Analysis of Body Movement Patterns and Subjective Discomfort Ratings in Long-Duration Sitting

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16. Abstract

A laboratory study was conducted to evaluate the hypothesis that discomfort in long-duration sitting is associated with more-frequent posture changes. Two nominally identical production automobile driver seats were obtained for testing and one was modified in ways that were expected to increase discomfort. Twenty-four men and women with a wide range of age and body size sat in each of the seats for one hour on two different days while watching videos and completing a discomfort questionnaire every five minutes. Posture was monitored using a video, pressure sensors in the seats, and a Microsoft Kinect depth sensor. A variety of posture change metrics were computed from each data source. The modified seat produced significantly higher discomfort ratings. However, no difference in movement frequency was observed between the seats, and no relationship between maximum discomfort and movement frequency was observed.

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Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
In	inches	25.4	millimeters	mm
Ft	feet	0.305	meters	m
Yd	yards	0.914	meters	m
Mi	miles	1.61	kilometers	km
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
Ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
FORCE and PRESSURE or STRESS				
N	Newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
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CONTENTS

ABSTRACT

A laboratory study was conducted to evaluate the hypothesis that discomfort in long-duration sitting is associated with more-frequent posture changes. Two nominally identical production automobile driver seats were obtained for testing and one was modified in ways that were expected to increase discomfort. Twenty-four men and women with a wide range of age and body size sat in each of the seats for one hour on two different days while watching videos and completing a discomfort questionnaire every five minutes. Posture was monitored using a video, pressure sensors in the seats, and a Microsoft Kinect depth sensor. A variety of posture change metrics were computed from each data source. The modified seat produced significantly higher discomfort ratings. However, no difference in movement frequency was observed between the seats, and no relationship between maximum discomfort and movement frequency was observed.

INTRODUCTION

The standard method of measuring discomfort in seating remains the subjective questionnaire in spite of decades of effort to identify objective measures that are strongly associated with discomfort. Subjective assessments are the most direct way to measure discomfort, since the phenomenon is inherently subjective, but asking a study participant to provide subjective responses necessarily changes the sitting experience. Consequently, a less-intrusive measurement that could reliably predict subjective discomfort ratings would be valuable.

Posture change has been proposed as a measure of discomfort. Specifically, an increased number of posture changes may be an indication of increased discomfort. This potential measure has not been studied extensively due to the difficulty in measuring posture, particularly in automotive settings. Most posture measurement methods have required attaching sensors or markers to the sitter's body, which could be more intrusive than subjective assessments. However, newer sensing technologies have made markerless, unobtrusive posture measurement feasible.

The current study used three methods to monitor posture changes during one-hour laboratory seating sessions. In sessions on separate days, participants sat in each of two identical-appearing seats, one of which had been modified to make it less comfortable. The participants rated their discomfort every five minutes using a standard visual analog scale, and their postures were monitored using video, pressure measurements on the seat cushion, and depth data from a Microsoft Kinect sensor. The data were analyzed to determine if the subjective responses were correlated with posture-change metrics.

METHODS

Seats and Mockup

Two visually identical seats were provided by Magna for this study. One seat (B) was modified in ways that were intended to make the seat uncomfortable. Among other changes, the padding in the seat cushion was stiffened and the lumbar support removed. The SAE J826 H-point manikin was used to establish the H-point of each seat. The seat travel, pan angle, and head restraint adjustments were then locked so that the seat height (H30) was 270 mm, the seat pan was at 14.5 degrees (A27), and the head restraint was at its lowest and least prominent setting. Figure 1 show the seats mounted to wooden platforms that could be locked onto the mockup test fixture, ensuring they were consistently positioned. The mockup was a platform with a 27" video screen placed 1600 mm in front of and 650 mm above the of seat H-point (Figure 2).

Figure 1. The standard Seat A and modified softness Seat B from left to right; photo of Seat B showing modified foam areas (dark).

Figure 2. Seat B on mockup platform and the monitor used as a video screen.

Instrumentation

A Microsoft Kinect version 2 sensor was mounted on a tripod in front of the vehicle mockup. The Kinect sensor provides 512 x 424-pixel 3D point-cloud data and 1920 x 1080-pixel video data which was recorded at 10 Hz. Figure 3 shows the Kinect and its color video field of view.

Figure 3. Kinect (left) and Kinect field of view showing laboratory setup

Each seat was instrumented with 48 pressure sensors (8 rows by 6 columns) placed in the seat cushion below the trim. The pressure sensor data were recorded during each trial at 10 Hz and synchronized with the Kinect data recording. An initial frame was recorded with the seat empty prior to the trial; the pressure values from this “zero” frame were subtracted from the subsequent frames prior to analysis.

Participants

Twenty-four participants, 12 men and 12 women, were recruited for this study. They ranged in age from 20 to 74 years, in stature from 1565 mm to 1879, and 30% of them had a body mass index (BMI) over 30 kg/m^2. Table 1 summarizes the participant age and anthropometry. Figure 4 shows weight and stature distribution by gender.

Table 1
Participant Description

Measure	Mean	SD	Min	Max
Age (yr)	31	14	20	74
Stature with shoes (mm)	1702	88	1565	1879
Stature without shoes (mm)	1682	83	1558	1835
Weight (kg)	76.1	19.6	45.0	122.2
Erect Sitting Height (mm)	883	42	804	965
Buttock-Popliteal Length (mm)	492	33	446	566
BMI (kg/m^2)	26.7	6.1	18.1	39.8

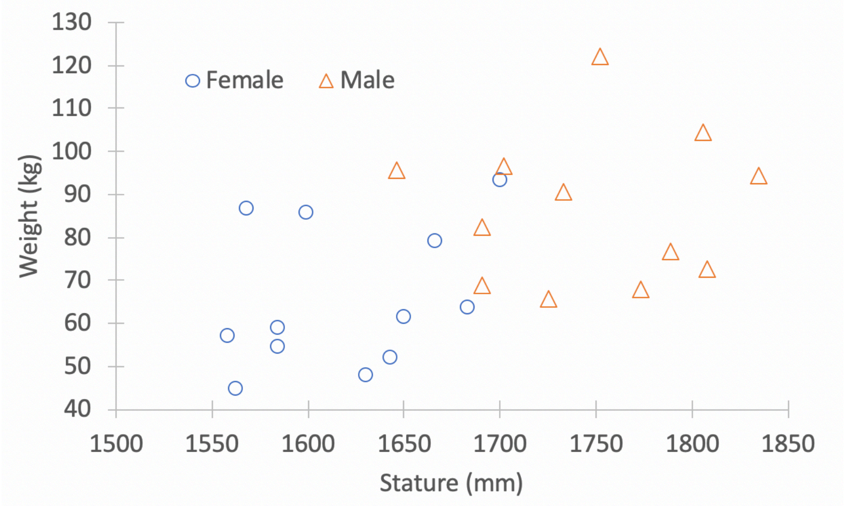


Figure 4. Weight versus stature for study participants.

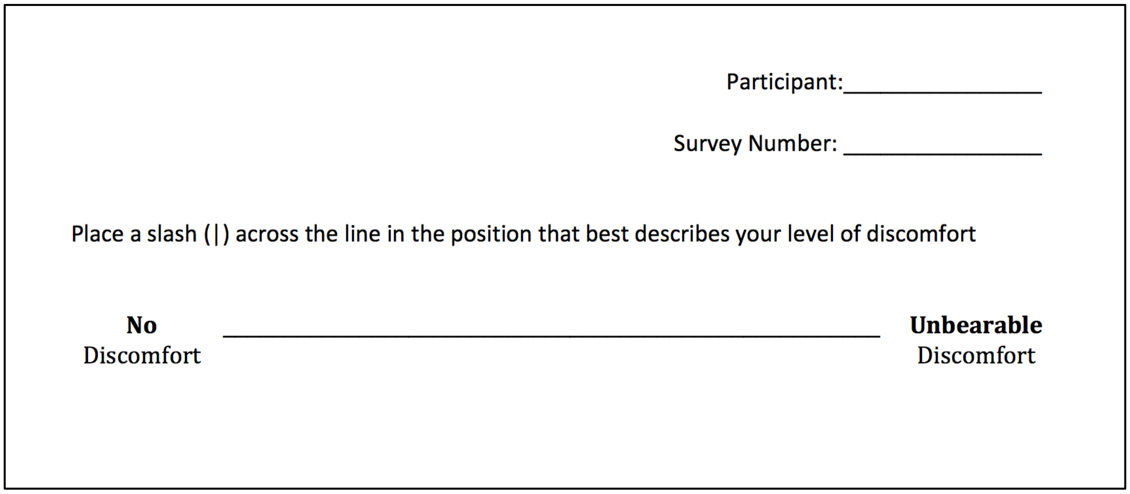
Protocol

The study protocol was approved by an institutional review board for human-subject research at the University of Michigan (HUM00161389). Volunteers participated in two test sessions that were scheduled to be two or three days apart. The participants were asked to wear the same shoes and the same or similar clothes for the two sessions. The protocol was the same for both sessions, except during the first session the anthropometric measures in Table 1 were recorded, and at end of the second session an additional exit questionnaire was administered (Appendix C).

Each participant experienced each seat on a different day, and the order of presentation of seats was randomized across participants. Participants were not told of any differences between test conditions. The seat was placed on the mockup before the participant arrived, and the seat back angle was set to 23 degrees (SAE A40). The seat not being used was stored covered and out of sight of the participant. Upon entering the laboratory, the participant was asked to sit in the seat and adjust the recline angle until it was comfortable and then exit the seat. (See Appendix A for the investigator scripts.) The investigator then marked the angle and covered the recline lever so that it could not be adjusted by the participant again during the session. The seat surface without the participant was recorded with the Kinect. While the participant was standing, the investigator read instructions for the long duration sitting portion including how to use the discomfort questionnaires.

The participant was then asked to sit again. A stack of identical discomfort questionnaires (Figure 5) numbered 0 though 12 were placed on a small clipboard with a pen attached on a rolling table next to the participant. The table was positioned so that it did not occlude the participants in the Kinect's field of view and so that the participants could reach the questionnaires without moving their upper bodies but not contact the table with their legs in any posture they might choose. On the table was a closed drop box for the completed questionnaires, a box of facial tissues, hand sanitizer and a 2-way radio. Figure 6 shows a participant and the table. Immediately after sitting down, the participant was asked to mark the first questionnaire. The investigator then started one of two randomly assigned videos, *Ocean Deep* or *Shallow Seas*, from the Planet Earth television series, and then left the room. The participants were told they could contact the investigator either via the 2-way radio or by knocking on the wall next to them, as the investigator would be sitting at a desk in the lab adjacent to them. A live-feed webcam in the back of the room allowed the investigator to monitor the participant, checking that he/she stayed seated for the duration of the study. Participants were asked to stay seated for the entire session and not to eat, drink or use their phone. The scripted instructions are as follows:

> *… we ask that you remain seated for the full testing period of one hour, unless you feel you must get up. If you do so, please contact me and let me know that you have gotten up and for what reason. Remember you may discontinue your participation without affecting your pay. Also, please do not eat, drink or use your phone while sitting here.*



Participant:________________

Survey Number: ________________

Place a slash (|) across the line in the position that best describes your level of discomfort

No Discomfort ____ **Unbearable** Discomfort

Figure 5. Discomfort questionnaire

Figure 6. Participant in test seat

As the video played, a pop-up screen appeared over the video every 5 minutes asking them to “Please take survey numbered [*number inserted here*]. Rate your level of discomfort. Place it in the box." Figures 6 and 7 shows the box in which they inserted their completed questionnaires. After the hour of sitting, the investigator returned and asked the participant to remain seated. The participant was then given the questionnaire in Appendix B. If it was the second day of testing the participant was also given the questionnaire in Appendix C.

Figure 7. Questionnaire drop box

Data Processing

In the questionnaires in which a mark was placed upon a line, both the entire length of the line and the distance from the left end of the line to the mark the participant placed on it were measured using a ruler. (The line length was measured to address potential differences due to reproduction of the questionnaires.) The discomfort rating was analyzed as the fraction of full scale from the left side of the line (0 to 1).

Analysis of Kinect Data – Depth

Kinect data frames were extracted at 5-second intervals for analysis. To facilitate data processing, each depth frame was masked to extract only the pixels in the area of the image around the participant, and the resolution of each frame was reduced to 106 x 128 by averaging blocks of pixels. A variety of metrics were computed to quantify movement during the trial.

Mean Distance – The mean pixel depth (distance from the sensor) was computed for each frame. Most posture changes will result in a change in the mean depth.

Depth Variability – Large variation in the depth measurement for a particular pixel is indicative of movement in that area of the frame. The standard deviation was computed for each pixel across the duration of the trial. Figure 8 shows the pixel standard deviations for one trial, illustrating higher variability (i.e., movement) in the areas of the head, hands, and lower extremities. A variety of metrics were calculated from the per-pixel standard deviations: mean standard deviation, quantiles of standard deviation, and the fraction of standard deviations larger than several cutoffs. In general, larger variability across the trial is associated with more frequent and larger movements.

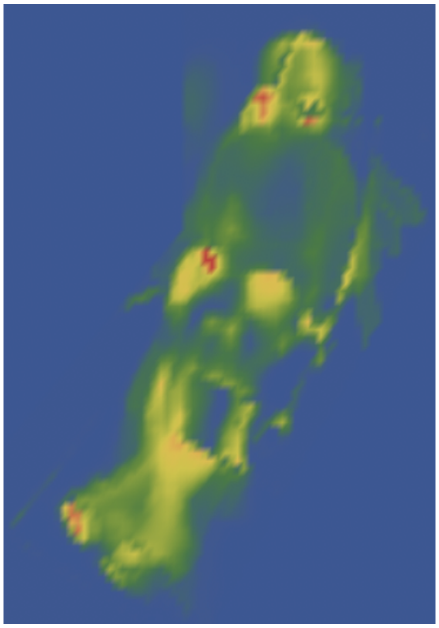


Figure 8. Pixel depth standard deviations. Areas of yellow and red have higher variability, blue indicates low variability (background).

Frame-to-Frame Changes – When the participant moves, the depth readings from pixels in the area of the movement change. A large movement is associated with changes in a large percentage of the pixel depth data. Two thresholds determine whether a movement was judged to occur between two frames: the marginal change in depth at a pixel and the fraction of pixels in a frame that change by that margin. Movement thresholds of 5, 10, and 20 mm were used along with moving-pixel fractions of 10, 15, and 25% of the region of interest around the participant. These calculations produced a binary movement/no-movement for each frame relative to the preceding frame at 5-second intervals. These movement indications were then summed across the trial.

Analysis of Kinect Data – OpenPose

OpenPose is an open-source image-processing library that estimates human posture from single images (https://github.com/CMU-Perceptual-Computing-Lab/openpose). Figure 9 shows examples of postures obtained from applying the OpenPose software to video frames from the Kinect sensor. The posture data consist of 15 landmarks (generally representations of joint centers) in the 2D coordinates of the video frame. Posture change was identified by the magnitude of change in the landmark locations (pixels) between frames sampled every five seconds. A threshold of 200 pixels of total location change was found through visual verification to be a good indication of a substantive posture change. The analysis was further restricted to the lower extremities only, since arm-pose changes were not of interest and torso posture changes were not well captured by the 2D analysis. The number of lower-extremity posture changes exceeding the 200-pixel distance threshold were obtained for each trial. Values ranged from zero to 75 posture changes using this metric.

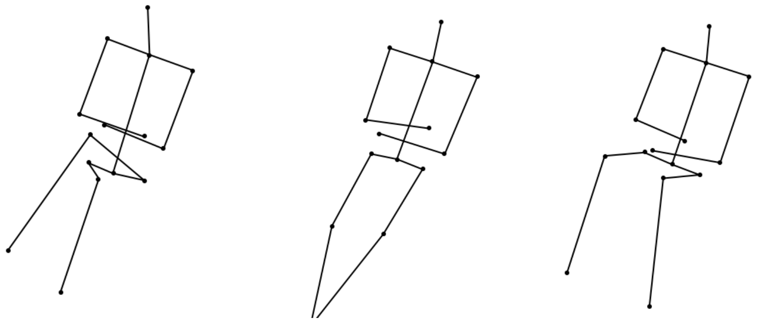


Figure 9. Examples of postures obtained using OpenPose.

Analysis of Pressure Data

An initial frame of pressure data from the unoccupied seat was subtracted from all frames from the trial to account for pressure offsets. A center of pressure (COP) was calculated relative to the sensor grid. Figure 10 shows an example of the COP (large dot) relative to the pressure grid. The location of the COP was tracked over time to examine posture changes. The COP shifted side-to-side with asymmetrical changes in thigh posture and moved fore-aft when the thighs were raised or lowered, changing the engagement with the seat cushion. Figure 11 shows a COP trajectory for one trial. Note that some sensors did not provide good data and were zeroed for all frames.

Comparison of the COP trajectory with the OpenPose and Kinect depth analyses indicated that a change in the COP of 0.25 (i.e., one-quarter of the sensor pitch) was a good indication of a posture change. Values ranged from zero to 15 posture changes. The number of movements based on this criterion was computed for each trial.

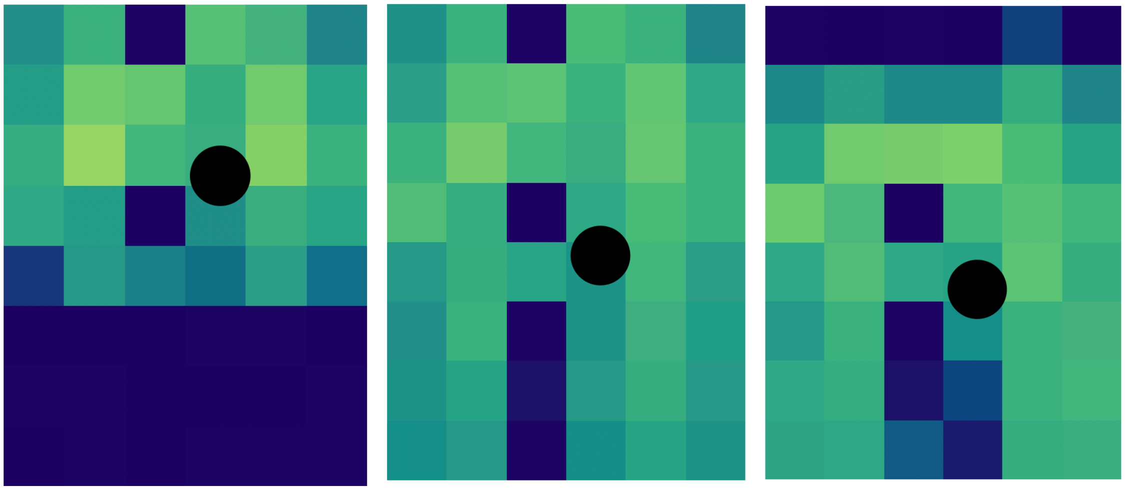


Figure 10. Center of pressure (large dot) relative to the pressure-sensor grid (higher pressures shown as lighter colors). Front of seat is at the bottom of the image.

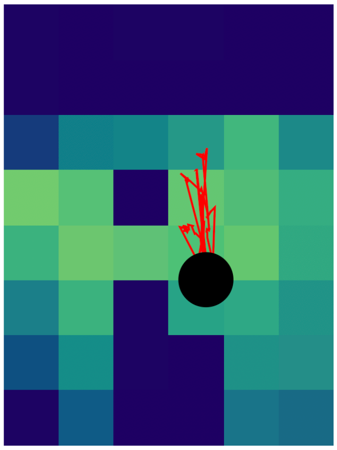


Figure 11. Center-of-pressure trajectory for one trial (red line). The pressure pattern for one frame is shown for reference. Front of seat is at the bottom of the image.

RESULTS

Discomfort Ratings

The subjective ratings of discomfort from the questionnaires administered every five minutes tended to increase over time. Figures 12 and 13 show the data for men and women. Six participants were low responders, with values below 10% on at every interval. Several participants appeared to have been unwilling to report any discomfort, attempting to mark the left end of the scale at every interval.

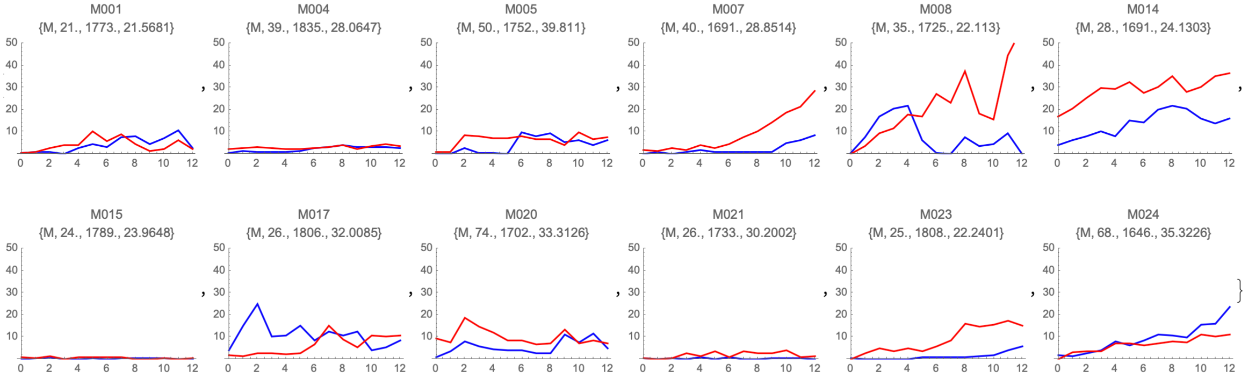


Figure 12. Trends in discomfort ratings (% of full scale) over time for **men**. **Blue** is seat A, **Red** is seat B. Horizontal axis is time in 5-minute increments. Plots are labeled with {sex, age, stature, BMI}.

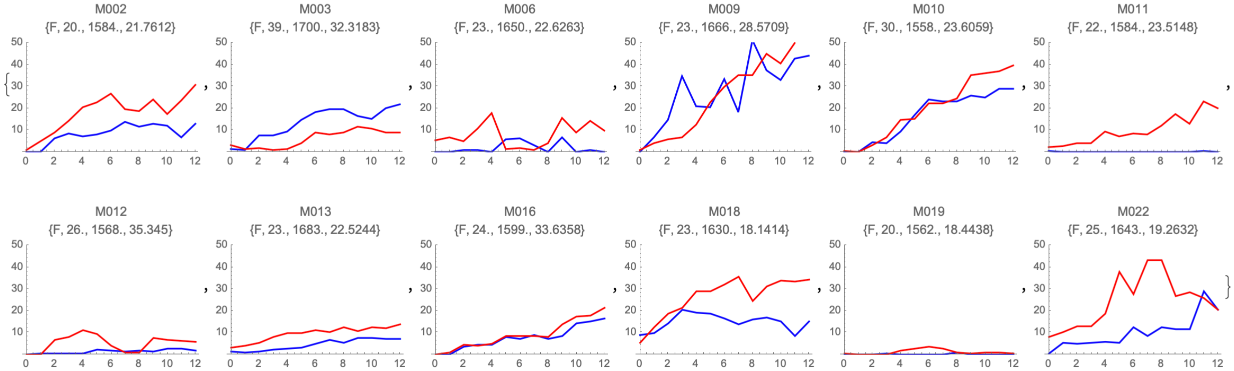


Figure 13. Trends in discomfort ratings (% of full scale) over time for **women**. **Blue** is seat A, **Red** is seat B. Horizontal axis is time in 5-minute increments. Plots are labeled with {sex, age, stature, BMI}.

Because the discomfort ratings tended to increase monotonically over time, the maximum rating during the trial was analyzed as an aggregate measure of discomfort. Figure 14 shows the maximum discomfort ratings for all subjects for the two seats. On average the modified seat (Seat B) was rated as more uncomfortable (higher discomfort) but five participants produced higher discomfort ratings on Seat A.

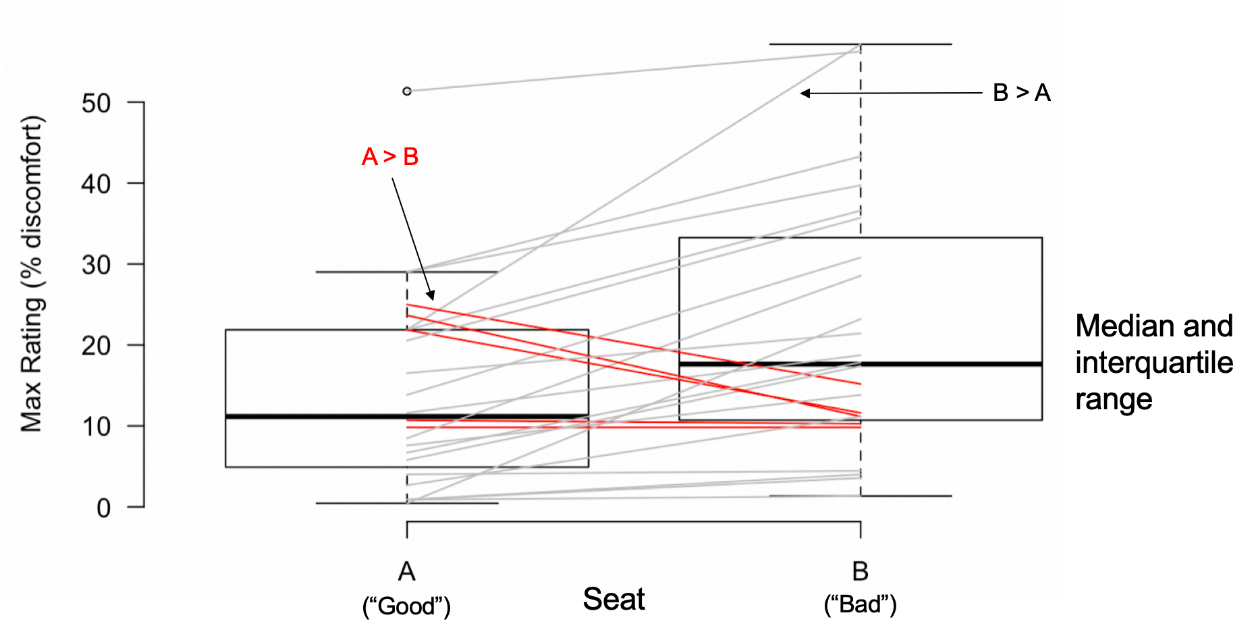


Figure 14. Maximum discomfort ratings. The box plots show the median and intequartile range and the whiskers extend to the range of the data. Lines connect each subject's data. The four participants who rated the "good" seat as more uncomfortable than the "bad" seat are shown in red.

Discomfort ratings were not significantly related to participant characteristics, such as stature or body mass index. The difference in ratings between seats A and B was also not significantly related to participant characteristics.

Trial Exit Questionnaire

Figure 15 summarizes the discomfort responses from the exit questionnaire. The seat bottom (cushion) was perceived as being more uncomfortable in Seat B than in Seat A, but the responses for the seat back were not meaningfully different. The overall discomfort rating was also slightly higher in Seat B, though the variability was high and the median response was only 20% of full scale.

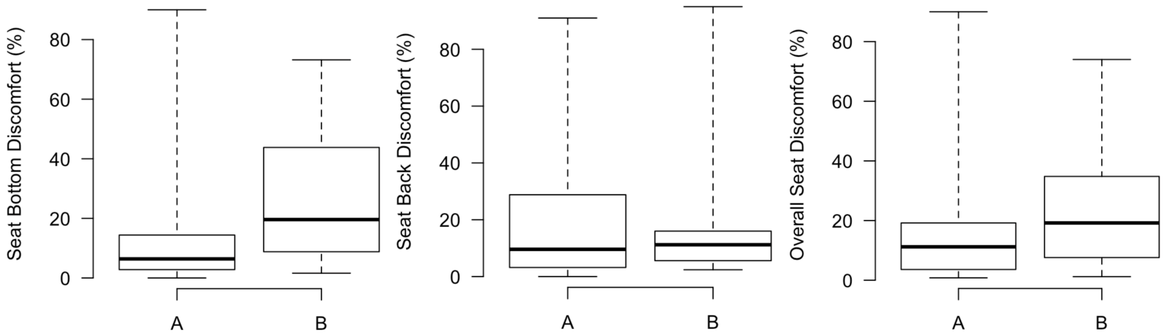


Figure 15. Boxplots of subjective discomfort ratings (% of full scale) for exit questionnaire. Bold line shows median, box shows interquartile range, whiskers cover range of data.

Tables 2 and 3 summarize the categorical seat feature ratings from the seat questionnaire. Most of the responses were “just right” (neutral) for most questions. Notable differences were seen in “seat bottom shape at rear” where a larger number of participants said they “feel like they’re sitting on top”. Consistent with those results, more participants thought the seat bottom was too firm in Seat B. Seat back evaluations were not meaningfully different between seats except for more ratings of “too firm”.

Table 2
Summary of **Seat Bottom** Responses from Seat Questionnaire

		Seat A	Seat B
Seat Bottom Width at Thighs			
	Slightly too narrow	2	2
	Just Right	22	22
Seat Bottom Length			
	(Left Blank/Missed Question)	0	1
	Slightly too short	3	2
	Just Right	20	17
	Slightly too long	1	4
Seat Bottom Shape at Front			
	Feels like I'm sinking in slightly too much	1	2
	Just Right	20	17
	Feels like I'm sitting on top slightly too much	3	4
	Feels like I'm sitting on top too much	0	1
Seat Bottom Shape at Rear			
	Feels like I'm sinking in too much	1	1
	Feels like I'm sinking in slightly too much	4	2
	Just Right	16	9
	Feels like I'm sitting on top slightly too much	3	11
	Feels like I'm sitting on top too much	0	1
Seat Bottom Firmness			
	(Left Blank/Missed Question)	0	1
	Just Right	15	9
	Slightly too firm	9	8
	Much too firm	0	6

Table 3
Summary of **Seat Back** Responses from Seat Questionnaire

	Seat A	Seat B
Seat Back Bolster Support		
Slightly too little	2	2
Just Right	17	15
Slightly too much	5	7
Seat Back at Upper Back		
Feels like I'm sinking in slightly too much	2	1
Just Right	17	16
Feels like I'm sitting on top slightly too much	5	7
Seat Back Shape at Lower Back		
Feels like I'm sinking in slightly too much	5	4
Just Right	15	18
Feels like I'm sitting on top slightly too much	3	1
Feels like I'm sitting on top too much	1	1
Seat Back Width		
Slightly too narrow	2	4
Just Right	20	20
Slightly too wide	2	0
Seat Back Firmness		
Just Right	20	16
Slightly too firm	4	7
Much too firm	0	1

Movement Analysis

Table 4 summarizes the mean and maximum values for each of the movement metrics along with the definitions of each metric. The maximum number of movements identified by the count metrics was 220. The mean values ranged from 5 to 80, depending on the thresholds used.

Table 4
Mean and Maximum Values for Movement Metrics

Metric	Mean	Max	Definition
MeanSD	5.6	13.7	Mean SD of depth in region of interest
SD75	4.6	15.1	75th %ile of frame SDs
SD90	18.9	49.2	90th %ile of frame SDs
SD95	34.7	74.5	95th %ile of frame SDs
SD99	68.4	137.1	99th %ile of frame SDs
MF5.15	81.4	220	Number of movements based on pixel threshold of 5 mm and 15% of pixels moving (count)
MF10.15	33.1	155	10 mm and 15% (count)
MF20.15	7.6	62	20 mm and 15% (count)
MF5.20	81.0	219	5 mm and 20% (count)
MF10.20	33.0	151	10 mm and 20% (count)
MF20.20	7.5	62	20 mm and 20% (count)
MF5.25	69.8	168	5 mm and 25% (count)
MF10.25	24.3	131	10 mm and 25% (count)
MFS20.25	4.5	46	20 mm and 25% (count)
OpenPoseLX200	18.1	75	Number of times lower extremity landmarks moved a total of 200 mm between frames (count)
COPMovement0.25	4.4	15	Center of pressure movement between frames of 0.25*sensor spacing or more (count)

The primary analysis of interest is the examination of potential correlations between the subjective assessment and movement data. Specifically, is the frequency of motion related to discomfort ratings?

Because all of the candidate metrics were intended to capture the amount of movement, some correlation among the metrics is expected. Table 5 lists correlation coefficients for some of the candidate metrics. The whole-body metrics based on the standard deviation of depth (MeanSD, SD75, and SD95) were well correlated with each other, as expected. The depth-based movement-counting metrics MF*N.T* (where *N* is the distance cutoff in mm and *T* is the threshold for fraction of the region-of-interest changing) were likewise well correlated among each other and fairly well correlated (0.7 to 0.8) with the SD-based metrics. The OpenPose metric was computed only on the lower extremity landmark locations, and hence was less correlated with the depth-based metrics (0.35 to 0.59). The COP-movement metric was at best weakly correlated with the depth-based metrics, but fairly well correlated (0.62) with the OpenPoseLX metric, consistent with the expectation that most of the changes in COP would be driven by lower-extremity posture changes.

Table 5
Correlation Coefficients (Pearson's r) Between Movement Metrics

	MeanSD	SD75	SD95	MF10.15	MF20.15
MeanSD	1.00	0.85	0.95	0.82	0.69
SD75	0.85	1.00	0.71	0.91	0.88
SD95	0.95	0.71	1.00	0.69	0.51
MF10.15	0.82	0.91	0.69	1.00	0.80
MF20.15	0.69	0.88	0.51	0.80	1.00
MF10.20	0.82	0.91	0.68	1.00	0.80
MF10.25	0.83	0.91	0.72	0.98	0.75
OpenPoseLX200	0.55	0.44	0.59	0.40	0.35
COPMovement0.25	0.12	-0.01	0.26	-0.01	-0.07

	MF10.20	MF10.25	OpenPoseLX200	COPMovement0.25
MeanSD	0.82	0.83	0.55	0.12
SD75	0.91	0.91	0.44	-0.01
SD95	0.68	0.72	0.59	0.26
MF10.15	1.00	0.98	0.40	-0.01
MF20.15	0.80	0.75	0.35	-0.07
MF10.20	1.00	0.98	0.40	0.00
MF10.25	0.98	1.00	0.42	0.06
OpenPoseLX200	0.40	0.42	1.00	0.62
COPMovement0.25	0.00	0.06	0.62	1.00

Using a regression analysis, no significant difference between seats was found for any of the metrics. That is, the number and magnitude of movements were not significantly different between seats, based on these metrics. The analysis also considered whether maximum discomfort rating was related to movement across trials. Note that this is also a between-subject analysis with N=48, since each subject contributed one data point for each seat. No significant relationships between maximum discomfort during a trial and the movement metrics were found.

Movement metrics were not significantly related to participant characteristics, such as stature or body mass index. The difference in movements between seats A and B was also not significantly related to participant characteristics.

Figure 6 shows plots of several of the metrics versus the maximum discomfort rating. Weak trends toward reduced discomfort with higher movement was observed, but these trends were not statistically significant.

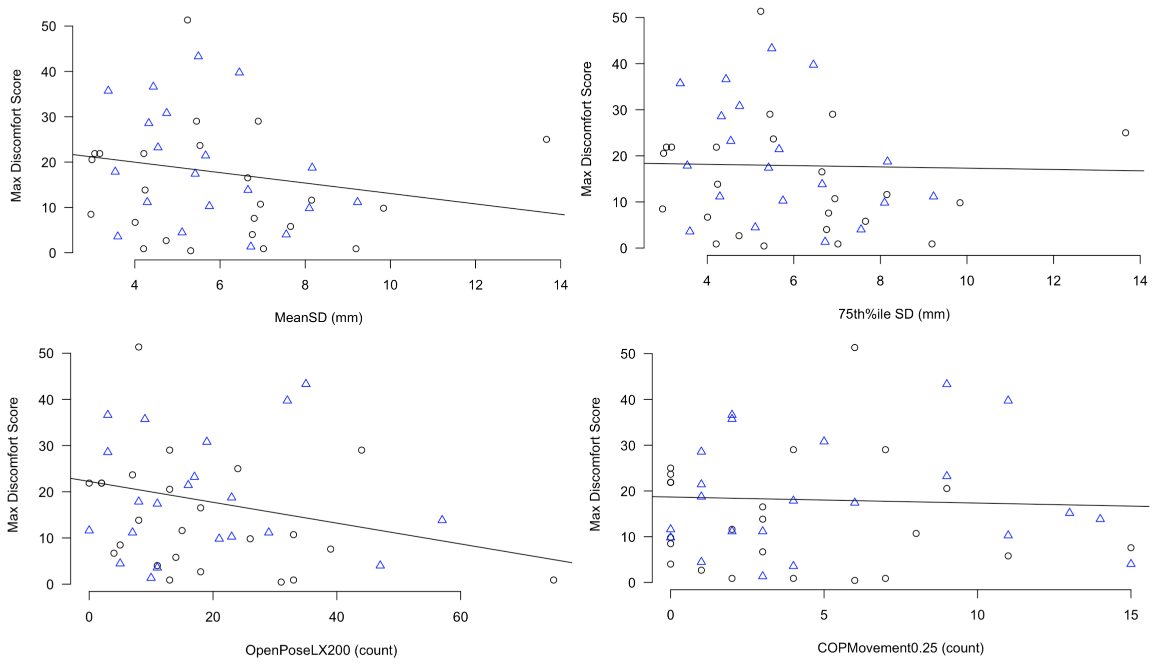


Figure 16. Movement metrics vs. subjective responses. Seat A is shown with circles, Seat B with triangles. Regression line is for all data. None of the regressions is significant (p>0.05).

Final Questionnaire

The final questionnaire (Appendix C), administered after the second trial, included questions about the participants' own vehicle. Table 6 summarizes the results. Most participants indicated they could sit in their own vehicle for more than an hour before becoming uncomfortable. When asked what they would change about their current vehicle seat, most mentioned shape ("other" responses related to shape, such as lumbar support, were included in shape). About a third of participants thought a softer seat would be more comfortable for all trips, whereas only two thought a firmer seat would always be more comfortable. More than a third of participants thought the videos were fascinating and the remainder thought it was interesting. None reported that they were not very interesting or very boring.

Table 6
Summary of Final Questionnaire Responses

Sit Before Uncomfortable	
30 mins	4
1 hr	6
> 1hr	14

Feeling on Long Trips	
OK	17
Boring	3
Interesting	4

Prefer Own Vehicle Seat to Be	
Softer	7
Firmer	1
Shape	14
None	2

Video	
Fascinating	9
Interesting	15
Not very interesting	0
Very boring	0

Softer Seat is More Comfortable	
All Trips	8
Daily Trips	8
Long Trips	7
Never	1

Firmer Seat is More Comfortable	
All Trips	2
Daily Trips	8
Long Trips	8
Never	6

DISCUSSION

This study was conducted to explore the hypothesis that seating discomfort is associated with increased frequency of movement. However, no evidence to support that hypothesis was found. The seat that was modified to be uncomfortable produced slightly higher discomfort ratings, but several participants found the unmodified seat to be more comfortable.

A wide variety of movement metrics were computed across three modalities (Kinect depth, video image analysis, and seat surface pressure). As expected, the metrics were generally correlated, except that the video analysis was deliberately restricted to the lower extremities and hence was the only metric correlated with the pressure-based metric. None of the metrics was found to differ significantly between seats, and none was meaningfully correlated with discomfort ratings. The results from the pressure-based analysis were most similar to those of the posture-based analysis that was focused on the lower extremity, but the pressure metrics were apparently less sensitive to posture change than the video-based method.

The study has several important limitations. The difference in task between normally driving and riding may be the most important. The videos, which were displayed on a fairly large screen, were found to be interesting by all participants. In contrast, video watching is not a common activity for drivers and most passengers would watch video on a small screen, if at all. Only 4 of 24 said they normally find long-distance driving to be interesting (final survey).

The sitting duration of one hour is longer than about 95% of trips in the US, so the exposure to potential discomfort was relatively high on that basis. However, the laboratory mockup was stationary, though it is not clear whether vehicle ride motion would tend to worsen or lessen discomfort.

Appendix A
Scripts and Investigator Instructions

Consent Script

Thank you for volunteering today. The purpose of the study is to understand the effects of seat design on seat comfort, body posture, and motion. If you choose to participate, you will be asked to sit in an automobile driver seat for an hour while watching a video. During the sitting session you will fill out a discomfort survey every five minutes and complete another longer survey at the end. During the sitting session, we will monitor your posture and motion with a motion-tracking camera system and pressure sensors in the seat.

You may become uncomfortable during the sitting session. If the discomfort becomes unacceptable to you, you may discontinue your participation without affecting your pay. The investigator (or I) will be in the office in the next room. Please knock on the wall or use the walkie-talkies we provide if you need his (my) help or have a question.

You will participate in two sessions on two separate days. Each session will last about 90 minutes in total and you will be paid for both sessions after the end of the second day.

(Subject signs consent form)
(Anthro Measurements are taken and the subject is escorted to the Lab)

In a moment I will ask you to take a seat and get in a comfortable position, after doing this we ask that you remain seated for the full testing period of one hour, unless you feel you must get up. If you do so, please contact me and let me know that you have gotten up and for what reason. Remember you may discontinue your participation without affecting your pay. Also, please do not eat, drink or use your phone while sitting here.

Before we begin your time sitting, would you like to use the restroom?

Sitting Instructions

Please have a seat and get in a comfortable position. You may adjust the back recline angle to a comfortable position now. Please keep your feet in the area of the platform in front of you. In other words, you should not hang a foot over the side of the platform.

(once the subject says they are in a comfortable position)

Please step out of the seat, and I will record the seat position.

(record with Kinect and pressure system; mark recline angle on back and then tape down back angle position lever on seat)

Subjective Measurement Instructions
(Participant standing)

These are the forms that you will be filling out as you are watching the video. *(show sheets on the clipboard).* The left end of line is no discomfort and the right end is unbearable discomfort. You will place a slash along the line to show us your level of discomfort at that moment you are filling out the form. During the video a window will pop up every 5 minutes telling you what survey number to fill out. The survey number is located at the top right of the page. Place the completed survey in the box. The video may be shorter than 1 hour, but you will still fill out at least 12 survey forms.

There are tissues and hand sanitizer on the table if you need them, and again I will be right next door. Please contact me by knocking or by pushing this button on the walkie-talkie if you need anything or have any questions.

Beginning Data Collection

Please have a seat. As a reminder please keep your feet in the area of the platform in front of you.

As an initial indicator of your discomfort level please fill out survey 0 now. (watch to make sure they fill it out correctly)

Once you mark the survey place it in the container and place the clipboard and other surveys back on the table.

Do you have any questions before we start? (answer questions)

Ok, I will now start the video and leave the room (*start video, adjust sound, start Mathematica code and place its window in the lower right-hand corner)*

At the End of Each Day
(After the hour, but with the participant STILL SEATED). **Please fill in this survey.**

At the End of the 1st Day
When you return for your second appointment, please wear the same clothes and shoes (if at all possible).

At the End of the 2nd Day
(After the they stand up). Today we have an additional survey for you.
Payment

Appendix B
Seat Questionnaire

Participant Number____________ **Date**____________

Instructions: Please answer the questions that best describe how **you** interact with the seat. Remember that there are no right or wrong answers.

Please respond to this type of question by circling one response. Here is an example:

Amount of light in this room	Much too dark	Slightly too dark	[✓ Just right]	Slightly too bright	Much too bright

Please respond to this type of question by marking an X for your response. Here is an example:

How do your feet feel in your shoes? No ←——X——————————→ Unbearable

	Seat bottom width at thighs	Much too narrow	Slightly too narrow	Just right	Slightly too wide	Much too wide
	Seat bottom width at buttocks	Much too narrow	Slightly too narrow	Just right	Slightly too wide	Much too wide
	Seat bottom length	Much too short	Slightly too short	Just right	Slightly too long	Much too long
	Seat bottom firmness or softness	Much too soft	Slightly too soft	Just right	Slightly too firm	Much too firm
	**Seat bottom shape at front of seat bottom**	Feels like I'm sinking in too much	Feels like I'm sinking in slightly too much	Just right	Feels like I'm sitting on top slightly too much	Feels like I'm sitting on top too much
	**Seat bottom shape at rear of seat bottom**	Feels like I'm sinking in too much	Feels like I'm sinking in slightly too much	Just right	Feels like I'm sitting on top slightly too much	Feels like I'm sitting on top too much
	**Seat bottom bolster support**	Much too little	Slightly too little	Just right	Slightly too much	Much too much

Overall seat bottom comfort rating: No discomfort ←——————————→ Unbearable discomfort

	**Seatback width**	Much too narrow	Slightly too narrow	Just right	Slightly too wide	Much too wide
	Seatback firmness or softness	Much too soft	Slightly too soft	Just right	Slightly too firm	Much too firm
	**Seatback at upper back**	Feels like I'm sinking in too much	Feels like I'm sinking in slightly too much	Just right	Feels like I'm sitting on top slightly too much	Feels like I'm sitting on top too much
	**Seatback shape at low back**	Feels like I'm sinking in too much	Feels like I'm sinking in slightly too much	Just right	Feels like I'm sitting on top slightly too much	Feels like I'm sitting on top too much
	**Seatback bolster support**	Much too little	Slightly too little	Just right	Slightly too much	Much too much

Overall seatback comfort rating: No discomfort ↔ Unbearable discomfort

Overall entire seat comfort rating: No discomfort ↔ Unbearable discomfort

Next, please share your feelings about what you 1) loved, 2) thought was just ok, or 3) hated in the seat you just sat in.

1) What did you love about the seat you just sat in?

2) What was just ok about the seat you just sat in?

3) What did you hate about the seat you just sat in?

Participant Number_____________

Instructions: Please answer the questions that best describe how **you** personally feel. Remember that there are no right or wrong answers.

Please respond to this type of question by circling one response. Here is an example:

What day of the week is today?

a. Saturday b. Sunday c. Friday [✓ d. Other]

Please respond to this type of question by marking an X for your response. Here is an example:

How do your feet feel in your shoes? No discomfort ←——X——————→ Unbearable

1) Please mark the scale for how you feel sitting in your own vehicle's seat for **Daily Trips**

No discomfort ←————————→ Unbearable discomfort

2) Please mark the scale for how you feel sitting in your own vehicle's seat for **Long Trips**

No discomfort ←————————→ Unbearable discomfort

3) How long are you able to sit before you are uncomfortable in your own car?

a. <15 minutes b. ~30 minutes c. ~1 hour d. >1 hours

4) The most important change to make the seat in my vehicle more comfortable on a *long trip* would be:

a. Make it a different shape b. Make it softer c. Make it firmer d. No changes wanted

e. Other change needed: ____

5) I believe a softer seat is more comfortable than a firmer seat (circle one):

a. For daily trips b. For long trips c. All trips d. Never

6) I believe a firmer seat is more comfortable than a softer seat (circle one):

a. For daily trips b. For long trips c. All trips d. Never

7) How do you feel while driving on a long trip?

a. Very interested, I enjoy watching my surroundings b. It's ok, I can pass the time with music / other way c. Very boring, can't wait to get where I'm going

8) How did you feel about the Planet Earth video?

a. Fascinating, could have watched even longer b. Somewhat interesting, and helped pass the time c. Not very interesting, barely kept my attention d. Very boring, couldn't wait for it to end

Appendix C
Exit Questionnaire

Participant Number_____________

Instructions: Please answer the questions that best describe how **you** personally feel. Remember that there are no right or wrong answers.

Please respond to this type of question by circling one response. Here is an example:

What day of the week is today?

a. Saturday b. Sunday c. Friday [✓ d. Other]

Please respond to this type of question by marking an X for your response. Here is an example:

How do your feet feel in your sho No ←—X——————→ Unbearable

1) Please mark the scale for how you feel sitting in your own vehicle's seat for **Daily Trips**

No discomfor ←——————————→ Unbearable discomfort

2) Please mark the scale for how you feel sitting in your own vehicle's seat for **Long Trips**

No discomfor ←——————————→ Unbearable discomfort

3) How long are you able to sit before you are uncomfortable in your own car?

a. <15 minutes b. ~30 minutes c. ~1 hour d. >1 hours

4) The most important change to make the seat in my vehicle more comfortable on a *long trip* would be:

a. Make it a different shape
b. Make it softe
c. Make it firme
d. No changes wanted

e. Other change needed: ____

5) I believe a softer seat is more comfortable than a firmer seat (circle one):

a. For daily trip
b. For long trip
c. All trips
d. Never

6) I believe a firmer seat is more comfortable than a softer seat (circle one):

a. For daily trip
b. For long trip
c. All trips
d. Never

7) How do you feel while driving on a long trip?

a. Very interested, I enjoy watching my surroundings
b. It's ok, I can pass the time with music / other way
c. Very boring, can't wait to get where I'm going

8) How did you feel about the Planet Earth video?

a. Fascinating, could have watched even longer
b. Somewhat interesting, and helped pass the time
c. Not very interesting, barely kept my attention
d. Very boring, couldn't wait for it to end