is considered to be more robust than other statistics and appropriate to use in the case of multiple response measures (Olson, 1976; O’Brien & Kaiser, 1985). The Greenhouse-Geisser controls for type I error while maximizing power (Muller & Barton, 1989). An alpha level of .05 was used for all statistical tests and $\eta^2_p$ was calculated as the effect size.

SPSS GLM for repeated measures was used for analysis of mean differences across the independent variables on the four dependent measures “effort”, “safety”, “traction”, and “comfort”. SPSS contrast analysis for repeated measures was conducted a priori to test for differences among the levels of each factor. Since this test produced pairwise multiple comparisons of the mean differences between each measure, no post hoc procedure was conducted.

Independent variable “ramp” representing three ramp conditions had three levels, the variable “direction” for ascending and descending each ramp
consisted of two levels, and variable "aid" representing two wheelchair user groups resulted in two levels. Multivariate analysis of variance (MANOVA) results indicated statistically significant within subjects main effect for "ramp" treatment on the dependent measures, \(F(8,72)=3.39, p=.002, \eta_p^2=.273\). Descriptive statistics are summarized in Tables 3 and 4.

Table 3. Descriptive statistics for upward ramp travel.

<table>
<thead>
<tr>
<th>Ramp Treatment</th>
<th>Measure</th>
<th>Wheelchair</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD Square Alignment</td>
<td>Effort</td>
<td>manual</td>
<td>4.00</td>
<td>.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.52</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>manual</td>
<td>3.93</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.61</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>3.63</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>2.82</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>Comfort</td>
<td>manual</td>
<td>4.30</td>
<td>.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.09</td>
<td>1.60</td>
</tr>
<tr>
<td>Brushed Concrete</td>
<td>Effort</td>
<td>manual</td>
<td>4.07</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.55</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>manual</td>
<td>4.17</td>
<td>.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.48</td>
<td>.97</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>3.80</td>
<td>.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.06</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>Comfort</td>
<td>manual</td>
<td>3.90</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.73</td>
<td>1.07</td>
</tr>
<tr>
<td>TD Diagonal Alignment</td>
<td>Effort</td>
<td>manual</td>
<td>4.40</td>
<td>.83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.88</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>manual</td>
<td>3.90</td>
<td>.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.73</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>3.60</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>2.82</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>Comfort</td>
<td>manual</td>
<td>4.40</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.73</td>
<td>1.84</td>
</tr>
</tbody>
</table>

\(^a_n = 10\) for manual chair users, \(n =11\) for power chair users

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Table 4.
*Descriptive statistics for downward ramp travel.*

<table>
<thead>
<tr>
<th>Ramp Treatment</th>
<th>Measure</th>
<th>Wheelchair&lt;sup&gt;a&lt;/sup&gt;</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD Square Alignment</td>
<td>Effort</td>
<td>manual</td>
<td>3.07</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>2.91</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>manual</td>
<td>3.93</td>
<td>.93</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>3.52</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>3.93</td>
<td>.86</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>2.91</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>Comfort</td>
<td>manual</td>
<td>4.37</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>3.91</td>
<td>1.65</td>
</tr>
<tr>
<td>Brushed Concrete</td>
<td>Effort</td>
<td>manual</td>
<td>3.37</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>3.18</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>manual</td>
<td>4.17</td>
<td>.76</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>3.82</td>
<td>.64</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>4.30</td>
<td>.60</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>4.03</td>
<td>.92</td>
</tr>
<tr>
<td></td>
<td>Comfort</td>
<td>manual</td>
<td>4.23</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>3.73</td>
<td>.99</td>
</tr>
<tr>
<td>TD Diagonal Alignment</td>
<td>Effort</td>
<td>manual</td>
<td>3.68</td>
<td>1.62</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>3.42</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>manual</td>
<td>4.03</td>
<td>.79</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>3.73</td>
<td>1.94</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>4.23</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>2.79</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>Comfort</td>
<td>manual</td>
<td>4.43</td>
<td>.89</td>
</tr>
<tr>
<td></td>
<td>power</td>
<td></td>
<td>3.88</td>
<td>1.91</td>
</tr>
</tbody>
</table>

<sup>a</sup>n = 10 for manual chair users, n = 11 for power chair users

Between-subjects analysis for wheelchair type, manual versus power chair, had no statistically significant effect on overall means for dependent variables “effort”, “safety”, “traction”, and “comfort”, \( F(4,16) = .915, p = .479, \eta^2_p = .186 \). Within-subjects analysis for the directional variable, up versus down, did not show statistically significant effect on the overall means for the four
dependent variables relating to safety and ramp negotiability, $F(4,6)=1.79$, $p=.181$, $\eta_p^2=.309$.

**Univariate Analysis for Participant Data**

Follow-up univariate analysis was conducted to determine statistically significant effects on each of the outcome measures by the independent variable "ramp". Univariate results for each measure showed a small effect size for the independent variable "ramp" on the dependent variable "traction", $F(1.36, 25.8)=5.53$, $p=.018$, $\eta_p^2=.226$. Examination of the mean score across ramp conditions suggest that traction was improved for ramps that had been installed with truncated domes. Ramp treatment did not show statistically significant effect on the remaining measures for "comfort", $F(1.28, 24.3)=.367$, $p=.602$, $\eta_p^2=.019$, "effort", $F(1.37, 26)=2.41$, $p=.125$, $\eta_p^2=.112$, and "safety", $F(1.35, 25.6)=.144$, $p=.781$, $\eta_p^2=.008$.

**Participants Preference for Ramp Treatment**

Participants were asked to rank order each of the three ramps in order of preference. Table 5 summarizes the total for participant ranking of the three ramps in terms of "best", "second", and "least". The participants who negotiated the ramps using manual wheelchairs were almost equally divided in ramp preference for truncated domes square alignment (n=5) and brushed concrete ramp without domes (n=4). Participants using powered chairs showed the greatest preference for the brushed concrete ramp (n=7). Overall, most of the
participants considered the brushed concrete ramp without treatment (n=11) as “best”. However, nine of the twenty-one participants expressed preference for the treatment ramp installed with truncated domes in a square array. More than half the participants ranked the ramp installed with the domes diagonally as “least” preferred.

Table 5. 
Total for participants ranking of ramp by preference.

<table>
<thead>
<tr>
<th>Wheelchair type</th>
<th>Ramp treatment</th>
<th>Best</th>
<th>Second</th>
<th>Least</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual (n=10)</td>
<td>TD Square alignment</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Brushed concrete – no domes</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>TD Diagonal alignment</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Power (n=11)</td>
<td>TD Square alignment</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Brushed concrete – no domes</td>
<td>7</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>TD Diagonal alignment</td>
<td>0</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>

Research Question One: Difference in Negotiability of Ramps

Negotiability was measured in terms of “effort”, “traction”, and “comfort”.

Overall, both manual and power chair users perceived that traction was improved on both treatment ramps for both directions when compared to the brushed concrete control ramp (see Table 6 and 7 for descriptive statistics). A contrast analysis was conducted to examine the differences between ramp conditions. Although the means for the manual chair group indicated that traction was improved for the treatment ramps in either direction, more traction was noted
Table 6. *Descriptive statistics by raters for upward travel.*

<table>
<thead>
<tr>
<th>Ramp Treatment</th>
<th>Measure</th>
<th>Wheelchair</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD Square Alignment</td>
<td>Effort</td>
<td>manual</td>
<td>4.06</td>
<td>.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.00</td>
<td>.00</td>
</tr>
<tr>
<td></td>
<td>Stability</td>
<td>manual</td>
<td>3.86</td>
<td>.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.97</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>4.11</td>
<td>.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.11</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td>Entrapment</td>
<td>manual</td>
<td>4.22</td>
<td>.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.06</td>
<td>.09</td>
</tr>
<tr>
<td>TD Diagonal Alignment</td>
<td>Effort</td>
<td>manual</td>
<td>4.47</td>
<td>.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.00</td>
<td>.00</td>
</tr>
<tr>
<td></td>
<td>Stability</td>
<td>manual</td>
<td>3.73</td>
<td>.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.98</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>4.21</td>
<td>.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.04</td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>Entrapment</td>
<td>manual</td>
<td>4.37</td>
<td>.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.05</td>
<td>.12</td>
</tr>
</tbody>
</table>

*Note: n = 8 for manual chair users, n = 5 for power chair users*

going down the ramp with the truncated domes aligned in a square configuration (see Figure 6). Traction performance was significantly better for the power chair group for both treatment ramps when compared to the control ramp. Direction of travel did not appear to affect the amount of traction perceived by the participants who negotiated the ramps using power chairs (see Figure 7).

The measures for "comfort" and "effort" did not differ significantly across the ramp conditions. Although, participants reported that traction improved on the ramps treated with domes, the ramps were a little less comfortable to negotiate in comparison to the brushed concrete ramp. This was particularly true for the manual chair group whose means for "comfort" were higher for both
Table 7.
Descriptive statistics by raters for downward ramp travel.

<table>
<thead>
<tr>
<th>Ramp Treatment</th>
<th>Measure</th>
<th>Wheelchair$^a$</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Effort</td>
<td>manual</td>
<td>4.08</td>
<td>.17</td>
</tr>
<tr>
<td>TD Square Alignment</td>
<td></td>
<td>power</td>
<td>4.00</td>
<td>.00</td>
</tr>
<tr>
<td></td>
<td>Stability</td>
<td>manual</td>
<td>3.74</td>
<td>.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.91</td>
<td>.19</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>4.18</td>
<td>.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.03</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>Entrapment</td>
<td>manual</td>
<td>4.28</td>
<td>.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.02</td>
<td>.06</td>
</tr>
<tr>
<td>TD Diagonal Alignment</td>
<td>Effort</td>
<td>manual</td>
<td>4.11</td>
<td>.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.02</td>
<td>.06</td>
</tr>
<tr>
<td></td>
<td>Stability</td>
<td>manual</td>
<td>3.64</td>
<td>.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>3.86</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>Traction</td>
<td>manual</td>
<td>4.28</td>
<td>.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.10</td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>Entrapment</td>
<td>manual</td>
<td>4.33</td>
<td>.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>4.14</td>
<td>.14</td>
</tr>
</tbody>
</table>

$^a$\(n = 8\) for manual chair users, \(n = 5\) for power chair users

ramps with truncated domes in comparison to the means of the brushed concrete ramp. Closer examination of the means for the manual chair users indicate that the ramp with the domes in a diagonal array created more discomfort than did the ramp with domes in a square alignment. It appears that the research participants did not perceive that any of the three ramp conditions posed significant hardship in terms of negotiability. Statistics indicate that negotiability was improved on the ramps treated with truncated domes due to the perceived increase in traction.
Figure 6. Mean traction for manual chair users (n=10.) The ramps that had been treated with truncated domes provided more traction. Domes aligned in a square array provided manual chair users more traction for both directions.

Figure 7. Mean traction for power chair users (n=11). Traction was significantly improved for the ramps with truncated dome detectable warnings. Traction improved for both directions regardless of the dome alignment.
Research Question Two: Safety Concerns

Participants did not perceive that the ramps treated with truncated domes in either square or diagonal alignment posed any significant safety risks. No statistically significant differences were found in "safety" across ramp conditions. Examination of the means for the manual chair group, however, indicates that these participants perceived that safety was improved for the ramps with truncated domes as compared to the brushed concrete ramp without domes. The means for the power chair group indicates that the participants perceived that the ramp treated with domes in a square alignment slightly more safe for downhill travel as compared to the brushed concrete ramp and the ramp with domes aligned diagonally.

Section Two

Rater Data Analysis

Two independent raters reviewed videotapes using a rating scheme similar to that used for data collection from the research participants (Appendix E). The instrument designed for rater data collection consisted of a seven-point Likert-type scale with "4" representing the participant’s baseline performance on the brushed concrete ramp without truncated domes. A score of less than "4" indicated improved performance with "1" = "much better" than the brushed concrete ramp. Scores greater than "4" represent less favorable than the baseline performance with "7" = "much worse" than brushed concrete ramp. Inter-observer agreement was 83% overall for the actual analysis. The raters
observed participants traversing each ramp for behavior reflecting ease of
negotiability and safety. Negotiability and safety were measured in terms of
“stability” (tipping and balance of wheelchair), “traction” (wheel slippage),
“entrapment” (wheels caught between domes), and “effort”.

The variable “view” was factored into the analysis since data was collected
from four cameras, placed in different locations, to determine the effects of ramp
treatment and direction on the measures for “propulsion effort”, “wheel
entrapment”, “traction”, and “stability”. “View”, however, had no actual effect on
the participants’ performance on the ramps. Utilizing four video angles enhanced
the raters’ ability to detect any difficulty encountered by the participants in ramp
traversal that may have otherwise gone unnoticed. Raters worked independently
from each other viewing each participant traversing the brushed concrete ramp
first as a baseline performance from which to compare the participant’s
performance on the experimental ramps. Multivariate statistics were used for
analysis. An alpha level of .05 was used for all statistical tests.

**Inter-rater Agreement**

To add validity to participant responses, objective data was collected and
reviewed by two raters. For reliability, the raters were trained to a criterion of
90% agreement on the videos simulating the behaviors that were to be observed
in the actual analysis. An exact agreement formula, in which the total number of
agreements was divided by the total number of agreements plus disagreements
and multiplied by 100, was used to calculate the inter-observer agreement.
(Hartman & Wood, 1990). Inter-observer agreement was assessed separately for each level of the independent variables “ramp”, “direction”, and “aid” on four measures of ramp negotiability and safety. The dependent variables used to determine negotiability and safety were “stability”, “effort”, “traction”, and “wheel entrapment”.

Each rater observed a total of 1,248 (n=13 X 4 measures X 4 camera angles X 3 ramps X 2 directions) behaviors. Behaviors observed were associated with safety and ease of travel up and down each ramp condition. The brushed concrete ramp served as a comparison for baseline performance. “Safety” was not considered separately as the idea of safety may not have been independent of “wheel entrapment” and “traction”. For example, one could equate difficulty in directional control of the chair (due to wheel entrapment or slippage) to safety concerns. Considering this, the question of ramp negotiability and the separate question relating to safety were not addressed as two distinct questions in the case of rater observations. Instead, the raters were asked only to observe behaviors related to stability, traction, effort, and wheel entrapment.

**MANOVA for Rater Data**

Type of aid, manual versus power chair, did not have statistically significant between-subject effects on any of the four outcome measures, $F(4,16)=2.75$, $p=.105$, $\eta^2_p=.579$. Likewise, no statistical differences were noted for the independent variables “ramp”, $F(8,4)=.498$, $p=.814$, $\eta^2_p=.499$, and “direction”, $F(8,4)=1.99$, $p=.190$, $\eta^2_p=.498$, on the dependent measures for
negotiability. However, MANOVA results showed statistically significant within-subject interaction effect for independent variables “direction” and “ramp”, $F(8, 40)=2.47, p=.028, \eta_p^2=.331$.

Univariate Analysis of Rater Data

Follow-up univariate analysis indicated a statistically significant interaction effect between direction of travel and ramp treatment on the dependent measure “effort”, $F(2, 22)=4.46, p=.024, \eta_p^2=.289$ (see Figure 8). As anticipated,

Figure 8. Factors ramp X direction interaction for the measure “effort”. Raters perceived that participants expended more effort negotiating ramp with domes diagonally aligned (diagonal up, $\bar{X}=4.23$; diagonal down, $\bar{X}=4.08$) in comparison to ramp with domes in square alignment (square up $\bar{X}=4.06$; square down, $\bar{X}=4.01$).
participants using manual chairs exerted more effort traversing up each ramp than did the participants in the power chair group. The raters perceived that the participants using manual chairs exerted more effort when traversing up the ramp installed with domes aligned diagonally ($M=4.7$, $SD=.32$) in comparison to the ramp installed with domes aligned square ($M=4.06$, $SD=.29$). Direction of travel had little effect on the amount of effort demanded of the participants using power chairs regardless of the ramp treatment. Descriptive statistics for rater analysis are presented in Tables 6 and 7.

*Research Question One: Difference in Observed Negotiability of Ramps*

Findings from rater video analysis did not indicate any main effect for the independent variables “ramp”, “direction”, and “aid” on the dependent variables representing ease of negotiability. However, the combination of “ramp” treatment and “direction” resulted in an increase in the amount of effort required to ascend both ramps that had been installed with truncated domes. The raters observed that the ramps that had been treated with truncated domes adversely affected the ease of negotiability for manual chair users in terms of energy expenditure. Data indicates that the participants in the manual chair group exerted more effort traversing up the ramp installed with domes diagonally as compared with the ramp having domes aligned square and the brushed concrete ramp. No difference in effort was shown for the power chair group in negotiating each of the three ramp conditions.
Research Question Two: Observed Safety

The behaviors most associated with safety, "traction" and "wheel entrapment", were not statistically significant across ramp conditions or for direction of travel. The raters did not observe the participants to have significantly increased issues with wheel slippage or wheels being caught between domes for the ramps installed with truncated domes as compared to the brushed concrete ramp. The measure for "stability" was associated with chair balance and/or tipping. Though not statistically significant, the means for stability was less than the means for the brushed concrete comparison ramp. The participants were observed to be a little more stable when traversing the ramps that were installed with truncated domes. Implications of these findings will be addressed in the following chapter.
DISCUSSION

Subjective and Objective Data Comparison

Both participant and rater data suggest that ramp treatment has a small effect on the negotiability of ramps by individuals using wheelchairs. Findings from this research do not support the notion that ramps installed with truncated domes (regardless of dome alignment) are less safe than brushed concrete ramps without domes. In fact, analyses of participant responses provide evidence that traction is improved when the ramps were treated with truncated domes. Application of detectable warnings may, in fact, be beneficial for individuals using wheelchairs.

Rater analysis indicated that, for manual chair users, upward traversal of ramps with truncated domes required more effort than power chair users, particularly when negotiating the ramp installed with domes in a diagonal array. The finding that manual chair users exerted more effort than individuals using power chair is not surprising. What is noteworthy, though not statistically so, is that rater data indicate that the ramps with domes aligned in a square array required less effort of the manual chair users to ascend than did the ramp with domes aligned diagonally.

Although raters were used to supplement findings and to increase objectivity to the measures of safety and negotiability, it may be that complete elimination of subjective judgment is not possible. In this case, raters were asked to observe through video analysis whether participants' performance
reflected issues relating to effort and traction. Whether one can accurately
determine for another individual the effects of “effort” and “traction”, qualities that
are typically experienced, can be argued. Examination of the rater raw data
showed that agreement was higher for participants that were observed to have
fewer difficulties in traversing the ramps (over 90%). While the raters agreed on
which participants had greater difficulties, they did not necessarily agree on the
measures associated with the behaviors or on the rating used to express the
degree of difficulty. This was especially true for the measures “entrapment” and
“traction”. Of the participants that were observed to require more effort in ramp
traversal, raters consistently identified “entrapment” and/or “traction” as
problematic but may not have agreed on the scoring. Nonetheless, the
independent raters generally agreed on whether participants had issues with
negotiability and safety. Further, none of the participants were observed to have
behavior ratings of greater than “5” indicating “a little worse” as compared to the
brushed concrete control ramp.

It is clear that participant and rater analyses show that ramps installed with
truncated domed surfaces did not pose any significant safety risks nor was ease
of negotiability seriously compromised. Both participant and rater data seem to
agree that truncated domes should be aligned in a square array to minimize any
issues with negotiability of ramps installed with the warning surface. As before
mentioned, it was not surprising that manual chair users exerted more effort
traversing up the ramps when compared to the power chair group. An
unanticipated finding was that the manual chair participants expressed that the truncated domes were particularly beneficial for downward ramp travel.

Current Findings and Previous Research

Performance data along with participants ranking of preferred ramp treatment argue in favor of the proposed ADA accessibility guidelines that truncated domes should be placed in a square array and limited to the bottom 24” of the ramp. Although not statistically significant, comfort was slightly compromised on the ramps treated with detectable warnings. However, this may be viewed as a worthwhile trade-off for the increased traction and perceived safety derived from the warning surfaces.

Both participant and rater analyses relating to dome alignment are consistent with findings from Bentzen’s et al. (1994) evaluation of different detectable warning products. Participants in Bentzen’s et al. study preferred square dome alignment to the diagonal dome alignment pattern perhaps due to the greater wheel-to-base surface contact with the warning surface. Rater analyses in both studies showed that skilled wheelchair users and those with less severe disabling conditions experienced the fewest difficulties in negotiating both experimental and control ramps. Raters generally agreed on the participants who exhibited the most difficulties but did not consistently agree as to what specific behaviors contributed to the overall difficulties. Power chair users in both studies did not demonstrate any difficulties negotiating the ramps that had been installed with truncated domes detectable warnings.
The findings from this study regarding participants' perception of improved traction are congruent to Hauger's et al. (1996) research in a community setting. The majority of the research participants in the earlier study reported that the ramps installed with detectable warning surfaces provided more traction than concrete ramps without domes. The participants in both studies expressed that the improved traction of the ramps with detectable warnings made them feel safer. Hauger et al. found that truncated domes detectable warning surfaces did not pose any significant safety risks or difficulties in ramp traversal for individuals who use wheelchairs.

Limitations of the Study

Currently, federal recommendations for detectable warnings are specific regarding dome dimensions and inter-dome spacing. It also requires that the surface is slip resistant. Cotel's surface applied polyurethane truncated domes was used in this study. It's dome dimensions and inter-dome spacing is 0.9 inches and 2.35 inches respectively. However, truncated domes detectable warning products are also produced in cast concrete, polymer resins, and ceramic materials and may have different dome dimensions and spacing (Bentzen, Barlow, & Tabor, 2000). It cannot be assumed that all detectable warning products would produce similar outcomes. When one considers the allowable range for dome width and inter-dome spacing under current ADAAG guidelines, the Cotel product has the smallest dome size allowed (0.9 inches) with an inter-dome spacing that approaches the maximum allowed (2.4 inches).
Additional research to evaluate whether other detectable warning surfaces would have similar effects on individuals with mobility limitations is warranted. It is this researcher's opinion that ramps installed with detectable warning products having larger domes and closer dome-to-dome spacing would result in different outcome measures than those reported in this document.

Another limitation of this study is the small sample size (n=21) and representation of only wheelchair users. Although the findings from this study support those of earlier research, the results are applicable only to the participants in this study and should not be generalized to the larger population of individuals using wheelchairs. A convenience sample was used for this research and thus, generalizability of the results to a larger population are purely hypothetical rather than empirical. Future research should consider the population distribution of individuals using mobility aids. Individuals using wheelchairs comprise only a small percentage of individuals who report having mobility impairments. Additional research is needed to examine the impact of detectable warning surfaces on individuals who utilize mobility aids such as scooters, walkers, crutches and support canes. Persons who do not use support devices but have gait instability should also be considered.

This study was conducted in a controlled outdoor setting. Ramps were poured with a 1:12 running slope, which is the maximum allowable under ADA guidelines. Surfaces were smooth and transition to the roadway was compliant to the ADA requirement that the transition is not abrupt. However, slope gradient varies in the real environment, surfaces are not always uniform without
blemishes, and transition to street level are sometimes rough. Installation of truncated dome detectable warning surfaces under these conditions may affect how individuals with mobility impairments perceive “negotiability” and “safety”. A number of participants in this study remarked how “smooth” and uniform the experimental ramps were in comparison to the ramps and sidewalks in their own communities. Lastly, it was determined for this study that data collection be conducted under dry conditions. A number of research participants were concerned with how adverse weather conditions would affect their ability to safely negotiate the ramps with the domed surfaces.

Future Research

Truncated dome detectable warning surfaces are becoming a more common feature of our built environment. Universal design principles dictate that products should accommodate users of all abilities. It also advocates an efficient design that can be used comfortably and with minimum fatigue. Detectable warning surfaces were designed for individuals with visual impairments. Truncated dome detectable warnings were initially met with disfavor among individuals with mobility impairments due to the anticipation of problems associated with safety and negotiability (Bentzen et al., 2000, O’Leary, Lockwood, & Taylor, 1995). Findings from this study and a previous study by Hauger et al. (1996) showed that detectable warnings could be beneficial for individuals who use wheelchairs since the surfaces seem to increase traction. Also, if one were to consider the “minimum fatigue” criteria of universal design
considerations, aligning the domes square rather than diagonally, would result in increased traction and safety while reducing fatigue.

It may be beneficial to collaborate with researchers from other disciplines in addressing the travel issues face by wheelchair users in the built environment. Two of the research participants commented that they felt that the suspension design of their wheelchairs added to their comfort while traversing the domed ramps. These individuals were para-athletes and utilized wheelchairs that were designed for sport participation. In a number of discussions with raters and research participants, it was apparent that wheelchair design, suspension, wheel camber, and wheel width all had influence on the participants' travel experience. It may be that with the addition of truncated domes as a standard in our built environment, wheelchairs should be redesigned to mitigate the effects of these domed surfaces. Research findings also suggest that power chair users had fewer difficulties negotiating the ramps and, in fact, seemed to benefit significantly from the increase traction when traversing the ramps with detectable warnings. Bentzen's et al. (1994) also showed that power chair users had little difficulties when maneuvering on the experimental ramp with truncated domed surfaces. This may have implications for policies regarding the type of wheelchair that a rehabilitation or insurance agency dispenses to an individual.

A recent research study sponsored by the Department of Veterans Affairs examined the effects of various surface materials on the wheelchair propulsion (Koontz, Cooper, Boninger, Yang, Impink, & Woude, 2005). None of the surfaces consisted of truncated domes. In fact, all prior research on detectable
warning surfaces and their effects has been conducted by professionals in the blindness field. This writer will make follow-up contact with Dr. Rory Cooper who is director of the Center for Wheelchair and Related Technology, Department of Veterans Affairs. Dr. Cooper is also a professor in the Department of Rehabilitation Sciences and Technology at the School of Health and Rehabilitation Sciences, University of Pittsburgh. The intent is to inquire whether Dr. Cooper is aware of the issues surrounding detectable warning surfaces and consumers of wheeled mobility devices and whether he may consider inclusion of truncated dome surfaces into his research agenda. This is timely as the Access Board Research Agenda for 2006 includes the “Effects of Slope and Surface on Wheelchair Maneuvering” (Access Board, 2006c).

Dr. Cooper is also the inventor of SmartWheel™, a product that was developed to measure propulsion data using computer analysis for calculation of propulsion efficiency and ease (Boninger & DiGiovine, 2005). The SmartWheel™ could provide a method for increasing objectivity in data collection in future research endeavors. Although this technology was available at the time of this study, the cost for such technology was cost prohibitive (at least $25,000) and could not be acquired for this research.

This study is the only research to date that examines the effects of truncated dome detectable warnings, using the current ADA Accessibility Guidelines, on individuals using wheelchairs. More research with a greater number of research participants would (1) support the findings of this study, and (2) make it possible to generalize the findings to the population. Future
researchers should consider collaboration with an institution owning a technology such as the SmartWheel™ to provide a means for more objective analyses. Collaboration with researchers who have interest in wheelchair design and propulsion mechanics could result in different wheelchair design criteria, especially if truncated dome surfaces are considered a standard feature in the built environment. Finally, as truncated dome detectable warning surfaces are becoming more commonplace in the urban setting, additional research should be conducted in the real environment involving participants who are more representative of individuals in the population who have mobility limitations.
REFERENCES


Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.


Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.


II: Best practices design guide. U.S. Department of Transportation.


February 17, 2006, from Washington, DC: U.S. Access Board web site
http://www.ap.buffalo.edu/idea/space%20workshop/

mobility. In Blasch, Wiener, & Welsh (Eds.), *Foundations of Orientation
and Mobility (2nd ed.).* 39-59. New York: American Foundation for the
Blind.


mapping the environmental values of wheelchair users. *Environment and
Planning A,* 27, 1069-1083.

Washington DC: Urban Mass Transportation Administration, Office of

March 3, 2006, from:
eid=000094946_01110204011328

station, Final report. Metro-Dade Transit Agency, Office of Transit Safety


Appendix A

Recruitment Flyer
LOOKING FOR RESEARCH VOLUNTEERS...

Western Michigan University Department of Blindness & Low Vision Studies is interested in recruiting individuals who are independent travelers and who utilize wheelchairs or scooter for mobility. We are conducting research to determine the effects of detectable warning surfaces on the negotiability of ramps by individuals who travel using wheelchairs or scooters. The test site is located in an industrial park on Cork near Burdick Street. Research will begin this summer 2004. Transportation will be arranged for participants if needed. The actual research process will take approximately one hour.

Detectable warnings have been installed to alert travelers with visual impairment of hazards and are currently recommended for new curb installations at intersections by the ADA Accessibility Guidelines. The installation of curb ramps in place of curb drop-offs make street travel more accessible to those who utilize ambulatory aids but resulted in loss of tactual information used by travelers who are visually impaired in street detection. Detectable warnings were developed to address this issue. This research will provide us with findings that will assist us in better understanding the impact that these detectable warnings have on persons who ambulate using wheeled mobility devices.

If you utilize a wheelchair or scooter to travel in the community independently and are interested in learning more about participating in this research project, contact:

Helen Lee, Assistant Professor
Western Michigan University Dept. of Blindness & Low Vision Studies
Helen.Lee@wmich.edu / 269-384-0340
Appendix B

Screening Script
Hello ____________________________, I'm Helen Lee and I will be conducting this research study about how detectable warnings on ramps affect travelers who use wheelchairs or scooters for mobility. I currently teach at Western Michigan University and am conducting this study as my dissertation project. Can you tell me how you found out about my research study? May I ask you a few questions before telling you more about participation in my study? Do you travel in the community on a regular basis? Do you travel alone? How many days a week do you travel around town? Do you use the transit system, paratransit, or do you have your own transportation? What type of wheeled mobility device do you use? Do you have any medical condition that limits how often or how long you can be out and about? Do you have, at this time, any specific questions regarding participation about this study? I'd like to tell you a little bit more about the actual research study. The intended aim of this study is to gather information about how these detectable warnings affect the maneuverability of wheelchairs and scooters under two conditions. That is, the raised domes will be arranged in two different patterns on two separate ramps. You'll be asked to travel up and down each ramp several times and will be asked to compare this to a regular concrete ramp without domes. We will ask you a few questions at the beginning and give you specific instructions at the research site. The whole process should take about an hour or less. Do you have any other questions about participating in this study? Are you interested in participating in this study? (If interested) Is there a phone number or email address that I can reach you at about the specific time and date for the actual research activity? When is the best time to contact...
you? Will you need transportation to the research site? Thank you for your interest in this study.
Appendix C

Participant Attributes
<table>
<thead>
<tr>
<th>No.</th>
<th>Mobility Aid</th>
<th>Age</th>
<th>Gender</th>
<th>Etiology</th>
<th>Onset</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Manual</td>
<td>45</td>
<td>M</td>
<td>Cerebral palsy</td>
<td>Birth</td>
</tr>
<tr>
<td>5.</td>
<td>Power</td>
<td>27</td>
<td>F</td>
<td>Arthrogryposis</td>
<td>Birth</td>
</tr>
<tr>
<td>6.</td>
<td>Power</td>
<td>34</td>
<td>M</td>
<td>Cerebral palsy</td>
<td>Birth</td>
</tr>
<tr>
<td>7.</td>
<td>Power</td>
<td>50</td>
<td>F</td>
<td>Diabetes</td>
<td>1 yr.</td>
</tr>
<tr>
<td>10.</td>
<td>Manual</td>
<td>33</td>
<td>M</td>
<td>Spina bifida</td>
<td>Birth</td>
</tr>
<tr>
<td>11.</td>
<td>Power</td>
<td>30</td>
<td>F</td>
<td>Thrombocytopenia</td>
<td>Birth</td>
</tr>
<tr>
<td>13.</td>
<td>Manual</td>
<td>28</td>
<td>M</td>
<td>Cerebral palsy</td>
<td>Birth</td>
</tr>
<tr>
<td>14.</td>
<td>Power</td>
<td>28</td>
<td>F</td>
<td>Muscular dystrophy</td>
<td>Birth</td>
</tr>
<tr>
<td>16.</td>
<td>Power</td>
<td>47</td>
<td>F</td>
<td>Amputee (congenital anomaly)</td>
<td>Birth</td>
</tr>
<tr>
<td>17.</td>
<td>Power</td>
<td>51</td>
<td>F</td>
<td>Cerebral palsy</td>
<td>Birth</td>
</tr>
<tr>
<td>19.</td>
<td>Power</td>
<td>43</td>
<td>F</td>
<td>Osteogenesis Imperfecta</td>
<td>Birth</td>
</tr>
<tr>
<td>20.</td>
<td>Power</td>
<td>18</td>
<td>F</td>
<td>Spinal muscle atrophy</td>
<td>Birth</td>
</tr>
<tr>
<td>21.</td>
<td>Power</td>
<td>68</td>
<td>F</td>
<td>Cerebral vascular accident</td>
<td>2 yrs.</td>
</tr>
</tbody>
</table>
Appendix D

Participant Data Collection Form
Participant ID: ___________________  Date: ________________

Trial #1: ___________________ (ramp & direction)

**Questions for Participants:**
(Circle the response for each question after traveling on each ramp)

Compared to a level sidewalk, how much effort did it take to travel on this ramp?

<table>
<thead>
<tr>
<th>EFFORT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Much less effort than level sidewalk</td>
<td>Same as a level sidewalk</td>
<td>Much more effort than level sidewalk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Compared to a level sidewalk, how safe did you feel when you traveled on this ramp?

<table>
<thead>
<tr>
<th>SAFETY</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Much safer than level sidewalk</td>
<td>Same as a level sidewalk</td>
<td>Much less safe than level sidewalk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Compared to a level sidewalk, how much traction did you have on this ramp?

<table>
<thead>
<tr>
<th>TRACTION</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Much more traction than level sidewalk</td>
<td>Same traction as a level sidewalk</td>
<td>Much less traction than level sidewalk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Compared to a level sidewalk, how comfortable did you feel travel on this ramp?

<table>
<thead>
<tr>
<th>COMFORT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Much more comfortable than level sidewalk</td>
<td>Same as a level sidewalk</td>
<td>Much less comfortable than level sidewalk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ADDITIONAL COMMENTS:**
Appendix E

Rater Data Collection Form
Rating Scales – Safety and Negotiability on Ramps

Ramp View Trial # Participant #
Mobility Aid

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Much better than brushed concrete ramp</td>
<td>Better than</td>
<td>Little better</td>
<td>Comparison ramp – brushed concrete w/o domes</td>
<td>Little worse</td>
<td>Worse than</td>
<td>Much worse than brushed concrete ramp</td>
</tr>
</tbody>
</table>

Better ←Baseline → Worse

Going Up:

1. Effort required (e.g. participant may lean forward in manual chair, may be slower traversing domes surfaces, may grip wheel rim tighter).

2. Stability (look for balance or tipping of wheelchair).

3. Wheels slip (look for discontinuity in wheel motion incongruent with activation of chair; or traction may be better).

4. Wheel(s) become trapped in between domes (look for difficulty maneuvering for directional control, exaggerated oscillation of front wheels).

Going Down:

1. Effort required.

2. Stability (see above).

3. Wheels slippage (or traction – see above).

4. Wheel(s) become trapped in between domes (entrapped).

Rater’s Comments:
Appendix F

Human Subjects Institutional Review Board Approval
Date:       June 17, 2004

To:    George Haus, Principal Investigator
       Helen Lee, Student Investigator for dissertation

From: Mary Lagerwey, Ph.D., Chair

Re:    HSIRB Project Number: 04-05-37

This letter will serve as confirmation that your research project entitled “Effects of Detectable Warnings on Individuals with Mobility Impairments” has been approved under the expedited category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination:       June 17, 2005