Designing movement into automotive seating - does it improve comfort?

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Abstract Comfort is important for a good driving experience and automotive seat technology is an important enabler of this. Movement through frequent changes in posture is beneficial for reducing fixed postures. This paper reports on a laboratory study to investigate a novel automotive seat movement concept aiming to delay the onset of driving-related musculoskeletal fatigue and improve feelings of comfort and wellbeing, making the driver feel refreshed and ultimately improving driver performance. The research involved comparison of three seat conditions while driving - no seat movement, fore-aft movement, cushion and backrest angle movement. The movement was designed to be at a fixed speed, slow, smooth and only slightly perceptible while driving. A sample of 10 participants was recruited to take part in a 60 minute drive for each condition - single blind, repeated measures, balanced order and sessions at a similar time of day. Discomfort and wellbeing questionnaires, driver Seat Fidgets and Movements (SFMs), posture capture and a de-brief were used as data collection methods. Results indicate that the two seat movement concepts were positively received. Statistically significant differences were found at minute 60 for buttock area discomfort, with less reported discomfort for the two movement conditions. As expected, overall discomfort ratings and SFMs frequency increased with time spent driving for all trials. Posture scores verified that driver posture was within comfortable ranges and as expected fairly static while driving.

Keywords: Driving; Musculoskeletal Fatigue; Automotive Seating; Car Seat Design

1 Introduction

Vehicle design can positively impact driver fatigue and lead to improved driver comfort, performance, wellbeing and safety. Driver fatigue is a result of the complex interaction of environmental, psychological, biological and vehicle factors exacerbated by conditions such as vibration, long duration sitting or high-workload driving [1].

Fixed postures from prolonged driving involve static muscle work and consequently blood vessel constriction, particularly in the spine, buttocks and thighs. As a result, local circulatory disruptions occur such that oxygen delivery, nutrient reserves and the removal of metabolic by-products are compromised, even for the low levels of sustained muscle contractions in driving. This process can cause local musculoskeletal fatigue, pain (e.g., low back pain (LBP), aches, cramps), discomfort, psychological fatigue and in the long-term chronical musculoskeletal problems [2]. The health and comfort benefits of dynamic seating are well established in the design of office furniture [3] but there is a lack of evidence for this in the automotive field.

Considering that driving for extended periods of time inevitably leads to feelings of reduced comfort and that movement is beneficial for reducing local musculoskeletal fatigue, a novel automotive driver seat movement concept was explored. This paper reports on a laboratory study to investigate the concept of engineering movement into automotive driver seating aiming to delay the onset of musculoskeletal fatigue, increase feelings of comfort, wellbeing and refreshment, and ultimately improving the driving experience. Participants (n=10) performed one hour of simulated driving under three seat conditions - two seat movement conditions and a no seat movement condition (repeated measures).

2 Methodology

This section outlines the experimental methodology developed for the laboratory study.

2.1 Sampling

A sample of 10 healthy participants (5 males and 5 females) was recruited from the Midlands area to include a good anthropometric spread. There was no age restriction but participants needed to hold a full UK driving license, with at least one full year of driving experience and be regular drivers in the last 12 months. Permission to conduct the study was granted by Loughborough University Ethical Advisory Committee.

Participants were asked not to exercise one hour before the session and to wear comfortable, close fitting clothing (no heeled shoes). In the first session, on participants' arrival, the height and weight of participants were measured.

2.2 Laboratory development

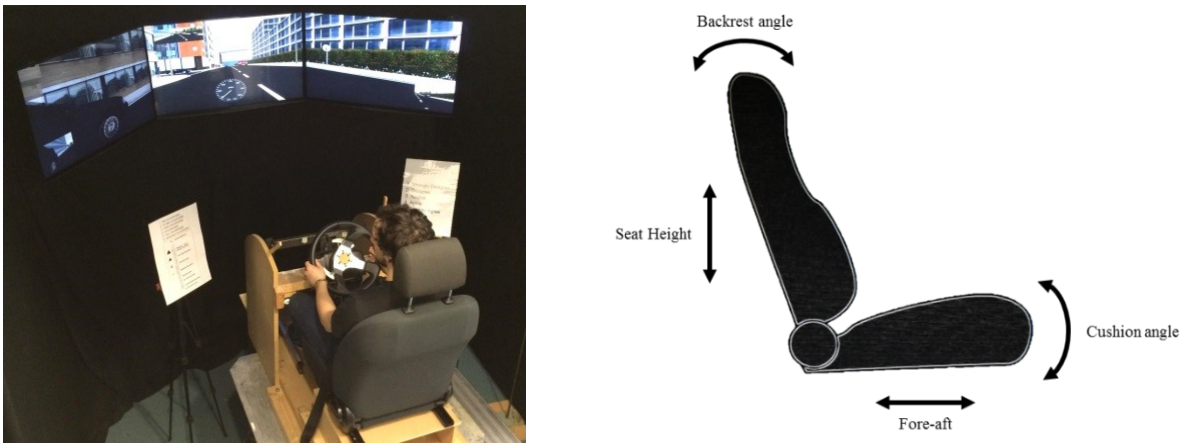
A realistic and repeatable simulation of the driving environment was used. A manufactured rig with the dimensions of a production car, automatic pedal transmission set-up and a non-adjustable steering wheel to control the driving simulator was mounted on to a platform, which was fixed to a 6 Degrees of Freedom (DoF) multi axis vibration simulator (MAViS) (Rexroth Hydraudyne B.V Micro Motion 600-6DoF-200-MK5 MAVIS) with closed loop control. A blackout driving environment was provided as feasibly possible. The driving simulation involved a 3-screen set-up, with four different 'follow driving' scenarios, including town and motorway routes, set up in a fixed sequence [4].

Before the first driving trial:

- A system characterisation was carried out with each participant using a Larson Davis Human Vibration Meter 100 (HVM100) to ensure they were exposed to the same target level of seat surface vibration, replicating a UK normal drive. The weighted acceleration equivalent value (aeq) was monitored. This was done while allowing participants to practice their simulation driving for a few minutes [5].
- A short fitting trial (standard iterative process) was conducted to set participants in their optimum driving position.

2.3 Seat movement development

A high quality seat (Figure 1(a)), four directions electronically-adjustable - fore-aft, vertical, cushion angle and backrest angle (Figure 1(b)) - with memory function was used. It was mounted on to the rig as close as possible to the dimensions of the manufacturer seat set-up of the production car. The full cab set up, e.g., steering wheel, pedals, control panel, was not replicated.



(a) (b)

Fig. 1. Simulated driving environment: (a) driving trial; (b) seat movement adjustable directions.

The seat movement aimed to change body contact points with the seat in order to affect driver position and refresh the driver and improve comfort. Iterative pilot studies were conducted in order to understand drivers' sensitivity/tolerance to the seat movement and to determine the seat movement ranges to be introduced in the seat.

A control system using Daisy Lab Software was developed for remote electronic operation of the seat by the researcher. The required seat movement was realised by input of the specific target position. Considering the capabilities of the seat movement (power and control), it was designed to:

- Not be annoying or disturbing to the driving task or cause any impediment to leg movement, steering and operating the pedals as well as dashboard full view.
- Be at a fixed speed, slow and smooth, within a small range and only slightly perceptible whilst driving.
- Have independent movement in each direction.

The final protocol was designed so that range of movement for each direction was interpolated for the 15 minute intervals (time between collection of discomfort ratings) and following a staircase protocol [6]. The research involved comparison of three seat conditions whilst driving:

- Condition 1 - No seat movement
- Condition 2 - Fore-aft seat movement
- Condition 3 – Cushion and backrest angle movement

Several malfunctions of the seat related to the seat lifter motor during pilot work lead to the decision not to risk using the seat height/vertical direction of movement in the study.

The three experimental conditions were evaluated on three separate days, at a similar time of day, single blind, repeated measures and in a balanced order. Each 90 minute session involved a 60 minute simulated driving task. The same protocol was used in accordance with the test condition - only the selected optimum driving position varied between participants.

2.4 Methods

A discomfort questionnaire was used in the study [6]. Part 1 collects body part discomfort and includes a body map [7] and a six point anchor from ISO 2631-1 [8]. Part 2 focuses on overall discomfort and comprises an adapted Borg CR-100 scale [9].

Discomfort scores were collected at each 15 minute time point (minute 0, 15, 30, 45, 60) for body parts - neck, shoulders, upper back, lower back, buttock area and ankles - and overall discomfort. An open question was also included asking if they had discomfort in any 'other' body area. The number of body regions was simplified to those mainly associated with driving and also considering the seat movement effects. The objective was to provide the least disruption to driving but at the same time ensure that the progression of discomfort over time was captured.

A wellbeing questionnaire was designed in order to evaluate the wellbeing of the driver. The descriptors were adapted from Ahmadpour et al. [10] and a five-point Likert scale (strongly disagree to strongly agree) was used to rate participants' responses. Time points sampled were minute 0 and 60.

Concerning subjective data collection, it should be noted that:

- Optimum visibility of the scales while driving was verified with the participant.
- Just before the driving trial (so that instructions were not forgotten), participants were trained on the use of the scales. On the second and third sessions, participants were reminded of the scales.
- Participants did not 'pull over' to provide ratings. This allowed continuous driving for the 60 minute trial.
- Ratings were collected at set time points but the driving workload was considered by the researcher (within 30 seconds). Failure to do this could affect the reliability of the data and compromise the driving.

An adapted version of Rapid Upper Limb Assessment (RULA) [11], a rank scoring/scale system focused on the upper body, was used to estimate posture. The score reflected the postural angles (upper arms, lower arms, wrist, neck, torso, legs) that the participant adopted at the sampled time. The protocol involved analysis of the video recordings of the driving posture adopted during the trial. The most typical/common posture within a 5 minute time frame was scored (at minute 15, 30, 45 and 60).

Driver Seat Fidget Movements (SFMs) is a measure of driver discomfort [5], also denominated in literature as Discomfort Avoidance Behaviours (DABs) or 'in chair movement'. It is a remote measurement technique whereby video data recorded of the driving session were reviewed and movements judged to be related to discomfort and not to the driving task were counted. The time and types of SFMs are described by Sammonds et al. [5].

At the end of the final session, participants were de-briefed on their perceptions of the seat movement.

3 Results and discussion

10 drivers (5 males and 5 females), aged 19-26, completed the seat movement study. The following comments should bear in mind that the ratings of body part and overall discomfort were generally low for the three conditions. This was to some extent expected, due to the use of a high-end production seat. Statistical analysis was carried out using Statistical Package for the Social Sciences (SPSS) for the discomfort rating data and wellbeing scores.

A Friedman test showed that there were no statically significant differences between Condition 1, 2 and 3 at each time period (0, 15, 30, 45, 60 minutes) for body parts and overall discomfort as well as for the wellbeing ratings. An exception was buttock area discomfort at 60 minutes (Figure 2), where a statistically significant difference was found ($\chi 2 = 7.692$, $p = 0.021$), with less reported discomfort for the two movement conditions, and Condition 3 having the least discomfort. Concerning overall discomfort at 60 minutes (Figure 3), Condition 3 had a lower rating (non-statistical trend) than both Condition 1 (no movement) and Condition 2. Regarding the wellbeing ratings at 60 minutes (Figure 4), there was a trend for the two movement conditions (Condition 2 and 3) to have better ratings than Condition 1 (no movement) for the descriptors 'I feel relaxed', 'I do not feel physically fatigued', 'I do not have heavy legs'. Condition 3 has better ratings than Condition 1 (no movement) for all the descriptors.

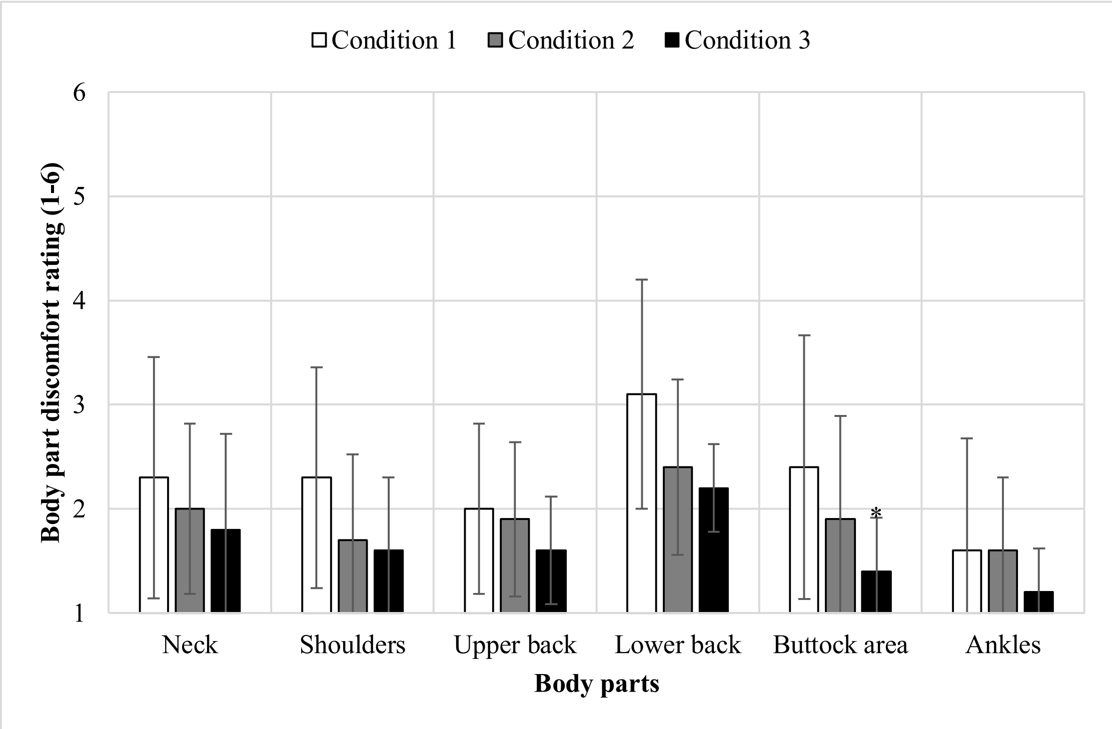


Fig. 2. Body part discomfort for Condition 1, 2 and 3 at 60 minutes of driving (*p<0.05).

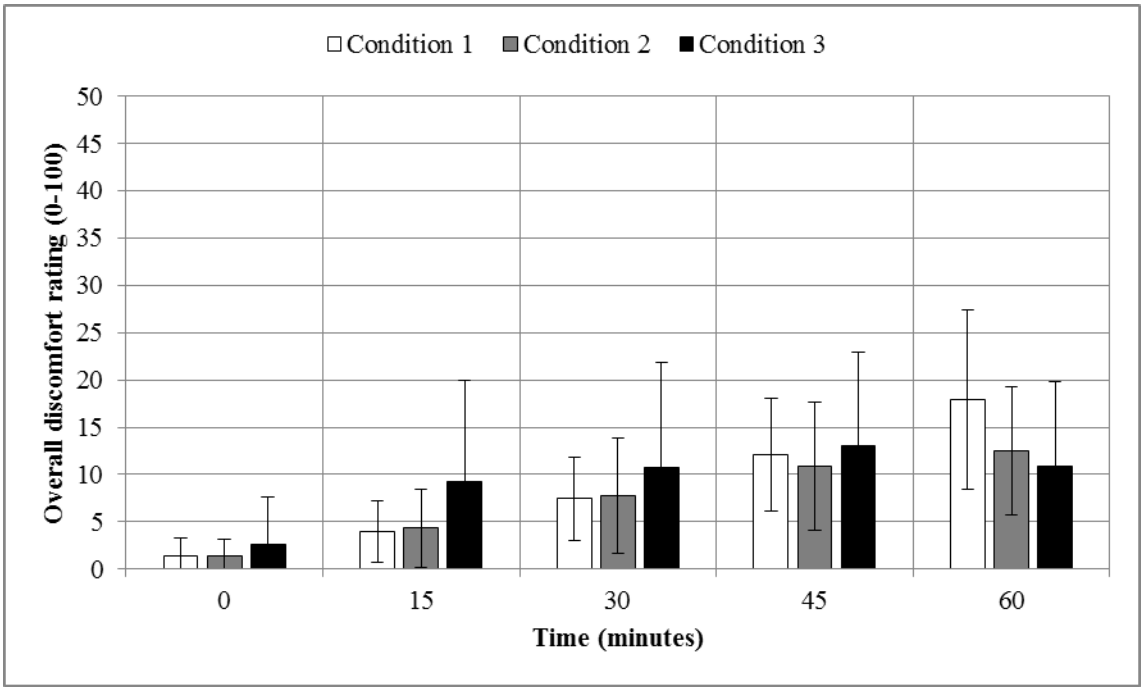


Fig. 3. Overall discomfort for Condition 1, 2 and 3 over the 60 minutes drive.

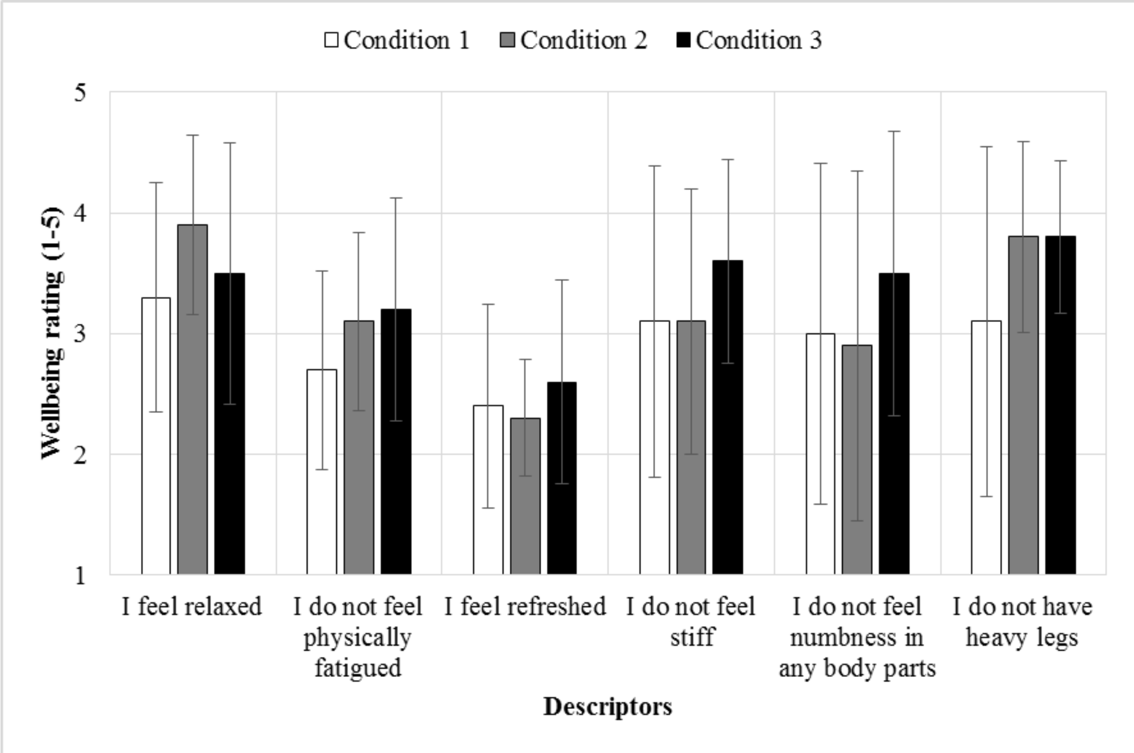


Fig. 4. Wellbeing ratings for Condition 1, 2 and 3 at 60 minutes of driving (*p<0.05).

Using mean rank (over the 60 minute drive), Conditions 2 and 3 had lower mean discomfort ratings than Condition 1 (no movement) for the neck, shoulders, lower back, buttock area and ankles. Condition 2 had lower mean discomfort ratings than Condition 3 for the neck, shoulders, upper back and lower back. Condition 3 had lower mean ratings than Condition 2 for the buttock area and ankles. As for mean overall discomfort, Condition 2 had the least discomfort.

As expected, the Friedman test indicates that for the three conditions there were a statistically significant differences in body part and overall discomfort over time (for the 60 minute drive) for:

- Neck - Condition 1 ($\chi 2$= 17.984, p= 0.01); Condition 2 ($\chi 2$= 13.159, p= 0.011); Condition 3 ($\chi 2$= 14.055, p= 0.007)
- Shoulders - Condition 1- ($\chi 2$= 20.567, p= 0); Condition 2 ($\chi 2$= 12.046, p= 0.17)
- Upper back - Condition 1 ($\chi 2$= 18.447 p= 0.001); Condition 2 ($\chi 2$= 15.287, p= 0.004)
- Lower back - Condition 1 ($\chi 2$= 26.101, p= 0); Condition 2 ($\chi 2$= 19.016, p= 0.001); Condition 3 ($\chi 2$= 19.167, p= 0.001)
- Buttock area - Condition 1 ($\chi 2$= 19.129, p= 0.001); Condition 2 ($\chi 2$= 15.695, p= 0.003)
- Ankles - Condition 2 ($\chi 2$= 15.781, p= 0.003);
- Overall discomfort - Condition 1 ($\chi 2$= 37.041, p= 0); Condition 2 ($\chi 2$= 31.668, p = 0); Condition 3 ($\chi 2$= 22.042, p= 0)

A Wilcoxon signed-rank Test showed also that there were statistically significant differences between the start (0 minutes) and end of the trial (60 minutes) for the three Conditions for body part and overall discomfort with better ratings at the end of the trial. Wellbeing ratings were also better at the end of the trial.

Posture scores verified that driver posture was fairly static during the 60 minute simulated drive. Posture scores were low and therefore postures were generally within comfortable ranges [11]. Preliminary findings from the SFMs analysis showed that, as expected, SFMs frequency increased with duration of driving for all trials [5].

Concerning the overall comments/participant verbatim from the de-brief conducted at the end of the final session, it can be inferred that the concept of seat movement was well received by participants. The majority of participants surmised that the discomfort levels they felt under the two 'seat movement' conditions were lower than under the no movement condition. Moreover, the majority of participants was well aware of the seat movement and noticed specifically which movement was produced in each session. Feedback was given regarding positive effects of the resultant repositioning and small body movements, as well as feelings of awakening, alertness, and improved concentration. Additionally, seat movement was reported not to disturb the driving experience. These comments require further exploration in future studies.

4 Conclusions

Although not statistically significant, the results indicate that the two seat movement conditions showed a trend for lower ratings of body part and overall discomfort over time. Wellbeing ratings were also better for the seat movement conditions. Statistically significant differences were found at minute 60 for buttock area discomfort, with less reported discomfort for the two movement conditions. As expected, overall discomfort ratings and SFMs frequency increased with time spent driving for all trials. Posture scores verified that driver posture was within comfortable ranges and as expected fairly static while driving.

The concept of seat movement was well received by participants and did not disturb the driving experience. Positive effects were reported with regard to the resultant repositioning and small body movements, feelings of awakening, alertness, and improved concentration.

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