Determining Anthropometric-related Comfort Areas of Automotive Seat Components: Results from a Subjective Comfort Evaluation

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Abstract In the past, there has been a lot of research on different factors influencing the comfort sensation of vehicle seats [1]. The results of several studies showed that the unique anthropometry of each human is a significant variable in seat comfort evaluation [2, 3]. Nevertheless, no study in the literature was founded, that explored anthropometric-related comfort areas of different seat components in more detail. Therefore, the objective of the presented study was to investigate if anthropometric-related comfort areas for different automotive seat components are existing and how they are affecting the comfort evaluation.

Seventy participants (36 males, 34 females) from a broad anthropometric spectrum tested two experimental car seats. On the first seat, the original adjustment tracks of the cushion depth adjustment (50 mm) and cushion tilt adjustment (approx. 5°) were increased by the factor of three. To enable a continuous adjustment of the side bolster angles for the cushion and backrest, special electromechanical adjustors were constructed at the second seat. With the new side bolster adjustments, the angles could be varied in a range of 15° and 20° to 90°. The aim of the seat modifications was an optimal adjustability of the respective seat components for each subject independently of their individual anthropometry. For researching anthropometric-related comfort areas, up to seven predefined discrete levels were tested in order to quantify the turning points from a good to a bad comfort experience. The measured body dimensions were *body height* and *weight, shoulder width, sitting height* and *waist circumference* on the upper and *sitting width, sitting depth* and *thigh circumference* on the lower body.

The results of the presented study showed various correlations between the individually preferred adjustment of the seat components and specific body dimensions. The anthropometric-related comfort areas were investigated by analyzing the subjective assessment of the discrete levels depending on the measured body dimensions. The statistical analysis of the anthropometric effects on the subjective comfort evaluation indicated that each seat component had specific anthropometric-related comfort areas.

In conclusion, with the method used in this experiment it was possible to determine anthropometric-related comfort areas of specific automotive seat components. Accordingly, specific design and adjustment recommendations can be given for future seat concepts considering anthropometric needs of occupants. Further research is necessary to explore how the anthropometry affects the comfort experience on other seat parts as well.

Keywords: Anthropometry, Automotive, Comfort Areas, Seat Components

1 Introduction

Many different factors are affecting the seat comfort experience in a vehicle. Beside the usage or task performed in a car, the seat characteristics are important parameters influencing the passenger´s perceived comfort. The contour of the backrest and seat cushion as well as the foam properties are essential for an optimal fit between the seat and passenger. The third main affecting factor is the human with its unique anthropometric and morphologic characteristics. The fact that humans are different concerning their individual anthropometry poses a significant challenge in the seat development process [4].

Various studies had previously researched how the anthropometry affects subjective and objective comfort parameters. The results generated by Paul et al. (2012) show several correlations between a variety of body dimensions, such as body weight, hip breadth, waist circumferences and pressure parameters. They concluded that more research is needed in order to quantify whether or not these values correlate with a subjective comfort evaluation [5]. The experiment of Kyung and Nussbaum (2013) found significant correlations and weak to moderate effects between different subjective comfort ratings and pressure parameters [6].

Heckler et al. (2018) studied anthropometric effects on subjective comfort sensation on serial production car seats in detail. They compared the effect of eight body dimensions on the comfort evaluation between two different car seats. The results of this investigation showed that there are stronger anthropometric effects on the rather simply and sportively shaped seat in relation to a highly adjustable and comfort-orientated contoured seat. The authors concluded that the unique anthropometry of each human still poses a great challenge, even in current modern seat design. They suggest that a deeper understanding of how the specific body dimensions influence the comfort sensation of different seat components is needed [3].

Based on the literature findings, a knowledge gap had been identified. No study was found that researched anthropometric-related comfort areas of automotive seat components in detail. Subsequently, the target of the experiment described in this paper seeks to fill the discovered gap in research regarding the influence of human anthropometry on the comfort experience of different automotive seat components.

2 Objective

The aim of the presented study was to define anthropometric comfort areas for various seat components. Therefore, two experimental seats had been constructed in order to enable a comfortable adjustment of different seat parts independently of the unique anthropometry of each individual. The analyzed seat components were cushion depth (CDA), cushion tilt angle (CTA), cushion and backrest bolster angle (CBA, BBA). The scope was to investigate the following hypotheses:

- Specific anthropometric-related comfort areas are existing for certain seat components.

For researching the anthropometric comfort areas, a study with a broad anthropometric sample was conducted. The participants evaluated several configurations of the modified adjustment tracks under static testing conditions in a partial body vehicle.

3 Method

3.1 Experimental seats and testing environment

Two manual sport seats of an Audi A6 (C8) were modified to investigate the influence of anthropometric properties on different seat components. On the first seat, the serial adjustment of the cushion depth (CDA = 50 mm) and cushion tilt (CTA = 5 °) was extended up to 150 mm and 15 ° travel distance. For the second seat, new seat adjustment mechanisms were designed to enable a continuous adjustment of the cushion and backrest bolster angle (CBA, BBA). The CBA and BBA tilt angles could be adjusted from 15 ° to 90 ° and from 20 ° to 90 °, respectively (Fig 1.).

Fig. 1. Experimental seats with modified adjustment tracks.

The aim of the modifications was to ensure that every subject found an optimal setting of each mentioned seat component independently of their individual body dimensions. Furthermore, the wide adjustment range of each part was intended to provide the possibility to determine individual comfort areas by defining the thresholds between a positive and a negative comfort sensation.

For a realistic sense of space, the tested seats were mounted in partial body Audi A6 with a fully equipped interior. The static experimental setup was constructed in a workshop hall.

3.2 Measurement tools

Overall, eight body dimension were measured of each subject by using an anthropometer, a statiometer and a scale. Besides *stature* and *body weight,* three body measurements of the lower body (*seat depth, hip breadth* and *thigh circumference*) and upper body (*shoulder breadth (bideltoid), sitting height* and *waist circumference*) were measured.

The comfort questionnaire from the experiment of Heckler et al. 2018 was used for quantifying the subjective comfort perception of each configuration. The questionnaire consisted of 22 items and a five-point ordinal evaluation scale in order to rate different influencing factors like the initial contact with the seat, the functionality, the contour of different seat components and the pressure distribution in eight body areas. The existing questionnaire was modified for the specific setting by adding the items cushion and backrest bolster angle.

The pressure distribution between seat and passenger was analyzed with two pressure mats (XSensor Technology Corporation, LX100:48.48.02). However, the results of the pressure analysis are not presented in this paper.

3.3 Experimental design and participants

The presented study was conducted with a mixed-model design. The independent variables (IV) are the different test conditions and the different body dimension groups. The dependent variables (DV) are the subjective comfort items of the questionnaire. The ordinal data were analyzed with non-parametric tests, such as the Friedman test, Kruskal-Wallis test and the Wilcoxon signed-rank test.

Table 1. Average values of the body dimension groups for eight anthropometric variables.

Anthropometric variable	small (n = 15)	mid (n = 15)	large (n = 15)
Stature	Ø 163.0 cm (SD: 4.3 cm)	Ø 175.6 cm (SD: 1.6 cm)	Ø 188.7 cm (SD: 4.6 cm)
Body weight	Ø 55.6 kg (SD: 3.3 kg)	Ø 73.0 kg (SD: 3.4 kg)	Ø 103.6 kg (SD: 11.7 kg)
Sitting height	Ø 84.2 cm (SD: 6.6 cm)	Ø 92.2 cm (SD: 0.4 cm)	Ø 98.6 cm (SD: 2.1 cm)
Shoulder breadth	Ø 39.6 cm (SD: 1.1 cm)	Ø 44.9 cm (SD: 1.1 cm)	Ø 51.9 cm (SD: 2.6 cm)
Waist circumference	Ø 69.3 cm (SD: 4.1 cm)	Ø 83.2 cm (SD: 2.7 cm)	Ø 109.1 cm (SD: 9.9 cm)
Seat depth	Ø 47.1 cm (SD: 1.3 cm)	Ø 51.3 cm (SD: 0.67cm)	Ø 55.7 cm (SD: 1.9 cm)
Hip breadth	Ø 35.6 cm (SD: 0.7 cm)	Ø 39.3 cm (SD: 0.6 cm)	Ø 42.6 cm (SD: 1.2 cm)
Thigh circumference	Ø 51.7 cm (SD: 1.8 cm)	Ø 57.3 cm (SD: 0.5 cm)	Ø 64.8 cm (SD: 4.8 cm)

Overall, 36 men (Ø 41.4 ± 10.9 years) and 34 women (Ø 32 ± 10.6 years) of a broad anthropometric spectrum participated in this study. For the investigation of the anthropometric comfort areas, the sample was divided in three groups for each measured anthropometric variable separately (Tab. 1).

3.4 Procedure and setup

The test subjects were asked to wear casual clothes for both experiment sessions. At the beginning, eight body dimensions were measured by the experimental staff. Then, the participants were instructed in the overall test procedure by explaining the items of the used questionnaire, the adjustability of the specific seat and the duration of each configuration.

After this procedure, the subjects took a seat in the vehicle and adjusted the seat to their preferred driving position only by using the original adjustment tracks. The participants rated their individual driving position with the whole questionnaire. The second comfort rating was obtained by evaluating the seat component, the pressure distribution in the affected body areas as well as the overall comfort. Starting from the optimal position, the experimenter adjusted the following discrete configuration of the specific seat component as shown in table 2. If the comfort rating reaches a comfort score of 1 (“seat is unacceptable”) for the item overall comfort the session has been aborted. For avoiding order effects, the test procedure was permuted by changing the evaluation order of the four modified seat components.

Table 2. Test conditions for the different seat components.

Test conditions	CDA [mm]	CTA [°]	CBA [°]	BBA [°]
Serial adjustment	0 - 50	15 - 20	63	55
Additional adjustment	0 - 150	15 - 30	15 - 90	20 - 90
1. Configuration	0	15	15	20
2. Configuration	25	17.5	30	34
3. Configuration	50	20	45	48
4. Configuration	75	22.5	60	62
5. Configuration	100	25	75	76
6. Configuration	125	27.5	90	90
7. Configuration	150	30	-	-

The evaluation time of each configuration was at least five minutes. For a standardized data collection, the pressure parameters of each setting were recorded after the first minute. Each experimental seat was tested in a separate meeting in order to avoid long testing sessions.

4 Results and discussion

In order to research anthropometric comfort areas of specific seat components, a variety of statistical tests were executed. The change of the subjective comfort sensation in the different configuration was tested with a Friedman test for each body dimension group separately. For defining anthropometric comfort areas, a mean comparison between the configuration "Additional adjustment" and the other configurations was calculated. Another comparison between the body dimension groups of each configuration was performed to highlight the anthropometric dependency in specific settings. For the multiple comparisons between the different configurations the significance level was adjusted with the Bonferroni method to $\alpha = 0.00625$.

The subjective evaluation of the cushion length for the modified CDA showed different comfort areas in dependence of the body dimension "*Seat depth"* (Fig. 2). For the group *"Seat depth short"* the Bonferroni-adjusted post-hoc analysis showed a significant worse comfort rating of the third configuration (Mdn = 2.0) compared to the configuration "Additional adjustment" (Mdn = 4.0; Wilcoxon test: z = -3.35, p = .001, n = 15). The comparison for group *"Seat depth mid"* revealed a first significant difference at the fourth configuration (Mdn = 2.0) compared to the configuration "Additional adjustment" (Mdn = 4.0; Wilcoxon test: z = -3.16, p = .002, n = 15). The first configuration of the group *"Seat depth long"* that was rated significantly worse was the fifth setting (Mdn = 2.0) in relation to the individual adjusted configuration (Mdn = 4.0; Wilcoxon test: z = -2.99, p = .003, n = 15). The statistical analysis between the three body dimensions of the test condition CDA showed significant differences in configuration three, four and five. The results corroborate the presence of specific anthropometric comfort areas for the CDA in dependence of the body dimension "S*eat depth"*.

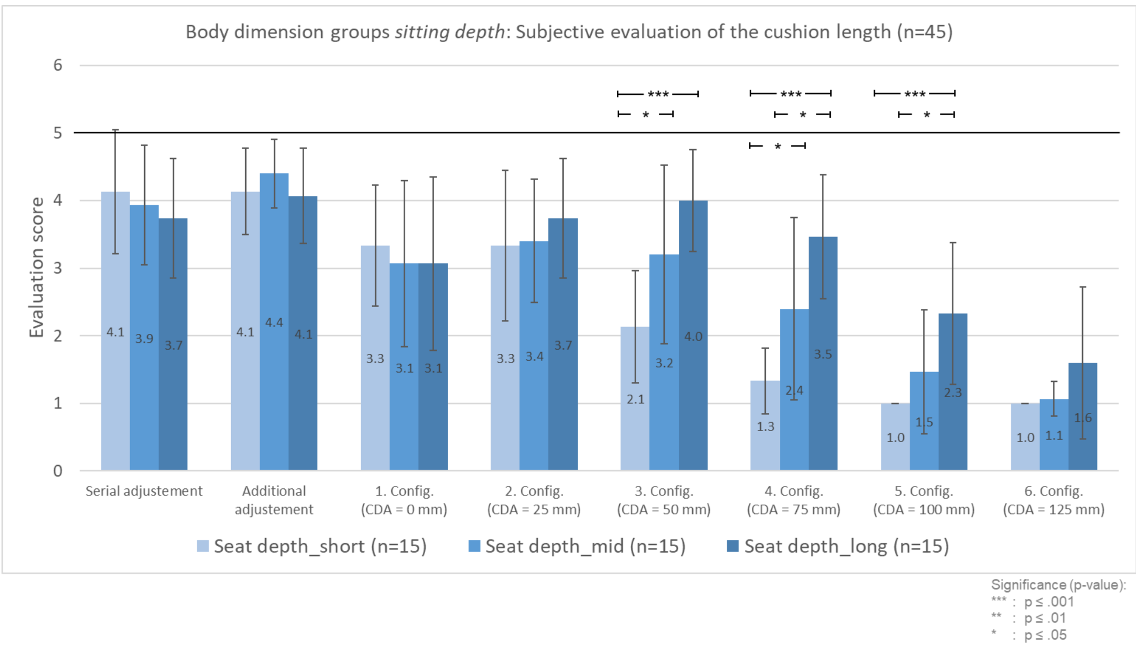

Fig. 2. Subjective evaluation of the CDA for the body dimension groups "*Seat depth"*.

The subjective evaluation of the item cushion bolster angle for the experimental seat with the modified CBA showed a significant improvement with the additional adjustment for two body dimension groups. For the group *"Hip breadth mid"* the configuration "Additional adjustment" (Mdn = 5.0) was rated significantly better compared to the "Serial adjustment" (Mdn = 4.0; Wilcoxon test: z = 2.57, p = .010, n = 15). For the group *"Hip breadth wide"* the configuration "Additional adjustment" (Mdn = 5.0) was rated significantly better compared to the “Serial adjustment” (Mdn = 3.0; Wilcoxon test: z = 3.10, p = .002, n = 15). In the second condition, the comfort rating of the cushion bolster angle differs between the body dimension groups (Fig. 3). The value of group *“Hip breadth thin”* (Mdn = 2.0) was significantly worse compared to the group *“Hip breadth wide”* (Mdn = 3.0; Mann-Whitney U test: U = 39.00, p = .002).

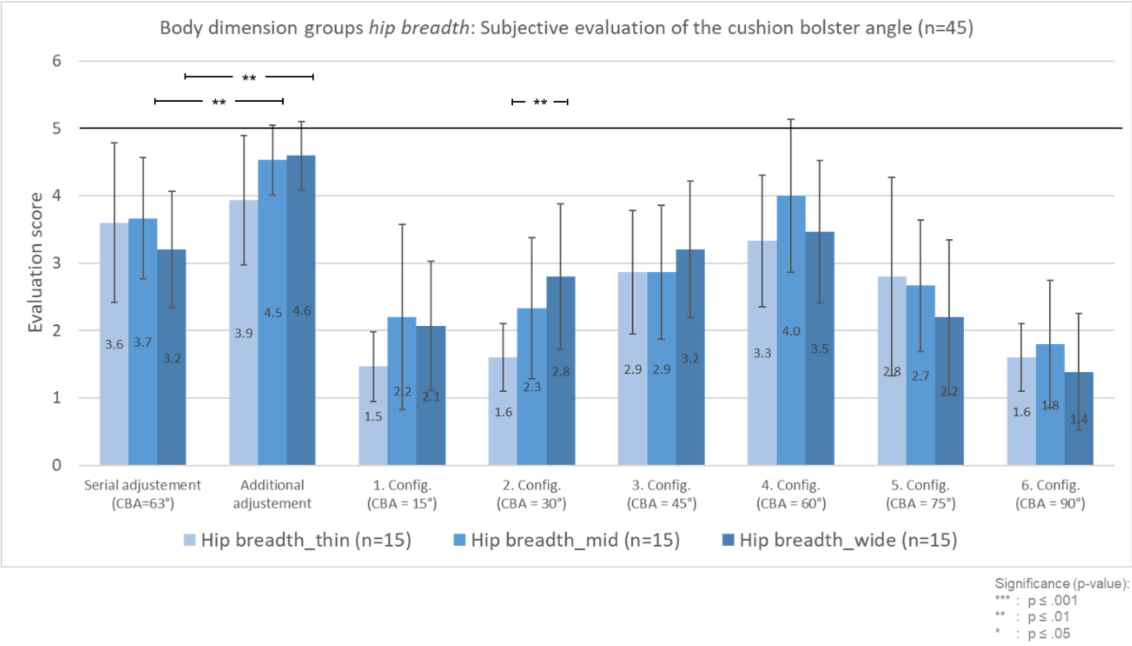

Fig. 3. Subjective evaluation of the CBA for the body dimension groups “*Hip breadth”*.

With the additional BBA adjustment, a significant effect on the evaluated item cushion bolster angle has been detected for all body dimension groups of the *“Waist circumference”* (Fig. 4). For the group *“Waist circumference thin,”* the configuration “Additional adjustment” (Mdn = 4.0) was rated significantly better compared to the “Serial adjustment” (Mdn = 3.0; Wilcoxon test: z = 2.33, p = .020, n = 15). The configuration “Additional adjustment” (Mdn = 4.0) of the group *“Waist circumference mid”* was also evaluated significantly better compared to the “Serial adjustment” (Mdn = 3.0; Wilcoxon test: z = 1.96, p = .050, n = 15). For the group *“Waist circumference wide”* the configuration “Additional adjustment” (Mdn = 5.0) was rated significantly better in contrast with the “Serial adjustment” (Mdn = 4.0; Wilcoxon test: z = 2.76, p = .006, n = 15).

The analysis of the configuration four, five and six showed significant effects between the body dimension groups. For example, in configuration five the group *“Waist circumference wide”* (Mdn= 1.0) rated the backrest bolster angle significantly worse compared to the group *“Waist circumference mid”* (Mdn = 4.0; Wilcoxon test: z = -2.98, p = .003, n = 15).

The results indicate the presence of anthropometric-related comfort areas for the BBA as well. The first three configurations up to a Backrest bolster angle of 48° were rated negatively and thus representing the lower level of the comfort areas for all three groups. The upper threshold of the comfort areas were different and specific for the groups. The upper level of comfort areas for the group with a wide waist circumference was between configuration four and five. The comfort rating of the other two groups only changed at configuration six to a negative rating.

The anthropometric effects on the CTA were not that strong in comparison to the other seat parts. Only small effects were recognized between the body dimension groups and thus the anthropometric-related comfort areas were almost the same for each group.

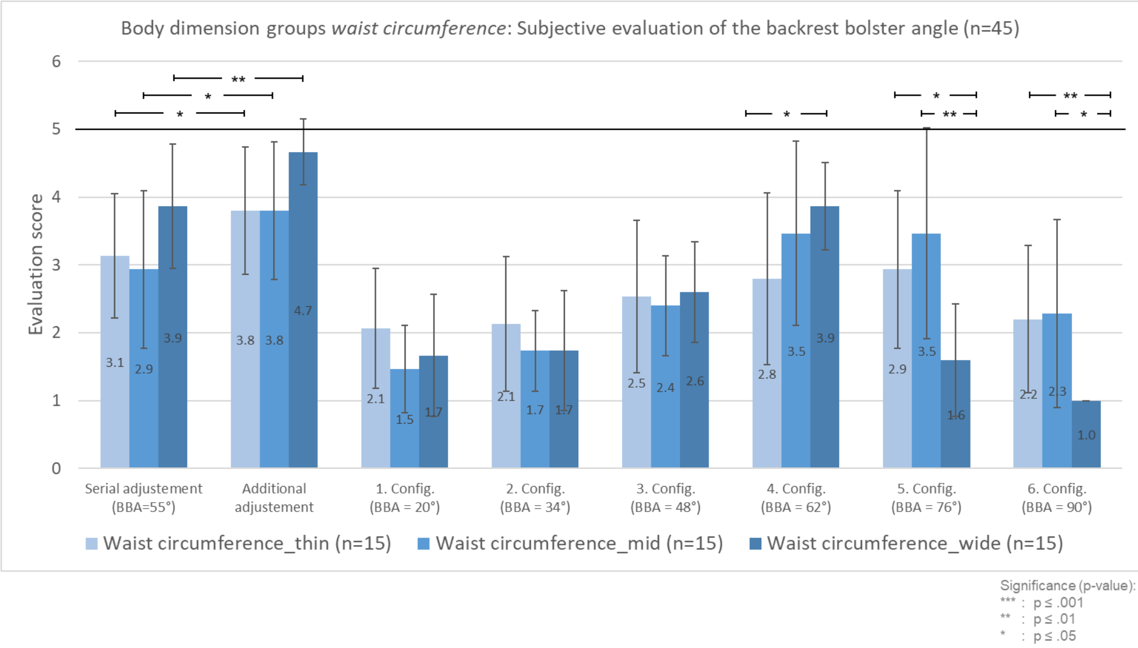

Fig. 4. Subjective evaluation of the BBA for the body dimension groups *"Waist circumference"*.

5 Conclusion

The aim of the present study was to define anthropometric-related comfort areas of different seat components. With the results, the initially formulated hypotheses was verified, by partly strong anthropometric effects on the comfort sensation in different configurations. It was observed that the body dimension *seat depth* has an effect on the individual comfort areas of the cushion depth adjustment. Furthermore, the adjustability of the cushion and backrest bolster angle lead to a significant increase on the subjective evaluation score for the respective seat component, indicating a strong individual preference of these seat components. The comparison between the different configurations for the specific body dimension groups showed that anthropometric-related comfort areas also exist for these two components.

It can be concluded, that the knowledge about anthropometric-related comfort areas is essential for designing the seat geometry in general as well as specifying the adjustability ranges of specific seat components. For example, a cushion depth adjustment of 75 mm in combination with a CTA appears to be sufficient to provide most passengers an optimal thigh support. Another insight of the experiment is the fact that an adjustment range of the cushion bolster angle from around 40° to 75° was needed for receiving a positive evaluation score for the participants. The comfort area of the BBA varies from 48° up to 76°. Any additional adjustability outside of these ranges only had a positive effect for individual participants and can be ascribed to personal preferences.

The fact that anthropometric-related comfort areas exist for the research seat components opens the possibility for preadjusting the seat in relation to the unique anthropometry of each passenger. This can increase the comfort experience of new seat concepts. Another important finding of this experiment is the containment of the adjustment ranges for the particular seat component to increase the comfort values in the subjective assessment by an optimal adaption of the seat.

Further research is needed to investigate if the determined comfort areas are although existing under real traffic conditions and during prolonged driving. To research how different design concepts of seat components can affecting the anthropometric-related comfort areas of different body dimensions seems to be another useful approach.

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