Experimental investigation of preferred seating positions and postures in reclined seating configurations

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ABSTRACT

In highly automated vehicles, new activities such as working, relaxing, or sleeping may be allowed for all occupants including drivers. Vehicle interiors will likely need to be adapted to accommodate these activities, and current interior concepts include reclining seats. To design these new seats, some knowledge of the preferred occupant postures in reclined seating conditions would be valuable. However, past studies mainly focused on preferred postures for driving. When reclining the seatback to adopt a relaxed position, occupants may also desire to modify the seat pan angle. Therefore, the present study aimed to investigate the preferred seat pan angle and occupant posture in reclined configurations. Two test experiments were performed. The first one focused on the preferred minimal and maximal seat pan angles selected by 18 volunteers for three seatback angles (21, 40, and 60 degrees from the vertical). The second one evaluated the seating postures of 13 participants corresponding to 11 seating configurations by combining 3 seatback angles (21, 40, and 60 degrees) and 4 seat pan angles (14, 27, 40 degrees from the horizontal, and self-selected). Results suggested that the preferred seat pan angles increased when reclining the seatback, especially for the preferred maximal seat pan angles. Concerning the occupant posture, the pelvis angle was influenced by both seat pan and seatback angles; but the pelvic angle variations were smaller than the seatback and seat pan angle variations.

KEYWORDS

Preferred seating position, Relaxing, Reclined seat, Highly automated vehicles

Introduction

In highly automated vehicles (HAVs), i.e. automation level 3 or above, the occupants are no longer driving. This may allow new activities, such as conversing, relaxing, or sleeping (Pfleging et al., 2016). A new vehicle interior will likely be needed to accommodate these activities. Reclined seats were found desirable (e.g. Bohrmann and Bengler, 2020). Some knowledge of the preferred postures in reclined seating conditions would be valuable to design new vehicle interiors and seating conditions. However, past studies were mainly focused on driving posture (Schmidt et al., 2014; Peng et al., 2017). It is only in recent years that researchers started to investigate postures other than for driving (Reed et al., 2018; Yang et al., 2018). Concerning reclined seating, these studies quantified the occupant posture for seatback angles up to 60 degrees. They used an existing seat designed for the driving position, with a fixed seat pan angle (set to around 14 degrees). However, biomechanical investigations revealed that such reclined configurations with a low seat pan angle could be challenging for the occupant restraint in case of an accident, especially for the pelvis (Richardson et al., 2020). Occupant pelvis restraint could be improved by increasing the seat pan angle (Grébonval et al., 2019). A more reclined seat pan could also improve comfort for sleeping (Stanglmeier et al., 2020). Grébonval et al. (2019) also observed that the pelvic angle (slouched or upright) could affect the pelvic restraint. However, little data are currently available concerning comfortable seating configurations considering both the seat pan and seatback angles (Stanglmeier et al., 2020), and the corresponding body postures were not analysed. To address that gap, the current study aims to quantify the preferred seat pan angles for reclined seatback ranging from 21 to 60 degrees and the corresponding occupant postures.

Materials and methods

Multi-adjustable experimental seat

The experimental seat was composed of three main structural components: the seatback, the seat pan, and the foot support (Figure 1A). The seatback was articulated with the supporting frame around a lateral axis passing through the reference point of the experimental seat (PRC). The backrest was composed of three back supports, mounted on the seatback frame. A wooden triangular block was added to the seat pan support so that the seat pan could be tilted from 9 to 45 degrees. The foot support was composed of a flat rectangular surface with an office footrest mounted on it. Twelve adjustable parameters of the experimental seat were used in this study (Figure 1B). They could be controlled either by an experimenter via a computer or directly by participants via a tablet. Adjustable features included the forward (x) and vertical position (z) of the three back supports, the seat pan, and the foot support; as well as the backrest and seat pan inclinations. Two armrests were also used and their positions could be adjusted manually. The foot support, the seat pan, the two armrests, and the three back supports were equipped with force sensors to measure the contact forces in the XZ plane. A more detailed description of the experimental seat can be found in Beurier et al. (2017).

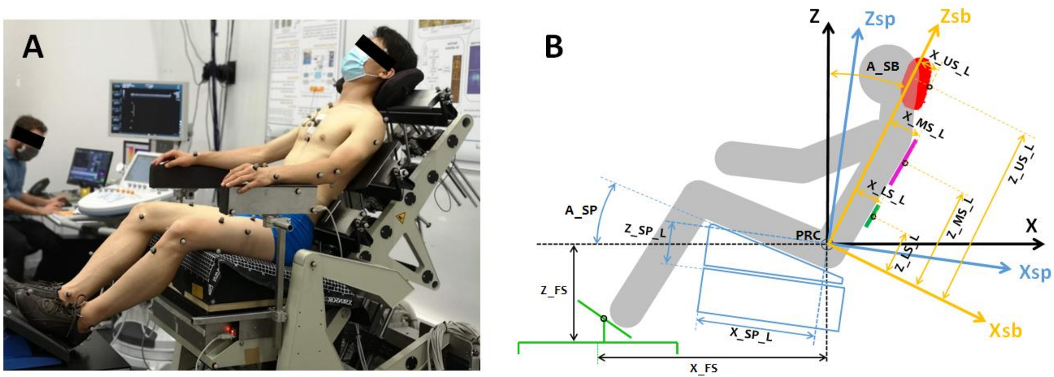

Figure 1: A view of a participant sitting on the experimental seat (A) and illustration of adjustable seat parameters (B)

Preferred seat configurations

The first experimental investigation (EXP_SEAT) aimed to quantify the preferred seat pan angles for a given back angle (A_SB). Nine males (Stature: 176±8cm; BMI: 24.3±3.7kg/m²) and nine females (Stature: 167±4cm; BMI: 21.3±1.2kg/m²) participated in the experiment. The experimental protocol was approved by the Université Gustave Eiffel Committee for research involving human subjects (CRPH). Three seatback angles (A_SB) were tested: 21, 40, and 60 degrees from the vertical. As the initial seat pan orientation could influence the self-selected seat pan angle (Theodorakos et al., 2018), two initial seat pan angles (A_SP) were tested. For each seatback angle, the seat pan could either set to 10 degrees to determine the minimal preferred seat pan angle or 40 degrees to determine the maximal preferred seat pan angle.

For each configuration, an experimenter positioned the middle and lower back supports approximatively at the height of the T9 and L3 vertebrae of the participant, respectively. The three back supports were initially aligned along the seatback z-axis (Zsb, Figure 1B). The seat pan length (X_SP_L, Figure 1B) was set to have a margin of approximately 50 mm between the popliteal fossa and the front of the seat pan while participants were asked to keep their back in contact with the lower and middle supports. Then, the foot support was adjusted (X_FS and Z_FS) until the thighs were in contact with the seat pan, and the knee angles were set to 110 degrees approximately.

After these preliminary adjustments, to adopt a comfortable relaxing position the participants were instructed to self-adjust head support position (X_US_L and Z_US_L), lower back support protrusion (X_LS_L), seat pan inclination (A_SP). They could also re-adjust seat pan length (X_SP_L) and foot support position (X_FS and Z_FS) if desired. Once a comfortable position reached, participants were asked to step off the seat in order to zero all the force sensors. Then, they were instructed to reposition themselves back on the seat and adopt a relaxed position. Preferred seat parameters were recorded at 20 Hz for 1.25 sec. Statistical analyses were performed using STATGRAPHICS Centurion 18 and statistic tests were considered significant if $p < 0.05$.

Occupant posture in reclined configurations

The second experiment (EXP_POST) aimed to quantify the occupant posture for a reclined seating configuration. Seven males (Stature: 177±6cm; BMI: 21.6±2kg/m²) and six females (Stature: 170±5cm; BMI: 21.5±0.6kg/m²) participated in the experiment. Among these thirteen participants, nine were also included in the first experiment (EXP_SEAT). The two experiments were separated by seven months.

Eleven seating configurations were defined by combining three seatback angles (A_SB: 21, 40, and 60 degrees from the vertical) and four seat pan angles (A_SP: 14, 27, 40 degrees from the horizontal, and self-selected initially set to 10 degrees). The combination (A_SB=21, A_SP=40) was considered unrealistic thus not used. The preferred seating procedure was similar to the one used for the EXP_SEAT trials, except that the participants could not change seat pan angle if it was predefined. In addition, the Vicon motion capture system was used to measure the position of 45 markers attached to the body for each trial. To better locate pelvis position, three landmarks (left and right anterior superior iliac spine, pubis symphysis) were also manually palpated.

Prior to the experiment, participants were scanned in a standing position to locate the spine joint centres using the method by Nerot et al. (2016). From the standing position, a personalized kinematic model including thighs, pelvis and spine was defined. Joint angles were defined as illustrated in Figure 2. To estimate the pelvic and spinal joint location once seated, an inverse kinematic algorithm was used to match the position of the markers attached on the trunk and thighs as well as the three manually palpated pelvic landmarks. The joint centre for the lower extremities and the head were estimated using external landmarks position as described in Reed et al. (1999).

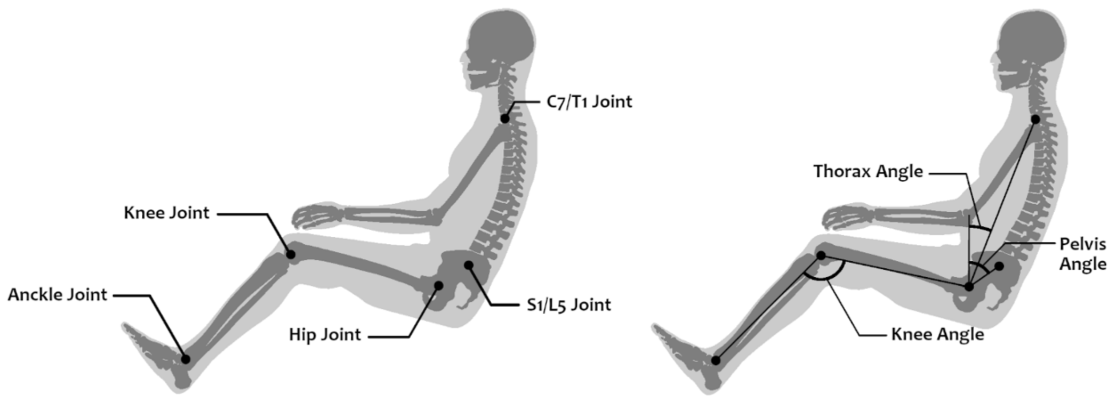

Figure 2: Postural angles definition

Results

Preferred seating configurations

The minimal preferred seat pan angle (i.e. self-selected, initially set to 10 degrees) were 12.2±2.1, 13.4±3.8, and 13.7±4.8 degrees for A_SB of 21, 40, and 60 degrees, respectively. The differences between the three were not significant (Figure 3A). The maximal seat pan angle (i.e. self-selected, initially set to 40 degrees) was significantly higher for the two reclined configurations (A_SB=40 and 60) than for the condition with a normal seatback inclination (Figure 3B). The maximal preferred seat pan angles were 30.8±6.8, 38.2±3.7, and 39.5±2.7 degrees for A_SB of 21, 40, and 60 degrees, respectively. Furthermore, the range of preferred seat pan angle (i.e. the interval defined by the minimal and maximal preferred seat pan angles) was significantly higher for the two reclined configurations (Figure 3C).

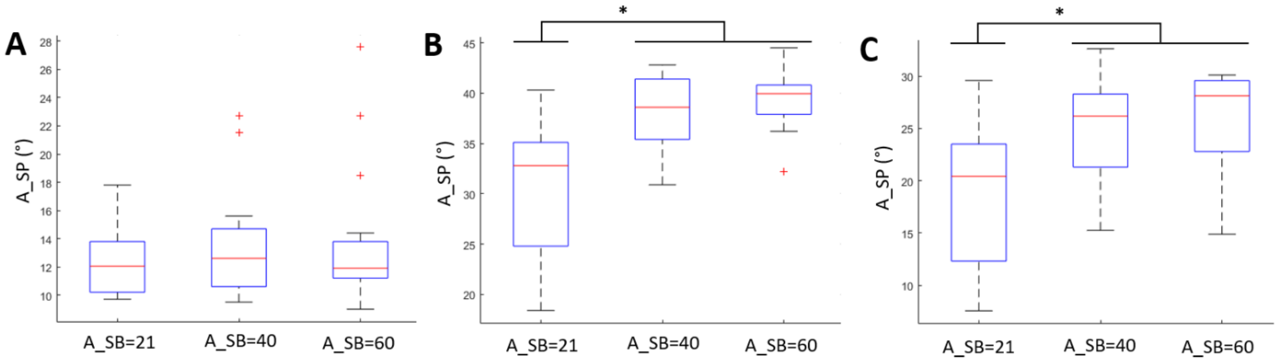

Figure 3: Minimal preferred seat pan angles (A), maximal preferred seat pan angles (B), and range of preferred seat pan angle (C) for each seatback angle (EXP_SEAT, n=18). Significant differences ($p<0.05$) are denoted with *.

As the lower back support protrusion (X_LS_L, Figure 1B) could be adjusted by the participant, the seatback profile angle (i.e. middle and lower back support line relative to vertical) could differ from the A_SB (backrest frame angle, which corresponds to the seatback profile angle if the back supports are aligned along the Zsb-axis). The seatback profile angles were 20.9±3.7, 38.3±2.4, and 55.1±4.2 degrees for A_SB being 21, 40, and 60 degrees, respectively.

In addition, as nine participants were included in both experiments, the reproducibility of both the minimal preferred seat pan and the seatback profile angles was analysed (Table 1). The seatback profile angles were similar and not statistically different between the two experiments. However, the minimal preferred seat pan angles were significantly higher in the second test campaign (Table 1).

Table 1: Reproducibility of the seat preferred configurations between the EXP_SEAT and EXP_POST trials (n=9). A_BackProfil: Seatback profile angle; A_SP_min: Minimal preferred seat pan angle.

Variable	**A_SB=21**		**A_SB=40**		**A_SB=60**	
(°)	EXP_SEAT	EXP_POST	EXP_SEAT	EXP_POST	EXP_SEAT	EXP_POST
A_BackProfil	20.6±1.4	20.5±1.5	38.5±2.4	38.5±1.6	55.5±3.7	56.8±6.2
A_SP_min	12.9±2.4	13.4±3.5	15.1±4.5	21.0±6.5	15.6±6.1	20.7±6.5

Occupant posture in reclined configurations

Table 2 summarizes the means and standard deviations of the body segment angles for the EXP_POST trials. The pelvis rotated more rearward when increasing either the seatback or the seat pan angle. As expected, a more reclined seatback increased the trunk angle (A_Trunk), which seemed not to be affected by the seat pan angle.

Table 2: Occupant posture in reclined configurations. Data from all EXP_POST trials were analysed. A_SB: Seatback angle; A_SP: Seat pan angle.

Variable	**A_SB=21**		**A_SB=40**			**A_SB=60**		
(°)	**A_SP=14**	**A_SP=27**	**A_SP=14**	**A_SP=27**	**A_SP=40**	**A_SP=14**	**A_SP=27**	**A_SP=40**
A_BackProfil	21.6±2.0	21.7±2.6	39.6±1.4	40.5±2.5	39.7±3.4	57.0±3.9	56.4±2.3	54.9±5.6
A_Trunk	24.9±2.4	24.6±2.0	39.6±2.9	42.2±3.7	41.3±3.9	56.0±3.7	55.5±2.3	53.9±5.8
A_Pelvis	61.3±5.3	67.6±5.9	67.2±4.8	75.3±10.0	79.0±6.7	73.7±5.3	78.0±5.5	81.4±7.2
A_Knee	118.6±9.7	113.5±6.9	122.4±8.8	113.9±7.6	110.2±10.6	120.7±5.8	114.4±7.1	112.4±12.3

Discussion and conclusions

The current study aimed to quantify both the preferred seat parameters and corresponding occupant postures in reclined seatback conditions. Results showed that the preferred seat pan angle highly depended on the initial seat pan inclination, as already observed by Theodorakos et al. (2018) using the same experimental seat. This finding suggests that a range of 23 degrees for A_SP could be considered as ‘preferred’ for a given back angle. Furthermore, current results indicate that reclining the seatback increased the range of preferred sitting configurations. The minimal preferred A_SP was around 13 degrees for A_SB of 21 and slightly higher for two other A_SB angles, but the maximal preferred SPA increased while reclining the seatback (31, 38, and 40 degrees for A_SB being 21, 40, and 60 degrees, respectively).

Postural results indicated that the pelvis rotated rearward when increasing either the seat pan or the seatback angles, but the pelvis angle variations were much smaller than the ones of seat angles. Using a current front vehicle seat (A_SB: 23, 33, 43, and 53 degrees), Reed et al. (2018) also observed that the pelvis rotated rearward when increasing A_SB.

Concerning the future vehicle interior, results suggest that the seat pan inclination seems not to be critical from point of view of seating comfort as a large range of seat pan angles may accommodate sitters in a more reclined seat. However, from a safety perspective, a more reclined seat pan may improve the pelvis restraint and reduce the submarining risk (Grébonval et al., 2019) but could also increase the spinal load and lead to lumbar spine fracture. Therefore, additional biomechanical investigations should be carried to establish if a safe range of sitting configurations (combination of A_SB and A_SP) exists within the range of comfortable positions. This is one of the aims of the ongoing ENOP Project in which the current postural results will be used to help position the occupant.

The present study has some limitations that should be addressed in future work. As an experimental seat with rigid contact surfaces was used, possible effects of soft cushion may need to be investigated. The preferred seating configurations were obtained during a short duration sitting session, effects of long-term sitting were not considered.

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