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Objective classification of vehicle seat discomfort

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The objective of this study was to identify how physiological measures relate to self-reported vehicle seating discomfort. Twelve subjects of varied anthropometric characteristics were enrolled in the study. Subjects sat in two seats over a 2-h period and were evaluated via three physiological measures (near-infrared spectroscopy, electromyography and pressure mapping) yielding six testing sessions. Subjective discomfort surveys were recorded before and after each session for nine regions of the body. Conditional classification discomfort models were developed through dichotomised physiological responses and anthropometry to predict subjective discomfort in specific body locations. Models revealed that subjects taller than 171 cm with reduced blood oxygenation in the biceps femoris or constant, low-level muscle activity in the trapezius tended to report discomfort in the lower extremities or neck, respectively. Subjects weighing less than 58 kg with reduced blood oxygenation in the biceps femoris or unevenly distributed pressure patterns tended to report discomfort in the buttocks. The sensitivities and specificities of cross-validated models ranged between 0.69 and 1.00.

Practitioner Summary: Discomfort has been studied extensively in order to enhance the seating design process. However, biomechanical and physiological responses relative to subjective discomfort have been largely ignored in the literature. Considering these responses along with anthropometry may provide insight into why a specific individual reports a seat as uncomfortable.

Keywords: seating; sitting; car; physiological discomfort

1. Introduction

In recent years, vehicle seat designs have placed an emphasis on mitigating seat discomfort as a response to consumer demands. Traditionally, the seating development process has been dependent upon an iterative design process that involves trial and error (Verver et al. 2005). This approach is very time consuming, costly and often ineffective for informing design decisions (Kolich and Taboun 2004). Hence, there is a need for a better approach towards understanding the causal pathway of discomfort in seat design.

Many approaches have been utilised in an attempt to understand discomfort but have tended to be subjective in nature. Subjective evaluations are highly variable and can fluctuate depending on several parameters such as aesthetic bias, distraction through entertainment systems, psychological status and environment (De Looze, Kuijt-Evers, and Van Dieen 2003; Helander 2003; Alamdari 1999). People can subjectively report whether they feel discomfort in a seat but have difficulty explaining why they feel that way. Subjective impressions tend to be weak measures because they require a large subject pool to reduce the variability (Lee and Ferraiuolo 1993). The measurement of subjective responses tends to be a crude evaluation of a person's physical state of discomfort because the mind's filter can potentially distort or bias interpretations. Hence, many efforts to quantify discomfort have been unable to provide an objective understanding of discomfort. Quantification of physiological responses due to tissue loading might facilitate a more objective understanding of the magnitude of physical exposure that would elicit discomfort. The location, magnitude and timing of tissue loading relative to seat features and reported comfort are poorly understood. Previous studies suggest that there may indeed be a link between discomfort and biomechanical measures and physiological measures, and these relationships may provide a rationale to make seating design more objective (Helander and Zhang 1997; Zhang, Helander, and Drury 1996).

In order to obtain objective quantification of discomfort, it would be desirable to understand the potential causal pathways leading to reports of discomfort. Previous work quantifying discomfort has considered various features such as anthropometry (Kolich and Taboun 2004; Kolich 2003, 2004; Stubbs, Pellettiere, and Pint 2005), physiological change (Jianghong and Long 1994; Bush et al. 1995; Callaghan, Gregory, and Durkin 2010; Durkin et al. 2006), vibration (Ebe and Griffin 2000; Inagaki et al. 2000), pressure distribution (Kyung and Nussbaum 2008; Gyi and Porter 1999; Fenety, Putnam, and Walker 2000) and kinematics (Kingma and van Dieen 2009; Lengsfeld et al. 2000; Solaz et al. 2005). These approaches

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provide potential concepts to objectively understand what may systematically lead to discomfort. However, it still remains unclear on how much physiological change may elicit reports of discomfort and how individual differences, such as anthropometry, may affect those changes. For example, postural kinematics may be influenced by seat design features and an individual's anthropometry. In smaller vehicle cockpits, taller people may have more of a forward-flexed posture during seating which may induce a flexion-relaxation response, offsetting the load to the ligaments (O'Sullivan et al. 2006). When the ligaments are loaded in tension, pain receptors may be stimulated (Solomonow 2009), thus triggering discomfort. Understanding these connections may shed light on why some designs may lead to ischaemia, fatigue and discomfort in some people but not others.

Quantifiable measurements were chosen depending on the context that comfort and discomfort are separate entities relative to the findings of Zhang et al. (1996). They contend that comfort was typically driven through aesthetic bias (subjective), whereas discomfort was dependent on biomechanical and physiological responses (objective). In our study, three measurement tools were chosen due to their differing associations with the mechanisms of discomfort. Electromyography (EMG) provided an understanding of how muscle recruitment patterns may shift during fatigue (McLean et al. 2001). Near-infrared spectroscopy (NIRS) provided a general understanding of changes in localised blood volume and levels of oxygen saturation which may be connected to ischaemic-related fatigue. Pressure mapping provided external reactions to discomfort based upon movement as it tends to progressively increase over time (Fenety, Putnam, and Walker 2000) or when the seat has an inadequate pressure distribution (Ahmadian et al. 2002).

The objective of this study was to understand which physiological meaningful measures in conjunction with anthropometry might lead to reports of discomfort.

2. Methods

2.1 Approach

An experiment was conducted in an attempt to understand which measurements are best able to quantify seating discomfort. Three different quantitative measures were used to acquire physiological responses relative to reported discomfort and as a function of varying seat features: NIRS, EMG and pressure mapping. Discomfort surveys were collected prospectively to evaluate changes in perceived discomfort for each 2-h experimental session. Post-processed results of the physiological measures provided the input into a series of dichotomised, conditional classification models for the quantification of discomfort.

2.2 Study design

The study consisted of a completely randomised design using two different automotive seats (one expected to be very comfortable and one expected to be marginal in comfort) and three different physiological (dependent) measures over a total of six experimental testing sessions. Discomfort surveys were collected at the beginning and end of each session.

2.3 Subjects

Twelve subjects (six males and six females) were recruited from the local population. Anthropometric measurements can be found in Table 1. All subjects provided informed consent and reported no history of back pain within the previous 6 months. This study was approved by the university's institutional review board.

2.4 Instrumentation

Localised muscle oxygenation from eight pairs of muscles on the trunk and lower extremities was collected at a 50 Hz sampling rate using a custom-made 16-channel NIRS system. NIRS measures the instantaneous change of localised tissue

Table 1. Anthropometry of subjects.

	Overall			Males			Females		
	Age	Height (cm)	Weight (kg)	Age	Height (cm)	Weight (kg)	Age	Height (cm)	Weight (kg)
Mean	33.0	169.8	69.2	29.8	175.9	75.5	34.3	164.6	59.9
StDev	13.4	9.5	13.2	13.4	7.7	12.8	11.8	5.9	4.6

oxygen saturation as well as the changes in total blood volume (saturated and unsaturated haemoglobin and myoglobin). Localised oxygenation was measured using the wavelengths of 730 and 810 nm. Sensors were placed bilaterally on the trapezius, latissimus dorsi, upper erector spinae, lower erector spinae, rectus abdominus, external obliques, gluteus maximus and biceps femoris muscles. These muscles were chosen based upon an overview of studies involving seating (De Looze, Kuijt-Evers, and Van Dieen 2003). Electrode placement locations were defined from Mirka and Marras (1993) and NIOSH (1992).

Muscle activity from eight pairs of muscles (same muscles as NIRS set-up) on the trunk and lower extremities was collected at a 1000 Hz sampling rate using bi-polar surface EMG electrodes (Delsys® Inc., Bagnoli™-16, Boston, MA, USA). Signals were band-pass filtered at 30–450 Hz and notch filtered at 60 Hz.

Pressure data were collected at 40 Hz using the X3 Pro pressure imaging platform (XSENSOR™ Technology Corporation, Calgary, AB, Canada). Two piezoelectric mats were used: one for the seat pan and the other for the seat back.

2.5 Experimental procedure

Anthropometric data including gender, age, height and weight were collected from each subject. In order to not confound the physical experimental responses measured with the influence of aesthetic bias, the seats were shrouded for each session. Seats were also set in the manufacture design position as specified by Kolich (2003). Subjects were advised to sit in the seat with their low back against the lumbar support and the researcher adjusted the footrest to the subject's desired position. A 10–12 min time period of adjustment (prior to the beginning of the study) was provided in order to allow for any final adjustments for the footrest. The procedure required that the subject sit in an automotive seat for 2 h while responding to a randomised series of prompts on a monitor by clicking a mouse (Figure 1). This provided a low-level task to help prevent subject drowsiness during testing. The subjects were instructed to not talk and to limit the amount of large motions while the session was in progress. Physiological measures were collected during separate sessions in order to minimise cross-talk between sensors. There were three different sessions (total of six sessions per subject) for each seat: oxygenation, EMG and pressure mapping. Subjects filled out a discomfort survey at the beginning (baseline) and the end of each session to evaluate subjective discomfort.

2.6 Analysis procedure

A series of steps were taken to analyse the data. The data were first post-processed and discomfort parameters were operationally investigated for their association with the physiological measures (i.e. higher visual analogue scale (VAS) was associated with subjective discomfort and lower blood saturation equated physiological discomfort). Using the post-processed data, 70% of the data were randomly selected to produce cross-validated, dichotomised, classification models. These models were produced by a median split method to define cut-off thresholds separating discomfort from no report of discomfort. Sensitivities and specificities were calculated to evaluate the robustness of the discomfort classifications. The process was repeated 10 times and the mean of the thresholds as well as the sensitivities and specificities were reported to evaluate the consistency of the models.

2.6.1 Independent variables

Two different comfort design seats, the 2008 models of the Audi A8 seat and Chrysler Sebring seat were investigated. These seats were chosen based an unpublished subjective comfort comparison report ($n = 410$). The report indicated that the Audi



Figure 1. Experimental set-up.

A8 seat was expected to be more comfortable than the Chrysler Sebring. However, throughout the course of the study, no consistent physiological associations were found between the seats. Therefore, both seats were lumped as one parameter.

2.6.2 Dependent variables

Dependent variables considered for model development consisted of muscle oxygenation, EMG cycling, pressure mapping and subjective discomfort. These data were used to create the dichotomous classification models.

The oxygenation responses measured for the 16 different muscles included saturation and total blood volume. Raw data from these measures were zeroed to a baseline value and then converted into the means of each quarter (Q1–Q4) of testing time (30 min each). Oxygenation values below the threshold classification value were operationally defined as physiological discomfort.

EMG cycling was measured from 16 different muscles over each test period. An increase or decrease in the mean frequency by 5 Hz and then shifting by another 5 Hz after the signal stabilised was operationally defined as a cycle (McLean et al. 2001). Low numbers of cycling indicated inadequate muscle fibre resting periods. Therefore, cycling results below the threshold classification value were operationally defined as physiological discomfort.

Summary measures of the pressure map data consisted of four variables: seat pan distribution (SPD) (Equation (1)), pan and back high pressure point percentages and pan and back oscillations. SPD was defined per Ahmadian et al. (2002). The pressure point percentages referred to the proportion of points on the mat > 6.4 kPa relative to the amount of area contacted. This value was chosen based upon an average of values in relation to discomfort (Gyi and Porter 1999). Oscillations referred to the postural shifts in the seat over the 2-h period. Postural shifts were operationally defined relative to pilot work as the number of times the peak pressure increased/decreased by 6.4 kPa and then returned back to a steady-state value throughout the 2-h period. Pan and back oscillations (the number of motions within the seat over a 2-h period) were evaluated for the seat pan and back. For all pressure mapping responses, results above threshold classification values were operationally defined as physiological discomfort.

$$\text{SPD}\% = \frac{\sum_{i=1}^n (p_i - p_m)^2}{4np_m} \times 100, \quad (1)$$

where n is the total number of nonzero elements, p_i is the pressure of the i th cell and p_m is the mean of the nonzero elements.

2.6.3 Subjective discomfort

Discomfort data were collected before (baseline) and at the end of each session using a 10 cm VAS for several body regions (Hawker et al. 2011; Huskisson 1974; Scott and Huskisson 1976). The difference between the ending report and baseline provided the change in discomfort over each session. Nine body regions were assessed including the neck, upper back, lower back, abdominals, buttocks, shoulder, hip, upper leg and knee. These regions were chosen to allow us to investigate the relationships between reports of discomfort relative to the physiological response. Values were marked on a continuous scale from 0 to 10 cm. Subjects were asked to rate discomfort in the context of the study by marking the linear scale. Anchors were described to the subjects as 0 cm being the lack of discomfort for each limb, to 10 cm which was defined in the context of this study as being unbearable to sit in for long periods of time.

2.6.4 Discomfort model developments

The processed physiological data and associated anthropometry were used to predict reported discomfort through the cross-validation of dichotomised, conditional classification models. Continuous physiological, anthropometric and subjective discomfort measures were dichotomised using a median split method. Dichotomised physiological and anthropometric measures were used to predict dichotomised subjective discomfort. Therefore, a subject was considered either physiologically uncomfortable or had no report, anthropometrically large or small, and had either a report of discomfort or no discomfort, respectively. If all three conditions were satisfied, the discomfort was listed as a true positive. Sensitivities and specificities were recorded to assess the robustness of the models.

3. Results

A series of conditional classification models were produced using physiological responses and anthropometric groups to predict subjective discomfort (VAS). Biologically plausible models are reported in Table 2(a),(b) with cross-validation sensitivities and specificities. An example of how the values from Table 2 operate is shown in Figure 2. It shows that if a subject is taller than 177 cm and their total blood volume drops by 13.4% relative to baseline in the 60–90 min window for

Table 2. (a) Quantitative models of discomfort for the neck and back and (b) quantitative models of discomfort for the hip, buttocks, upper leg and knee.

VAS region	Measure	Anthropometric measure	Inequality	Threshold	Muscle	VAS predicted >	Cross-validation sensitivity	Cross-validation specificity
(a)								
Neck	EMG	Height (cm)	>	171	Trapezius	1.0	0.79	0.86
		Cycling (#)	<	14				
Upper Back	EMG	Height (cm)	>	171	Upper erector spinae	1.5	0.74	0.83
		Cycling (#)	<	4				
Lower Back	Pressure	Age	>	40	–	5.0	0.74	0.85
		SBO	<	47				
	NIRS	Age	>	40	–	5.0	0.74	0.82
		BackPP%	<	2.6				
		Height (cm)	>	171	Lower erector spinae	3.5	0.69	0.79
		SatQ4	<	3.9				
(b)								
Hip	Pressure	Height (cm)	>	171	–	2.6	0.94	0.84
		SPD%	<	5				
Buttocks	NIRS	Height (cm)	>	171	Biceps femoris	3.3	0.75	0.78
		TotQ1	<	-1.2				
	Pressure	Weight (kg)	>	58	–	6.0	1.00	0.87
		SPO	<	43				
Upper Leg	NIRS	Height (cm)	>	167	Biceps femoris	3.6	0.69	0.72
		TotQ4	<	-2.1				
	NIRS	Weight (kg)	>	68	Biceps femoris	3.6	0.69	0.79
		TotQ4	<	-2.1				
Knee	Pressure	Weight (kg)	>	71	–	3.7	0.83	0.87
		PanPP%	<	14				
	NIRS	Height (cm)	>	177	Biceps femoris	3.7	0.72	0.87
		TotQ3	<	-13.4				
NIRS	Weight (kg)	>	78	Biceps femoris	3.7	0.72	0.87	
	TotQ3	<	-13.4					
NIRS	Height (cm)	>	171	Biceps femoris	1.3	0.75	0.78	
	TotQ1	<	-1.2					

Note: Refer to Figure 2 for an example of how a model is used. SBO, seat back oscillations; SPO, seat pan oscillations; BackPP% and PanPP%, the percentages of points greater than >6.4 kPa relative to contact area for seat back and seat pan; SPD%, seat pan distribution; Tot, total blood volume; Q1–Q4, quarters 1–4 (relative to 2-h period); Sat, oxygenated blood saturation.

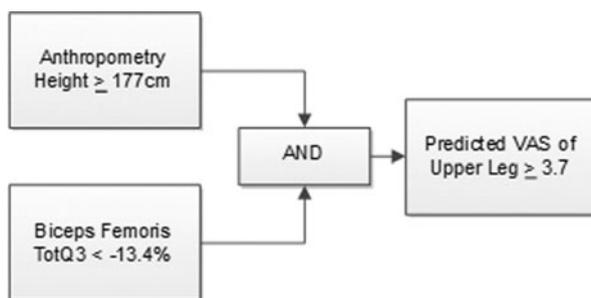


Figure 2. Sample use of a discomfort model. TotQ3, change in total blood volume in the third quarter. The threshold values were median values from the cross-validated data. Based upon the dichotomised data, if a person is taller than 177 cm and their total blood volume in the biceps femoris has dropped by 13.4% or more during the 60–90 min time window, then they are most likely to report a VAS score in the upper leg >3.7 cm.

their biceps femoris, then their reported upper leg discomfort is likely going to be greater than 3.7 cm. VAS scores (measured in cm) for subjective discomfort were reported from seven regions of the body: neck, upper back, lower back, hip, buttocks, upper leg and knee. Physiological measures came from the trapezius, upper erector spinae, lower erector spinae and biceps femoris muscles.

For this particular model, a prediction of discomfort must satisfy all three conditions in order to be considered a true positive.

The following summarise the physiological and anthropometric dichotomies that yield dichotomised discomfort predictions in the series of conditional classification models. Many models were evaluated; however, only biologically plausible models with cross-validated sensitivities and specificities greater than 0.6 were reported.

3.1 Neck discomfort

EMG results showed that subjects taller than 171 cm with lower than 14 cycles in the trapezius were likely to report discomfort in the neck region with a VAS > 1.0.

3.2 Upper back discomfort

Subjects taller than 171 cm with fewer than four cycles in the upper erector spinae over the 2-h period tended to report discomfort in the upper back with VAS > 1.5.

3.3 Lower back discomfort

Subjects over the age of 40 with 47 seat back oscillations or greater than 2.6% high-pressure points in the seat back tended to report low back discomfort with VAS > 5.0.

3.4 Hip discomfort

Taller subjects (> 171 cm) with an SPD score of greater than 5% tended to have reports of discomfort in the hip region (VAS > 2.6). Also, if the taller subjects had decreases in total blood volume of more than 1.2% in the first 30 min in their biceps femoris muscles were also likely to report discomfort in the hip (VAS > 3.3).

3.5 Buttock discomfort

Subjects who were less than 58 kg and had more than 43 seat pan oscillations reported discomfort in the buttocks (VAS > 6.0). Shorter subjects (< 167 cm) or lighter subjects (< 68 kg) with more than a 2.1% decrease in total blood volume in the biceps femoris during the fourth quarter of testing primarily reported discomfort in the buttocks (VAS > 3.6).

3.6 Upper leg discomfort

Subjects who were heavier than 71 kg and had greater than 14% high pressure points in the seat pan relative to contact area tended to report discomfort in the upper leg region (VAS > 3.7). Subjects heavier than 78 kg or taller than 177 cm that had total blood volume decreases of more than 13.4% in the biceps femoris muscle during the third quarter of testing tended to report discomfort in the upper leg (VAS > 3.7).

3.7 Knee discomfort

Subjects taller than 171 cm who had decreases in the total blood volume of more than 1.2% in the first 30 min in their biceps femoris muscles were likely to report discomfort in the knee (VAS > 1.3).

4. Discussion

Overall, the preliminary findings suggested that discomfort may indeed be quantified in physiological or biomechanical terms and were also conditionally dependent upon anthropometry. Anthropometric categories of age, height and weight appeared to be critical dimensions that resulted in different levels of physiological responses in association with subjective discomfort values. In this study, gender did not result in any significant discrimination in explaining discomfort responses. Most of the associations were relative to tissues in contact with the seat pan. It is interesting to note that even though there appears to be a focus on low back discomfort in seating research, the greatest number of discomfort reports in this study was consistently reported from the buttocks.

Three distinct regions of the body were found to have quantifiable connections to discomfort: neck, back and the lower extremities. These regions were associated with physiological discomfort in the trapezius, upper and lower erector spinae, gluteus maximus and biceps femoris muscles.

4.1 Neck discomfort

Neck discomfort appeared in subjects taller than 171 cm. An observational finding (J.D. Power and Associates 2011) found that many consumers were complaining of neck discomfort due to the headrest because of its forward leaning angle. EMG data supported the subjective responses of discomfort because of the constant low-level activation of the trapezius musculature, which was observed through a lower number of cycles. Discomfort was typically reported in the neck region when less than 14 cycles were found in the trapezius over the 2-h time window. This may indicate that the muscles in that region may not be substituting over time to rest certain fibres. Therefore, the constant activation may have led to fatigue and thus a report of discomfort. Support for this observation comes from a study by McLean et al. (2001) in which they found that a lower number of cycles resulted in reports of discomfort in the neck during computer work.

4.2 Torso discomfort (upper back and lower back)

Upper back discomfort was reported in subjects taller than 171 cm when there were less than four EMG cycles in the upper erector spinae over the 2-h session. This is suspected to be a systematic effect from neck flexion due to the head rest, which may have increased the kyphosis of the thoracic spine. The upper erector muscles may contract for postural stabilisation to mitigate forward displacement, therefore resulting in constant activation and discomfort. Support of this postulate can be observed in a study by Zedka, Kumar, and Narayan (1998). They found that when the centre of gravity of the torso moved forward, the back muscles engaged for postural stabilisation.

Relative to the low back, older subjects tended to report discomfort more than younger subjects. For subjects older than 40 years, low back discomfort was associated with greater than 47 seat back oscillations and greater than 2.6% high pressure points on the seat back. The high percentage of pressure points seemed to be associated with the higher number of seat back oscillations and thus, reported discomfort. The age association seems to be linked to the symptoms of cumulative low back discomfort which tend to appear between the ages of 35 and 55 years (Leboeuf-Yde 2004).

4.3 Lower extremity discomfort (hip, buttocks, upper leg, knee)

Discomfort in the buttocks region was associated with lighter people (less than 68 kg). They tended to have the highest discomfort reports and had lower oxygenation in the biceps femoris muscles in relation to heavier people. A possible explanation is that in lighter people, there may be an insufficient amount of adipose or muscle tissue to pad the ischial tuberosities. Garber and Krouskop (1982) support this conjecture since they found that thinner people tended to have higher pressures on the ischial tuberosities. In order to alleviate the discomfort, the hamstrings (biceps femoris muscles) may contract to assist to shift the pressures. This contraction may be linked to the buttocks discomfort as NIRS data showed a total blood volume decrease in the biceps femoris of 2.1% between 90 and 120 min of sitting in association with subjective ratings in the buttocks greater than 3.6. Previous work from van Geffen et al. (2010) found that when more than 40% of the load is placed on the tuberosities in lighter people may cause ischaemia. As time progresses, the body continues to attempt to alleviate the discomfort through subtle movement. Pressure mapping data showed movement due to the discomfort and motion tends to occur more often in the later aspects of the session. More specifically, lighter people who had more than 43 oscillations in the seat pan over the 2-h period were more likely to report discomfort scores of 6 or above in the buttocks region. Therefore, we suspect that there is a link between lighter people, higher pressure on the ischial tuberosities, the shortening of the hamstring over time to adapt, hence, a reduction in blood flow and thus motion in order to alleviate the pressure from discomfort. Previous work from Fenety, Putnam, and Walker (2000) has shown an association between in-chair movement and discomfort. Our study provided the context of how much movement may be associated with discomfort.

Subjects who were taller reported discomfort in the upper legs. Taller people tended to sit with more flexion in the hips and knees due to vehicle cockpit constraints. This in turn distributed the pressure unevenly, thus occluding the blood flow in the hamstrings. Subjects taller than 171 cm had reports of hip discomfort when the SPD score was greater than 5%. This suggested that the uneven distribution increased forces in the hamstrings region, which made several points of contact higher relative to the mean contact pressure. This uneven pressure distribution was speculated to be associated with the reduction of the total blood volume by 1.2% in the biceps femoris within the first 30 min of seating. When the total blood volume decreased by 13.4% in the biceps femoris for the 60–90 min time window, upper leg discomfort was typically reported at the end of the 2-h session. According to Houle (1969), high pressure points and uneven load distributions may lead to tissue ischaemia from the occlusion of blood flow. Previous work from Sprigle, Chung, and Brubaker (1990) has shown that a reduced amount of pressure peaks with even distribution is ideal to mitigate discomfort in the thigh region.

4.4 General context for application in seat design

From this study, it is believed that the understanding of physiological responses in relation to anthropometric differences may provide meaningful measures for the optimal design of seats when compared with subjective responses alone. There appears to be a conditional dependence between height, weight and age differences that play a role in affecting physiological responses relative to the postural constraints of the seat and thus overall discomfort. Understanding the linkage between design and physiological response/anthropometry may assist in reducing the number of iterations within the design process. Through quantification, a potential pathway of why people eventually report whether they are uncomfortable may be assessed between designs. Attention to these details may allow seat designers to fine-tune designs to fit their target markets.

4.5 Limitations

Several potential limitations should be considered in order to place this study in proper context. First, the physiological/biomechanical predictive measures of discomfort were predicted under laboratory conditions. However, this study provides insight into the links between the physiological response and anthropometric classification relative to subjective discomfort. Future studies may address changes in seating design features, configurations and vibration. Second, 12 subjects participated in this study. Although we had a reasonable spread of anthropometry between the subjects, a larger sample size would be necessary to achieve normality. As more subjects are added to the pool, discomfort thresholds may also change. However, we believe that the general relationships would still hold. Third, automotive seats were used in this study. Different seats may produce differing results. However, an independent test set with different automotive seats was used to evaluate the robustness of the models and the relationships still held fairly well. Finally, future studies should seek to understand whether and how design perception may influence the physiological responses. These were controlled in this study.

5. Conclusions

This study provides preliminary evidence that a few anthropometric factors play a role in physiological responses of the body during prolonged sitting. The interaction between anthropometry and sitting appears to initiate physiological responses that are associated with changes in discomfort reporting. Future studies need to consider this response system along with perceptual influences due to design so that we can truly understand the influence of seat design on discomfort perception.

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Notes

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