A 3D BODY SCAN METHOD TO MEASURE POSTURAL DEFORMATIONS IN FLEXIBLE MATERIAL CHAIR BACKS

Anshu Agarwal and Alan Hedge
Cornell University
Dept. of Design and Environmental Analysis
MVR Hall, Forest Home Drive
Ithaca, NY 14853-4401, USA

A 3D whole-body laser scanning method was used to evaluate the deformations of flexible material chair backs. Twenty-four Ss of different gender and body sizes sat in each of two ergonomic chairs (B, G). 3D images were analyzed for volumetric deformations. The chair back was divided into an upper region (from the lumbar through the thoracic to the shoulders), and a lower region (the lumbar/lower back area). When Ss sat with their back leaning against the chair back the upper region deformation was comparable for chair G (984.9 cm^3) and for chair B (952.1 cm^3). The lower region deformation, however, was significantly greater (p = 0.000) for chair G (393.3 cm^3) compared to chair B (268.7 cm^3). There were no significant differences in ratings of chair comfort.

INTRODUCTION

In recent years, ergonomic chairs made with flexible materials have appeared. The use of a sensor pad to measure seat or back pressure with these chairs may yield inaccuracies because the pressure pad material itself has a different flexibility than the chair's material surface. Other methods, such as an ultrasonic contouring system, force sensing probe system, strain gauge system, and a shape sensing array system can measure 3D shapes; however, each of these approaches has limitations in assessment and in adapting to a wide range of body-seat interface designs (Li & Aissaoui, 2004).

Newer methods exploring the use of 3D technology have still not progressed to assessing the person-chair interaction without any physical contact. This study explores the use of a 3D whole-body laser scanning method to evaluate how chair backs made from flexible material provide support to the upper and lower back regions of a seated person. The whole-body scanner uses eight cameras and four lasers to capture approximately 300,000 data points per 3D scan (Explore Cornell, 2003). Moreover, this non-invasive 3D whole-body laser scanning method examines the person-chair interaction without adding anything to either the chair or the subject.

Three main research questions were investigated in this study. First, how does the use of the 3D body scanner aid in assessing the person-chair interface? Second, how do anthropometric variations influence the way the chair back responds to the seated subject? And last, how is deformation related to the perceived comfort ratings of the chair and how are perceived overall back comfort ratings related to the perceived comfort of specific chair back attributes?

METHODS

Subjects

Twenty-four healthy Ss (14 women, 10 men) volunteered for the study. Ages ranged from 18 to 53 with a mean age of 23. The mean height for females was 162.4cm and for males it was 178.45 cm. Ss were requested to wear tank tops and shorts. Ss were recruited by opportunity from Cornell University and were paid $10 for their participation. This research project was reviewed and approved by the Cornell University Committee on Human Subjects.

Apparatus

Two ergonomic chairs mesh fabric backs were compared: "B" (Herman Miller Aeron) and "G" (Humanscale Liberty Production model). Both chairs provide lumbar back support in different ways. Chair B uses a shaped and tensioned pellicle as well as a detachable solid lumbar support (this had to be removed because it obscured the scanner). Chair G has a flexible mesh that automatically adjusts to the user's lumbar curve as well as an additional chair back articulation that was fixed in position for scanning. Prior to testing, both chairs were secured to limit seat rotation and reclining movement. Appropriate software (Polyworks IM Inspect and IM Edit) was used to analyze the 3D body scans of each subject. Prior to scanning, Ss height, spine beginning, lumbar beginning, spine end, and shoulder width were recorded using a meter stick. Ss shoulder blade length was measured using a caliper. Perceived chair comfort was assessed by a questionnaire in which Ss rated their initial perceptions of comfort of both the chair seat and back on a scale of 1 to 10.

Procedure

A repeated-measures design was used in this study. Ss were randomly assigned to counterbalanced chair order (B or G) and scan condition (sitting with the back straight or leaning back into the chair). Prior to scanning, all Ss removed their shoes and a variety of anthropometric measurements were taken. The body scanner was then fully explained. As a 'practice' trial Ss were scanned standing on the platform with their arms held out at a 45 degree angle. The first chair (either B or G) was placed onto the scanner platform and Ss were allowed to adjust the height of the chair until it felt the most comfortable. No guidance on appropriate chair adjustment was given. Ss were asked to keep their feet flat on the floor and their knees close to 90 degrees. Following initial adjustment, Ss were scanned sitting upright and leaning back. Sitting and leaning scans were then repeated to ensure proper scanning and data collection. Following the completion of scans, Ss were given the perceived comfort questionnaire for the first chair and were allowed to sit in it again to verify their ratings. The second chair was then placed onto the scanner platform and the procedure was repeated.

Data Analysis

Examples of full 3D body scans in both chairs, prior to editing, may be seen in Figure 1. Scanned subject files were processed and edited using software. The 'better' of the 2 scans that appeared the most complete was chosen to be analyzed. Images of Ss and excess portions of the chair were manually removed to retain only the chair back image. Scans of Ss sitting upright and leaning back in the chair were then automatically aligned on top of one another. Horizontal cross sections were generated through these aligned scans with a vertical distance of 12mm in between each cross section. Curves were then created from each cross section, and each chair back image had as many as 50 cross section curves. Each of these curves was made up of fragmented lines due to the resolution of the scanning hardware. Before cross section areas could be calculated, each individual curve had to be manually completed. Two segments were then created to divide the chair back: segment 1 represented the upper back and shoulder area while segment 2 represented the lower back and lumbar region.

The series of closed curves in the chair back were analyzed as a group of conical frustums as seen in Figure 2; each frustum represented a horizontal cross sectional slice of the deformation in the chair back. The volume of each conical frustum was calculated using the formula $V = (1/3)*h*(A1 + A2 + \text{square root } (A1*A2))$ where h = the height of the conical frustum, $A1$ = the area of the base circle, and $A2$ = the area of the top circle. Total volume for segments 1 and 2 was equal to the sum of the distinct frustum volumes within each respective segment. Summed volumes of segments 1 and 2 represent the total deformation that occurred in each chair back.

Data analysis to analyze both volumetric and questionnaire data was performed using SPSS 13. Paired samples t-tests were used to test the deformation in the backs of both chairs.

Anthropometric data were analyzed using factor analysis. Regression analysis was used to test subject attributes, perceived comfort, and lower back deformation for each chair.

Figure 1. Full 3D Whole Body Laser Scan

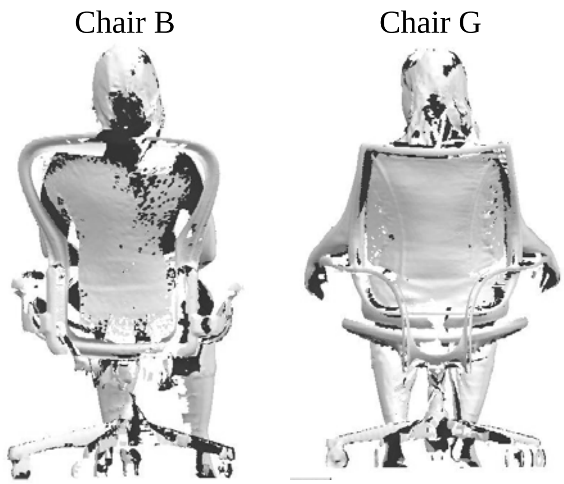


Figure 2. Conical Frustums in the Chair Back

RESULTS

Volumetric Chair Deformation

The lower back of chair G deformed significantly more than that of chair B, t= -5.394, df 23, *p*=0.000; lower back deformation was 46.4% greater for chair G (393.3 cm3) compared to chair B (268.7 cm3). The difference between the upper back deformation was not significant between chair G (984.9 cm3) and chair B (952.1 cm3). Figure 3 shows sagittal sections for each chair with the summed volumes of each cross section curve equal to the total chair deformation (note: the body has been extracted from the image).

There were no significant differences in self-rated short-term sitting comfort between the two chairs (Table 1).

Figure 3. Sagittal sections of the deformation of the chair back with a seated person.

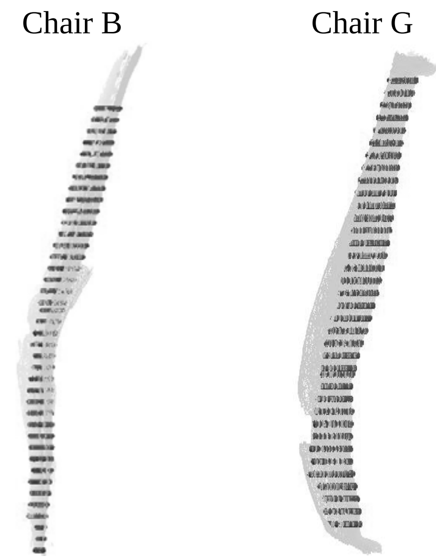


Table 1. *Mean comfort ratings for chair characteristics (scale 1-10)*

	B	**G**
Cushion Support	7.6	8.2
Seat Length	7.4	7.3
Seat Width	8.2	7.8
Seat Height	7.0	7.5
Seat Contour	7.8	7.1
Seat Shape	7.8	7.6
Seat Overall	8.1	7.5

Chair Deformation and Anthropometric Dimensions

Factor analysis with varimax rotation of the anthropometric data resulted in two factors that explained 79.4% of the total variance. Factor 1 had high loadings for Ss height, shoulder blade length, spine length, and shoulder width and a lower loading for lumbar length. Factor 1 was most related to the overall size of the Ss; Factor 2 had a high loading for Ss age.

Identical regression analyses were then conducted to test the effects of Ss attributes on lower chair back deformation for each chair. For chair B, lower back deformation was significantly associated with spine length and shoulder width, $F(7,15) = 3.203$, $p=0.028$, $R^2=0.599$. The chair G model was not significant.

Regression analysis of the total deformation for each chair back (upper and lower back regions) was also performed with subject attributes as predictors. For chair B the total back deformation was significantly associated with shoulder width, $F(7,15) = 4.656$, $p=0.006$, $R^2=0.685$. For chair G the total chair back deformation was significantly associated with shoulder width and sex, $F(7,15) = 2.956$, $p=0.037$, $R^2=0.580$. Subject attributes, especially shoulder width, were strongly associated with the total chair back deformation in both chairs.

Perceived Comfort and Chair Attributes

Results (paired sample t-test) indicated that there were no significant differences in the overall comfort ratings of the chair seats and backs.

Regression analysis of perceived chair attributes and perceived overall comfort ratings of the chair back was performed. For chair B the regression model was significant, $F(4, 19) = 30.37$, $p = .000$, and overall back comfort ratings were most associated with the perceived comfort of the lumbar support and the upper back support. For chair G the regression model was also significant $F(4, 19) = 42.36$, $p=0.000$, $R^2=0.899$); overall back comfort was associated with the perceived comfort of the lumbar support.

Perceived Comfort and Anthropometric Dimensions

Regression models of subject attributes as predictors of perceived chair back comfort were not significant for either chair B or G.

Perceived Comfort and Chair Deformation

The back of chair G deformed significantly more to the seated S than did chair B for the lower portion of the chair back (see Figures 4 and 5). The regression model for chair B was significant, $F(2,21) = 3.519$, $p=0.048$, $R^2=0.251$, and chair comfort was significantly associated with lower back deformation. Interestingly, lower back deformation was related negatively to overall back comfort ratings; therefore, as deformation decreased in chair B, comfort ratings increased. For chair G neither upper nor lower back deformation of the chair back was significantly associated with perceived comfort ratings.

Figure 4. Rearview of the back deformation of chair B with a seated person (maximum deformation indicated by dashed ellipse).

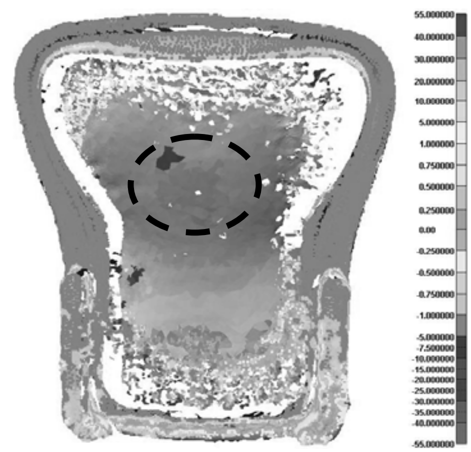
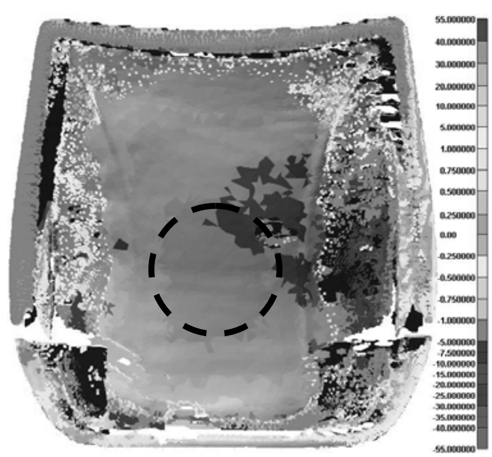


Figure 5. Rearview of the back deformation of chair G with a seated person (maximum deformation indicated by dashed circle).



DISCUSSION

The study has shown that a new method can be used to measure volumetric changes when people of varying size and proportion sit in a chair with a material back. This new method also eliminated any influence on the subjects seating behavior and had no affect on the properties of the flexible material chair back. Results show that different chair designs respond in different ways when people sit with their backs against the chair. In the two chairs tested, the design of one chair back (B) created a more rigid structure that deformed less when the upper back leaned against this, whereas the design of the other chair (G), provided for more deformation and more flexible contouring and support of the upper back. Lumbar support, however, was comparable for the two chairs.

For both chairs B and G, total deformation was best explained by the anthropometric measurement of shoulder width, which was related to Ss size. Size may itself be a surrogate for subject body mass index (BMI). A study by Hostens, Papaioannou, Spaepen, and Ramon (2000) found that there was a linear relationship between increased pressure and increased Ss BMI. 3D whole-body scanning methods and volumetric deformation may therefore be a valid alternative to pressure-mapping methods for assessing the person-chair interaction. Future studies should record Ss BMI in addition to other anthropometric measurements.

Subjective measurement methods of comfort should aim to include assessment of well-being and aesthetic impressions in addition to perceived comfort ratings (Helander & Zhang, 1997; Zhang, Helander, & Drury, 1996). The effect of visual appearance on perceived comfort may be mitigated by blindfolding subjects prior to their sitting experience in the chair, which was not performed in this study due to possible safety hazards.

Perceived overall back comfort was not found to be related to Ss anthropometric measurements for either chair. This may have been due to a lack of extreme cases of poor person-chair fit; both chair B and G are designed for the majority of the population, which accommodate Ss within average dimensions. A larger sample size with a wider range of anthropometric dimensions should be utilized to explore the influence of anthropometrics on perceived comfort and deformation. Additionally, future research may examine the perceptions of long term [dis]comfort and its relationship to volumetric deformation.

Both of the chairs studied are high quality ergonomic chairs and there were no significant differences in measures of short-term comfort. This new 3D body scanning method may be expanded to study a larger range of chairs and to better understand how flexible materials deform and provide support to the seated person.

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