Safety Science 105 (2018) 128–133

Contents lists available at ScienceDirect

Safety Science

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

Reducing non-collision injuries aboard buses: Passenger balance whilst walking on the lower deck

Xenia Karekla*, Nick Tyler

Department of Civil, Environmental and Geomatic Engineering, Centre for Transport Studies, University College London, Gower Street, London WC1E 6BT, UK

A R T I C L E I N F O

Keywords:
Non-collision injuries
Bus acceleration
Level walking
Balance
Accessibility

A B S T R A C T

Travelling by bus is a way millions of people choose for their everyday activities. However, the large acceleration levels, and therefore the associated increased number of falls and non-collision injuries, force current users to shift to other modes of transport, with cars still remaining the preferred choice.

This study investigates whether there is a possibility to improve the safety and comfort of buses, where all passengers can walk naturally inside a moving bus. Twenty-nine regular bus users, between 20 and 80 years old, were invited to participate in a series of experiments. Their natural gait whilst walking on a flat surface was monitored in a static laboratory and was compared to their gait whilst walking on the lower deck of a moving bus. The examined acceleration levels (low – 1.0 m/s^2, medium – 1.5 m/s^2, high – 2.5 m/s^2) were set in the range of accelerations experienced by passengers on the real bus service in London.

An ANOVA test was conducted on measures of changes in gait (double support time) as a measure of balance, taking into account passengers' age and gender as well as the acceleration of the bus. The results revealed that, although the dimensions of the lower deck of the bus are narrow, passengers are still able to move to the back of the stationary bus whilst sustaining their natural balance. However, their ability to control balance reduces with the increase of acceleration.

1. Introduction

There are more than 6000 injuries on buses in the UK reported every year, with half of them suffered by 65 year olds and over (Kendrick et al., 2015). However, there seem to be 800 falls every day for people over 65 that are not officially reported and occur due to the developed accelerations (Age UK, 2009). Non-collision injuries on buses in London have increased by 82% between 2014 and 2015, and more female than male bus passengers are reporting balance loss incidents (Transport for London, 2015). Statistics from other countries in Europe and states in the USA are similar to those reported for the UK (O'Neill, 2016).

Passenger comfort is affected by technical, physiological or psychological factors (Oborne, 1978). Although comfort is subjective, it can be influenced by the design and ambience of the vehicle, e.g. position of handrails, noise and vibration, heating and ventilation, crowding (Bird and Quigley, 1999; Suzuki et al., 2006; Cox et al., 2006). The lack of perceived safety and comfort of buses, especially for older people, may act as a barrier to use. In England, bus journeys in the first quartile of the year 2016 reduced by 2.5% compared to those undertaken between 2014 and 2015 (Department for Transport, 2016). Similar trends are recorded for Europe (Eurostat, 2016).

One of the main documented reasons (3rd most important) for passenger dissatisfaction with the bus service and for making them turn away from using bus services is the lack of smoothness of the bus acceleration (London Travel Watch, 2010). Due to the high acceleration levels, 18% of bus passengers in England report to be dissatisfied with the smoothness of the service (Transport Focus, 2014), whereas many older people over 65 refrain from using the service as they think it is dangerous (Green et al., 2014). The danger they are referring to lies with the feeling of reduced stability they experience during their journeys. Generally, older people have weaker limbs and sway more than younger people (Hsue and Su, 2014), hence they present reduced balance in static environments (Era et al., 2006). One would expect this behaviour to be amplified when they negotiate dynamic environments, such as a moving bus, but this has not been investigated before the present study.

Buses are not used only by healthy individuals. More than 20% of bus journeys in England are made by people with a disability or long-term illness, and accessibility is an issue for them just as it is for those travelling with heavy luggage or small children. Passenger dissatisfaction related to the smoothness of the bus service for these people reaches up to 24% in some areas of England (Transport Focus, 2015).

* Corresponding author.
E-mail address: x.karekla@ucl.ac.uk (X. Karekla).

https://doi.org/10.1016/j.ssci.2018.01.021
Received 23 June 2017; Received in revised form 31 January 2018; Accepted 31 January 2018
Available online 22 February 2018

Hence, there is a general dissatisfaction with bus services around the world, and passenger falls or injuries require large national funds for treatment. Indicative, in 2010 £4.6 million was spent every day in the UK and US$ 82 million in the USA to cover fall-related costs (Age UK, 2010).

Buses interact with and depend on the movement of other vehicles on the road. Therefore, the accelerations recorded on them are much higher than those on other public transport modes and can often exceed the recommended threshold of 2.0 m/s^2 within which standing passengers can only maintain balance when holding a handrail (Browning, 1972; De Graaf and Van Weperen, 1997; Dorn, 1998). For example, the bus service in Amsterdam reaches accelerations of 2.2 m/s^2 compared to 1.5 m/s^2 on the metro system (De Graaf and Van Weperen, 1997), and buses in London reach accelerations of up to 2.5 m/s^2 (Sale, 2007), much higher than the 1.3 m/s^2 level of acceleration recorded on the London Underground network (Transport for London, 2009). Passengers' comfort is also affected by the rate of acceleration. Levis (1978) found that perceived comfort correlates more with jerk than acceleration. Acceleration rates below 0.9 m/s^3 offer a comfortable journey to passengers (Castellanos and Fruett, 2014), whereas an acceleration rate of 0.6 m/s^3 is considered ideal (Vuchic, 1900). In theses initial experiments, the impact of bus acceleration on passenger gait and balance is studied. Subsequent experiments can be focused on the effect of jerk on passenger movement.

This paper investigates people's ability to control balance inside the dynamic environment of a moving double-decker bus, a mode of transport widely used by many people in international urban centres, with the aim to define an acceptable level of bus acceleration below which most passengers can move freely during their journeys. This is achieved by monitoring people's natural gait in a static environment and comparing it to their gait, and therefore ability to remain upright whilst moving inside a moving bus. The observed differences in walking style will indicate the impact of the environment, e.g. bus design or movement, on passengers' balance. Taking into account that balance deteriorates with age and that women sway more than men (Hsue and Su, 2014), passengers' age and gender will also be considered when comparing their walking style.

2. Methods

A series of randomly repeated experiments under controlled conditions was organised in the static environment of a university laboratory (PAMELA, UCL) and on a real double-decker bus, owned by UCL. After obtaining ethical approval (4464/001), 29 regular bus users, between 20 and 80 years old, were recruited to undertake these experiments on two different days (16 males, 13 females, 47.2 (± 16.1) years, 172.9 (± 10.4) cm, 73.0 (± 14.3) kg). More information on the physical characteristics of each age group can be found in Table 1.

In the static environment, participants were asked to take ten steps on a flat surface at their preferred speed, whilst their natural gait was being recorded by an in-shoe plantar pressure system (F-Scan mobile system, Tekscan Inc., Boston, USA – error order: ± 3%). All participants were wearing sport shoes and the pressure sensors were trimmed to their shoe size. The sensors were calibrated based on the participants' weight over the plantar area at which this was applied during a single stance calibration test. On a different day, and equipped with the same gait monitoring device, they were asked to walk on the straight part of the lower deck of the double-decker bus, moving from the front door towards the back of the bus, simulating the situation of a boarding passenger who is searching for a seat on the lower deck (Fig. 1). Initially the bus was stationary and participants' gait was compared to their natural gait (that recorded in the static environment), revealing whether the bus layout affects gait. Subsequently, on the same day, the same task was repeated when the bus was moved at a 'low' (1.0 m/s^2), 'medium' (1.5 m/s^2) or 'high' (2.5 m/s^2) acceleration rate, in order to explore whether the bus movement alters natural gait. The bus was driving on the straight parts of a public road, the surface of which presented a similar good condition to the roads where the London bus service operates, and was not affected by the city traffic. The examined level of acceleration was set in the range of accelerations passengers experience on the current bus service in London (Karekla, 2016) and was monitored by a wireless accelerometer (MT SDK 3.8.1., Xsens Technologies, Netherlands – error order: 0.05 m/s^2). Each task was repeated three times in each environment and participants could use the bus handrails whenever necessary. The two monitoring devices were synchronised and their use did not affect participants' gait.

For the analysis of the data, participants were divided into three age groups following Steenbekker and Van Beijsterveldt's analysis on balance (Steenbekkers and Van Beijsterveldt, 1998): young (20–39 years); middle-aged (40–59 years) and older (over 60 years). Furthermore, changes of temporal and spatial gait parameters, such as walking speed, stance, double support time (DST) and step width, have been shown to be an indication of instability and to provide accurate predictions between fallers and non-fallers. From biomechanical principles, an increase in the value of such parameters leads to greater stability and may be regarded as compensation for instability (Gabell and Nayak, 1984; Kalron and Achiron, 2014). At the same time, an increase in the variability of gait parameters, e.g. DST, indicates poor ability to control balance and increased risk of falls (Gabell and Nayak, 1984; Kloos et al., 2012). This paper focuses on DST, a temporal gait parameter, and analyses the changes and variation of it identified in gait patterns between different environments, which provide information about people's balance. This is important where the reason for instability is the result of having to respond to dynamic changes in the environment, rather than some inherent lack of capability in the participant.

Table 1
Physical and demographic characteristics of the examined sample, mean (SD).

Characteristic	Young (n = 12)	Middle-aged (n = 8)	Older (n = 9)
Gender (M/F)	7/5	4/4	5/4
Age (years)	31.1 (5.2)	49.8 (5.5)	66.7 (4.9)
Height (cm)	176.6 (10.0)	171.1 (9.8)	169.6 (11.2)
Weight (kg)	68.6 (17.7)	74.5 (13.9)	77.1 (12.1)
UST (sec)	30.1 (21.6)	7.7 (12.3)	7.4 (9.6)
TUAG (sec)	12.0 (1.8	11.8 (1.5)	12.6 (2.0)
Step width (cm)	26.9 (9.4)	29.1 (5.7)	26.9 (7.4)
Step length (cm)	69.9 (8.7)	63.2 (10.1)	65.3 (10.9)
Leg power (Watt)	125.9 (84.0)	109.4 (54.9)	78.2 (46.2)
Arm length (cm)	72.5 (5.0)	71.8 (5.0)	71.1 (5.5)
Grip strength (kg)	42.3 (13.4)	34.1 (11.3)	29.3 (7.1)

Note: Unipedal Stance Time (UST) test indicates risk of falling, Timed Up and Go (TUAG) test reflects balance deficits in gait.

3. Results

A three-way independent ANOVA test was conducted and revealed that age, $F(2,3181) = 52.56, p < .001$, gender, $F(1,3181) = 18.50, p < .001$, and acceleration level, $F(4,3181) = 54.20, p < .001$, have a significant effect on double support time. Furthermore, the combined effect of age and acceleration, $F(8,3181) = 4.24, p < .001$, gender and acceleration, $F(4,3181) = 3.142, p < .05$, as well as age, gender and acceleration, $F(8,3181) = 7.87, p < .001$, on double support time was also proven significant.

When all participants were considered at each acceleration level, the mean DST value in the static environment was 0.23 s. On the stationary bus a value of 0.24 s was found, while at low acceleration (0.18 s) and at medium and high accelerations (0.15 s) lower values were found (Fig. 2). *Gabriel post hoc* tests revealed that the difference in the mean value of DST between the static and stationary environments is not significant ($p > 0.05$), however the reduction in mean DST during low, medium and high accelerations is significantly different from the mean DST of both the static and stationary environments