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Combining Psychophysical Measures of Discomfort and Electromyography for the Evaluation of a New Automotive Seating Concept

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The purpose of this study was to determine if the advantages and disadvantages of a new automotive seating concept, known as the micro-adjuster control system, could be reliably evaluated using both a physiological assessment technique (i.e., electromyography [EMG]) and a subjective questionnaire. The results indicate that psychophysical measures of discomfort and the root mean squared (RMS) activity of the EMG are statistically related, r (8) = –.788, p = .020. More specifically, subjective perceptions of comfort were found to improve with decreasing levels of muscle activity. This implies that seat comfort can be evaluated on the basis of physiological as well as subjective responses to prolonged driving. This finding should drastically improve automobile seat design efforts.

automotive seating   psychophysics   electromyography

1. INTRODUCTION

As customer expectations rise, comfortable automobile seat design is becoming more and more important. Recognizing this, the automotive seating industry has made the production of an optimal state for the occupant one of its primary goals. To this end, new concepts are constantly being developed. One such example is the micro-adjuster lumbar support mechanism.

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This concept is designed to continuously vary the amount of muscle activity, which should, theoretically, combat various problems associated with fixed sitting postures. In the research literature, these postures have been relatively neglected even though they are progressively and constantly increasing in frequency. To describe these postures, Grieco (1986) originally coined the term "postural fixity." This phenomenon occurs when an individual sits in one position, without significant postural movement, for an extended period of time. This is an extremely common occurrence in the driving environment where postures are determined and therefore fixed by the pedals, the steering wheel, the seat belt, the visual demands of the task, and the seat itself. Static loading of the back musculature in this fashion can result in a restriction of blood flow, which can cause aches, cramps, and fatigue. Simply put, comfort is compromised by sitting in one position for long periods of time. In addition to compromising comfort, postural fixity is a risk factor for the various spinal segments. In fact, many studies and authors have tended, in some way, to confirm the assumption that fixed and prolonged sitting postures increase the risk of alterations and disorders of the lumbar spine (Andersson, 1981; Damkot, Pope, Lord, & Frymoyer, 1984; Kelsey, 1975; Magora, 1972).

The design of the micro-adjuster mechanism also considered the generally accepted notion of lumbar support for the increase or decrease of lumbar lordosis. Keegan (1953) and Keegan and Radke (1964) were among the first to recommend that a firm pad be located in the lower part of the seatback to restrain the lumbar spine from flexing extensively. These investigations suggested that seats be designed to produce a lumbar lordosis about midway between the typical standing lordosis and a flat contour. This recommendation was made because it was observed that people under treatment for low back disorders were often more comfortable sitting in a reclined posture with lumbar lordosis than in an upright posture with a flat spine curvature.

By the mid-1970s, most lumbar support recommendations were strongly influenced by physiological studies of the load on the lumbar spine. Andersson et al. (Andersson & Ortengren, 1974a, b; Andersson, Ortengren, Nachemson, & Elfstrom, 1974a, b) used quantitative measurements of back extensor muscle activity and internal lumbar disc pressure to assess spine loads for a range of postures. In general, Andersson and his coworkers found that, for reclined postures, increasing the lumbar lordosis toward the standing posture decreases lumbar intradiscal pressure. In subsequent experiments with a car seat, Andersson et al. (1974b) found the lowest levels of back extensor muscle activity and intradiscal pressure with a seatback angle of

120° and a lumbar support prominence of 5 cm. Based on the assumption that low muscle activity and disc pressure are favourable, he and his co-authors recommended these as target values for seat design. These recommendations have been echoed by many others since (Chaffin & Andersson, 1991; Reed, Schneider, & Eby, 1995; Reynolds, 1993). To summarize, a lumbar support intended to preserve the standing lordosis will be located at approximately the apex of the standing curvature, around the third lumbar vertebra (L3), and will be longitudinally convex to mate with the desired spine curvature.

The micro-adjuster mechanism attempts to amalgamate the idea of lumbar support with the previously described concept of postural fixity. This mechanism is attached directly to the automobile seat's back frame in the lumbar support area. It is designed to combat the musculoskeletal problems associated with fixed sitting postures by forcing the user to undertake subtle shifts in body position at predetermined time intervals. This is accomplished by varying the degree of the lumbar support prominence through a series of timed "in" and "out" movements. At its maximum point, the micro-adjuster mechanism protrudes 5 cm into the seated occupant's lower back (as per Andersson et al., 1974b). In general, micro-adjustment is thought to be beneficial because it stimulates blood flow to the musculature of the lower back. This musculature would, under normal sitting conditions, be statically contracted; thereby enhancing occupant comfort.

Unfortunately, the concept of comfort is difficult to objectively define and measure. According to Thakurta, Koester, Bush, and Bachle (1995), this difficulty can be attributed to many factors including user subjectivity, occupant anthropometry, seat geometry, and amount of time spent sitting. Despite the highly subjective nature of seat comfort, the automotive seating industry has started to express interest in seating evaluation methodologies that provide objective, quantitative data. One such objective indicator of automobile seat comfort is electromyography (EMG; Bush, Mills, Thakurta, Hubbard, & Vorro, 1995; Lee & Ferraiuolo, 1993; Sheridan et al., 1991). The underlying premise is that gross changes of the seating system (like those induced by the micro-adjuster mechanism) affect posture, which in turn affects muscle activity and, as a consequence, can be detected by EMG. More specifically, localized low back muscle fatigue is accompanied by characteristic changes in EMG signal parameters, such as an increase in amplitude and a decrease in mean power frequency (Jonsson, 1991).

From a more detailed physiological perspective, significant ergonomic problems arise from localized muscle fatigue attributable to long-lasting static loading. In the past, responses to static work were mainly concerned with contraction levels above 15–20% of maximum (Lippold, Redfearn, & Vuco, 1960). More recently, it has been shown that muscle fatigue may be elicited by 1-hr sustained isometric contractions at 5–10% of maximum (Jorgensen, Fallentin, Krogh-Lund, & Jensen, 1988). Based on this rather limited body of work, many researchers now believe that low level sustained contractions, even under 5% of maximum, can be problematic. It is this type of contraction that is common in sitting.

At this time, however, it must be stated that EMG, much like all other currently available objective technologies, has not emerged as a singular predictor of automobile seat comfort (Lee & Ferraiuolo, 1993). This lack of analytical measurables has forced the seating industry to, just as in the past, rely on jury evaluations as the main measure of seat comfort.

2. OBJECTIVE

To remain consistent with current trends in automobile seat design, this study used subjective data as the primary measure of comfort. The information obtained in this manner was supplemented with EMG data in hopes of demonstrating that both methods, used in isolation or in conjunction, can adequately evaluate the advantages and disadvantages of a particular seat design. If EMG can be used to draw conclusions that are comparable to those obtained using subjective evaluations, the task of designing comfortable automobile seats should become easier and more efficient.

To summarize, the ultimate purpose of this investigation was to determine whether both psychophysical measures of discomfort and EMG could be used to better evaluate a new automotive seating concept known as the micro-adjuster lumbar support mechanism.

3. METHOD

3.1. Participants

Five male and five female university students served as voluntary participants. Their demographic and anthropometric characteristics are outlined in Table 1.

TABLE 1. Demographic and Anthropometric Characteristics Participants

Participant No.	Gender	Age (years)	Weight (kg)	Height (m)
1	Male	22	91	1.79
2	Female	20	85	1.75
3	Female	20	58	1.66
4	Female	19	80	1.75
5	Male	27	83	1.80
6	Male	24	76	1.72
7	Female	21	63.5	1.65
8	Male	23	75	1.77
9	Female	20	54	1.63
10	Male	23	77.5	1.71
M		21.9	74.3	1.72
SD		2.3	11.44	0.06

Prior to the beginning of the first experimental session, each volunteer signed a consent form to indicate his or her willingness to participate in the study. At the conclusion of their participation, participants were compensated at the minimum wage rate as set by Canadian law.

3.2. Apparatus

For the purposes of this study, a fully trimmed, leather automobile seat from a luxury vehicle was mounted on a wooden base and equipped with a micro-adjuster lumbar support mechanism. The mechanism could move either in (away from the seated occupant) or out (towards the lower back of the seated occupant). A motor requiring a 12-V power supply controlled the two-way movement of the system.

To obtain an indication of fatigue, low back muscle activity was measured using surface EMG. According to Giroux and Lamontagne (1990), surface EMG has been shown to be reliable on a day-to-day basis, quick and easy to administer, and safe. The EMG equipment consisted of six pairs of 10-mm diameter bipolar surface electrodes (Grass Instrument Company, USA), a high performance AC preamplifier (Grass Instrument Company), a 486 personal computer, data acquisition software called VIEWDAC (Keithley ASYST, 1992), and an analog-to-digital conversion program.

3.3. Experimental Design

Cycle, wait, and pulse were the three micro-adjuster control system variables that could be manipulated. These definitions are best understood through an examination of Figure 1.

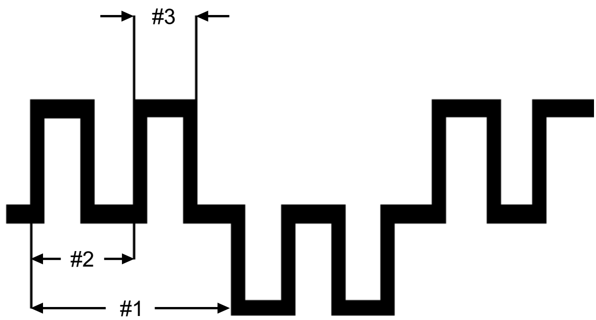

Figure 1. Operational definitions of micro-adjuster control system variables. *Notes.* #1—cycle, #2—wait, #3—pulse.

Cycle was the time duration for controlling the direction (in and out) of the micro-adjustments. It was arbitrarily set to two levels: 2 and 5 min. Wait was the time delay between the start of one micro-adjustment and the start of the next micro-adjustment. It was also arbitrarily set to two levels: 15 and 30 s. Pulse was the time duration of the micro-adjustment. It was considered an index of intensity. That is, the greater the pulse, the more pronounced the micro-adjustment. Once again, it was arbitrarily set to two levels: 0.8 and 1.1 s.

As a result, in this design, there were a total of eight possible treatments. In each treatment, participants were required to sit in the experimental automobile seat for 2 hrs. Therefore, each participant sat for a total of 16 hrs. It should also be stated that each participant completed all eight treatments within the span of 2 weeks. No participant participated in more than one treatment per day. Table 2 summarizes the details of the aforementioned experimental design.

Occupant preferences in seat position were speculated to have a potential confounding effect on the results of this experiment. This was dealt with by (a) fixing the seatback angle at 120° (Andersson et al., 1974b; Hosea, Simon, Delatizky, Wong, & Hsieh, 1986) and (b) requiring participants to maintain the designated heel point (i.e., participants were not permitted to move their legs closer or farther away or to cross their legs). By fixing the

TABLE 2. Experimental Design

Condition	Cycle (min)	Wait (s)	Pulse (s)
1	2	15	0.8
2	2	15	1.1
3	2	30	0.8
4	2	30	1.1
5	5	15	0.8
6	5	15	1.1
7	5	30	0.8
8	5	30	1.1

seatback angle and heel point, only the occupants' knee and hip angles could vary. This variation was due entirely to differences in occupant anthropometry.

Fixing the heel point also served to better simulate the driving environment because, in an actual vehicle, the pedals dictate the heel point. For the purposes of improved simulation, participants were also required to remain attentive and forward facing (with their heads up). To help facilitate this, a television screen was set up approximately 5 m directly in front of the participants and movies were shown.

3.4. Procedure

The experimental sessions were conducted at times convenient to both the volunteer participants and the investigator. Participants were asked to refrain from any strenuous physical activity for the time frame leading up to a particular test session. In this way, participants were assumed to arrive for their respective test sessions without any excessive back muscle activity. Prior to the beginning of each participant's first experimental session, the procedure was thoroughly explained and consent was obtained through a signature.

Before each session, the participant was asked to select a number from 1 to 8. Each number corresponded to one of the eight possible conditions. In this way the conditions were randomized. Once a condition was selected, the participant was not allowed to select the same condition in a subsequent experimental session. This was done to avoid any unnecessary replication of conditions. Although this method may not have ensured a truly random presentation order, the amount of time between experimental conditions should have alleviated any possible residual treatment effect on the musculature of the lower back. For this reason, order effects were not thought to confound the results.

Next, precautions were taken to ensure that a pure EMG signal was obtained (i.e., one with little noise). To this end, if there was hair covering the electrode attachment sites, it was shaved. The entire lower back region was also cleaned using a piece of cotton moistened with rubbing alcohol. This served to remove dry skin cells.

At this point, electrodes were attached to the lumbar area of the participant. Extreme care was exercised when positioning these electrodes because muscle geometry and bone location can both affect the EMG signal. To improve the signal, a bio-compatible electrode paste was used between the skin and the electrodes. Following the lead of Andersson et al. (1974b), the six pairs of electrodes were placed 3 cm lateral to the vertebral column (three pairs on each side) at the L1, L3, and L5 levels. The level of the tips of the spinous processes, which could be palpated, determined the vertebral level. This arrangement targeted the erector spinae, which is considered a postural muscle group.

In ergonomics literature, the relationship between muscle activity and muscle fatigue is usually studied using low pass filtering techniques or so-called full wave rectification (Chaffin & Andersson, 1991). This study abides by this principle.

EMG data were collected every 10 min for the full 2-hr test session. To aid in this process, time triggers were built into the data acquisition software. VIEWDAC sequences were set to capture 45 readings per second from the six channels. Specially written macros provided the average root mean squared (RMS) value from all six channels at each 10-min time interval. The ΔRMS value served as the actual response variable. For this study, ΔRMS was defined as the difference between the highest and lowest RMS value obtained during the experimental session. A positive ΔRMS value implied that EMG activity tended to decrease as a result of the experimental treatment. Comparatively, a negative ΔRMS value implied that EMG activity tended to increase. Due to the manner in which the dependent variable was defined, data normalization was unnecessary. This is an acknowledged departure from most other EMG studies.

During the course of the test session, data were also collected using an investigator-administered pre-prepared questionnaire. The objective of this questionnaire was to provide quantitative information on subjective perceptions of discomfort attributable to the experimental treatment. To this end, participants were asked to rate their perceived level of lower back discomfort using the following 5-point scale: 1—*very comfortable*, 2—*comfortable*, 3—*neutral*, 4—*uncomfortable*, 5—*very uncomfortable*.

The participants were not required to respond using only integer values (i.e., they could respond 2.5, for example). Ratings were collected beginning at the 30-min mark and continuing in 30-min intervals for the entire duration of the experiment. The actual questionnaire is shown in Appendix A.

4. RESULTS AND DISCUSSION

4.1. Psychophysical Discomfort Results

Subjective perceptions of lower back comfort were studied using a two-way ANOVA. The factors of interest were (a) experimental condition and (b) time spent experiencing the experimental condition. The results are summarized in Table 3.

TABLE 3. ANOVA Summary Table for Psychophysical Discomfort of Lower Back

Factor	*SS*	*df*	*MS*	*F*	Significance
Main Effects					
Combined	20.963	10	2.096	6.402	.000
Condition	19.684	7	2.812	8.588	.000
Time	1.278	3	0.426	1.301	.274
2-Way Interactions					
Condition × Time	8.484	21	0.404	1.234	.221
Model	29.447	31	0.950	2.901	.000
Residual	94.300	288	0.327		
Total	123.747	319	0.388		

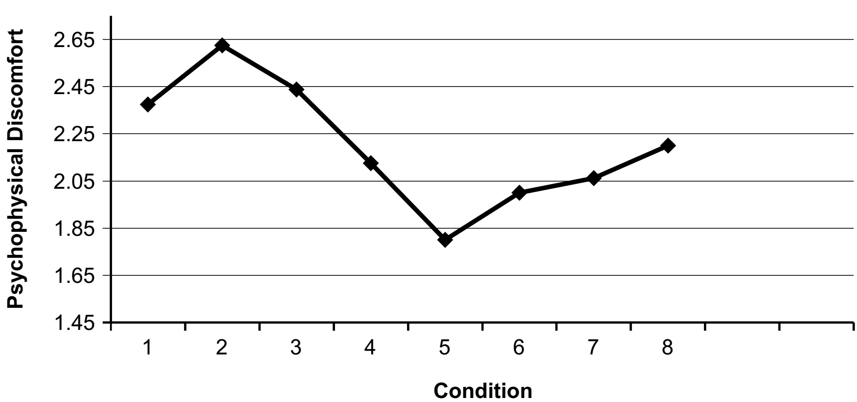

Figure 2. Psychophysical discomfort rating of the lower back.

There was no difference between subjective ratings of lower back discomfort at the 30-, 60-, 90-, or 120-min mark. In other words, time did not have a significant effect on subjective ratings. The condition did, however, have a statistically significant effect ($p < .05$). This effect is represented graphically in Figure 2, which shows that the average lower back rating was best in condition No. 5.

4.2. EMG-ΔRMS Results

A one-way ANOVA was used to determine if the experimental condition had a statistically significant effect on ΔRMS values. The results, shown in Table 4, revealed that the condition did, in fact, have a significant effect ($p < .05$). In other words, some conditions resulted in comparatively less low back muscle activity than others did.

TABLE 4. One-Way ANOVA Summary Table for EMG–ΔRMS Results

Factor	*SS*	*df*	*MS*	*F*	Significance
Between Conditions	0.0006306	7	0.00009008	2.321	.034
Within Conditions	0.0027940	72	0.00003880		
Total	0.0034250	79			

In Figure 3, the average ΔRMS value is graphed as a function of experimental condition.

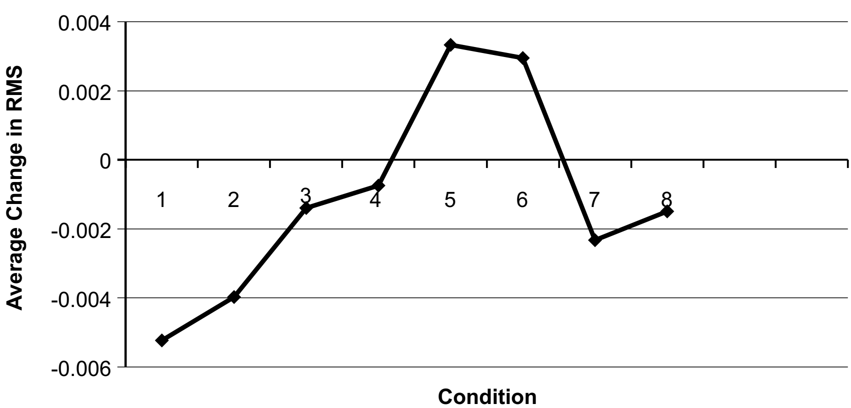

Figure 3. Average ΔRMS for each experimental condition.

Figure 3 reveals that condition No. 5 and condition No. 6 are the only experimental treatments that resulted in positive ΔRMS values. This result implies that, in these conditions, lower back muscle activity tended to decrease over time.

4.3. Combination of Psychophysical Measures of Discomfort and EMG-ΔRMS Values

Table 5 presents summary statistics, by condition, for (a) the psychophysical discomfort ratings and (b) the ΔRMS values.

TABLE 5. Lower Back Discomfort Score Versus ΔRMS Value

Condition	Statistics	Psychophysical Discomfort	EMG–ΔRMS
1	*M*	2.3750	–0.005230
	N	40	10
	SD	0.6430	0.003673
2	*M*	2.6250	–0.003970
	N	40	10
	SD	0.9624	0.003269
3	*M*	2.4375	–0.001140
	N	40	10
	SD	0.4227	0.002120
4	*M*	2.1250	–0.000742
	N	40	10
	SD	0.4564	0.002524
5	*M*	1.8000	0.003325
	N	40	10
	SD	0.4414	0.005594
6	*M*	2.0000	0.002947
	N	40	10
	SD	0.4529	0.008432
7	*M*	2.0625	–0.002330
	N	40	10
	SD	0.5711	0.009398
8	*M*	2.2000	–0.001490
	N	40	10
	SD	0.4641	0.009202

To determine if there was a statistically significant relationship between the two different types of measures, a Pearson r value was computed. The result is as follows: r (8) = –.788, p = .020. The Pearson r is negative because as psychophysical discomfort ratings decrease, the ΔRMS values increase. Recall that the lower the discomfort rating, the more comfortable the occupant and the higher the ΔRMS value, the larger the decrease in muscle activity over time. The r^2 value was .621.

5. CONCLUSION

It would be incorrect to conclude, based on the results of this investigation, that low level sustained contractions are beneficial. In fact, as stated earlier in this paper, many researchers now believe that sustained contractions, even at extremely low levels, can be problematic. This study contribution is unique in that it suggests that the negative effects of low level sustained contractions, caused by prolonged sitting in an automobile seat, can be diminished by a variation in muscle activity brought on by the micro-adjuster lumbar support mechanism. The most beneficial conditions (based on psychophysical discomfort ratings) were accompanied by the largest decreases in muscle activity over time. In other words, the hypothesis that perception of seating discomfort is associated with quantifiable changes in low back EMG activity was supported. Furthermore, the changes that occur are directly affected by the micro-adjuster lumbar support mechanism.

Perhaps, at least for the automotive seating industry, the degree of uniformity between the very different modes of assessing automotive seating preferences is the most important result. In an industry that has, for many years, struggled to quantify comfort, explaining 62% of the variance in discomfort ratings using EMG is a promising result. Based on the literature reviewed in preparation for this study, no other objective indicator of automotive seating comfort approaches this figure.

It should also be noted that this study was not designed to determine an optimal combination of micro-adjuster control system variables. For this reason, further investigation is needed to determine what levels of the three factors (i.e., cycle, wait, and pulse) result in the most optimal state for the human being. It was, however, interesting to note that condition No. 5, based on both subjective and objective indicators, appeared to have the most beneficial effect on occupant comfort.

Finally, the validity of the psychophysical measure of discomfort employed in the present study can, justifiably, be questioned. This is a problem with most, if not all, studies designed to assess subjective perceptions of automotive seating comfort. For this reason, future work needs to be conducted to establish a psychophysical discomfort questionnaire that is both reliable and valid. The goal should be the development of a universally accepted measure that can be used to streamline automotive seat comfort development. All that can confidently be stated about the question used in this study is that it had good face validity.

To summarize, both psychophysical discomfort ratings and EMG-RMS activity provide a reliable means of improving automobile seat deign. This finding may prove to be extremely useful for future evaluations of seating comfort.

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APPENDIX A

Psychophysical Discomfort Questionnaire

1. With respect to your lower back, indicate your perceived level of discomfort/comfort using the following scale:

   1. Very Comfortable
   2. Comfortable
   3. Neutral
   4. Uncomfortable
   5. Very Uncomfortable

	$^1/_2$ hr	1 hr	$1^1/_2$ hrs	2 hrs
Lower Back				