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## Long-term discomfort evaluation: Comparison of reported discomfort between a concept elevated driving posture and a conventional driving posture

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### Abstract

Mounting a seat higher in a vehicle, in comparison to a conventional driving posture, will benefit vehicle design by reducing vehicles' mass and as a result, possibly reducing emissions over the lifecycle of the vehicle. This paper reports on a study with the objective of comparing reported long-term discomfort between a concept elevated posture seat and a production conventional driving posture seat. A sample of 20 commercial drivers (10 males, 10 females) aged 19-65, were recruited for the study. A concept seat was developed from a seat fitting trial study [1] and a second rig was designed and constructed to replicate a benchmark production seat in a conventional LCV driving posture. In two separate trials, participants were required to perform a driving simulation task whilst exposed to whole-body vibration and report their discomfort in 10 minute intervals over 50-minutes of driving. Results indicated that at 50-minutes of driving, there were significant differences in reported discomfort for the right shoulder and the lower back between the postures, with the conventional posture having the higher discomfort ratings. Additionally, the musculoskeletal fatigue effects for both postures (progression of discomfort over time) fell in line with the literature.

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## 1. Introduction

Vehicles designed for city use (e.g. rail vehicles, trams, buses, cars, delivery vehicles, vans) require a balance between being light and compact and the benefits of having a large load capacity. A light and compact vehicle can in turn lead to an increased manoeuvrability. The context of this research is to investigate an elevated driving posture which has positive economic and environmental impact in regards of loading considerations. This can be achieved with either an increase in the overall loading space or a reduction in the length of the vehicle itself whilst maintaining the same loading space. The full context of how this is achieved is detailed in a journal paper prepared by the same author [2].

The primary purpose of a vehicle driver's seat is to allow the driver to negotiate the respective driving task safely and comfortably. There are many factors which can affect subjective automobile seat discomfort, with anthropometry, posture, transmission type and seat foam stiffness to name a few [3]. Additionally, these factors are influenced by the presence and magnitude of vibration and by the duration of time sat in the seat [4, 5, 6]. The literature identifies that a seat requires both good static and dynamic properties in order to reduce occupants' levels of discomfort during driving [11].

This study was aimed at comparing reported long-term discomfort between an elevated posture seat and a conventional posture seat. This was conducted by immersing occupants in a simulated driving task replicating diverse driving conditions and by exposing them to normal road levels of vibration. The results compared the overall discomfort between postures at the end of the trial and explored the onset of discomfort in relation to the literature.

## 2. Methods

The following section details the methods that were designed in order to carry out the long-term discomfort evaluation between the two separate driving posture seats.

### 2.1. Sampling

20 commercial drivers, 10 males and 10 females, were recruited from the population of staff and research students at Loughborough University to take part in these long-term discomfort evaluation trials. The inclusion criteria for recruitment were that participants were aged 19-65, had held a full UK driving license for at least 2 years and had driving experience with light commercial vehicles (e.g. Vans, trucks, minibuses, horse boxes, camper vans). The context of this study was aimed at drivers with LCV experience, in order to provide a point of reference when assessing a comfortable driving position aimed at that vehicle type. The sampling strategy was to include as large an anthropometric spread as feasibly possible. Loughborough University Ethical Advisory Committee (LUEAC) approved this study.

### 2.2. Rig design and build

It was necessary to design and construct a driving rig to evaluate the elevated driving posture. A concept elevated posture seat (Figure 1) was designed and constructed, using a current production model as a donor seat, based on the output of a seat design parameter study [1]. The rig had an automatic pedal transmission set-up (accelerator and brake pedals only) and a fully adjustable steering wheel position (adjustments in X, Z and wheel angle). This rig was designed to be mounted on to one platform which could be fixed to a vibration platform plate securely and safely.



Fig. 1. Elevated driving posture concept seat.

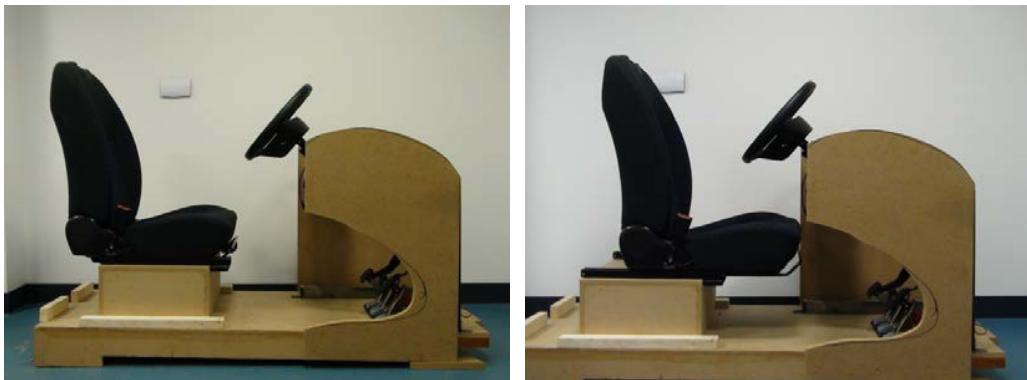


Fig. 2. Convention posture driving seat rig.

A conventional driving posture rig was also created to replicate a current production driving package, which was used as the benchmark posture for the LCV market (Figure 2). This rig was designed using carry over parts for the seat, wheel and pedals and was constructed using MDF and metal fixings. The rig had the following specification:

- Actual seat slide range as observed in the production vehicle
- Fixed back angle of 15°
- Accelerator and brake pedals in the same starting positions (X, Y and Z)
- Replicated pedal forces and stroke values (no adjustment)
- Replicated steering wheel angle and position

### 2.3. Multi-axis vibration simulator

Both rigs were designed with the ability to be mounted on to the vibration platform at Loughborough University. The capabilities of the platform with 6 degrees of movement allowed for a realistic and repeatable exposure to road surface levels of vibration. The long-term discomfort trials used a pre-recorded pavé road surface input and a seat point vibration total value magnitude at the seat surface of 0.35 m/s<sup>2</sup> r.m.s. (r.s.s. of x-y-z-axis motion). This vibration sequence was set to loop and run for 10-minutes in line with each driving scenario.

The vibration on the seat surface and platform was measured before each trial using a standard ‘SAE pad’ on the seat and accelerometers mounted on the motion platform. The system settings were adjusted to compensate for the dynamics of the seat-person system so that seat surface vibration was set at the target level. This pad was then removed before the driving simulation began, to ensure that it did not influence the seat comfort ratings across the trial.

#### *2.4. Driving simulator*

The driving software system used for the discomfort evaluation trials offered dynamic driving simulations which incorporated both town and motorway driving. The software was designed to include both types of driving as they represented two categorical driving environments and interactions for drivers. Motorway driving required less pedal operation and so the driver was expected to have a more static posture whilst driving. The town scenarios were more dynamic with frequent pedal operation and negotiation and use of the steering wheel, resulting in a more dynamic posture whilst driving. The driving simulator had a 3-screen set-up which provided a 180° field of view, rear-view and wing mirrors, and a speedometer rendered on the central screen. Three pre-planned routes were devised for the driver to navigate around the town map, offering different roads, directions and decision making.

#### *2.5. Laboratory set-up*

A blackout environment was constructed around and above the motion platform and simulator to help immerse drivers in the driving simulation. This environment helped to engage drivers in the task which helped in the repeatable collection of reported discomfort scores over time. To compensate for an obscured line of vision between the investigator and participant, two Microsoft LifeCam HD-300 webcams were fitted to the TV screens for observation during the trial.

In addition to the visual output from the driving simulator, the audio output was ‘Mackie thump’ powered loud speakers, which had two layers; the first being the engine noise and the second being the pre-recorded navigation instructions to direct the driver around the map, which was controlled by the investigator from the control panel.

#### *2.6. Experimental design and reporting discomfort*

On participants’ arrival, anthropometric measurements were taken relevant to seat design and driving posture.). Before each trial, participants were taken through a short fitting trial to set themselves in their optimum driving posture. Once this was set and the trial began, the posture could not be changed. Participants completed 5 driving scenarios, each 10-minutes in length (50-minutes of overall driving). Every participant started and ended with the same motorway driving scenario to control for learning effects and the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> town driving scenarios were conducted in a randomised order.

Participants were asked to rate 10 body parts before the trial began to provide a base level of discomfort. Participants were subsequently asked to complete a further five discomfort maps, one at the end of each driving scenarios (every 10-minutes). A seven-point scale was used based on Gyi and Porter’s body map [7] using anchors from ISO 2631-1 [8]. Verbal anchors (not uncomfortable to extremely uncomfortable) were designed for use in motion environments in laboratory settings.

### **3. Results and discussion**

#### *3.1. Sample*

A total of 20 participants (10 males and 10 females) with LCV driving experience completed the long-term discomfort evaluation trials. The distribution is summarised in Table 1, showing that the highest proportion of both male and female drivers were aged 19-34. The range of anthropometric percentiles of the sample is detailed in Table 2. This data shows that there is a good anthropometric spread for the sample. Knowledge of this posture identifies that leg length is a good predictor of an occupant’s seat position in the elevated posture. For this sample there was a

percentile range between Japanese female 1<sup>st</sup> percentile (JF01) to American male 87<sup>th</sup> percentile (AM87), representing the extreme ends of the population.

Table 1. Sample group age and gender distribution (n=20).

| Sample age group | Participation number | % of sample |
|------------------|----------------------|-------------|
| Male: 19-34      | 7                    | 35%         |
| Female: 19-34    | 7                    | 35%         |
| Male: 35-50      | 1                    | 5%          |
| Female: 35-50    | 2                    | 10%         |
| Male: 51-65      | 2                    | 10%         |
| Female: 51-65    | 1                    | 5%          |

Table 2. Sample anthropometric percentile range (n=20) using Japanese female and American male [9].

| Anthropometric dimension | Percentile (%) |
|--------------------------|----------------|
| Sitting height           | JF22 – AM85    |
| Shoulder width           | JF02 – AM82    |
| Sitting hip width        | JF01 – AM99    |
| Knee height              | JF75 – AM84    |
| Popliteal length         | JF12 – AM84    |
| Seat height              | JF55 – AM99    |
| Leg length               | JF01 – AM88    |

### 3.2. Descriptive analysis

The descriptive analysis identified that the elevated posture had the biggest range of adjustment in pedal to heel (PH) gap (108mm) with the heel step (HS; heel-to-hip height) having a slightly smaller range of adjustment (98mm), detailed in Table 3. These adjustment ranges are comparable with the findings from a seat design parameter study [6] where all drivers were able to set themselves in a comfortable self-selected elevated driving posture before the trial began. Additionally, all participants were able to select a comfortable conventional driving position.

Table 3. Final elevated seat positions for the long-term discomfort evaluation.

| Seat sub-component | Minimum (mm) | Maximum (mm) | Range (mm) | Mean mm |
|--------------------|--------------|--------------|------------|---------|
| Heel Step          | 547          | 645          | 98         | 589     |
| Pedal-Hip gap      | 638          | 746          | 108        | 677     |

### 3.3. Overall discomfort (after 50-minutes of driving)

Mean discomfort scores after 50-minutes of driving showed the largest differences for the left shoulder, right shoulder and lower back, where scores were higher for the conventional driving posture. For the majority of body parts (n=10) there were ties. The plots in Figure 3 highlight the verbal anchor ‘uncomfortable’ at discomfort rating 4, a level which was not reached in the mean discomfort scores for either posture.

Significant differences in discomfort were observed between the elevated and conventional posture at the end of the trial (50-minutes) only for the right shoulder ( $t = -2.438$ ,  $df = 19$ ,  $p < 0.05$ , two-tailed) and the lower back ( $t = -2.238$ ,  $df = 19$ ,  $p < 0.05$ , two-tailed) with the conventional posture having the higher discomfort ratings. There were no significant differences in mean discomfort ratings taken at 0 minutes, between the two postures. This suggests that baseline discomfort was similar for both postures.

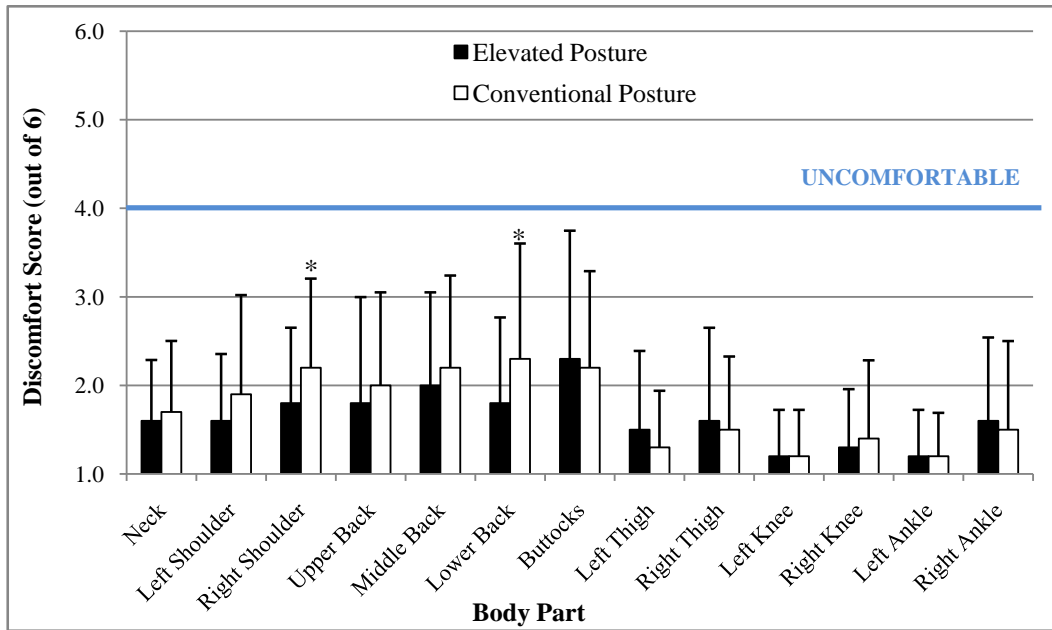


Fig. 3. Whole sample mean discomfort scores at 50-minutes between the elevated and conventional posture (\* $p < 0.05$ ).

There was no gender differences observed for overall discomfort in the sample of drivers tested. The results show that the elevated posture performed as well as the conventional posture for 11 of the body parts reported on and performed better for 2 of them (right shoulder and lower back). These findings indicate that occupants can drive in the elevated posture for an extended period of time without experiencing unusual levels of discomfort.

#### 3.4. Musculoskeletal fatigue effects

For the elevated posture, the results indicate that the mean discomfort score increased for 9 of the 13 body parts (left shoulder, right shoulder, upper back, middle back, lower back, buttocks, left thigh, right thigh, right ankle) from the beginning to the end of the driving trial (Figure 4). Descriptive statistics showed that discomfort reported between 0-minutes and 50-minutes of driving in the elevated posture, was significantly different for the left shoulder ( $t = -3.327$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), right shoulder ( $t = -3.584$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), upper back ( $t = -2.896$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), middle back ( $t = -3.387$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), lower back ( $t = -3.249$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), buttocks ( $t = -3.133$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed) and right ankle ( $t = -2.932$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed) with the highest discomfort ratings observed at the 50-minute recording.

For the conventional posture, the results indicate that the mean discomfort score was higher for 7 of the 13 body parts (left shoulder, right shoulder, upper back, middle back, lower back, buttocks, right ankle) from the beginning to the end of the trial (Figure 5). Descriptive statistics showed that discomfort reported between 0-minutes and 50-minutes of driving in the conventional posture, was significantly different for the left shoulder ( $t = -3.199$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), right shoulder ( $t = -3.847$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), upper back ( $t = -3.621$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), middle back ( $t = -4.414$ ,  $df = 19$ ,  $p < 0.001$ , two-tailed), lower back ( $t = -3.567$ ,  $df = 19$ ,  $p < 0.01$ , two-tailed), buttocks ( $t = -5.146$ ,  $df = 19$ ,  $p < 0.001$ , two-tailed) and right thigh ( $t = -2.666$ ,  $df = 19$ ,  $p < 0.05$ , two-tailed) with the highest discomfort ratings at the 50-minute recording.

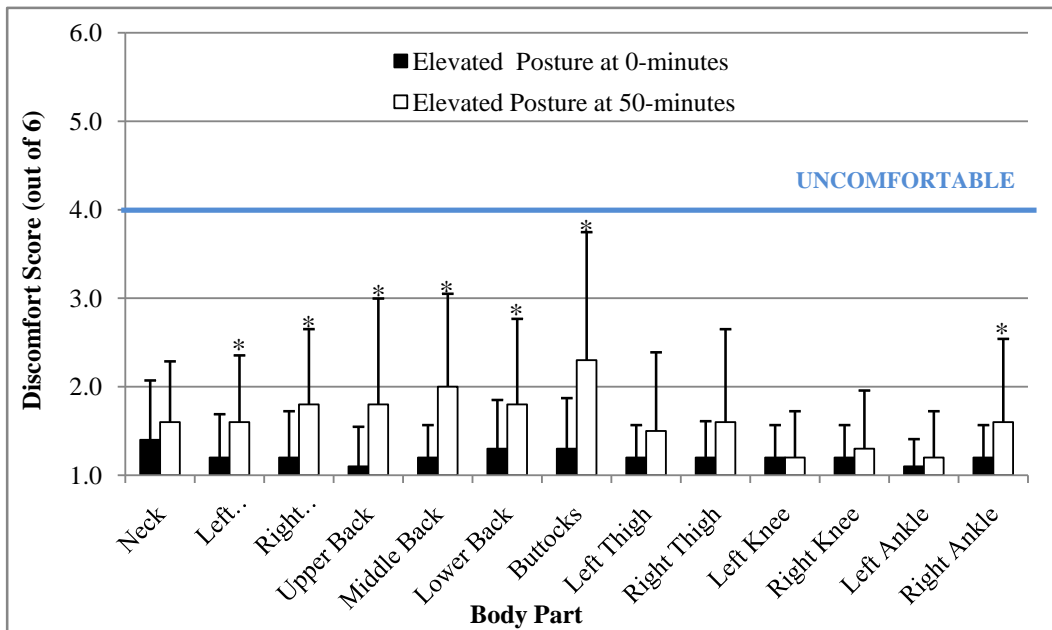


Fig. 4. Discomfort for the elevated posture between 0 and 50-minutes of driving (\*p<0.05).

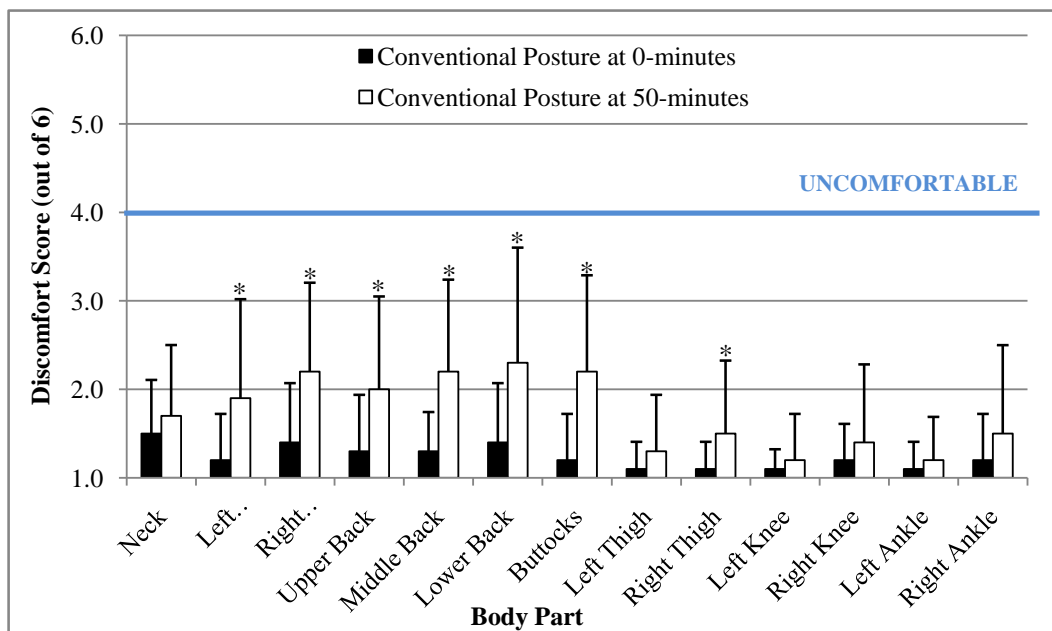


Fig. 5. Discomfort for the conventional posture between 0 and 50-minutes of driving (\*p<0.05).

The results show signs of musculoskeletal fatigue after 50-minutes of driving, with 7 body parts having significantly higher reported discomfort at the end of the trial compared to the beginning in both the elevated and the conventional driving posture. This indicates that the progression of discomfort reported in the elevated posture is comparable with a current production conventional driving posture seat.

### 3.5. Onset of discomfort

For the elevated posture, results showed that significant differences in discomfort occurred after as little as 20-minutes of driving (upper back and buttocks). These results show that the on-set of discomfort for drivers in the elevated posture occurred between 20-40 minutes of driving exposure and that there were no significant increases between 40 and 50 minutes of driving.

For the conventional posture, results showed that significant differences in discomfort occurred after as little as 10-minutes of driving (middle back). These results show that the on-set of discomfort for drivers in the elevated posture occurred between 10-50 minutes of driving exposure.

This onset of discomfort effect is in agreement with the findings in the literature [10,11] which observed significant differences in seat discomfort after only 30-minutes and 40-minutes respectively. The findings from this study support the hypothesis that the elevated posture is at least similar to and may have potential advantages over a conventional driving posture in delaying the onset of discomfort.

### 3.6. Participant verbatim

The majority of participants surmised that the discomfort levels they felt in the elevated posture throughout the trial, was comparable to that they would experience in their normal driving posture (in their own vehicle). There was feedback that the more upright elevated driving posture felt intuitive and natural to adopt, and also that this posture made drivers much more aware of the backrest support and how they interacted with it whilst seated.

## 4. Conclusions

The study confirmed that overall discomfort at the end of the trial was significantly different for the right shoulder and lower back, where the conventional posture had higher reported discomfort. These findings indicate that the elevated posture seat performs as well for driver comfort as a current production conventional posture seat. The study also identified that the onset of discomfort for both postures is in agreement with the literature and suggests that the elevated posture may have advantages beyond vehicle packaging in terms of occupant comfort and musculoskeletal fatigue.

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