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Maintaining balance on a moving bus: The importance of three-peak steps whilst walking on the lower-deck

Karekla Xenia*, Tyler Nick

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

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ABSTRACT

The numerous falls reported on buses due to sudden accelerations indicate the importance of examining the effect of dynamic environments on people's gait and balance. Although such falls are more common for the elderly and increase the cost of medical care, they also reduce younger passengers' satisfaction for the service.

This study investigates the differences between natural gait and that resulting from the bus environment. 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. A medium level of acceleration (1.5 m/s^2) was examined, which falls in the range of accelerations experienced by passengers on the real bus service in London.

A new method of measuring and analysing gait in dynamic environments was established. *Chi-square* tests were conducted on measures of changes in gait (step type), which encloses important information about body balance, considering participants' age and gender and the bus acceleration. The statistical analysis has shown that as acceleration increases bus passengers use more three-peak steps, which denote that the entire foot is under pressure and in full contact with the ground, thus increasing balance.

This is the first study investigating people's gait inside moving vehicles, hence the gait of healthy people was examined so that the differences in walking patterns would be unaffected by health-related conditions, and to increase understanding of the real challenges passengers experience during bus journeys. The presented methods and outcomes can be used to improve research around eliminating risk of falling for people with mobility difficulties.

1. Introduction

Postural stability, also referred to as balance, is defined as the ability of an individual to maintain the centre of mass (CoM) within the base of support with minimal postural sway (Lord et al., 2007; Shumway-Cook et al., 1988). The base of support is the area of the body that is in contact with the support surface and depends on the task that is undertaken. For instance, the support base when standing relaxed is the area within the feet (Shumway-Cook and Woollacott, 2007).

Stability is equally affected by the environment within which the task is taking place (Shumway-Cook and Woollacott, 2007; Darowski, 2008), which provides complicated multi-sensory information that aid people to remain in control of their balance.

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

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However, processing sensory information from the environment as well as body functions become more difficult with normal ageing, and therefore poor balance is often observed in older individuals (O'Sullivan et al., 2013). As a result, elderly people are at an increased risk of falling. In the UK, one in three people over 65 (3.4 million people) suffers a fall (AgeUK, 2010) and are more likely to have fear of falling.

A fall is an event which results in a person coming to rest unintentionally on the ground or floor or other lower level (World Health Organisation, 2015) and it depends on the person's characteristics, such as disability, or is affected by the environment altering a person's balance, such as the sudden acceleration of a bus. Stumbling or tripping are also an indication of altered balance. However, in these cases a fall can be avoided through recovery. In older people, 53% of trips result in falls due to the person's reduced body capabilities (Lord et al., 2007). Within the bus environment, such events are more common than actual falls but are of equal importance because the increase in fear of falling retains people from using buses or even going out of their house. This has implications for both physical and mental well-being and there is a substantial cost associated to it as a result of medical treatment and loss of earnings. In the UK and the USA in 2010, £4.6 million each day and US$30 billion were spent respectively to cover falls-related costs (AgeUK, 2010).

People, regardless of their gender or age, increase their walking speed after a perturbation of their gait (Krasovsky et al., 2014) and apply a higher force on their heel and toes (Burnfield et al., 2004; Chung and Wang, 2012). In the static environment, a correlation between increased body mass and higher pressure on the middle part of the foot is identified (Walsh et al., 2017), and older people present a higher minimum value at mid-stance than younger people (Yamada et al., 1988). This, however, contradicts the findings of Toda et al. (2015), who identified no significant differences between the minimum value at mid-stance of young and older people. However, assessing level walking in a static environment provides limited information regarding an individual's walking style and their ability to respond to events that put them out of balance in the range of environments they have to navigate in daily living. When gait takes place in a moving vehicle, maintaining balance becomes more challenging, which decreases comfort whilst travelling. In a moving environment, older people have more difficulties in maintaining their balance and take extra steps in order to compensate for a missing double support phase, which provides the highest stability as both feet are on the ground (Krasovsky et al., 2014). Surprisingly, a higher likelihood for falling is observed for younger women, as older women walk with more caution from the beginning, whereas falling in men does not correlate with their age (Pavol et al., 1999).

A number of reviewed studies, discussed in Karekla (2016), mainly considered moving passengers in a stationary vehicle or non-moving passengers in a moving vehicle. This reveals a gap in the literature, in relation to passengers moving within moving vehicles, as studying the real-life situation has yet to be addressed. The acceleration and deceleration phases of a vehicle's movement, are considered as one of the most dangerous parts of a journey with the majority of non-collision injuries, especially for older people, recorded in these phases (London Travel Watch, 2010; Bird and Quigley, 199). Hence, it is crucial to investigate people's gait when the bus is in motion and to examine the changes the bus environment brings to passengers' movement, in order to be able to offer more comfortable and safer journeys. Moving passengers cannot maintain their balance when acceleration is higher than 2.0 m/s^2. The current London bus service occasionally operates at accelerations higher than this limit (Karekla, 2016). Hence, investigating how this affects passenger walking would be essential to improve the provided service.

This study is aiming at identifying people's walking style in the real environment of a double-decker bus, a transport mode that many people use for their everyday movements, especially in cities with intense bus services, such as London, Hong Kong, or Singapore. Participant's natural gait will also be recorded in a laboratory and will highlight the effect of bus acceleration. The type of steps, age and gender of passengers will provide an insight regarding the balance mechanisms they adopt in order to remain upright. The present paper considers the case of walking along the lower floor of a double-deck bus.

1.1. Natural gait during level walking

The human gait is a bipedal cycle that describes the way body weight is shifted from one limb to the other in order to achieve a forward movement. It consists of repetitive events and can be described as the time interval between two consecutive occurrences of such events. For more information on level walking, its events (e.g. stance) and their length, two widely acclaimed textbooks are recommended for further reading (Whittle, 2014; Perry and Davids, 1992).

The force that a person applies to the ground during walking generates an equal and opposite force (reaction) from the ground to the person's plantar (Newton's third law). Ground Reaction Forces (GRF) have two components, a horizontal and a vertical one, but the main interest in this paper focuses around the vertical component.

The profile of the vertical GRF during level walking forms an M-shape curve with two distinct peaks of equal intensity, and reflect the support of the CoM (Toda et al., 2015); the first coincides with the initiation of the stance phase and the second with its termination. The events of a gait cycle in a static environment can be seen in Fig. 1.

The presence of one or both peaks in the GRF profile depends on the person's walking style and physical characteristics and the environment in negotiation. This was investigated with a series of experiments, the process of which and their results are discussed in the following sections.

2. Methods

2.1. Participants and experimental process

People's walking in dynamic environments is still an unexplored area of research and hence, to be able to identify the true