Assessment of Aging Effects on Drivers' Perceptual and Behavioral Responses Using Subjective Ratings and Pressure Measures

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ABSTRACT
A study was conducted in which a total of 22 younger and older participants completed six short-term driving sessions. These sessions involved a subset of combinations of vehicle class (sedan and SUV), driving venue (lab-based vs. field) and seats (from vehicles ranked high and low by J.D. Power and Associates' Comfort Score). Three subjective ratings (comfort, discomfort, and overall) were obtained, along with 36 driver-seat interface pressure measures. For both age groups, localized comfort ratings were found to be more effective at distinguishing among automotive seats / packages, compared to global ratings or localized discomfort ratings. In addition, older individuals appeared to be less sensitive to discomfort than younger individuals. Several pressure measures indicated different dynamic behaviors or loading patterns (due to postural differences) between the two age groups, and bilateral asymmetry of driving postures in general. These results indicate that, when designing car seats and interior geometries, different pressure requirements should be specified and used separately for each age group and for each seat side.

Author Keywords
Aging, comfort, discomfort, driving experience, interface pressure.

ACM Classification Keywords
H5.2. User Interfaces: Ergonomics, User-centered design.

INTRODUCTION
For most people, aging leads to several decrements including poor eyesight, slow reaction time, lack of muscular strength and dexterity, susceptibility to fatigue (Warnes et al., 1993), and loss of joint flexibility (Haywood et al., 1991), each of which has the potential to adversely affect an individual's driving experience and posture. As a specific example highlighting the importance of understanding aging effects in the context of seat design, Reynolds (1993) showed that different forms of spinal curves (i.e., "flatter and more kyphotic") were observed in the sixth decade of life. Hence, to the contrary to its intention, a contoured seat back could actually make the elderly uncomfortable. Aging effects on driving posture and postural sensitivity have been observed previously in automotive seating (Kyung and Nussbaum, 2009; Kyung et al., 2007), with older drivers preferring to sit closer to the steering wheel. From a safety perspective, Burger et al. (1977) showed that the design of the vehicle interior contributed to at least 7.5% of all accidents. However, with respect to driver workspace and interface design, age-related differences in the efficacy of perceptual ratings have not been investigated, nor is there any evidence regarding whether a single rating scheme might be effective across a diverse age range.

Perceived (dis)comfort can affect drivers' performance, safety, and even posture. Specifically, visual (dis)comfort induced by vehicle in/exterior design is related to hazard misperception (e.g., gap, distance) as well as hazard non-perception (e.g., vision obstruction, reduced visibility), both of which are regarded as major crash contribution factors (Wierwille and Tijerina, 1996). Anshel's study (2005) on man-computer systems showed that visual information is so dominant that its deficiency was compensated by changing body posture. Most elderly individuals have slower and limited abilities in static and dynamic visual acuity (Eby and Kantowitz, 2006; Nicolle and Abascal, 2001), compared to younger individuals. Hence, the former group is more likely to adopt different driving postures due to the decrement in their vision, as well as due to the difference in their normal posture (e.g., kypothic spine). Postural or physiological differences between age groups likely lead to different behaviors (hence, different loading patterns on the seat) within a driver workspace, which necessitates age-specific requirements in terms of interface pressure between the seat and the driver. Hanson et al. (2006) disclosed that driver sitting experience is related to both comfort and discomfort, similar to sitting experience in office or home chairs (Helander and Zhang, 1997; Zhang et al., 1996).

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Though not a necessary condition, nociceptors at the nerve endings are generally responsible for nociception, the perception of pain (Brooks and Tracey, 2005). Pain is a factor of discomfort along with poor biomechanics and tiredness, whereas comfort factors are well-being and plushness (Zhang et al., 1996). Less is known, however, whether there are differences between age groups in the perceptions of comfort and discomfort of sitting experience, in terms of magnitude and dominance of each perception. The goals of this study were to investigate whether aging affects 1) the efficacy of each of three subjective ratings (i.e., comfort, discomfort, and overall) when used for designing and evaluating driver workspace, 2) preference for sedan and SUV settings, 3) the decision processes involved when relating whole-body and localized perceptions of comfort and discomfort, and 4) the associations between subjective ratings and pressure measures.

EXPERIMENTAL METHODS

Overview of Experiment And Participants

Eleven older individuals were newly recruited, whereas 11 younger individual data were selected from among 27 younger individual data (used in Kyung and Nussbaum, 2008; Kyung et al., 2008). The latter were selected in order to achieve a close match in terms of gender distribution, stature, body mass, and data size between the two age groups (Table 1). No significant differences existed in terms of stature and body mass (t-test, p = 0.68 and 0.23). Each participant completed six driving sessions, and subjective ratings and interface pressure measures were obtained in the same way as described in (Kyung and Nussbaum, 2008; Kyung et al., 2008). Each participant completed an informed consent procedure, approved by the local Institutional Review Board, prior to the first experiment session. Brief descriptions of the experimental procedure and settings, and subjective and objective measures used in this study, are given below. For more information, readers are referred to Kyung et al. (2008) and Kyung and Nussbaum (2008).

Six driving sessions (later called Seat Condition) combined two vehicle classes (sedan [S]; SUV [U]), two driving venues (lab-based, [-L]; field-based, [-F]), and two seats (from vehicles ranked high [1] and low [2] by J. D. Power and Associates (2005)' Comfort Score) per vehicle class.

	Age Group	
	Younger	Older
# of Participants (M/F)*	11 (6/5)	11 (6/5)
Mean (SD) Stature (cm)	168.9 (11.2)	168.2 (11.7)
Mean (SD) Age (year)	21.8 (3.2)	71.4 (8.6)
Mean (SD) Body mass (kg)	67.9 (11.1)	73.5 (22.0)

* Number of males and females

Table 1. Participant characteristics.

Hence, specific Seat Conditions were S1-L, S1-F, S2-L, U1-L, U1-F, and U2-L. Participants completed three sessions (two in the lab and one in the field) for each vehicle class. An adjustable driving rig was used in the lab-based sessions that involved simulated driving, and two cars were used for the field sessions that involved on-the-road driving. In both cases, driving was conducted for 20 minutes. Before and during driving, participants adjusted the seat and steering wheel to best support their preferred driving postures. As in Kyung et al. (2008), a modified method of fitting trials (Jones, 1969) was used for the initial adjustment.

After driving, and while maintaining their preferred postures, participants rated their postures in terms of comfort, discomfort, and a combination of these two (overall rating). Several scales were used by participants, at the end of each driving session, to assess drivers' perceptions. Comfort and discomfort scales were derived as combinations of versions developed by Borg (1990) and Corlett-Bishop (1976), and used for the whole body and six local body parts (bilateral thighs and buttocks, and lower and upper back). In addition, a visual analogue scale (VAS) was used to obtain overall perceptual ratings of the whole body. The Karolinska Sleepiness Scale (KSS) by Horne and Reyner (1995) was used to measure drivers' alertness level. Two Tekscan (South Boston, MA, USA) pressure mats (5330 CONFORMatTM) were used to collect a variety of pressure data over the course of each driving session. The first pressure mat was used on the seat cushion and was divided into four areas corresponding to bilateral thighs and buttocks. The second pressure mat was hung on, and tied to the seat back, and divided into two areas corresponding to the lower and upper back. Six types of variables were measured from each of six divided area: contact area, contact pressure, peak pressure, and ratio of each of these three variables (local to global). Hence, a total of 36 interface variables were used to describe the driver-seat interface.

Data Collection and Processing

Subjective ratings were obtained after each session, in a consistent order to minimize confusion (discomfort, comfort, and then overall ratings). Pressure data was collected continuously during the driving sessions, using two Tekscan (South Boston, MA, USA) pressure mats (5330 CONFORMatTM). Each pressure mat was comprised of 1024 (32 x 32) thin (1.78mm) resistive sensors that could easily conform to the contour of the seat, and measure up to 250 mmHg (5 PSI). Each mat had an active area of 471.4 mm x 471.4 mm, and sensor pitch was 14.73 mm (0.5 sensor / cm2). Pressures were recorded at 0.5 Hz, the maximum possible due to hardware limitations. This sampling rate, however, was considered sufficient, as the frequency of postural changes and resultant pressure changes were not observed to occur within an order of magnitude of the sampling rate.

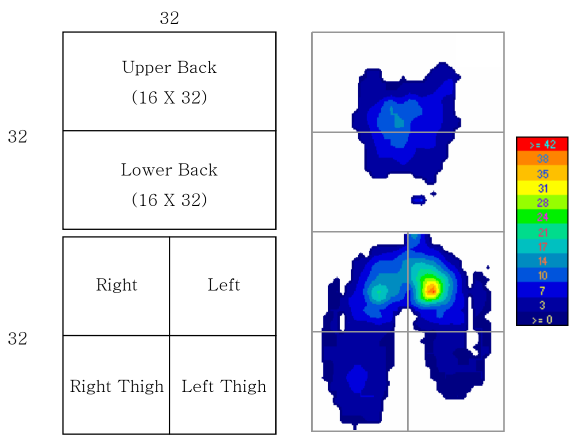

Figure 1. Division of two pressure mats for six local body parts (left, number of sensors in parentheses; row by column) and exemplar pressure distribution (right, a higher peak pressure on left buttock) - (Kyung and Nussbaum, 2008)

Pressure data from the two mats were divided into six groups (Figure 1). Bolsters on the sides of the car seat play a role in supporting thighs, hips, and back (especially when turning), and can affect sitting comfort and discomfort (Andreoni et al., 2002). To account for this, pressure data corresponding to bolstered areas were also included in the data analysis. Contact area and contact pressure were calculated by including only data from sensors that were pressed (i.e. a positive value) at least once, and average (arithmetic mean) values were determined for the last five minutes of driving. Earlier data were excluded here, as they were 'transient' due to settling into the seat (Reed et al., 1999). Contact area and pressure values were obtained from the Movie Contact Averaging function available in the CONFORMat Research software (version 5.80c).

Data Analysis

Methods for data analysis are similar to those described earlier ((Kyung and Nussbaum, 2008; Kyung et al., 2008), except that an Age factor was assessed rather than Stature. Specifically, a mixed-factor analysis of variance (ANOVA) was used to determine the effects of Age (2 levels, between-subjects) and Seat Condition (6 levels, within-subject) on each of the three subjective ratings. Tukey's Honestly Significantly Different (HSD) test was used, where relevant, for post-hoc pairwise comparisons. Effects were considered 'significant' when $p \leq 0.05$, with potential trends highlighted when $0.05 < p \leq 0.1$. Specific pairwise comparisons were done to determine if there were driving venue (lab vs. field) effects (S1-L vs. S1-F, U1-L vs. U1-F) and/or seat effects within vehicle class (S1-L vs. S2-L, U1-L vs. U2-L). In addition, a linear contrast of vehicle classes (S1-L + S2-L + S1-F vs. U1-L + U2-L + U1-F) was tested to compare preferences between the two classes. Ratings between bilateral body parts (thighs, buttocks) were examined using matched pairs comparisons, for each age group. Bivariate coefficients of correlation (ρ) were obtained among the several subjective ratings, at both local and global levels, for each age group. Possible aesthetic effects of four seats on comfort ratings were examined using a univariate repeated-measures ANOVA. Additional bivariate coefficients of correlation (ρ) were obtained between each of three whole-body subjective ratings and alertness level.

With respect to the 36 pressure variables, a Multivariate Analysis of Variance (MANOVA) was conducted to preserve the overall significance level, prior to an additional mixed-factor ANOVA. The later was similar to the one described above, but involved different dependent variables (i.e., 36 pressure variables). The same pairwise comparisons as described above were also used as post-hoc analysis. Among these, the comparison between sedan seats (S1-L vs. S2-L), and the contrast between vehicle classes (sedans vs. SUVs) were of particular interest, as only these two were previously found to be differentiated based on subjective ratings obtained from younger individuals (see Kyung et al., 2008). Driving venue effects were also of interest, as only one driving venue (field) involved exposure to road/vehicle vibration, and which was expected to affect the pressure variables as observed in Kyung and Nussbaum (2008). Comparisons between bilateral pressure measures (i.e. at the thighs and buttocks) were made using matched-pairs t-tests. Additionally, bivariate coefficients of correlation (ρ) were obtained between each of the three subjective ratings and each of the 36 pressure variables. The presence of the following three statistical results was interpreted as supporting the general use of a pressure variable in seat design and evaluation, regardless of drivers' age: 1) an association between a given pressure variable and any of the subjective ratings; 2) a significant Seat Condition effect on the pressure variable; and 3) a lack of a significant Age effect on the pressure variable.

As in Kyung and Nussbaum (2008), relationships between subjective ratings and pressure variables were further investigated using two steps: 1) a principal component analysis (PCA); and 2) a multiple regression of each subjective rating on the factors from the PCA. Here, the focus was to develop a method that can be applied to improve car seats and packages for both age groups. The number of factors were determined by two criteria : 1) eigenvalue > 1; and 2) the cumulative percentage of variance close to 90% (Lehman et al., 2005). The selected factors were rotated using the varimax method.

RESULTS/DISCUSSION

Major results from the current study are listed below.

- At the whole-body level, none of the three rating schemes was particularly effective at distinguishing car seats.
- At the localized level, Age effects were identified, but, only in terms of comfort.
- Several pressure measures also supported that there were

different pressure loadings (due to postural differences) between two age groups.

- From the correlation and regression analyses, average pressure at the right buttock (avgBTR) should be higher to reduce discomfort and increase comfort.
- There are additional ways of improving seat design using the pressure measures obtained in this study (e.g., the seat cushion should be made softer, especially the area contacting the buttocks).
- Lower back and upper back discomforts had, respectively, the highest correlations (ρ=0.74, 0.54) with whole body discomfort than any other local body part discomfort for the younger and older groups.

CONCLUSION

The current study showed that at local levels, comfort ratings are effective at evaluating driver workspace, and that age did not influence the processes used when determining whole-body perceptions based on localized perceptions. Some age-related differences were also identified; different preferences for vehicle class, different local body part predominantly determining whole-body discomfort, and several pressure measures of significantly different values. In addition, older individuals appeared to be less sensitive to discomfort than younger individuals. These similarities and differences should be carefully considered when designing the driver workspace.

REFERENCES

1. Andreoni, G., Santambrogio, G.C., Rabuffetti, M., Pedotti, A. Method for the analysis of posture and interface pressure of car drivers. *Applied Ergonomics, 33*, 6 (2002), 511-522.
2. Anshel, J. Computer Vision Syndrome. In J. Anshel (Ed.), *Visual Ergonomics Handbook*, Boca Raton: Taylor & Francis Group (2005), pp. 23-35.
3. Borg, G. Psychophysical scaling with applications in physical work and perception of exertion. *Scandinavian Journal of Work, Environment and Health, 16*, 1 (1990), 55-58.
4. Brooks, J., Tracey, I. From nociception to pain perception: imaging the spinal and supraspinal pathways. *Journal of Anatomy, 207*, 1 (2005), 19-33.
5. Burger, W., Smith, R., Queen, J., Slack, G. *Accident and near accident causation: the contribution of automobile design characteristics* (No. HS-5-01216): Department of Transportation, 1977).
6. Corlett, E.N., Bishop, R.P. A technique for assessing postural discomfort. *Ergonomics, 19*, 2 (1976), 175-182.
7. Eby, D.W., Kantowitz, B.H. Human Factors and Ergonomics in Motor Vehicle Transportation. In G. Salvendy (Ed.), *Handbook of Human Factors and Ergonomics* (3rd ed.): John Willey & Sons, 2006.
8. Hanson, L., Sperling, L., Akselsson, R. Preferred car driving posture using 3-D information. *International Journal of Vehicle Design, 42*, 1-2 (2006), 154-169.
9. Haywood, K.M., Williams, K., Vansant, A. Qualitative assessment of the backswing in older adult throwing. *Research Quarterly for Exercise and Sport, 62*, 3 (1991), 340-343.
10. Helander, M., Zhang, L. Field studies of comfort and discomfort in sitting. *Ergonomics, 40*, 9(1997), 895-915.
11. Horne, J.A., Reyner, L.A. Sleep related vehicle accidents. *British Medical Journal, 310*, (1995), 565-567.
12. Kyung, G., Nussbaum, M.A. Driver sitting comfort and discomfort (part II): Relationships with and prediction from interface pressure. *International Journal of Industrial Ergonomics, 38*, 5-6 (2008), 526-538.
13. Kyung, G., Nussbaum, M.A. Specifying comfortable driving postures for ergonomic design and evaluation of the driver workspace using digital human models. *Ergonomics, 52*, 8 (2009), 939-953.
14. Kyung, G., Nussbaum, M.A., Babski-Reeves, K. Driver sitting comfort and discomfort (part I): Use of subjective ratings in discriminating car seats and correspondence among ratings. *International Journal of Industrial Ergonomics, 38*, 5-6 (2008), 516-525.
15. Kyung, G., Nussbaum, M.A., Lee, S., Kim, S., Baek, K. Sensitivity of preferred driving postures and determination of core seat track ranges. *SAE Technical Paper Series (2007-01-2471)*, 2007.
16. Nicolle, C., Abascal, J. *Inclusive Design Guidelines for HCI*: Taylor & Francis, 2001.
17. Reed, M.P., Manary, M.A., Schneider, L.W. Methods for measuring and representing automobile occupant posture. *SAE Technical Paper Series (1999-01-0959)*, 1999.
18. Reynolds, H.M. Automotive seat design for sitting comfort. In B. Peacock (Ed.), *Automotive Ergonomics* London, Washington, D.C.: Taylor & Francis, (1993), 99-116.
19. Warnes, A.M., Fraser, D.A., Hawken, R.E., Sievey, V. Elderly drivers and new road transport technology. In A. M. Parkes, S. Franzen (Eds.), *Driving Future Vehicles* London, Washington, D.C.: Taylor & Francis, (1993), 99-117).
20. Wierwille, W.W., Tijerina, L. An Analysis of Driving Accident Narratives As a Means of Determining Problems Caused by In-Vehicle Visual Allocation and Visual Workload. In A.G. Gale, I.D. Brown, C.M. Haslegrave, S.P. Taylor (Eds.), *Vision in Vehicles*, Amsterdam, The Netherlands: Elsevier, (1996). 79-86.
21. Zhang, L., Helander, M., Drury, C. Identifying factors of comfort and discomfort. *Human Factors, 38*, 3, (1996). 377-389.