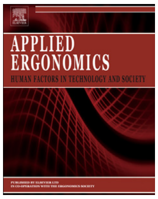
Applied Ergonomics 49 (2015) 25–33

Contents lists available at ScienceDirect

Applied Ergonomics

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



Driving performance and driver discomfort in an elevated and standard driving position during a driving simulation

Jordan Smith [a, b, *], Neil Mansfield [a], Diane Gyi [a], Mark Pagett [b], Bob Bateman [b]

[a] Loughborough Design School, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK
[b] Nissan Technical Centre Europe, Cranfield Technology Park, Cranfield, Moulsoe Road, Bedfordshire MK43 0DB, UK

ARTICLE INFO

Article history:
Received 27 November 2012
Accepted 6 January 2015
Available online 4 February 2015

Keywords:
Driver comfort
Driver posture
Driving performance

ABSTRACT

The primary purposes of a vehicle driver's seat, is to allow them to complete the driving task comfortably and safely. Within each class of vehicle (e.g. passenger, commercial, industrial, agricultural), there is an expected driving position to which a vehicle cabin is designed. This paper reports a study that compares two driving positions, in relation to Light Commercial Vehicles (LCVs), in terms of driver performance and driver discomfort. In the 'elevated' driving position, the seat is higher than usually used in road vehicles; this is compared to a standard driving position replicating the layout for a commercially available vehicle. It is shown that for a sample of 12 drivers, the elevated position did not, in general, show more discomfort than the standard position over a 60 min driving simulation, although discomfort increased with duration. There were no adverse effects shown for emergency stop reaction time or for driver headway for the elevated posture compared to the standard posture. The only body part that showed greater discomfort for the elevated posture compared to the standard posture was the right ankle. A second experiment confirmed that for 12 subjects, a higher pedal stiffness eliminated the ankle discomfort problem.

1. Introduction

The design of vehicles (e.g. rail vehicles, trams, buses, cars, delivery vehicles, vans) for city use requires a balance between the benefits of being light and compact, and the benefits of having a large load capacity. Lightness and compactness can increase fuel economy and manoeuvrability. If it is possible to shorten the overall space required to accommodate the driver, the vehicle could benefit from a more compact design. Most current vehicle designs require the driver to sit in a low seat with a semi-recumbent posture with legs extended towards the front of the vehicle. If the height of the seat is increased the driving posture can be altered such that the feet are positioned further back, thus reducing the need for space in front of the driver. Further advantages of this elevated posture include improved ingress and egress for drivers and/or passengers, and improved visibility. Whilst some vehicles use an elevated driving posture, there is little evidence to determine the suitability of this posture for comfort and control of the vehicle.

Rebiffe (1969) explored the posture and position of the driver to best fit the requirements of the driving task and was able to propose theoretical joint angles of the body for comfort and correct posture. Porter and Gyi (1998) augmented this theoretical framework with observed driving postures. New guidelines for optimum postural comfort were developed regarding body angles and inter relationships between adjacent joint angles. It was noted that even with theoretically optimal postures, not all people will be comfortable with the whole range of adjustment practically achievable with production vehicles.

Postural assessment alone is insufficient to determine the overall comfort of a vehicle seat occupant. Mansfield et al. (2005, 2014) identified factors affecting discomfort that can include the seat shape itself, the fit of this to the occupant, the materials, the thermal environment, exposure to whole body vibration (WBV), opportunity for changing posture and the length of time sitting in the same seated position. These factors can be broken down through numerical analysis of subjective discomfort ratings in order to predict discomfort under different conditions. During driving, drivers will be exposed to vibrations from the road surface.

---

[*] Corresponding author. Loughborough Design School, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK. Tel.: +44 1509 226934.
E-mail address: j.smith2@lboro.ac.uk (J. Smith).

http://dx.doi.org/10.1016/j.apergo.2015.01.003

Griffin et al. (1982) described how vibration, in combination with a seated posture increases the level of discomfort, especially during journeys of long duration. In real driving environments the vibration at the seat surface and backrest are transmitted through the body and interact with vibration from the steering wheel and pedals to form the sensation of vibration, which can lead to discomfort with increased vibration dose. El Falou et al. (2002) tested sensations of fatigue for two seat conditions, 'uncomfortable' and 'comfortable', and found that for both experimental conditions discomfort of the spine and back increased significantly over the 150-min trial. Drivers are required to maintain vigilance over long periods of time during which they are exposed to whole-body vibration and can become fatigued. Studies of long-term discomfort have shown gradual increases in discomfort over time, irrespective of how well designed the seat might be. Whilst it is known that vibration accelerates the onset of discomfort it is currently unclear whether fatigue is also reflected in driving performance or vigilance.

One method of assessing driver performance is to use the measure of 'headway', defined as the distance from a lead car to a following car. Driving manuals and learner guidance often point towards a 2-s headway as being the ideal minimum safe distance (Department for Transport, 2007) when driving in normal conditions e.g. good visibility, dry road conditions. However, in reality the headway allowed by a driver can be influenced by the traffic density, the characteristics of the driver (Jonah, 1996), the perceived ability to judge physical situations better than other drivers (Van Winsum and Heino, 1996), as well as the physical capabilities of the vehicle and circumstantial factors surrounding the journey e.g. routine vs. urgent journey. In some cases it is not possible to maintain a preferred headway if the space becomes occupied by other drivers changing lanes, therefore in practice the headway selected by 'safe' drivers is often less than 2 s (Rudin-Brown et al., 2004; Simons-Morton et al., 2005). With both of these studies classifying 'risky' driving as headways of <1.5 s, a 'time headway' of ≥1.5 s in normal driving conditions (replicated in the driving simulation) was considered as safe for this study.

A second method of assessing driver performance is reaction time. The reaction time (RT) has important consequences for the design of safe roads and vehicles, and is predicted to be effective in establishing whether a posture change (the higher hip point) changes the time taken to move between the accelerator and brake pedal. Green (2000) conducted an analysis of driver perception-brake times and found that previous study results vary greatly because investigators have used many different signals, responses and testing conditions. Green continued that when fully aware of the time and location of the brake signal, drivers could move their foot from the accelerator (A) to the brake (B) pedal in approximately 0.70–0.75 s. Green also noted that times can be affected by driver age, gender, cognitive load and the urgency of the driving situation. Engström et al. (2010) explored the effects of working memory load and repeated scenario exposure on emergency braking performance. A driving simulation was set-up whereby a lead car would pull in front of the driver at a predetermined time in the simulation, accelerate to headway of 1.5 s and then suddenly brake. The study decomposed the reaction time to the time taken to release the A pedal and then the time taken to switch the foot from the A pedal to the B pedal. The results indicated, firstly, that there was no effect of working memory load on accelerator-brake reaction time, indicating that this method of measurement is consistent. Secondly, the accelerator-brake reaction times were between 0.6 and 0.8 s. Decomposing the reaction time to discover the accelerator-brake time requires accurate data collection and lends itself to a high fidelity driving simulation. Whilst driver performance under 'normal' driving conditions is relatively well understood, the interaction of driver posture with performance is unknown.

This paper considers a study comparing a current production vehicle set up (the standard posture) with a seat height of 375 mm with a new specification driving position with an elevated seat height of >400 mm, the current maximum production hip point. It was hypothesised that the elevated driving posture would be no worse than the current vehicle in terms of comfort or performance. The reasoning for this is that the biomechanics of the elevated posture opens up the body angles (hip angle; knee angle) and moves them closer to their neutral and thus more comfortable position. Potential weight savings, benefits for visibility and ingress/egress were not investigated in this study. The current production vehicle is categorised as a 'small Light Commercial Vehicle (LCV)' and was set up with the production seat and corresponding adjustment slide, a standard pedal arrangement for the automotive sector and a standard steering system. Assessing comfort in this new elevated driving position allows this study to explore the range of optimum driving positions with an elevated seat height, with reference to the pedals and the steering wheel. This comparative experimental study used a motion platform and driving simulator to study discomfort ratings as well as fatigue effects, using self-selected headway and reaction time.

2. Methods

2.1. Sampling

12 participants, 6 males and 6 females were recruited from the population of staff and students at Loughborough University to take part in the trials. The criteria for recruitment were that each participant held a full UK driving license, had at least 1 full year of driving experience and was between the ages of 18–65. The age range that was recruited was 20–60 years. The Loughborough University Ethical Advisory Committee (LUEAC) approved the study.

2.2. Equipment

Two driving rigs were constructed for the study: the first represented a driving position (standard posture) from a small LCV production vehicle with conventional pedal and steering operations and actual seat slide adjustment range, as illustrated in Fig. 1. The driving rig was set up for Automatic Transmission with just the accelerator (A) and brake (B) pedals and a fixed steering wheel position. The seat height for this small LCV production vehicle was 375 mm in Z, with the distance to the pedals from the front edge of the seat ranging from 245 mm (foremost position) to 475 mm (rearmost position) in X. The seat base length was 460 mm in X, from the front edge of the seat cushion to the point at which the cushion meets the backrest. The standard posture rig was built using carry over parts from the vehicle including the seat, steering wheel and pedal set with replicated pedal stiffness.

The second rig was designed to accommodate an elevated seat height and a shorter seat base length, with adjustability in both the seat height and the distance from the pedals, as illustrated in Fig. 2. The seat height had an adjustment range from 400 mm to 800 mm in Z. The seat base length was 350 mm in X, from the front of the seat cushion to the point at which the cushion meets the backrest. The distance from the seat to the pedals had an adjustment range between 450 mm and 850 mm in X. The steering wheel had nominally unlimited adjustment built in with the capability to change the height of the wheel from the floor in Z, the distance from the driver in X and the angle of the wheel itself. However, the steering wheel position was not a main focus of this study. The