

Investigating Car Passenger Well-Being Related to a Seat Imposing Continuous Posture Variation

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Abstract

Static sitting when travelling by car is known to cause physical fatigue. It is generally encouraged to periodically engage in non-sedentary activities, but this is not possible when traveling by car. The present study aims to investigate the influence of moving the vehicle occupant's body passively. This posture variation is realized by continuously varying the seat configuration, i.e., the seat pan and backrest inclination. For the experiment, 21 participants sat twice on the same seat for 45 minutes: Once in a static and once in a dynamic configuration. The measurements obtained were the observation of body movements and questionnaires on perceived discomfort, seating comfort and experiential feelings. The results show that participants move significantly more in the static configuration and that they perceive more discomfort. The seat's comfort and support are evaluated significantly better in the dynamic configuration. The dynamic configuration results in participants feeling significantly more active, energetic, stimulated, pleasantly surprised, pleased, comfortable, accepting and calm. The static configuration results in the participants feeling marginally more tired and significantly more bored. Further research should investigate the effects in the context of driving on the road and an actual driving task. However, it can be concluded that the continuous movements of the seat have a beneficial effect on objective and subjective indicators of well-being.

Keywords: Vehicle seat; Discomfort; Comfort; Micro-movements; Experimental feelings

Introduction.

Travelling by car usually involves being in a seated position over a substantial amount of time. This static sitting is known to cause physical fatigue [1] and restricted postures also lead to a higher risk of musculoskeletal complaints [2]. It is generally encouraged to periodically engage in non-sedentary activities [3], since remaining seated causes discomfort over time. However, this is not possible when traveling by car since both the vehicle interior and the driving task restrain posture [4] and thus it would result into abandoning the driving task and interrupting the journey.

Previous research on comfort in office work has suggested that allowing for body movement is beneficial when the task does not allow for non-sedentary activities [5-13]. For instance, it seems necessary to enable frequent change between body postures provided that they are healthy and stable in order to improve seating comfort [5]. Graf et al. [6] also supported that natural movements (within an acceptable range) are desirable in workplaces. Furthermore, Fujimaki and Noro [7] showed in their research that during prolonged sitting natural movements occur in order to decrease discomfort. In their comfort model, Vink and Hallbeck [8] also identify body posture change as an enabler for comfort. Office chairs offering dynamic sitting have been developed according to this knowledge. These chairs are provided with certain swinging mechanisms for example, and these systems allow for a greater variation in the inclination angles of the seat [9]. Research shows positive effects of these kinds of chairs on muscle activity [10]. Groenesteijn et al. [11] also found that such a swing-system chair is related to positive comfort evaluations in the context of posture-restricting computer tasks. Moreover, an office chair with an unstable seat pan resulted in significant lower heart rate as well as the maintenance of oxygen levels in the tissues surrounding the ischial tuberosities [12]. Van Deursen et al. [13] also found that passive rotation in an office chair results in significantly more spinal length compared to no passive micro-movements for the same office tasks. Hence, posture variation can be considered beneficial to provide comfort during prolonged sitting.

Here, the concept in the present research is to enable well-supported postural change when travelling in a car by varying the seating angles. By alternating the seat configuration, different postures can be offered rather than solely providing micro-movements locally. Hypothetically, this could counter physical fatigue or discomfort, since it should result into variation in pressure distribution and muscle activity. Recurring posture variation could not only decrease discomfort from prolonged sitting, but could also result in more perceived comfort for car drivers since pleasant stimulation of tactile sensation is related to comfort [8]. For car seats, the possibilities to vary posture are limited: Fast moving or instable systems could be dangerous during driving, the space in the vehicle interior is limited, and the driving task restricts the size and the direction of body movement. Therefore, this postural change cannot be achieved with swinging mechanisms as used in office chairs because of safety concerns. For this reason, the vehicle occupant's body is moved passively by varying the seat configuration electrically in this study.

Although several studies examined the relation between bodily movements and discomfort, there seems to be no consensus on the frequency and range of movement that should be offered [14,15]. For instance, Vergara and Page [14] defined macro-movement as a distinctive change of posture every 5 to 6 minutes. On the other hand, Callaghan and McGill [15] described that dynamic sitting consists of at least 3 posture variations in 2 hours. Therefore, prior experiments

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[16] have been carried out in order to determine which succeeding steps of the seat movement the body can sense using the method of just-noticeable differences by Helander et al. (2000) [17] and what seat movements do not affect the driving task. From these experiments a range of motion and step size was derived as shown in figure 1. This range of motion allows for the backrest to move $1,5^\circ$ backwards, and for the seat pan to move 1° upwards and 1° downwards. The present research' objective is to evaluate if passive posture variation with those parameters in a car seat leads to more well-being. Therefore, this study aims to answer the following research questions:

- Does passive posture variation have a positive influence on perceived seating comfort?
- Does passive posture variation lead to less perceived discomfort?
- Does passive posture variation lead to less body movements?
- How is passive posture variation experienced?

Method

In order to answer the research questions a laboratory study was carried out with 21 participants (8 female, 13 male; height 161-196 cm ($176,8 \pm 8,8$ cm), aged 25 to 57 ($35 \pm 9,65$)). The car seat used for the experiment was a high-end model with leather upholstery which can be adjusted electronically. Each participant came in twice on separate days to evaluate the seat once with the periodic movement (dynamic) and once with the seat in static configuration. The order was systematically varied and both sessions were scheduled on the same time of day. On average there were 5 days between the two experiments. Figure 2 shows the research set-up. In front of the participants, a television was installed showing a video of the view through the front window during a continuous highway drive with moderate traffic density.

Prior to the experiments, participants filled out the informed consent, personal information and the questionnaires on discomfort and experiential feelings. Subsequently, the participants were instructed to sit in the seat, with their back fully against the backrest and the feet on the footrest. At this point, the seat configuration was exactly the same for all participants. They were then allowed to adjust the backrest inclination. The backrest inclination was freely chosen by the participant for both sessions. Next, the subjects would sit for 45 minutes. Afterwards, the participants were asked to fill out the questionnaires on discomfort, experiential feelings and seating comfort, and they were interviewed to retrieve additional remarks. Here, they were asked to describe their experience freely in their own words and to assess the movements of the seat in terms of size and frequency.

Seat movement system

During the session with the periodic movement, the seat's first movement started after five minutes of sitting and then the movements were continuously repeated throughout the remaining 40 minutes of the session. It was chosen to not have the seat move in the first 5 minutes based on the preliminary test, which showed that participants were annoyed when the seat movements started immediately. First, the backrest moved backwards for $1,5^\circ$ and then back to starting position. Secondly, the seat pan moved up 1° , and then it moved back to starting position. Next, it moved down 1° following by movement returning to starting position. The pause experienced between two subsequent movements was 5 s. The duration of each movement varied a little depending on for instance occupant weight as explained hereafter, but on average the perceived duration of a movement was 7 seconds.

The seat movements were controlled with a system (Figure 3) based on time and position values. The difference between the current position and the time left to finish the movement was used to generate the PWM (pulse-width modulation)-signal for the motor. The 8-bit PWM-signal allows the seat pan and backrest to move much slower than usual and this also created a soft start and stop for each movement. The frequency of the signal was set on 31250 Hz (ultrasound frequency) so that there was no acoustic or vibration disturbance. The pulse width was stored in a look-up table in order to compensate for the influence of the motor and seat characteristics. The occupant behavior and characteristics (e.g., weight, or pushing against the seat) were considered to be an unpredictable noise in the system, which can influence the duration of a movement. However, the control system made sure that the actual range-of-motion was the same for all participants regardless their weight.

Observations

Since body movements are an indication of discomfort [7,15,18], recordings were made of postural changes by observation. In order to determine the participant's posture, a rapid coding technique was used as applied by for instance Kamp et al. [4] or Branton and Grayon [19]. Due to the restriction of the trunk by the seat, only the position of the head, arms and legs were observed. The denotation of body postures is shown in Table 1. This denotation was determined before the study, but extended where necessary during the experiment. This resulted into adding position 4 of the arms and the legs. For analysis, the number of positions for each body part was counted and the sum of positions calculated. Since the data were not normally distributed, a Wilcoxon signed-rank test using SPSS 20 was executed to determine significant differences in posture variation between the two configurations ($\alpha=0.05$).

Questionnaires

The questionnaires were used to evaluate seating comfort, perceived discomfort and experiential feelings for both conditions. There are several questionnaires for recording seating comfort [20,21]. For this experiment, a selection of the questions applied by Groenesteijn et al. [11] in a study on dynamic office chairs was used, because it had a similar research objective and it evaluates several constructs of seating comfort separately. The participants were requested to reply to the following statements on seat comfort, mobility, support and acceptance in a systematically varied order using 9-point Likert scales:

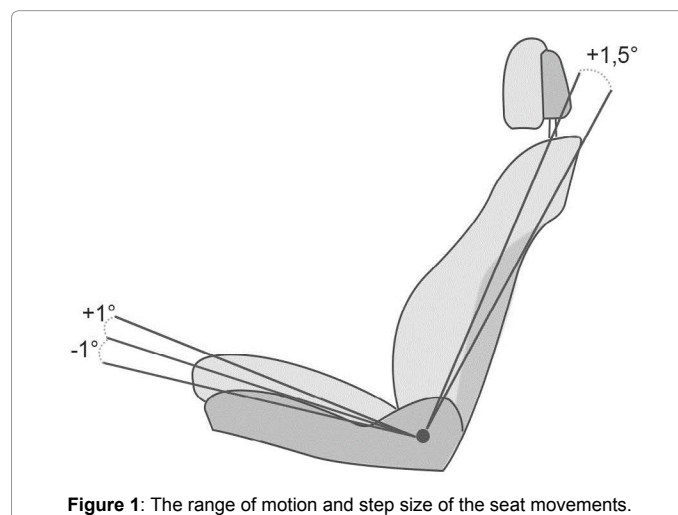


Figure 1: The range of motion and step size of the seat movements.



Figure 2: The experimental set-up.

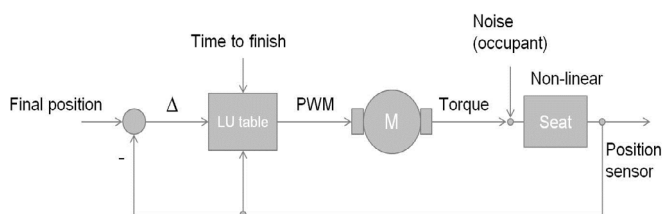


Figure 3: The control system for the seat movements.

1. How much would you like to have this seat?
2. How do you assess the comfort of this seat?
3. How do you evaluate the overall comfort of the backrest?
4. How do you evaluate the overall comfort of the seat pan?
5. Does this seat assist your physical well-being?
6. How do you like the mobility of the seat pan?
7. How do you like the mobility of the backrest?
8. How do you like the overall mobility of the seat?
9. How do you like the support of the seat pan?
10. How do you like the support of the backrest?
11. How do you like the overall support of the seat?

For statistical analysis, a Wilcoxon signed-rank test using SPSS 20 was used to evaluate differences in seating between the two configurations ($\alpha=0.05$) since the data was not normally distributed. For the evaluation of perceived discomfort, a variation on the LPD-questionnaire by Van Grinten [22] was used. This method was adjusted because participants had difficulties filling out the LPD-questionnaire correctly during previous experiments [23]. Instead of the entire body map, parts of the body map were shown concerning the neck region, upper back, lower back and buttocks with upper legs. These were accompanied by 10-point Likert-scales on discomfort (Figure 4). Prior to filling out the questionnaire, the researcher explained that discomfort means the perception of numbness, stiffness, and feelings of pain or unpleasant pressure [24]. Participants were requested to fill out the questionnaire before and after sitting in the seat. The level of discomfort before and after sitting for 45 minutes was compared for both configuration with a Wilcoxon signed-rank test in SPSS 20 ($\alpha=0.05$) since the data were not normally distributed. For further

analysis, the difference in discomfort prior to and after the experiment was calculated. These values of both configuration were compared using a Wilcoxon signed-rank test in SPSS 20 ($\alpha=0.05$).

According to James [25], a sensation of a stimulus – in this case the movement of the seat – consists of a physiological response and a perceptual or experiential component. Therefore experiential feelings are also evaluated in this study. In general the perception of emotions has two dimensions: pleasantness and arousal [26]. In this study experiential feelings are evaluated, since products elicit combinations of emotions that are low in intensity [27]. For this purpose, constructs from various questionnaires evaluating experiential feelings [28-31] were selected on relevance for this study. The constructs evaluated were 1) Active - calm, 2) Energetic - tired, 3) Stimulated - bored, 4) Pleasantly surprised – annoyed, 5) Pleased – displeased, 6) Comfortable – discomfort, 7) Relaxed – nervous, and 8) Accepting – rejecting.

The constructs 1-4, 6 and 7 were rated prior to and after sitting. The other statements were only rated after sitting for 45 minutes since they are rather specific to product experience (for instance being rejecting either the seat movement or being forced to sit in one position over time). A survey of 16 questions (see Figure 5) with 9-point Likert scales was developed using this selection of keywords to assess how participants experience the movement of the seat. For the constructs that were rated twice, the difference in value was calculated. Those

Nr.	Head	Arms	Legs
1	Against headrest	Next to trunk and legs	On footrest
2	Upright	On lap	Crossed
3	Tilted sideward	Crossed	Wide
4		Behind head	Pulled up

Table 1: Posture denotation.

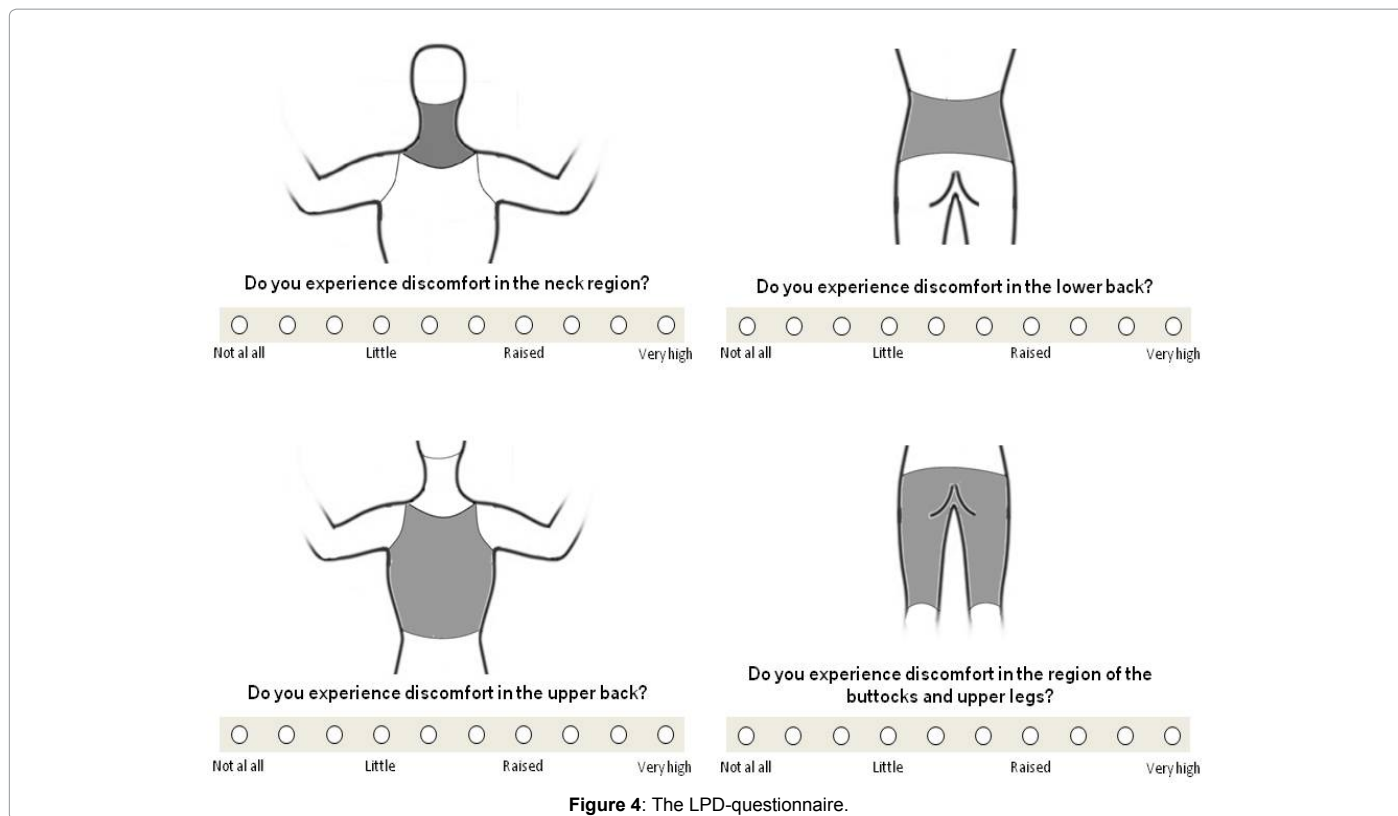
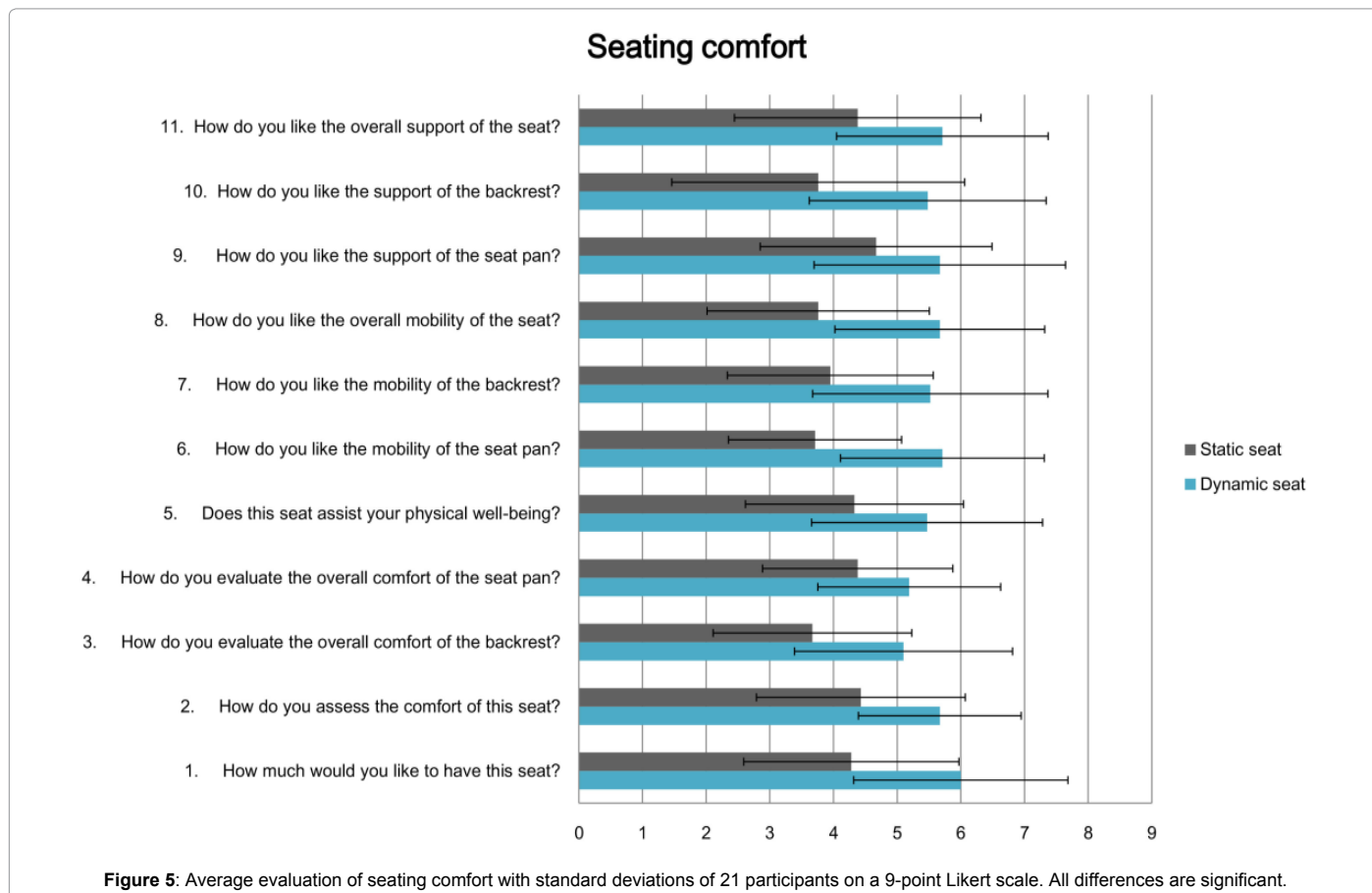


Figure 4: The LPD-questionnaire.



values and the absolute values for the other constructs' were compared between the two configurations with a Wilcoxon signed-rank test using SPSS 20 ($\alpha=0.05$) since the data was not normally distributed.

Results and Discussion

Observations

The measurement of body movements is as an objective indication of discomfort, similarly to the research of Telfer et al. [18]. Table 2 shows the total number of body postures observed during the experiments, as well as the number of positions of the head, arms and legs for both the static and the dynamic seat configuration. On average, 15 postures are observed in total for the static seat compared to 7 postures for the dynamic seat. These results show significant more body movement in the static seat for all body sections. This indicates that over time the human body could reject the position in which it is forced by the seat or that the resulting pressure distribution could grow uncomfortable. Therefore, the body posture is repeatedly adjusted. However, the urge to adjust the position of the head, arms, or legs is lower when the seat executes continuous movements in the seat pan and backrest. A possible explanation is that alternating the pressure distribution and body posture results in less experienced strain. Present literature seems to support this interpretation. For instance, a study carried out by Callaghan and McGill [15] evaluating dynamic posture strategies in office work showed that people who continuously vary their body posture appear to relieve their passive tissues. Moreover, Vergara and Page [14] concluded that frequent change of body posture indicated discomfort. Fujimaki and Noro [7] also observed that body movements start to occur when discomfort reaches a certain level during 60 minutes of sitting.

Seating comfort

Figure 5 shows the responses to the seating comfort questionnaire. The dynamic configuration is evaluated significantly better for all the questions (see Figure 5). The same car seat is evaluated significantly more comfortable (overall $p=0.015$, seat pan $p=0.010$, backrest $p=0.002$). During the interview, participants indicate that they perceived the movements as pleasant and appreciate the sensation it gave. The support of the car seat is also rated better with the continuous movements (overall $p=0.006$, seat pan $p=0.041$, backrest $p=0.005$), although the same seat is used with the same shape and foam properties. Perhaps the overall more comfortable experience leads to a better evaluation of product features that are not manipulated. Such a halo effect has also been reported by McMullin [31], who found that the same seat was evaluated as being more comfortable depending on the overall aircraft interior design. However, it is also possible that participants – who are laymen in comfort theories – do not clearly distinguish between support and comfort when rating the seat. The mobility awareness is also assessed more positively for the dynamic seat (overall $p=0.002$, seat pan $p=0.005$, backrest $p=0.017$).

In hindsight, it is probably not purposeful to compare the two configurations on this construct of the questionnaire since the difference in seat mobility was so large. Some participants also struggled with these questions for the static configuration if they had experienced the dynamic one first. However, it can be concluded that movements of the seat principally are experienced rather positively regarding comfort.

Discomfort

When comparing the level of discomfort before and after sitting for 45 minutes for the static configuration, significantly more discomfort is

found afterwards in the neck ($p=0.021$), the lower back ($p=0.023$) and the buttocks ($p=0.042$). For the dynamic configuration, no difference is found in discomfort prior to and after sitting (neck: $p=0.282$, upper back $p=0.105$, lower back: $p=0.589$, buttocks: $p=0.319$). Table 3 shows the difference in perceived discomfort before and after the 45 minutes of sitting. The sum of discomfort is significantly lower after experiencing the dynamic configuration compared to the static situation ($p=0.030$). These results are in accordance with the observations on posture variations: less body movement and less self-reported perceived discomfort both indicate reduced physical strain from sitting when continuous seat movements are applied. When considering the body regions separately, there is no significant difference between both seat configurations for the neck ($p=0.178$), upper back ($p=0.842$) and buttocks ($p=0.144$). This indicates that either the difference is caused by just the lower back, or that the main region of discomfort differs among participants. The difference in discomfort for the lower back is not only significant ($p=0.018$), but on average discomfort in the lower back for the dynamic configuration is less than before the experiment. Thus, the movements seem to have a particular beneficial effect locally in the lower back. This could indicate similar effects as local massage systems reported by Kingma and Van Dieën [32,33] and Van Deursen et al. [13] since several participants also indicated that they experienced the seat movements as some kind of massage (see section 3.5). However, further research is necessary to verify the effects when actually driving and to investigate any long term effects as will be discussed in the limitations section (3.6). It must also be noted that although significant differences are found the absolute levels of discomfort are very small. However, this is not unusual for the average interaction with a seating environment. For instance, Vink et al. [34] also found low levels of discomfort but significant differences when investigating the possibility for postural variation in office work.

Experiential feelings

Figure 6 shows the response to the experience questionnaire for both configurations visualized in the circumplex of arousal and valence of Russel [26]. The dynamic configuration results in participants feeling significantly more active ($p=0.047$), energetic ($p=0.020$), stimulated ($p=0.001$), pleasantly surprised ($p=0.001$), pleased ($p=0.001$), comfortable ($p=0.003$), accepting ($p=0.009$) and calm ($p=0.016$). However, participants felt significantly less active after sitting compared to before the experiment for both the static ($p=0.000$) and the dynamic ($p=0.013$) configuration. On the other hand, participants felt significantly less energetic after sitting in the static configuration ($p=0.001$) but not for the dynamic configuration ($p=0.245$). Furthermore, it cannot be said that participants feel very active or very calm although they feel more active ($p=0.047$) and calm ($p=0.016$) in the dynamic seat compared to the static configuration. After sitting, participants feel not significantly more or less calm or relaxed for both either the static ($p_{\text{calm}}=0.174$, $p_{\text{relaxed}}=0.242$) or the dynamic ($p_{\text{calm}}=0.244$, $p_{\text{relaxed}}=0.212$) configuration. They do feel significantly more tired after sitting in the seat statically ($p=0.001$), but not after sitting dynamically ($p=0.278$). Participants also feel significantly less stimulated after sitting in the static configuration ($p=0.001$), but significantly more

	Static configuration	Dynamic configuration	p
Head	4.60 ± 4.73	1.85 ± 1.18	0.001
Arms	5.60 ± 5.40	2.15 ± 2.74	0.006
Legs	5.40 ± 3.03	3.05 ± 2.24	0.008
Sum	15.60 ± 10.53	7.05 ± 5.36	0.000

Table 2: The total number of recorded body postures over 45 min. of sitting during both configuration (mean ± std. dev.) and the results of statistical analysis.

	Static configuration	Dynamic configuration	p
Sum	3,24 ± 4,75	1,10 ± 2,79	0,030
Neck	0,90 ± 1,87	0,38 ± 1,56	0,178
Upper back	0,62 ± 1,53	0,52 ± 1,40	0,842
Lower back	1,05 ± 1,83	-0,14 ± 1,01	0,018
Buttocks	0,67 ± 1,39	0,33 ± 1,39	0,144

Table 3: The difference in perceived discomfort before and after sitting for 45 minutes (mean ± std. dev.) for both configurations and the results of statistical analysis.

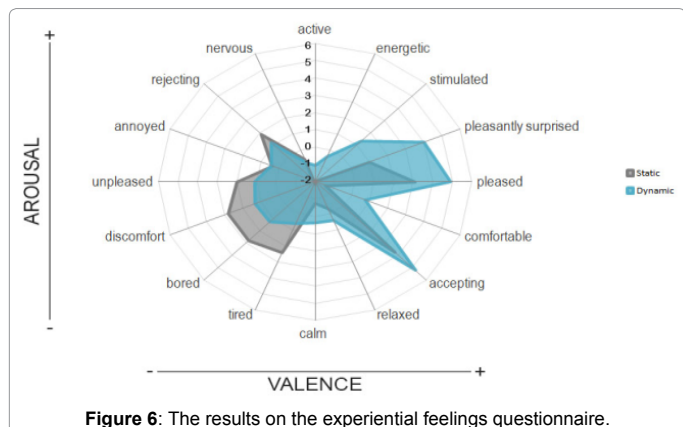


Figure 6: The results on the experiential feelings questionnaire.

stimulated after the dynamic configuration ($p=0.013$). However, they are significantly more bored after experiencing both the static ($p=0.000$) and the dynamic ($p=0.004$) configuration. Moreover, they feel significantly less nervous after sitting in the seat both statically ($p=0.028$) as well as dynamically ($p=0.007$).

After sitting in the static configuration, participants feel marginally more tired ($p=0,050$), significantly more bored ($p=0,035$) and experience significantly more discomfort ($p=0,008$) compared to the dynamic configuration. The latter corresponds to the self-evaluation of discomfort and the assessment of seating comfort. Since previous studies have found a relationship between movements and fatigue, the fact that people feel more tired and bored could also explain the increase in body movements for the static configuration. Rogé et al. [35], for instance, found that subsidiary body movements increase when vigilance decreases during simulated driving. Takanashi et al. [36] also found that small, repeating movements are related to objective measures of fatigue.

Overall, it can be stated that the static configuration is accompanied with more negative valence and feelings of deactivation when looking at the circumflex. The dynamic configuration shows more positive valence, but it cannot be concluded that participants are aroused although they feel relatively more activated, energetic and stimulated. This is also supported by the fact that the increase in boredom is significant for both configurations. For the design of office chairs, De Looze et al. [37] stressed the importance of evoking feelings that are wanted by the user and Kamp [38] found that users desire feelings of positive valence and a little arousal for car seats. This is mostly the case for the dynamic configuration, although feelings of positive valence and a little deactivation are also experienced.

Interview

The remarks of the participants during the interview at the end of the experiments mostly confirm the results of observations and questionnaires. For instance, fifteen participants described the

movements of the seat as very pleasant. Furthermore, five participants stated that they felt less tired with movement or more tired in the static configuration. This corresponds to the results of the questionnaire on experiential feelings. Five participants also noted that they felt that they moved more or had more desire to move in the static configuration, which was also observed during the experiment. Moreover, five participants described that they perceived more backache in the static configuration. This is similar to the results of the discomfort questionnaire.

Via the interview, additional information on how the seat movements are experienced is also obtained. Seven participants described the frequency of the movements as just right. Of those who started with the dynamic configuration, two participants expressed that they were disappointed when the seat did not move. Four participants described the seat movement as a different kind of massage experience. One participant experienced a better thermal comfort of the seat. However, Rattling or vibration in the mechanics of the backrest was a recurring problem. This was mentioned by seven participants and resulted in an unpleasant sensation.

The impressions from the interviews, however, also show how the same functionality can be experienced differently by various individuals. For instance, one participant expressed the need to adjust the posture more due to the seat movements and another experienced feelings of pain in the neck region when the seat was moving. One participant also experienced a better thermal comfort of the seat. On several occasions either the movement of the backrest was perceived to prominent (4 times) or there was too much movement in the seat pan (2 times). Moreover, one participant noted that the seat movements are not appropriate for the driver seat.

General limitations and recommendations

The present study aims to investigate if passive posture variation has a positive influence on perceived seating comfort, if it leads to less perceived discomfort, if it leads to less body movements, and how it is experienced. The results show that the same seat is evaluated as more comfortable, that less perceived discomfort is reported (particularly in the lower back region), and that less body movements are observed for the dynamic configuration. Moreover, the seat movements are related to pleasant experiential feelings. However, a limitation of the study is that it was carried out in a laboratory and not under real driving conditions. This could lead to differences in the evaluation of the system. For instance, Philip et al. (2005) [39] investigated sleepiness in real driving and simulated driving. Although they found similar results in both experiments, but self-reported measures seemed more affected by the simulated task. In this particular case, it is also of interest to learn how vibrations affect the experience of the system. For example, it could be possible that the seat movements become less noticeable by the dynamics of driving depending on traffic and road conditions. The objective of the present study was to evaluate comfort without disturbances of dynamics or the driving task.

However, further research should also investigate how the system is perceived in the context of a driving task: e.g., do the movements interfere with for instance steering; do people feel confident using the seat movement system? Moreover, the results on experiential feelings might differ for the actual use case. When the motivations of the user are different (a reason to drive somewhere vs. just participating in a user test), for instance, the level of arousal could vary from those reported here. Furthermore, feelings might differ in valence if the user is expecting the seat to move. The present study already showed

that some participants that started with the dynamic configuration are disappointed if the seat does not move the second time. Further research could also investigate if there is any gender effect or effects of anthropometrics on the results.

The observations on posture variation provide an objective measurement on discomfort, and are supported by the self-evaluation on discomfort and seating comfort. However, Carcone and Keir (2007) [40] found that conditions that are rated highest in terms of comfort by participants are not necessarily biomechanically ideal. Therefore, evaluation with measurements on muscle activity (EMG) or oxygenation (near-infrared spectroscopy) could investigate any biomechanical effects of the moving seat. Such research should investigate long-term seating over several hours. Moreover, the backrest inclination should be exactly the same and not chosen freely by the participants for both conditions in order to guarantee comparable results for such studies. This way, the beneficial effect on the lower back could also be investigated further.

Conclusion

The present study aims to evaluate if moving the vehicle occupant's body passively leads to more well-being. It can be concluded that continuous variation of the seat configuration has a beneficial physical effect. This is supported by both objective and subjective indications for decreased discomfort, i.e., the observations of body movements and self-reported perceived discomfort. Moreover, the seat's properties are rated better in terms of comfort and support. Thus the system provides well-supported postural change. Finally, the data show that participants also perceive more positive experiential feelings and no deactivation during the dynamic configuration compared to the static configuration. The dynamic configuration is perceived a pleasant and stimulating. On the other hand, the static configuration is perceived as boring and tiresome. Regarding its limitations, the study shows that this topic is interesting for further research. Namely, this should investigate the effects in the context of driving on the road and an actual driving task.

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