ARTICLE IN PRESS

Journal of Transport & Health ■ (■■■■) ■■■–■■■

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Biomechanical demand analysis of older passengers in a standing position during bus transport

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ARTICLE INFO

Article history:
Received 15 June 2016
Received in revised form
6 December 2016
Accepted 7 December 2016

Keywords:
Bus transportation
Field study
Elderly
Ground reaction forces
Muscle activity
Handgrip forces

ABSTRACT

Bus driving maneuvers are likely to trigger perturbation forces that may cause postural instability in standing passengers and cause tumble. These noncollision incidents are considered a major cause of injuries and may induce passenger discomfort in public transport.

Therefore, we analyzed the effects of acceleration and deceleration forces on older passengers in an upright standing position in everyday bus transport situations. We recorded ground reaction and handgrip forces, electromyographic data of the leg muscles, and the acceleration pattern of 8 elderly participants (68.1 ± 5.2 years). The participants were exposed to acceleration and deceleration maneuvers while standing upright in three different positions: in the direction of travel (IT), against the direction of travel (AT), and sideways to the direction of travel (ST).

The acceleration pattern of the bus was similar to everyday driving situations (starting and stopping in traffic). Ground reaction forces were higher in free-standing positions, as expected, with peak forces of 135% (ST) to 165% (AT) of individual body weight, than in standing position by grasping a strap, with peak forces of 120% (all conditions). However, when participants grasped the strap, peak forces comprised 65% (ST) to 90% (AT) of individual maximal pulling power. A passenger may experience these forces numerous times during a typical bus transport. Electromyographic analysis revealed a correlation between jerk events and muscle activation and coactivation of antagonistic muscles.

This study presents, for the first time, relevant information with regard to the biomechanical demands of older passengers standing upright in bus transportation. On this basis, conceptual solutions may be introduced to improve passenger safety and comfort. Further research studies exploring the relationship between acceleration forces and travel safety of the elderly should be conducted.

1. Introduction

Mobility is indispensable for participation in modern society and contributes greatly to the quality of life. Limitations in individual mobility may have many consequences such as a reduced ability of independent movement and decreased social participation (Metz, 2000, Alsnih and Hensher, 2003). This is of crucial importance, particularly for older or disabled people. From a structure-analytic perspective, mobility can generally be subdivided into two components: primary and secondary

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http://dx.doi.org/10.1016/j.jth.2016.12.002

(Haas et al., 2013). The primary component comprises the ability to walk and to maintain postural control, whereas mechanical resources (e.g., modes of public transportation) form the secondary mode of mobility (Haas et al., 2013). To ensure a seamless mobility chain, both components have to be considered. If only one link of this chain is invalid (impeded or impossible use of a mobility mode), for instance, if construction barriers cause poor or limited accessibility to the transport mode, the need for coordinating both primary and secondary mobility components will become obvious. For example, imagine elderly people traveling by bus and intending to exit at the next station. Intuitively, they may move to the exit before the bus approaches the bus stop. During this time, people who are in an upright standing position are exposed to acceleration forces (perturbations) due to driving maneuvers of the bus. These perturbations, which affect the people's base of support, may be an immediate cause for tumble (Halpern et al., 2005) and may also be associated with passenger discomfort (Graaf and Van Weperen (1997)). A number of authors report that many passengers are injured by so-called "noncollision incidents" (Halpern et al., 2005, Bjornstig et al., 2005). Estimates of documented injuries not attributed to impact situations range from a maximum of nearly two-thirds (Zegeer et al., 1993, Halpern et al., 2005, Kirk et al., 2003) to a minimum of one half (Bjornstig et al., 2005) of injuries (with a positive trend with age). Acceleration forces and boarding and exiting situations are considered primary factors in noncollision incidents (Zegeer et al., 1993, Bjornstig et al., 2005, Halpern et al., 2005).

Traveling by bus is principally a safe undertaking. In Germany, in 2015, more than 5.2 billion passengers traveled by bus (Federal Statistical Office, 2016b). A study published by the Federal Statistical Office of Germany (Statistisches Bundesamt) showed that out of 6107 bus passengers injured in 2015, 21.4% were aged 65 or older, which implies a rate of approximately one injury per one million passengers [in comparison, 220,000 car accidents involving personal injury were reported in 2015, in which 10% of the involved people were aged 65 or older (Federal Statistical Office, 2016a)]. A study by Albertsson and Falkmer (2005), Enhanced Coach and Bus Occupant Safety Project (ECBOS), conducted in eight European countries (Austria, France, Germany, Great Britain, Italy, the Netherlands, Spain, and Sweden) cites a number of roughly 35,000 passengers injured annually because of bus transport incidents (ECBOS, 2001). Considering the total number of transported bus passengers, we can infer that there is a considerable number of unreported noncollision bus incidents in the eight countries cited. However, there are no statistics that show the absolute value of collision vs. noncollision bus incidents. Moreover, incidents due to acceleration and deceleration forces may not only lead to physical injury but more often to general passenger discomfort. Consequently, it is necessary to examine the biomechanical demands of older passengers to better understand safety and comfort in bus transportation (Brooks et al., 1978).

A common method in dynamic posturography is to challenge the participants' base of support to study postural control mechanisms (Nashner, 1976). Several strategies have been employed to maintain an upright posture under dynamic conditions. Here, we have to differentiate between the fixed-support strategies (ankle strategy, i.e., movements mainly of the ankle; hip strategy, i.e., movements mainly of the hip) and the change-in-support strategy (i.e., stepping strategy). With regard to the fixed-support strategies, the perturbation forces (i.e., amplitude, acceleration) are minor such that physically challenged people can easily maintain an upright standing position. The stepping strategy is applied at higher acceleration forces. This corrective motion represents the passengers' last opportunity to prevent tumble (Maki and McIlroy, 1997) and is often accompanied by a rapid grasping movement (grasping strategy).

Previous research has shown that the ability to perform compensatory movements to retain balance is impaired in the elderly because of a general age-related loss of sensory and executive functions (Maki and McIlroy, 2006). However, compared to the "translating platform paradigm" (Brown et al., 2001, Tokuno et al., 2010) conducted under laboratory environment conditions bus travel postural challenges show a more complex pattern (i.e., longer duration, different maximum values, and different signal morphologies) (Kirchner et al., 2014). Although there are studies whose sole objective is to simulate postural balance abilities during bus transport maneuvers (Robert et al., 2007), comparison to real-life bus acceleration forces remain questionable. Moreover, studies have shown that acceleration forces in bus transportation often exceed thresholds for balance maintenance (Graaf and Van Weperen, 1997, Palacio et al., 2009).

Therefore, to analyze bus perturbations with high ecological validity, it is indispensable to directly measure participants' behavior in a moving bus (Haas et al., 2013). In this study, the effects of bus acceleration and deceleration forces on standing passengers are measured in terms of biomechanical demands. The results present a basis from which these perturbation forces can be evaluated taking into consideration the risk and comfort of healthy older participants.

2. Methods

The experiment is approved by the ethics committee of the Fresenius University of Applied Sciences, Idstein, Germany, and complies with the provisions of the Declaration of Helsinki. Eight healthy elderly participants (4 females, 4 males; age: 68.1 ± 5.2 years; height: 168.9 ± 10.6 cm; weight: 74.8 ± 14.2 kg) provided written informed consent to the experimental procedure and voluntarily participated in this study. Before exposure to the bus transport situations, typical clinical tests were conducted to assess the participants' physical status (in a separate room). The typical clinical tests are as follows: functional gait assessment (FGA) (Wrisley et al., 2004), the timed up and go test (TUG) (Podsiadlo and Richardson, 1991), and the ten-meter walking test (TMW) (Watson, 2002).

First, the participants were asked to stand upright in a bus (Mercedes-Benz Citaro C2, automatic transmission) in three different positions: in the direction of travel (IT), against the direction of travel (AT), and sideways to the direction of travel (ST)

Please cite this article as: Schubert, P., et al., Biomechanical demand analysis of older passengers in a standing position during bus transport. Journal of Transport & Health (2017), http://dx.doi.org/10.1016/j.jth.2016.12.002