# Movement analysis to indicate discomfort in vehicle seats

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**Abstract** Long distance travel is associated with discomfort and fatigue. It is a significant challenge to design a seat that remains comfortable for the occupant over the several hours required for many long-distance journeys. When designing seats, an indication of the perception of comfort / discomfort can be useful either for research and development purposes or potentially for automated systems to take actions that might mitigate discomfort. This paper considered a system that uses measurements of body movement in a seat to provide an objective measure of perceptions of discomfort. The system uses cameras and image processing to recognize when a seat occupant makes a movement in the seat which could be associated with relief of discomfort. The system was validated using a laboratory driving simulator. 10 participants volunteered to complete a study in which they drove for 90 minutes and gave subjective ratings of discomfort every 10 minutes, whilst also being observed using the camera system. It was shown that using a simple algorithm an association could be made between the movements of the driver and subjective ratings of discomfort. However, there remain challenges to improve reliability, optimize movement detection thresholds, and to make it more robust to naturalistic driving scenarios.

**Keywords:** Seating, Discomfort, SFMs, Fidgets, Driving

## 1 Introduction

During long-term transport, drivers and passengers increase their discomfort irrespective of how good their seat is. Whilst improvements in contouring of the seat, fit to the individual and physical environment can help in maximising the comfort at any one time, there is a trend for discomfort to increase over time such that after a few hours of sitting most drivers and passengers are ready to take a break or carry out some distracting activity in order to provide some relief (Hiemstra-van Mastrigt et al., 2016; Mansfield et al., 2015; Ravnik et al. 2008). It has been shown in a variety of contexts that discomfort can be observed through ‘fidgeting’ motions. These have been referred to as ‘SFMs’, an acronym for Seat Fidgets and Movements.

Sammonds et al. (2017) classified SFMs according to their size where a Type 1 SFM can be considered as a movement of the upper limbs, Type 2 a movement of the torso and Type 3 a whole-body movement. It was hypothesised that a Type 3 movement would indicate more discomfort than a Type 1 movement – i.e. the vehicle occupant would be stimulated to make a larger movement due to greater discomfort. One problem with the SFM method is that it currently requires continual observation by an experimenter; a task that is tedious at best and potentially could be prone to inter- and intra-observer differences. When a well-trained operator is vigilant in their coding, it is possible to obtain good correlations between subjective measures of discomfort and SFMs.

Driver SFMs can be observed using a variety of techniques. At the most basic level, a simple subjective method based on pre-determined criteria is effective and correlates very well with subjective data obtained from validated discomfort questionnaires. Jackson et al. (5) used a pressure measurement system to indicate discomfort. One advantage of systems that are based on direct recording is that, if the algorithms are fit for purpose, they could be left to operate semi-autonomously. One could envisage an in-vehicle system that monitors the vehicle occupants to establish their acute level of well-being and comfort. The vehicle could then make adaptations to improve the comfort, make recommendations such as to take a break or to feed back to the manufacturer how occupants experience the product.

Whilst it might be desirable to create a system that replicates the measurements from a previous method (e.g. SFMs) this is not necessary. It is acknowledged that the SFM method has its limitations inasmuch that it is a tally system and requires the judgement of the observer. An alternative to tallying the number of SFMs could be to integrate a measurement of the comfort-relief movements made by the vehicle occupant to generate an alternative score for the discomfort.

One constant challenge in comfort research is the disconnect between the true sensations of comfort and the ability of the experimenter to elicit these in a form that is measurable. The physical environment influencing the comfort will directly affect the physiology of the subject (Figure 1). The physiological response will be interpreted with the subject psychology and this will generate a sensation of comfort. This can be considered the true feeling of well-being. However, in order to elicit this sensation, an experimental method must be used and this is often reliant on the participants being trained and capable of using the method. This is difficult to achieve for a large study using naïve subjects. The experimental data available to the experimenter is the final step of this process, after a cascade of potential variance in the data. Despite all participants being trained in an identical way, it is common for some to interpret instructions differently providing variance in data. Similarly, multi-lingual participants might have different understanding of the detailed nuances of vocabulary. It would be desirable to use a method that eliminates some of these steps.


**Fig. 1.** Multiple steps from the physical environment that might influence comfort through to the experimental data available to a researcher studying comfort in a user trial.

This paper presents research that has developed a camera-based system that is capable to determining the occurrence of SFMs in a driving simulator in the laboratory.

## 2 Camera-based analysis system approach

The demonstration system uses two HD cameras. The primary camera is mounted in front of the driver and captures their torso and head. The secondary camera acquires signals from the steering wheel and gear shifter, marked to improve contrast (Figure 2). Signals from the second camera are not considered in this paper. Images are captured to a PC and processed using MATLAB. The primary camera in front of the driver samples the image two times per second.

The demonstration system was installed onto an XPI driving simulator at Imperial College London, comprising three screens and a TFT binnacle display. The simulator was fitted with a seat from a Toyota Prius. The driving simulator includes urban scenarios representative of a UK town, including highway and urban settings, and is configured for a right-hand drive vehicle.

SFM detection software compares subsequent images in order to detect whether changes in the image have occurred. Movements of the head, shoulder, and torso are individually processed using an image recognition process. The process counts pixels in the image which have changed between subsequent frames. If the driver remains stationary in the seat then there is no difference between subsequent images and therefore a score of zero will be recorded. If there is significant movement in the relevant regions of the image then a non-zero score will be recorded; the more pixels that have changed, the higher the score. Therefore, raw data comprises three channels of data representing movement in the left torso, right torso and head. The MATLAB algorithm filters the data using a rectangular 5s sliding window.

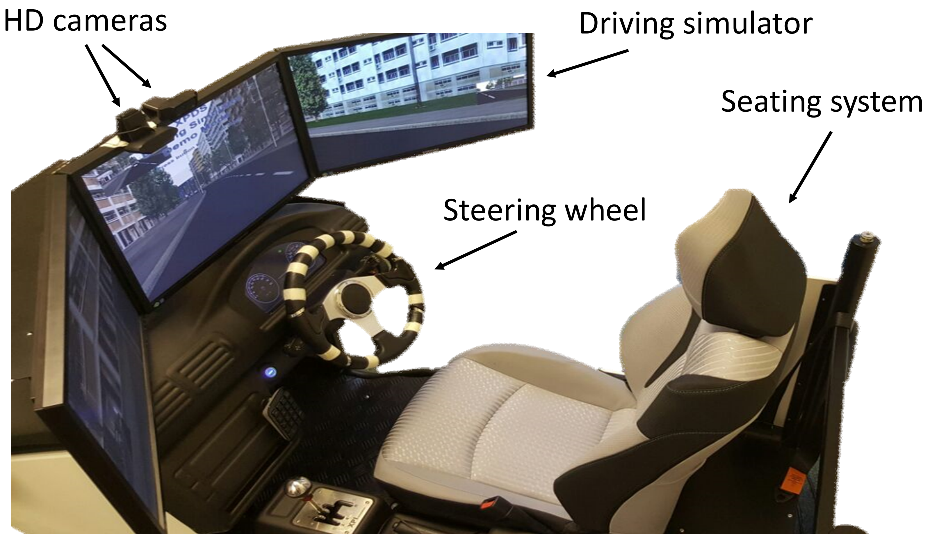


**Fig. 2.** Driving simulator with driver-facing cameras and high-contrast steering wheel.

## 3 Validation study

### *3.1 Method*

Ten volunteers participated in a study to validate the motion analysis system. All participants were students at Imperial College London; 8 were male and 2 were female. Participants drove using the driving simulator for 90 minutes. Participant motion was measured using the camera system describe in Section 2 for the duration of the drive. Due to the camera detecting changes in pixels, participants were required to wear plain clothing as garments with a high spatial frequency would generate exaggerated motion signals.

Participants were also required to complete a two-part standardized comfort questionnaire adapted from Sammonds et al. (2017) and using the Borg CR100 scale (Figure 3). The questionnaire requires body-part discomfort to be evaluated first as priming questions and then an overall discomfort rating to be elicited. It is administered verbally and does not require participants to stop driving.

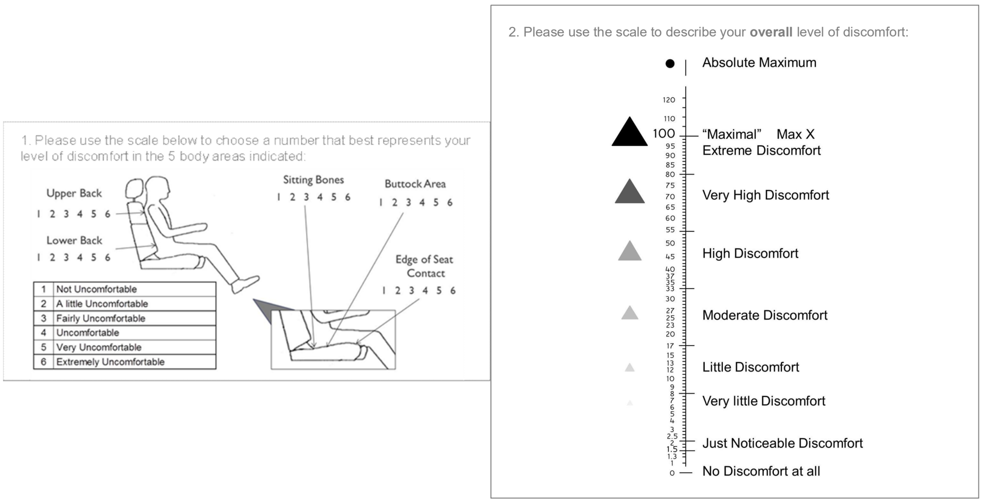


**Fig. 3.** Questionnaire design showing part 1; including the discomfort scale defined in ISO 2631-1 and a description of the body parts analysed, and part 2; including the adapted Borg CR100 scale (Sammonds et al., 2017)

## *4.2 Results*

The demonstration camera-based system performed as designed for all participants, recording data for the full 90 minutes and generating plausible data for each. Similarly, participants all completed the 90 minute session and were able to complete the subjective discomfort questionnaire. Typical results for one participant is shown in Figure 4. These data comprise the sum of left and right torso squared. This squaring algorithm emphasized the movements in the data (shown as the peaks). Head data did not provide a clear indication of body motion. For most participants the frequency of the peaks in the data increased over time.

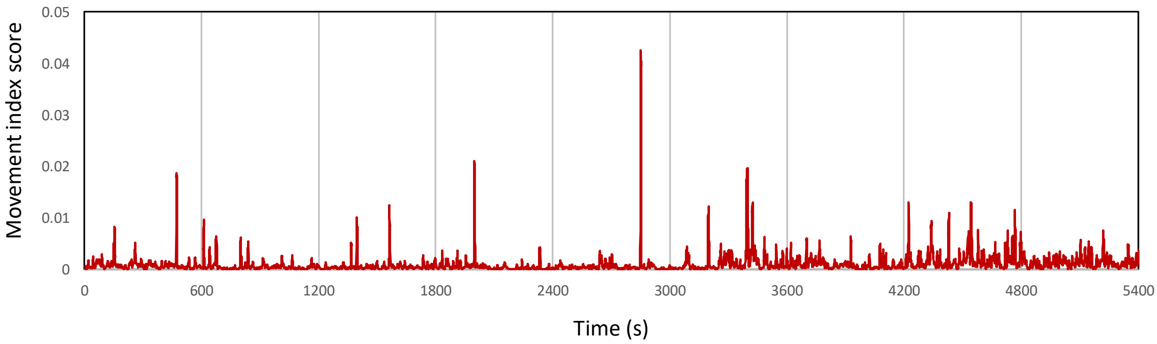


**Fig. 4.** Typical results for one participant – Data for left and right torso combined ^2.

As expected from the literature, the subjective discomfort generally increased over time (e.g. Mansfield et al. 2014; Figure 5). After 60 minutes all participants' discomfort was greater than at the beginning of the trial. However, scores improved for two of the participants between 60 and 90 minutes, with one returning to their score at zero minutes. Discomfort scores were significantly greater at the end of the trial than the beginning ($p < 0.001$, t-test)

Movement analysis data were split into 10 minute epochs representing each 10 minutes from 0 to 10, 10 to 20 etc. Within each epoch, the mean movement index score was calculated for the torso data squared. On average the amount of movement increased over the 90 minutes of the experiment (Figure 5). Whilst there was more variability in the movement analysis data than observed for the subjective data, the movement analysis index was significantly greater at the end of the trial than at the beginning ($p<0.05$, t-test).

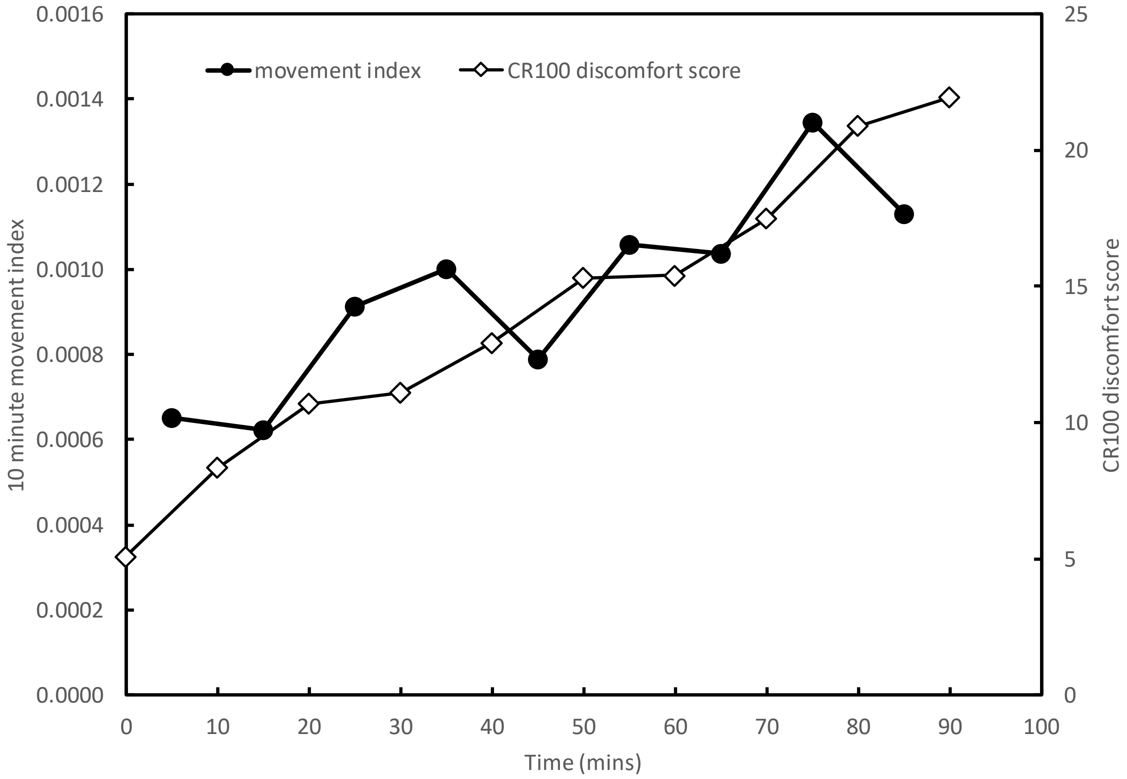


**Fig. 5.** Mean results for movement analysis and CR100 discomfort score. Movement analysis mean data for 10 minute epochs; movement index data points shown in figure correspond to middle minute of epoch.

## 5 Discussion

This investigation has demonstrated that it is possible to detect motion in a vehicle seat using a camera-based system. As hypothesized it shows that, on average, vehicle occupants move more as they have been occupying a seat for a longer period of time. Similarly, the well-established phenomenon of discomfort increasing with time has been replicated.

There are opportunities to improve the method that has been shown here. It has been argued that movements related to the driving task should not be categorized as SFMs (Sammonds et al. 2017) because they are not triggered by discomfort. The second camera system could be used to detect driving movements (i.e. steering controls and gear shifting) and to filter the motion from the primary camera to remove any driving-related movement. However, an alternative view could be that any driver movement activates muscles and improves the well-being, and thus driving-related motion could be beneficial. In autonomous or passenger transport systems, driving-related movements become irrelevant, although alternative tasks could present a similar challenge.

The algorithm used in the current version and presented here is simple and could be further optimized. The rectangular window could be improved; Hanning windows were investigated and slightly improved the ratio of the peaks in the motion to the background data, analogous to improving the signal-to-noise ratio. The optimal window design still requires validation. Using movement patterns detected by the camera to discern exact movements in the seat has also been explored. This has shown that one algorithm works very well for most participants but very poorly for others. Statistical analysis was unable to find clear associations with anthropometry and therefore this also needs exploration.

In the validation study some participants gave subjective responses that improved after one hour. This is possible but contradicts the general trends. It is possible that individuals found it difficult to interpret the

CR100 scale, and/or were unreliable in giving ratings. This is not unusual in comfort research. The phenomenon highlights a potential advantage of the camera-based system as this is less critical of the understanding of the participant and does not require specific training on interpretation of a novel concept of 'comfort rating'.

## 6 Conclusions and future work

- The camera-based movement analysis system worked for detecting driver movements in a laboratory setting. Further work is required to improve the computer vision system such that it can better distinguish different clothing patterns.
- The use of the secondary camera has not been considered in this study. Furthermore, primary camera positioning could also be optimized in future studies.
- On the basis on the data presented here, it is reasonable to associate driver movements with discomfort. This means that there are now three methods of generating 'discomfort' data: subjective ratings, SFMs, and driver movements; each method has its limitations. Further research is necessary to establish which method is most suitable when.
- It would be desirable to use this method in the field. For example, cameras could be installed in road, rail or air transport in order to discern growth of discomfort during long duration travel.

**Acknowledgments** The seats used in the experiment were supplied by The Bridgestone Corporation, Japan.

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