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Low-floor bus design preferences of walking aid users during simulated boarding and alighting

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Abstract. Low-floor buses represent a significant improvement in accessible public transit for passengers with limited mobility. However, there is still a need for research on the inclusive design of transit buses to identify specific low-floor bus design conditions that are either particularly accommodating or challenging for passengers with functional and mobility impairments. These include doorway locations, seating configuration and the large front wheel-well covers that collectively impact boarding, alighting and interior movement of passengers. Findings from a laboratory study using a static full-scale simulation of a low-floor bus to evaluate the impact of seating configuration and crowding on interior movement and accessibility for individuals with and without walking aids are presented (n=41). Simulated bus journeys that included boarding, fare payment, seating, and alighting were performed. Results from video observations and subjective assessments showed differences in boarding and alighting performance and users' perceptions of task difficulty. The need for assistive design features (e.g. handholds, stanchions), legroom and stowage space for walking aids was evident. These results demonstrate that specific design conditions in low-floor buses can significantly impact design preference among those who use walking aids. Consideration of ergonomics and inclusive design can therefore be used to improve the design of low-floor buses.

Keywords: Transportation, low-floor bus, accessibility, walking aids, inclusive design

1. Introduction

Public transportation is an essential public service that should be designed to benefit as many individuals as possible. United States (U.S.) federal regulations and guidelines require transit agencies to transport and accommodate mobility aids for persons with disabilities, particularly those who use wheeled mobility devices [10,11].

U.S. transit agencies are also faced with the challenge of having to accommodate other mobility devices such as walkers, canes, crutches, oxygen cylinders and service animals [3,5,8]. But federal regulations and guidelines for accessibility on transportation vehicles [10,11] are less specific on how to safely accommodate these devices. One concern with larger walking aids like walkers and rollators is the stowage space needed to prevent obstruction or risk to other passengers when they are otherwise stored in the aisle or in seats required for other passengers.

Low-floor buses represent a significant improvement in accessible public transit for passengers with limited mobility primarily by eliminating the need for steps at the entry doorway. However, there are still problems associated with the interior design of low-floor buses. These include constricted movement of passengers in the forward area of the bus due to large wheel-well covers, congestion due to irregular seating configurations, and the lack of adequate handholds for support [3,7-9]. These challenges may be

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particularly problematic for those who use mobility aids.

The aim of the present study was to evaluate the impact of interior design and crowding in low-floor buses on boarding, disembarking, and interior circulation for ambulant passengers with mobility impairments using walking aids such as canes and walkers.

2. Methodology

2.1. Simulation Description

A full-scale static simulation of a low-floor bus was constructed to systematically evaluate human performance across a wide variety of realistic bus interior design configurations through reconfigurable seating arrangements, wheelchair securement spaces, and different conditions of boarding and disembarking. Full-scale environment simulations provide a valuable and cost-effective method for evaluating whether the intended users can safely and effectively perform critical tasks in the expected use environment. Ergonomics researchers have previously used environmental simulations to evaluate design alternatives pre-production and generating new design requirements for transportation vehicles [2,6,12].

Based on a review of transit buses operating in the U.S., three bus layouts were identified for simulation purposes that differed substantially in physical configuration. The designs adhered closely to federal accessibility requirements [10] and dimensional clearances recommended by the U.S. bus industry [1] for aisle widths, wheelchair accessible pathways, seat spacing and the positioning of handholds and stanchions. Boarding and alighting occurred over a folding access ramp of a 1:6 incline slope. Side-facing fold-down seats were provided in the wheelchair securement area to accommodate seated passengers when the space was not occupied by a wheeled mobility device.

Bus layout 1 (L1) included an access ramp in the front doorway, a floor mounted fare payment box positioned adjacent to the driver's seat, two spaces for wheelchair securement immediately behind the front wheel-wells, and forward facing seats throughout the remainder of the bus interior. This layout is very typical of low-floor buses used in many U.S. cities, e.g. Buffalo, Washington, D.C.

Bus layout 2 (L2) included ramps located at the front and rear doorways, a wall-mounted fare payment box positioned near the rear doorway, side-facing seats along the sides of the bus interior i.e. perimeter seating, and two spaces located along the curb side of the bus for wheelchair securement. The rear doorway was used for boarding, and the front door for alighting.

Bus layout 3 (L3) included an access ramp located at the rear doorway, a wall mounted fare payment box positioned near the rear doorway, a wheelchair securement space on the road side and curb side of the bus to the right of the doorway, and forward facing seats throughout the remainder of the bus interior.

For each of the bus layouts, two levels of crowding were simulated using seated mannequins – high crowding where only one pair of seats were available restricting seating choice, and low crowding where only half the number of seats were occupied.

Study participants evaluated each of the six conditions by undertaking a simulated bus journey that included boarding from a sidewalk, fare payment using a smart-card, locating and moving to a vacant seat, getting into and out of the seat, moving to the exit door and alighting (Figure 1). Participants had the opportunity to sample different seating conditions involving combinations of front- or side-facing seat positions, as well as front and rear entry and exit conditions.

Following each journey, participants were asked to provide ratings of design related to the configurations and interviewed to assess their difficulty in completing various aspects of the journey. Movements were recorded using conventional video cameras and a three-dimensional active marker motion capture system.

2.2. Research Participants

Forty-one ambulatory adults between the ages of 18-80 years were recruited from the general public and local organizations serving the elderly and persons with disabilities to participate in the study. This included thirteen individuals who used a walking cane, eleven who used a walker, five who did not use an ambulatory aid but had a walking impairment, and twelve who did not have a walking impairment. A majority of the sample used fixed-route buses frequently, and only four walker users depended on ADA (Americans with Disabilities Act) paratransit services for transport. A summary of the four different sub-groups is presented in Table 1.

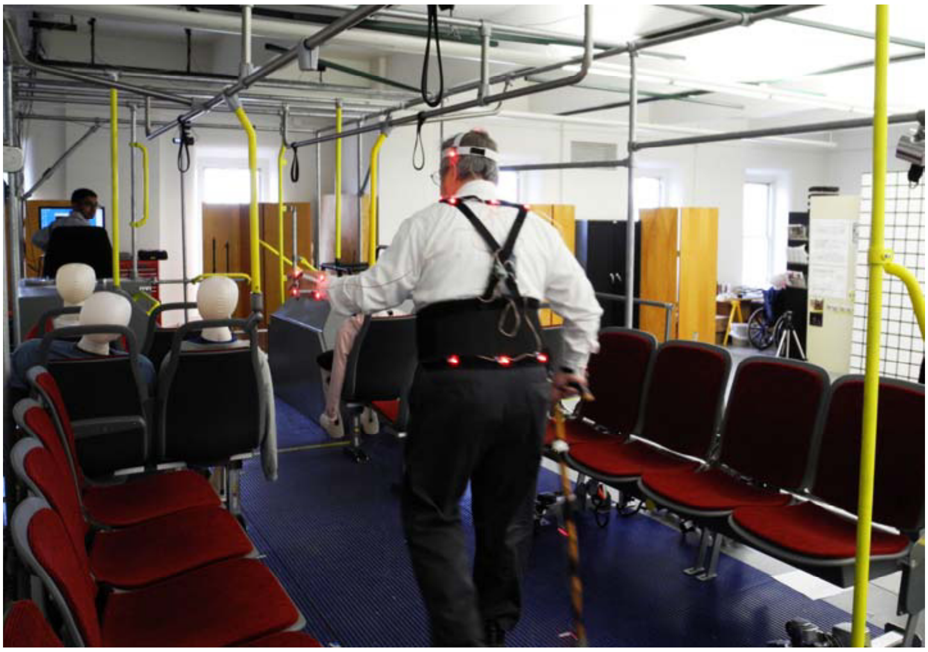

Fig.1. Photograph of the simulated environment depicting bus layout 3 with a cane user during the boarding process

Table 1

Demographic information of the study sample (n=41) stratified by use of walking aid and walking impairment.

	Cane Users (n=13)	Walker Users (n=11)	Mild Imp. (n=5)	Able-bodied (n=12)	Total (n=41)
Gender (F, M)	7 , 6	9, 2	2, 3	8 , 4	26, 15
Age: Mean (SD) yrs.	53.6 (11.1)	63.1 (10.7)	42 (10.7)	44 (9.3)	52 (13)
Bus Users (>= once a week)	10	6	4	9	29
Difficulty walking or climbing stairs e.g. entering home, boarding a bus:					
No difficulty	2	2	1	11	16
Some difficulty	10	6	3	1	20
A lot of difficulty	1	3	1	0	5

3. Results

3.1. Preference in Bus Layout Design

When asked to rate the travel conditions tested, the layout with a perimeter seating configuration (L2) was preferred overall in terms of physical access for both the low and high crowding conditions. The design with forward entry and exit (L1) was consistently rated poor in conditions with high crowding. Participant preferences are summarized in Table 2.

3.2. Boarding and Alighting

Regarding preference of doorway location for boarding, ten participants preferred the front door while eight preferred the rear door. Sixteen participants preferred the front door for alighting, and thirteen preferred the rear door. Many did not express any preference. Reasons for choosing the rear door included "taking less time for boarding", "less constrained for space", "easier to locate a vacant seat" and "quicker exit as most passengers sit up front". Regarding the use of the front door, participants commented on "needing to interact with the driver (in asking for directions)", "feeling safer" and "preferring to be seated closer to the driver".

Table 2

Preference in bus design for layouts L1, L2 and L3, across conditions of low and high crowding.

	Cane Users (n=13)	Walker Users (n=11)	Mild Imp. (n=5)	Able-bodied (n=12)	Total (n=41)
Low Crowding					
Most preferred	L1	L2	L2	L2	L2
Intermediate	L2	L3	L1	L3	L1
Least Preferred	L3	L1	L3	L1	L3
High Crowding					
Most preferred	L2	L2	L2	L3	L2
Intermediate	L3	L3	L3	L2	L3
Least preferred	L1	L1	L1	L1	L1

3.3. Interior Movement

Interior movement to and from the seat was relatively more difficult in conditions of high crowding and noticeably problematic for walker users. The narrower aisles adjacent to forward-facing seats encountered in high crowding conditions for designs L1 and L3 did not provide adequate space for walker users to turn and orient with the seat. Participants reported being concerned about finding a seat quickly to avoid delays or accidently bumping into passengers when moving through the aisles, and in finding a seat that allowed storage of the walking aid without obstructing other passengers.

A few participants also commented that finding a seat quickly without having to walk a distance was most paramount. Real-life experiences of the bus taking off before the person could find a seat was cited as the primary reason.

3.4. Seating

A large majority (91%) of the participants preferred side-facing seats over the front-facing seats. These included 7 of 13 (54%) cane users, all eleven (100%) walker users, 2 of 5 mildly impaired, and 8 of 12 (67%) able-bodied participants. Commonly cited reasons were "more legroom", "ease of getting in to and out of the seat", "wider aisle" and "more room for luggage". Three participants did not express any preference.

Walker users strongly favored side-facing seats as it provided for legroom and space to position the walker directly in front during sitting and standing and without the aid of a handrail or stanchion. During travel, participants tried to draw the walker close to the seat as possible with the intent of keeping the aisle clear for other passengers.

The primary complaint against forward facing seats was the inadequate leg-room, with walker users particularly inconvenienced by the lack of space for stowing the walker even when folded – although most users preferred to travel with the walker unfolded as it is used for support when getting into and out of the seat. For a few cases, the bags and purses hanging off the walker prevented it from folding properly.

Reasons for preferring front-facing seats included needing "to see where the bus was going", avoiding the "direct stare of other passengers" seated across the aisle, "less sway" during acceleration or deceleration. If the spacing between front-facing seats were to be increased it is likely that a few more individuals would prefer these seats over side-facing seats.

3.5. Use of support features

Among the different support features, vertical stanchions were most preferred and frequently used along with the horizontal handles on the back of forward-facing seats primarily in seating, standing up, and during interior movement. In general, overhead handrails were found to be too high for effective use.

In a response to questions about support features, more than half the number of participants (27 of 41) commented on having found stanchions very helpful, particularly among people with walking impairments "for support and balance", "when sitting down and getting up", "as the straps (on the overhead handrail) were too high", "handy if you had to travel standing" and "good to hold on to if the bus were moving".

Most of the participants including cane users needed a handhold or stanchion when getting into and out of the forward-facing seats. Walker users, however, relied on their walker for support when getting into or out of the seat.

4. Discussion

Individuals with mobility impairments were found to require longer time and reported greater difficulty for some tasks including getting into a seat, moving to a vacant seat, and getting to the exit door particularly in more crowded conditions. The study also showed the need for adequate device storage space and the importance of support features like handrails and vertical stanchions during ambulation and seating by people with mobility limitations. A detailed analysis of the video and movement data is being performed to more specifically characterize boarding and alighting movement and behavior during the trials.

Not all the designs considered in this study were equally favored based on previous literature and feedback from a few industry representatives, either due to prevailing market trends (e.g. forward-facing seats being more prevalent), limitations in existing station infrastructure (e.g. difficulties with ramp deployment and fare-payment in rear-boarding), and costs (e.g. use of two folding ramps). However, passenger concerns about inadequate stowage space for non-wheelchair mobility aids such as walkers, canes, other items carried with walking aids, and insufficient assistive design features like handholds and stanchions can be overcome by making modest but concerted changes to the bus interior.

In many of the low-floor buses that have forward boarding, the priority seats for the elderly and mobility impaired are often located in the same area designated for wheelchairs. Further, these might be the only side-facing seats on the bus that provide the necessary legroom, causing the ambulant disabled and wheeled mobility users to compete for the same space. The legroom provided between forward-facing seats was also commented as being inadequate by many participants that had walking impairments. During the study, the spacing between forward-facing seats was set at 675 mm (26.5 in.) and measured at seat pan height from the seat back cushion to the rear panel of the seat in front. This value represents the recommended industry-minimum [1] and was also observed in field measurements – but increasing the spacing is recommended.

Study participants were required to use a smart card for fare payment, which consists of a programmable card to automatically pay the fare when brought within a few inches of a sensing device or card-reader. Participants reported significant ease in using this system, decreasing payment time as well as the anxiety of handling coins and producing exact change. These systems are a significant improvement over the typical magnetic strip cards in terms of technology and usability [4] and have been introduced in some larger cities like Los Angeles and Washington, D.C.

The focus of this study was on the preferences that ambulatory individuals with and without walking aids had towards the physical configuration of the bus environment. While the study did not simulate the bus in movement, the use of the laboratory-based environmental simulation provides the opportunity to evaluate how new concept designs of transit vehicles could impact user performance. Results clearly demonstrate that design features in low-floor buses can impact design preferences; particularly for those who use walking aids. These results support the use of ergonomics and inclusive design to improve the design of future low-floor public transit buses.

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