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A large-scale controlled experiment on pedestrian walking behavior involving individuals with disabilities

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ABSTRACT

It is imperative to design walking facility infrastructures to accommodate the needs of all pedestrian, including individuals with disabilities. Unfortunately, individuals with disabilities are often overlooked due to the lack of available data. The purpose of this study was to measure the individual pedestrian walking behaviors of individuals with disabilities through controlled video tracking experiments of heterogeneous crowds in various walking facilities; including passageways, right and oblique corners, doorways, bottlenecks, and stairs. The goal of this paper is to provide an overview of conducting experimental research on pedestrian walking behavior involving individuals with and without disabilities, including automated video tracking methods, data collection, logistical issues, processing methods, and lessons learned from conducting a large-scale study. The findings support future large-scale experiments related to the pedestrian walking behavior of individuals with disabilities. The results can be used to calibrate and validate pedestrian traffic flow models capturing the behaviors and interactions of crowds which include different types of individuals with disabilities.

1. Introduction

Walking facilities are important infrastructures which must be designed to accommodate the behavior of pedestrians to be effective. Heterogeneity in pedestrian composition is one important factor generally overlooked in walking facility design guidelines. Particularly, individuals with disabilities are often overlooked due to a lack of available data on their pedestrian behaviors. Yet individuals with disabilities represent a significant portion of the population, accounting for 12.6% of the working age population (i.e., about 30.2 million) and 16.7% of the total population (i.e., about 51.5 million) of the United States (U.S. Census Bureau, 2010).

In the United States, the International Building Code (IBC) (ICC, 2012) comprises the relevant health, safety, and welfare codes for the design and construction of walking facilities. However, the guidelines overlook heterogeneity in pedestrian composition. To account for the needs of individuals with disabilities, the Americans with Disabilities Act Accessibility Guidelines guide the design and construction of accessible walking facilities for individuals with disabilities. These codes grew out of civil rights policy, the ADA, and are not necessarily evidence-based practices, but were developed through a public consensus process. Whether these regulatory standards, particularly those for pedestrian environments, effectively protect the health, safety, and welfare of individuals with disabilities is not well understood and little empirical research has been conducted to evaluate the standards for individuals with disabilities' needs.

Shi et al. (2015) completed a comprehensive review of the literature and found a great deal of research has been done to collect and observe pedestrian walking behavior. For example, Sisiopiku and Akin (2003) studied pedestrian behaviors and perceptions toward different pedestrian facilities such as signalized and unsignalized intersection crosswalks, unsignalized midblock crosswalks, physical barriers and crosswalk furniture. Some studies involved walking experiments to examine pedestrian behaviors in specific built environments and controlled conditions such as crowd environments. Daamen and Hoogendoorn (2003) conducted walking experiments in the Netherlands to derive walking behaviors in passageways and bottlenecks under different pedestrian

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flow scenarios such as un-directional, bi-directional, and cross pedestrian flows. Eighty individuals participated in ten experiments performed to observe pedestrian walking behavior in standard, station, and shopping conditions. The experimental process was recorded using a wide lens digital camera and walking trajectories were extracted and analysed to present microscopic (i.e., walking speed) and macroscopic (i.e., pedestrian flow) characteristics of the pedestrian stream in the various experimental scenarios.

Another series of large-scale walking experiments were conducted in Germany to observe pedestrian behaviors in corridors (Zhang, 2012; Zhang et al., 2012), bottlenecks (Seyfried et al., 2008, 2009; Kretz et al., 2006). Most of these studies explored macroscopic fundamental diagrams to study the impacts of different environments on the relationships of pedestrian speed, flow, and densities. Turning movements of pedestrians have been studied in complex geometrics such angled corridors (Dias et al., 2013, 2014; Gorrini et al., 2013; Aghabayk et al., 2015). For example, Dias et al. (2013) conducted a series of walking experiments to understand how different angled corridors impacted walking speed of individuals. They found that angles of more than 90 degree can significantly decrease the walking speed. While these empirical studies provide valuable knowledge on pedestrian needs, none of these studies addressed vulnerable pedestrians such as individuals with disabilities. The lack of research on the walking behavior of individuals with disabilities is in part due to the difficulty of data collection.

Notwithstanding, there are a limited number of studies on the walking behaviors of individuals with disabilities. For instance, Pecchini and Giuliani (2015) studied street crossing behaviors of individuals with disabilities. People with different types of disabilities were surveyed and design recommendations were suggested to better include the needs of individuals with disabilities. Few studies conducted controlled experiments to study on behaviors of individuals with disabilities. Boyce et al. (1999a) measured egress speed of 155 individuals involving unassisted ambulant, unassisted wheelchair users, assisted ambulant and assisted wheelchair users on level surfaces, ramps, corners, and stairs. They also conducted another study to measure the ability of 113 individuals with disabilities to negotiate doors (Boyce et al., 1999b). Kuligowski et al. (2013) conducted an experiment in a six-story building and studied the stair evacuation speed of older adults and people with mobility impairments. Wright et al. (1999) evaluated walking speed of 30 individuals with visual impairments through an egress route. Miyazaki et al. (2003) carried out a series of experiments using 30 participants and one participant with a wheelchair to describe the behavior of individuals encountering an individual using a wheelchair in a corridor with variable widths. Daamen and Hoogendoorn (2011) conducted an experiment to investigate the capacity of doorways with consideration of the elderly and people with disabilities in the Netherlands. In their experiments 75 children, 90 adults, 50 elderly individuals, 3 individuals using wheelchairs, and 3 individuals with visual impairments took part. The researchers tried to simulate different stress levels and collected behavior data using digital video and an infrared video cameras. Review of past studies demonstrates that most studies focused on the egress behavior of individuals with disabilities and few articles addressed the ability of individuals with disabilities to negotiate built environments in crowded situations. Therefore, large-scale empirical research is needed to examine to what extent the behavior of individuals with disabilities is affected by U.S. built environment regulatory standards.

To address this lack, in 2012 a series of large-scale controlled pedestrian behavior experiments which included individuals with disabilities were carried out at Utah State University (USU). The purpose of the study was to measure the stated and revealed pedestrian walking behaviors of individuals with disabilities in different walking facilities, including a level passageway, right angle, oblique angle, doorway, bottleneck, and stairway. This paper provides an overview of experimental research on individuals with disabilities' pedestrian walking behaviors, including automated video tracking methods, data collection, logistical issues, processing methods, and lessons learned from conducting a large-scale study. Moreover, this paper compares walking behavior differences between individuals with and without disabilities. Specifically, statistical analysis are presented to investigate the walking speed and spacing behaviors of different individual types. The findings support future large-scale experiments related to pedestrians with disabilities' walking behavior and advance our empirical understanding of the pedestrian behaviors of individuals with disabilities.

2. Experimental methods

2.1. Participants recruitment

Study participants were a mixture of people without disabilities and people with mobility-related physical, sensory, or other types of disabilities, including hearing and intellectual impairments. The criteria for a mobility-related disability were based on the definition from the U.S. Census Bureau's American Community Survey (ACS) (U.S. Census Bureau, 2010) as: (Sensory Disability) blindness, deafness, or a severe vision or hearing impairment; (Physical Disability) a condition which substantially limits basic activities such as walking, climbing stairs, etc.; or (Go-Outside-Home Disability) a condition which creates difficulty in going outside the home to shop or visit a doctor's office. Participants with disabilities were recruited in collaboration with the Center for Persons with Disabilities (CPD) at USU. Study participants without a mobility related disability were selected from USU students. Participants were partially compensated for their time with a $50 stipend for each day of experiments.

In total, 311 individuals between 17 and 80 years old participated. Specifically, we recruited 231 participants (189 without disabilities and 42 with disabilities) for the circuit experiments and 80 participants (60 without disabilities and 20 with disabilities) for the stair experiments. For the circuit experiments about 26% of the participants with disabilities had a visual impairment, 38% had a physical impairment, and 36% had other types of disabilities. For the stair experiments, 35% of the participants with disabilities had a visual impairment, 25% had a physical impairment and 40% had other disability types. Some participants had more than one disability. Fig. 1 shows the distribution of disabled participants in both the circuit and stair experiments. For detailed information about participant recruitment process, readers are referred to Sharifi (2016); Sharifi et al. (2015a,b); Sharifi et al. (2016) and Stuart et al. (2015).

2.2. Setting

For the crowd experiments, the Motion Analysis Lab of USU's department of Health, Physical Education and Recreation (HPER) was selected. The 280 square meter laboratory with 8-meter high ceilings was conducive to video tracking technology and camera suspension. A circuit was temporarily constructed within the Motion Analysis Lab to allow participants to pass through various walking facilities in an efficient loop. Eight foot tall panels formed the walking facilities designed to comply with Americans with Disabilities Act Accessibility guidelines (ADAAG, 2002) and the International Building Code (ICC, 2012). For the stairwell experiments, two standard stairwells in the HPER were chosen. Fig. 2 presents the layout of the study areas.