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Subjective Preferences and Discomfort Ratings of Backrest and Seat Pan Adjustments at Various Speeds

Jingdong Li and Yu Huang *

State Key Laboratory of Mechanical System and Vibration, Institute of Vibration Shock and Noise, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, China; lijingdong@sjtu.edu.cn
* Correspondence: yu_huang@sjtu.edu.cn

Abstract: Power seats (i.e., electrically adjustable seats that can be designed to move in several ways) have become increasingly common in airplanes, vehicles, and offices. Many studies have investigated the effects of seat attitude parameters, for example, the inclined angles of a backrest, on discomfort during the adjustment process. However, few studies have considered discomfort under different speeds during the adjustment process. In this study, we investigated discomfort with three speeds (i.e., "fast", "median", and "slow" corresponding to three durations of 15, 20, and 25 s, respectively) and two adjustments of a power seat, i.e., incline angle adjustment of the backrest and fore-and-aft position adjustment of the seat pan. We also investigated the effects of different physiological parameters on subjects' discomfort. Twenty-four subjects (12 males and 12 females) completed a questionnaire to indicate their adjustment condition preferences, to rate their overall discomfort during the adjustment processes on a category-ratio scale, and to rate their local body discomfort. The majority of subjects preferred the fast speed adjustment condition and the trend was that a lower backrest adjustment speed increased discomfort during the process. The dominant local discomfort was in the upper and lower back regions during the backrest adjustment, whereas there was no obvious dominant local discomfort during the seat pan adjustment. The physiological parameters also had significant correlations with discomfort in some adjustment movements, for example, the discomfort was negatively correlated with height during the backrest adjustment.

Keywords: human comfort; backrest angle; adjustment speed; seat pan position

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1. Introduction

Power seats (i.e., electrically adjustable seats that can move in several ways) with electrical control, for example, electrical backrest adjustment, are widely used in airplanes, vehicles, and offices for safety, convenience, and comfort. The speed of moving seat components, for example, the backrest and the seat pan, during an adjustment can influence subjective preference for a seat and could be related to the overall comfort of a seat [1]. In contrast to "comfort", "discomfort" is commonly used to describe subjective reactions (e.g., annoying, uncomfortable, and distressed) to environmental stresses, mainly associated with pain, tiredness, soreness, and numbness [2–4]. Discomfort can be influenced by changing the state of seat components, for example, varying the incline angle of a backrest affects posture and human–seat interface pressure, and therefore further influences a subjective evaluation of discomfort [2–4].

Kolich and Taboun conducted a subjective evaluation of seat discomfort through a survey and an objective evaluation of seat discomfort by measuring human–seat interface pressure; they established a multiple linear regression relation between subjective and objective results. Annett reported that the best way to obtain feedback about perception of comfort was through the administration of a questionnaire [5,6].

The inclination of a backrest significantly affects an occupant's static comfort, and many studies have been conducted to determine the most appropriate angle for static comfort [1,7–9]. Haynes and Williams [7] asked subjects to complete typing tasks in different sitting postures and concluded that different sitting postures as a result of different backrest angles (100°, 125°, and 160°) and seat tilt angles (5° and 40°) led to significant differences in typing performance and comfort. Wang and Cardoso [9] indicated that seat discomfort decreased with an increase in backrest angle. Vanacore and Lanzotti [8] failed to find a significant difference in comfort between different seat inclination conditions, but they proposed that an inclined backrest (cushion padding and degree of fit at the shoulder, middle back, and lower back) had a strong correlation with the overall comfort. Generally speaking, backrest angles affect body–seat interface pressure variables, for example, the average pressure, peak pressure, and contact area, and therefore influence the overall discomfort eventually [4,10–12].

Backrest inclination can also lead to various kinds of local discomfort affecting different body parts, i.e., the pressure distribution of the body–seat interface. Usually, higher pressure on body parts implies greater discomfort [13]. Bogie and Bader [14] indicated that the lumbar region supported more weight when the seat was tilted, since the center of the pressure distribution was shifted back to the ischial tuberosity. However, follow-up studies found that pressure on the buttocks and ischial tuberosity decreased, whereas pressure on the back region increased when the seat or the backrest was tilted [15,16]. Park and Jang [17] found that the pressures increased at the sacrococcygeal and decreased at the ischial tuberosity with increasing backrest tilt angle. Wang and Cardoso [9] indicated that backrest inclination affected the human–seat interface's pressure distribution (including the seat pan and the backrest) by changing the sitting posture or muscle activation.

The inclination of the backrest affects the dynamic discomfort of an occupant, along with magnitude, frequency, direction, and location of the vibration. The perception thresholds of vibration have been shown to significantly depend on the backrest inclination at a low frequency when the direction of vibration was normal to the back in the x-axis of the body [18]. Basri and Griffin [19] also found that discomfort significantly depended on the incline angle of the backrest when the subjects experienced whole-body vertical vibration, and they determined various equivalent comfort contours for various backrest angles at 0°, 30°, 60°, and 90°. Paddan and Mansfield [20] reported that different backrest angles (0°, 22.5°, 45°, 67.5°, and 90°) had significant impacts on discomfort. Through field measurements, Nawayseh [21] found that the vibration dose value (VDV) increased with an increasing backrest angle. However, several studies failed to show a significant effect of the backrest incline angle on discomfort under whole-body vibration. Basri and Griffin [22] indicated that the discomfort was independent of the backrest angle when the direction of vibration at the backrest was parallel to the back in the z-axis of the body. Howarth and Griffin [23] proposed that backrest inclination (15°, 30°, 45°, and 60°) did not influence discomfort caused by vibration on fast boats.

The inclination of a backrest can also lead to different local discomfort in the vibration environment. Basri and Griffin [16,20] found that the body part experiencing the most discomfort shifted from the buttock area to the back region when the angle between the backrest and the seat pan increased from 0° to 60° under whole-body vibration at x- or z-axis. They further indicated that local discomfort was felt on the body part supporting the greatest proportion of the weight at the vibrating surface (e.g., the back, buttocks, or the thighs), and that the most uncomfortable body part was changed by varying the backrest angle [24]. Howarth and Griffin [23] found that the most uncomfortable body part was the buttocks when the angle between the backrest and the seat pan was 90° and the discomfort shifted to the upper and middle back when the angle was 45–60°.

The physiological parameters (i.e., the gender, stature, weight, etc.) are the potential factors related to discomfort in a seat [4,13]. Male and female subjects report different stress load conditions and experience different levels of discomfort [25,26]. Vink and Lips [27] indicated that there were significant differences between males and females regarding sensitivity to pressure from the backrest and the seat pan. Subjects with different statures preferred different sizes of seats; relatively, taller subjects reported less discomfort in larger seats than in smaller seats, and vice-versa [1,8]. Na and Lim [28] reported that stature showed significant effects on local discomfort in the neck, shoulders, hips, and thighs. Kyung and Nussbaum [29] studied driving discomfort, in the field and laboratory, by grouping subjects into tall, middle, and short groups. They found marginal effects of stature on discomfort; subjects in the middle stature group rated the lowest discomfort, possibly because contemporary car seats accommodate subjects of middle height the best. Wang and Cardoso [9] investigated seat discomfort by grouping subjects by stature, weight, and gender. They indicated that the larger contact area between the human–seat interface led to lower average pressure and peak pressure for the larger BMI subjects, and therefore the large male group had the lowest discomfort ratings. Jones and Park [30] detected that a subject with a large BMI could have a high ratio of pressure exerted on the backrest bolster relative to the insert, which implied poor fit and increased discomfort.

The above studies mainly investigated sitting discomfort in a fixed (could be multi-group) posture, under a static or dynamic environment. However, few studies have investigated subjective preference and discomfort during seat component adjustment processes, starting from a trigger until finishing the movement, which is necessary to design a power seat.

In this study, we investigated the effects of adjustment speed on overall and local discomfort during adjustment processes. We set two adjustment movements (i.e., adjustment of backrest angle and adjustment of seat pan fore-and-aft position) with three speed conditions. We also investigated the correlation between discomfort and physiological parameters (i.e., stature, weight, BMI, and gender). There are three hypotheses as follows: (1) increased speed reduces discomfort during an adjustment, (2) the most uncomfortable location is the back region during the adjustment of the backrest angle, (3) subjects with different physiological parameters experience different discomforts during seat adjustments.

2. Method

2.1. Subjects

Twenty-four subjects (12 males and 12 females), with median age 23 years (18–24 years), stature 1.71 m (1.58–1.83 m), weight 61.8 kg (46.5–90.7 kg), and BMI 21.4 (15.7–30.3) volunteered to participate in this experiment (Table 1). Among the males, the median age was 23 years (18–24 years), stature 1.75 m (1.67–1.83 m), weight 65.4 kg (48.8–90.7 kg), and BMI 22.8 (15.7–30.3); among the females the median age was 23 years (21–24 years), stature 1.68 m (1.58–1.75 m), weight 59.0 kg (46.5–78.9kg), and BMI 20.9 (18.4–25.8).

Table 1. Demographic and anthropometric characteristics of subjects.

Gender	Item	Stature (cm)	Weight (kg)	BMI	Age
	Mean	171	64	22	23
All	Std	7	12	3	1
Subjects	Minimum	183	91	30	24
	Maximum	158	47	16	18
Male	Mean	175	69	22	22
	Std	4	13	4	2
	Minimum	167	49	16	18
	Maximum	183	91	30	24
Female	Mean	167	59	21	23
	Std	6	9	2	1
	Minimum	158	47	18	21
	Maximum	175	79	26	24

The Biological Experimentation Safety and Ethics Committee of the Bio-X Research Institute at Shanghai Jiao Tong University approved the experiment. All subjects gave informed consent to participate in the experiment.

2.2. Apparatus

The power seat was made by mounting a seat frame (500 × 650 × 830 mm) on an aluminium platform (height 500 mm). The seat surface was covered by a polyurethane foam cushion (thickness, 60 mm at the position of ischium, 30 mm at the thighs, and 100 mm at the back; 25% indentation load defection hardness, 120 N) and polyurethane leather upholstery (thickness, 1.2 mm).

We used two reversible servo motors with sensors for the two seats adjustments, i.e., moving the backrest up and down, and moving the seat pan back and forth. A switch turns on the motor, which rotates the gear and flexible driving shaft, and then the seat adjuster begins to move. When the regulator reaches the end of the stroke, the soft shaft stops rotating.

We defined the adjustments of the seat pan as "forward" and "backward" movements, and those of the backrest angle as "lying" and "rising" movements (Figure 1). The range of the adjustments was 0 to 220 mm for the seat pan position, and 90° to 135° for the backrest angle, respectively. We set three different speed conditions as "fast", "medium", and "slow" with durations of 15, 20, and 25 s, respectively, for the adjustments. The velocities of three speed conditions were 14.7, 11, and 8.8 mm/s for the seat pan for-and-aft adjustments, and 3, 2.25, and 1.8°/s for the backrest incline angle adjustments (Table 2).

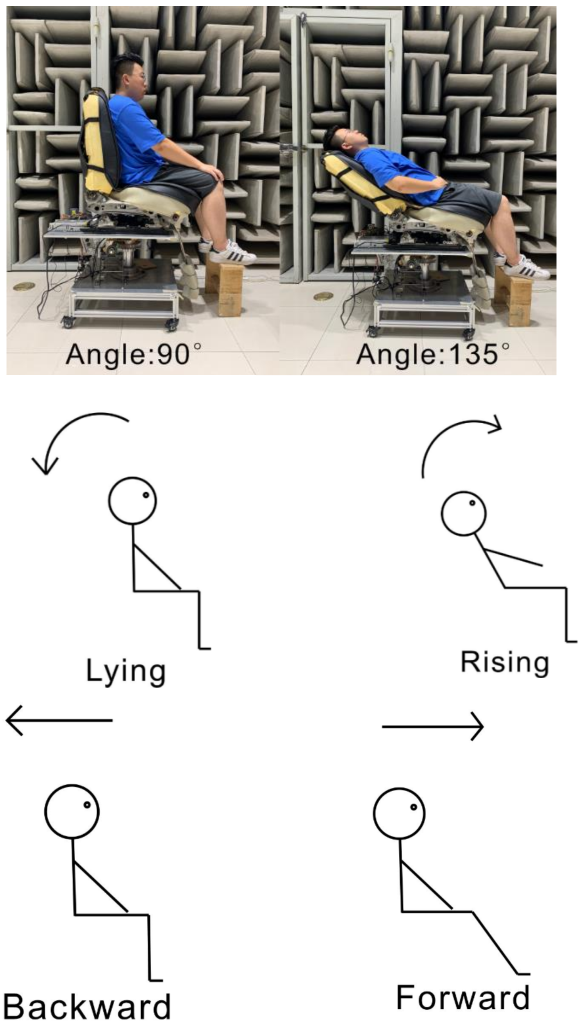

Figure 1. Subject sitting on the automobile seat in the extreme positions of the backrest (left 90°, right 135°).

Table 2. The adjustment settings of each speed condition.

Adjustment	Speed Conditions	Duration (s)	Speed
Backrest angle	Slow	25	1.8°/s
	Medium	20	2.25°/s
	Fast	15	3°/s
Fore-and-aft position	Slow	25	8.8 mm/s
	Medium	20	11 mm/s
	Fast	15	14.7 mm/s

The experimenters, rather than the subjects, used a control pad to operate the power seat's movements. The control pad included four switches (for "forward", "backward", "lying", and "rising" adjustments) and three gears rods (for "fast", "medium", and "slow" speed conditions)

The movement started by pressing the button and stopped automatically by reaching the limiting position.

The experiment consisted of two sessions for each subject, i.e., the backrest adjustment session and the seat pan adjustment session. Subjects attended two sessions in a balanced random order; 12 subjects started with the seat pan adjustment session, and the other 12 subjects started with the backrest adjustment session. The subjects left the test rig for a 10-min break between sessions. The duration of the entire experiment was about 40 min. The subjects were not informed of the specific adjustment conditions during the experiment.

We used a questionnaire, including a preference survey, a category-scale (CR) rating scale, and an experimental body map. We set the CR100 scale for the overall discomfort based on careful consideration of methods from previous related studies [31–33]. The body map (Figure 2) for the local discomfort was proposed by ISO 2631-1:1997. The following preference survey questions were asked after each movement (i.e., "lying", "rising", "forward", and "backward") with different speed conditions: (1) Which is your preference condition among the three? (2) The possible reason you preferred the speed condition.

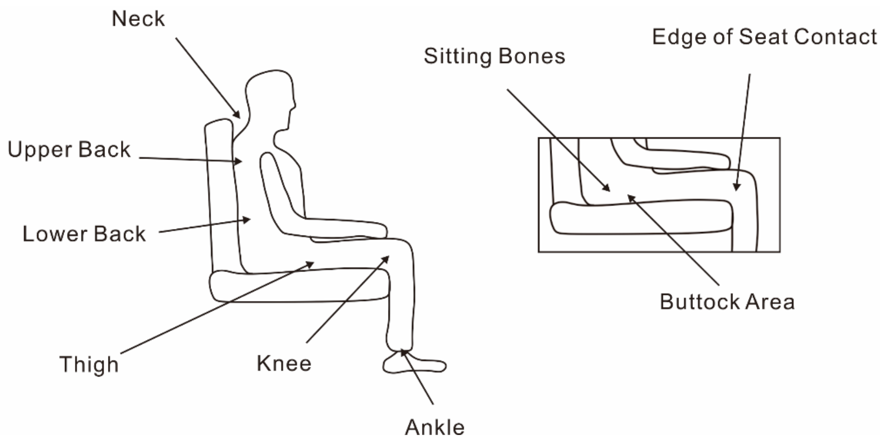

Figure 2. The body map for the local discomfort, adapted from the body map proposed by ISO 2631-1:1997.

Subjects sat in a comfortable upright posture and put their hands on their laps. Their feet were supported by an adjustable wooden stool (if necessary) to keep their knees at the same height as the seat pan. They were required to maintain contact with the backrest and the seat pan during the entire experiment. For the backrest adjustment session, subjects randomly experienced a combination of two adjustment movements (i.e., "lying" and "rising") and three speeds (i.e., "fast", "medium", and "slow"). After each adjustment movement, subjects verbally reported their overall subjective discomfort using the CR100 scale and indicated their most uncomfortable body part on the body map (Figure 2). Subjects could ask for the adjustment movement to be repeated until they felt confident giving a numerical value of discomfort. After the overall and local discomfort rating, the subjects experienced three speeds for one of the "lying" and "rising" movements in random order and answered the questions, and three speeds of the other movement in random order and answered the questions again. For the seat pan adjustment session, subjects randomly experienced a combination of two movements (i.e., "forward" and "backward") and three speeds, rated their discomfort and completed the questionnaire. Subjects were not informed of the specific conditions they were experiencing throughout the experiment.

2.3. Analysis

First, we employed the normal distribution test on the obtained data, and then we used nonparametric statistical methods. The Friedman two-way analysis of variance and the Wilcoxon matched-pair signed-rank test were used to test the differences between related samples. The Spearman correlation analysis determined whether there was a correlation between the discomfort and the physiological parameters (i.e., height, weight, and BMI) of subjects. The Mann–Whitney U test detected the impact of gender. The significance level (i.e., the *p*-value) in the report was adjusted via the Bonferroni correction for multiple comparisons.

3. Results

3.1. The Effect of the Adjustment Duration on Overall Discomfort

The data obtained for all conditions did not obey a normal distribution ($p < 0.05$, Kruskal–Wallis), except for the condition of "lying" with "medium" speed ($p = 0.022$, Kruskal–Wallis). Thus, we used nonparametric statistical tests to avoid assuming a normal distribution of data. The medians, lower and upper quartiles, and interquartile ranges (IQRs) of overall discomfort in different adjustment movements are shown in Figure 3 and Table 3. There was no significant difference in discomfort between any two speeds for the same adjustment movement ($p > 0.25$, Wilcoxon) except for the discomfort between the "medium" and "slow" ($p < 0.05$, Wilcoxon) for the "backward" movement. The "lying" and "rising" movements caused different discomfort significantly for all speeds ($p < 0.01$, Wilcoxon), whereas there was no significant difference in discomfort between "forward" and "backward" movements for any of the three speeds ($p > 0.5$, Wilcoxon).

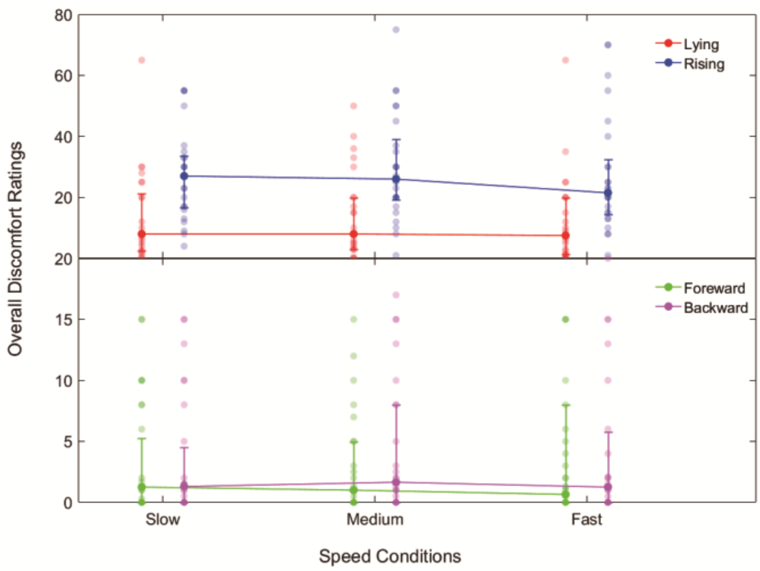

Figure 3. Individuals, medians, and interquartile ranges (IQRs) of overall discomfort ratings for 24 subjects.

Table 3. Medians, lower and upper quartiles, and interquartile ranges (IQRs) of overall discomfort ratings.

Adjustment Movement	Speed Condition	Median	Lower Quartile	Upper Quartile	IQR
Lying	Slow	8	2.5	21.25	18.75
	Medium	8	3	20	17
	Fast	7.5	1.3	20	18.7
Rising	Slow	27	16.75	33.5	16.75
	Medium	26	19.25	39	19.75
	Fast	21.5	14.5	32.5	18
Forward	Slow	0.65	0	8	8
	Medium	1	0	5	5
	Fast	1.25	0	5.25	5.25
Backward	Slow	1.25	0	5.75	5.75
	Medium	1.65	0	8	8
	Fast	1.3	0	4.5	4.5

Table 4 show the results from the questionnaires. During the “rising” movement, 46% of subjects chose the “fast” speed for the preference condition, and 25% chose the “slow” speed. During the “lying” movement, 50% of subjects chose the “fast” speed for the preference condition, and 25% chose the “slow” speed. Subjects could not detect the difference among the different speed conditions during the seat fore-and-aft position adjustments.

Table 4. The numbers and percentages of subjects reporting their preference for the adjustment speeds.

Adjustment	Slow	Medium	Fast	Total
Lying	6 (25%)	6 (25%)	12 (50%)	24
Rising	6 (25%)	7 (29%)	11 (46%)	24

3.2. The Local Discomfort

Figure 4 shows the numbers of the subjects reporting the locations of the body parts (regions) with the greatest discomfort. During the “rising” movement, 21 subjects reported the back region (including nine subjects who reported the upper back) and nine subjects who reported the neck. During the “lying” movement, eight subjects reported the back region (including six subjects who reported the lower back) and four subjects who reported the neck. Only one subject reported the greatest local discomfort at the knee during the “forward” movement, and at the ankle during the “backward” movement.

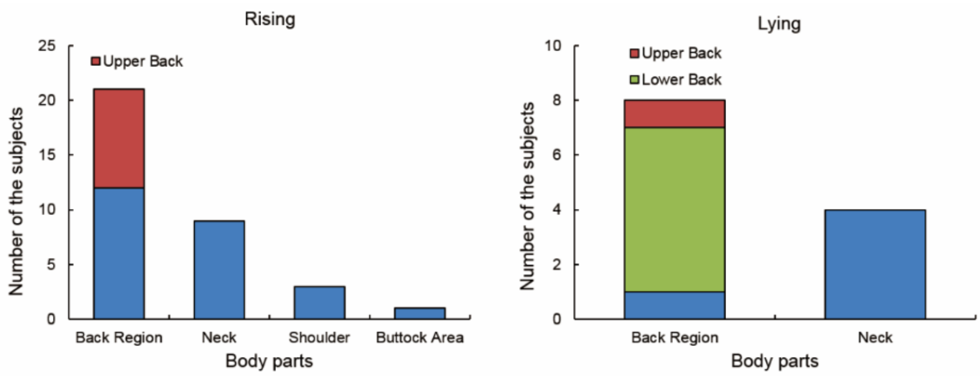

Figure 4. The numbers of the subjects reporting the locations of the body parts with greatest discomfort.

3.3. The Correlation between the Discomfort and the Physiological Parameters

There was no significant difference in discomfort between male and female groups for any conditions ($p > 0.05$, Mann–Whitney U test). The Spearman correlation coefficients between the overall discomfort and physiological parameters (i.e. stature, weight, and BMI) are shown in Table 5. During the "rising" adjustment movement, the discomfort negatively correlated with height at "fast", "medium", and "slow" conditions, and with weight under the "fast" and "slow" conditions ($p < 0.05$, Spearman). During the "lying" adjustment movement, discomfort negatively correlated with weight and BMI only under the "slow" condition ($p < 0.05$, Spearman). However, there was no significant correlation between discomfort and any physiological parameters during the fore-and-aft position adjustment.

Table 5. Spearman correlation coefficients between overall discomfort ratings and physiological parameters (*, $p = 0.05$).

Adjustment Movement	Speed Condition	Height	Weight	BMI
Lying	Slow	−0.161	−0.428 *	−0.46 *
	Medium	−0.337	−0.304	−0.216
	Fast	−0.24	−0.334	−0.31
Rising	Slow	−0.434 *	−0.588 *	−0.547 *
	Medium	−0.469 *	−0.269	−0.137
	Fast	−0.449 *	−0.437 *	−0.361
Forward	Slow	−0.12	−0.33	−0.362
	Medium	−0.104	−0.26	−0.274
	Fast	−0.045	−0.281	−0.317
Backward	Slow	0.033	−0.121	−0.178
	Medium	−0.11	−0.131	−0.168
	Fast	0.59	−0.111	−0.172

4. Discussion

4.1. The Effect of the Seat Adjustment Movements on Overall Discomfort

The discomfort caused by the "rising" movement was significantly greater than that caused by "lying" at all speeds. When the backrest was inclined, the back region supported more of the body weight, leading to increased pressure on the back area [11,17]. With the backrest inclined, the external force was concentrated on the back, especially on the upper back [23]. Pressure on the back dominated the evaluations of discomfort. Due to the movement's direction, the pressure during the "rising" movement was greater than the "lying" movement, hence, the discomfort caused by the "rising" movement was greater than "lying".

The median discomfort values of the "lying" (short, 7.5; medium, 8; long, 8) and "rising" (short, 21.5; medium, 26; long, 27) movement implied that the discomfort decreased with increasing speed, which was consistent with the results from the questionnaires that the majority of subjects preferred the "fast" adjustment speed among the three conditions (50% for '"lying" and 46% for "rising"). Groenesteijn and Vink [1][1] also found a significantly better rating for the chair with less adjustment time and indicated that the ease of chair adjustment could be the most decisive reason for the preference. The absence of statistical significance could be attributed to the smeared individual data, which was revealed by the large individual variabilities in Figure 3 and Table 3, for example, the interquartile range (IQR), i.e., 18.75 "lying" and 19.75 for "rising".

Figure 5 shows the distribution frequencies of the numerical values of discomfort for the backrest adjustment session; relatively high frequencies for low discomfort values can be observed. The distributions also implied that higher speed led to less discomfort. Most of the values distributed in the range of 0–26, with more frequencies under the "fast" condition (i.e., 22) than the "medium" condition (i.e., 19) and "slow" condition (i.e., 20) during the "lying" movement, and most of the values distributed in the range 0–30 with more frequencies under the "fast" condition (i.e., 18) than the "medium" condition (i.e., 16) and "slow" condition (i.e., 16) during the "rising" movement. Weber's law is applicable to the results. There was no significant difference in discomfort growth rate between "lying" and "rising" with an increase in adjustment time, either from 15 to 20 s, or from 20 to 25 s (lying, $p = 0.394$, Wilcoxon and rising, $p = 0.224$, Wilcoxon).

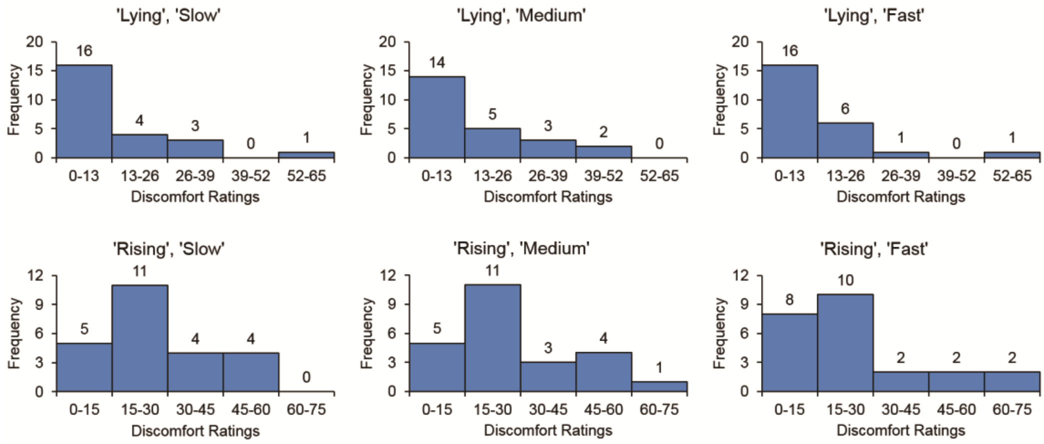

Figure 5. Histogram of frequency distribution of discomfort ratings caused by backrest adjustment.

4.2. Discomfort Rating and Preference

We conducted a study on comfort and preference by using quantitative (e.g., the CR) and qualitative (e.g., choice question) methods. Some previous studies have yielded consistent results by combining the subjective rating values and survey questions, for example, Na et al. who investigated muscle activity during hip adduction and abduction movements [34], and Parida et al. who asked the subjects to adjust the seating positions to their personal preference for given activities [35]. However, some studies have reported the opposite results. Annett recruited 42 subjects from different occupations to experience two different office chairs, a standard typist (ST) chair or a newly designed prototype multiposture (PMP) chair [5]. They found that discomfort ratings indicated that the ST chair was better, but the preference survey showed a majority chose the PMP chair. Viswanathan et al. found that most subjects (72%) felt that the continuous passive lumbar motion system (CPLMS) reduced back discomfort based on a preference survey, but failed to show a significant effect of CPLMS on discomfort of the upper back from results of discomfort ratings [36].

We found that the differences between all speeds were evident in the preference results, whereas they were not significant in the group data on the CR100 scale. The preference survey showed that most subjects preferred the "fast" condition because they experienced the external force for shorter durations than the "slow" condition. The external force might cause "discomfort" associated with the pain, tiredness, soreness, and numbness. A possible reason for the non-significance in discomfort rating could be that the CR100 scale, although precise, was not suitable for all subjects. Subjects without sufficient training might not adapt to the relatively small scales with fine increments (e.g., CR100 scale with one increment) for discriminating relatively small subjective intensities (most of which were less than 40) in this study [37].

4.3. Local Discomfort

In the backrest adjustment session, the body parts with the greatest local discomfort were the back region, neck, and shoulders. The back region was reported by 88% of subjects during the "rising" movement and 33% of subjects during the "lying" movement, which was consistent with previous studies by Basri and Griffin [16,20,22] and Howarth and Griffin [23]. The apparent local discomfort in the lower back might be attributed to the lack of lumbar support during the adjustment process [8,38–41]. The neck region was also reported by 38% of subjects during the "rising" movement and 17% of the subjects during the "lying" movement, possibly because the cervical spine sustained additional pressure to maintain the sitting posture without a headrest during the adjustments. Wang and Cardoso [9] indicated that the use of a headrest significantly reduced discomfort.

From Figure 4, the most uncomfortable body part changed with different movements. The discomfort was dominate in the upper back during the "rising" movement (nine subjects) due to an apparent pushing force against the backrest, whereas discomfort was dominate in the lower back during the "lying" movement (six subjects), due to the lack of fit between the lower back and the cushion [38]. Basri and Griffin [19] reported that the most uncomfortable body part tended to transfer from the thigh to the back region when the backrest inclination angle increased.

4.4. Differences between Individuals

The discomfort negatively correlated with height, weight, and BMI for the "rising" movement with "slow" adjustment speed (refer to Table 5). Figure 6 shows the scatter plots of overall discomfort versus height, weight, and BMI.

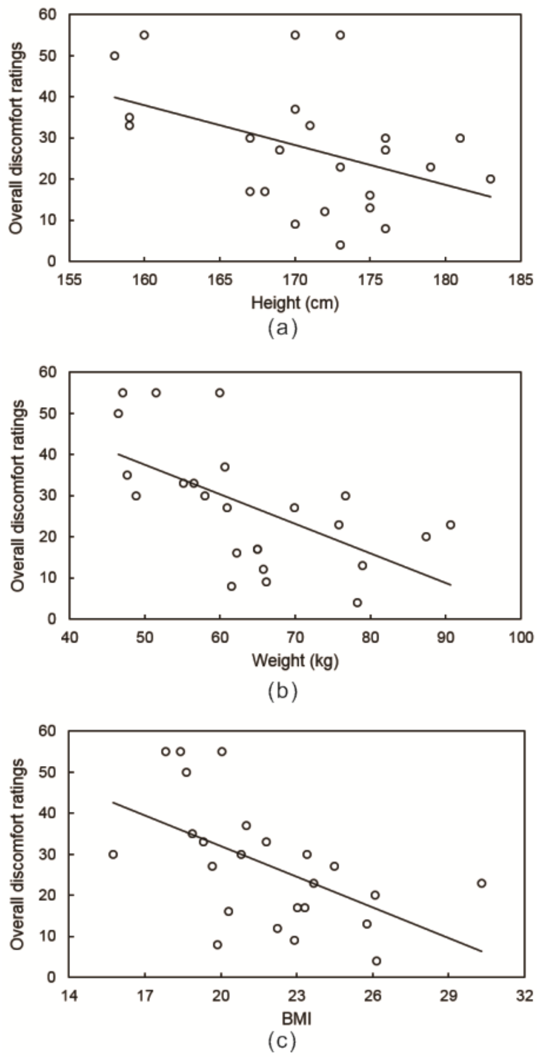

Figure 6. Scatter plot of overall comfort versus physiological parameters under the "slow" speed condition of the "rising" movement. (**a**) Height; (**b**) Weight; (**c**) BMI.

We found that the subjects with greater weight or BMI reported lower discomfort ratings during the backrest angle adjustments. Wang and Cardoso [9] indicated that individuals with greater BMI usually had a larger contact area and lower pressure between the body and seat, and therefore they reported less discomfort than larger BMI subjects. However, we found a negative correlation between height and discomfort, which was not consistent with previous studies [9,28]. This could be because local discomfort ratings showed that discomfort was dominate in the back region, and taller individuals were more likely to report neck and shoulder discomfort in this study.

4.5. Limitations

There were two potential limitations in this study. First, the sitting posture was not the same as that in real life, and the discomfort may be affected by the different sitting postures during the adjustment. Secondly, the sample size was not large enough to investigate the effects of physiological parameters, for example, gender, stature, weight, and BMI, on the discomfort, considering the significant individual differences in discomfort values of this study.

5. Conclusions

The faster speed led to less discomfort during the backrest angle adjustments (i.e., "lying" and "rising" movements), but no difference of discomfort caused by different speeds during the seat pan fore-and-aft position adjustments (i.e., "forward" and "backward" movements). The majority of subjects preferred the "fast" condition based on the questionnaire results.

Local discomfort was dominate in the upper back and neck body regions during the "rising" movement, whereas it was dominate in the lower back for the "lying" movement. There was no dominant region of local discomfort found during the fore-and-aft position adjustments.

In future work, we could investigate discomfort further by objective assessment such as body temperature, blood pressure, and heartbeat. We hope to establish a prediction model by combined subjective evaluation and objective measurement. A questionnaire with more specific and detailed preset questions could also be developed to investigate the relationship between the adjustment process and other influencing factors beyond comfort.

In summary, the keypoints from this study include the following:

- The major subjects preferred the fast speed condition during the adjustment of the backrest inclined angle.
- The locations of the greatest discomfort occurred in the upper and lower back regions during adjustment of the backrest.
- The results could guide manufacturers and seat design with careful consideration of the adjustment speed.

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Institutional Review Board Statement: The Biological Experimentation Safety and Ethics Committee of the Bio-X Research Institute at Shanghai Jiao Tong University approved the experiment.

Informed Consent Statement: All the participants provided informed written consent prior to experiment.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author, Yu Huang.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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