Volumetric Deformation: A New Objective Measure to Study Chair Comfort Using 3D Body Scanning Technology

Anshu Agarwal

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Professor Alan Hedge, Faculty Advisor

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ABSTRACT

Proper lumbar support is a necessary and fundamental requirement for any well-designed chair. Objective techniques to assess chair comfort necessitate the use of a sensing layer that may change the fundamental characteristics of the chair itself depending on its structure and materials. Other methods have attached equipment to subjects, which may influence their normal sitting behavior. In this study, I utilize new 3D body scanning technology to examine the person-chair interaction in flexible, material back chairs without adding anything to either the chair or the subject. I attempt to develop a new objective measure, volumetric deformation, which assesses the reaction of a flexible, material chair back to a seated user. In addition, this study aims to understand the relationships between perceived chair back comfort, objective volumetric deformation, subject anthropometric attributes, and ratings of perceived chair attribute comfort. Total chair back deformation is found to be significantly related to some subject anthropometric attributes, which provides further evidence that deformation is a useful objective measure for assessment of the chair back. Perceived overall back comfort is significantly associated to the perceived comfort of the lumbar support but not to any of the anthropometric measurements taken. The relationship between chair back deformation and pressure distribution should be explored in future studies.

INTRODUCTION

There is general agreement that proper lumbar support is a necessary and fundamental requirement for any well-designed chair. Andersson, Örtengren, Nachemson, and Elfström (1974) found that disc pressure was significantly higher in unsupported sitting as compared to standing. Furthermore, in supported sitting, increased lumbar support and backrest declination decreased pressure on the third lumbar disc (Andersson *et al.*, 1974; Nachemson, 1975). Ideal sitting posture maintains the natural lumbar lordosis that is present in the standing position, which reduces intradiscal pressure (Frey & Tecklin, 1986). Lumbar support functions to increase the sitter's perceived comfort and results in anatomical and physiological benefits for the human body through alignment of the spine and relaxation of the back muscles (Corlett & Eklund, 1984). Objective techniques to assess chair comfort necessitate the use of a sensing layer that may change the fundamental characteristics of the chair itself depending on its structure and materials. Other methods have attached equipment to subjects, which may influence their normal sitting behavior.

The purpose of this study is to develop a new objective measure, volumetric deformation, to assess the reaction of a flexible, material chair back to a seated user. New 3D body scanning technology is used to examine the person-chair interaction in flexible, material back chairs without adding anything to either the chair or the subject. In addition, this study aims to understand the relationships between perceived chair back comfort, objective volumetric deformation, subject anthropometric attributes, and ratings of perceived chair attribute comfort.

Lumbar Support

Proper lumbar support is essential; it functions not only to maintain lumbar lordosis but it also "stabilizes the pelvis, minimizes the muscular effort required to support the trunk, and relieves the lower spine of some of the upper body weight" (Coleman, Hull, & Ellitt, 1998). Inadequate lumbar support can lead to chronic health issues including lower back pain, shoulder pain, neck pain, fatigue, and discomfort (Makhsous, Lin, Hendrix, Hepler, & Zhang, 2003; Wehby, 1989). In sitting conditions, lumbar pain is the most important contributor to overall discomfort followed by neck and dorsal pain (Bishu, Hallbeck, Riley, & Stentz, 1991; Vergara &

Page, 2002). Proper lumbar support therefore reduces the development of discomfort in sitting conditions. In a study by Vergara and Page, results indicated that the lack of contact of the lower back with the back rest was statistically correlated with lower back discomfort (de Looze, Kuijt-Evers, & Dien, 2003; Vergara & Page, 2000).

Fatigue, discomfort, and pain can also result from the maintenance of muscles in a tense, static position for a prolonged period of time. Body postures in static positions create a buildup of lactic acid in the muscles (Wright, 1993). The maintenance of muscles in awkward postures further increases the amount of muscular effort required to maintain the posture. Labeled 'postural fixity,' this condition is often characteristic of operators of visual display terminals (Greico, 1986). The presence of lumbar support in the chair back and a workplace environment individually adjusted for each user together promotes healthy body postures. As technology is increasingly incorporated into the workplace the incidence of postural fixity and its resulting health problems may be on the rise. The importance of proper chair design is even more crucial given that the population of the United States is becoming increasingly sedentary in both their work and leisure life (Brown, Miller, & Miller, 2003; Brownson, Boehmer, & Luke, 2005; Ford, Kohl, Mokdad, & Ajani, 2005).

Multiple factors in the design of a chair may affect the overall perception of comfort. These may include lumbar support, upper back support, chair material, chair form, etc. Furthermore, the perceived comfort of specific chair attributes may provide insight for designers, who can then focus on the chair attributes that significantly improve both short-term and long-term comfort. The interaction between the human body and the chair interface is complex; nevertheless, high ratings of perceived comfort are desirable for an ergonomic chair.

Definitions of Comfort

No widely accepted definition of comfort has been agreed upon in the ergonomics literature (de Looze *et al.,* 2003). In many studies, comfort and discomfort are studied as two ends of a continuous spectrum. It is assumed that as comfort increases, discomfort decreases. Likewise, it is assumed that when discomfort increases, comfort decreases. However according to research by Helander, Czaja, Drury, Cary, and Burri (1987), comfort and discomfort may actually be based on to two sets of completely different criterion. Feelings of discomfort were associated with “pain, tiredness, soreness, and numbness,” which were a result of the physical dimensions of the chair (Helander & Zhang, 1997; Zhang, Helander, & Drury, 1996). Comfort, on the other hand, was associated with feelings of well-being and the positive aesthetic impressions of the chair. Additionally, feelings of discomfort increased with time during the workday (Helander & Zhang, 1997).

The most common discomfort ratings of sedentary workers occur in the neck and lumbar portions of the body; only discomfort in these areas has been found to cause decreased general comfort ratings (Vergara & Page, 2002). Interestingly, buttock and limb pain do not affect comfort ratings of chairs. Lumbar pain is the most important factor for determining comfort while seated (Bishu *et al.*, 1991; Page, Tortosa, Garcia, Moraga, & Verde, 1994; Vergara & Page, 2002).

Comfort is strongly associated with muscular strain rather than other issues such as intradiscal pressure or the imitation of the natural spine curve while standing (Vergara & Page, 2002). Furthermore, static muscular effort is the main cause of short term lumbar and dorsal pain (Vergara & Page, 2002). This finding supports the impact of postural fixity, the buildup of lactic acid in the muscles due to static postures, on perceptions of comfort and its implications on chair design. In a study by Reinecke, Hazard, and Coleman (1994), they write, “The positive effect of small movements around a posture to reduce muscular strain has already been considered by chair manufacturers, who produce chairs with flexible backrests.” The use of flexible back materials, such as mesh, may also promote small movements around a posture. Attention to chair design may therefore reduce the occurrence of static muscular effort, resulting in increased overall comfort.

The perceptions of comfort while sitting may also be significantly influenced by the anthropometric dimensions of the user, which determines the fit of the chair. While a small sized chair would be a bad fit for an individual with large dimensions, it would be appropriate for a person of small stature. Various issues may arise from inadequate person-chair fit, such as the compression of soft-body tissue that restricts blood supply. Any instance of poor person-chair fit where the chair is too big or too small may result in such compression of the body (Wright, 1993). In a study by Helander et al., subjects of a smaller stature disliked large chairs because the seat pan was too long and the lumbar support was too high. Likewise, larger individuals disliked the small chairs for the opposite reasons (Helander *et al.*, 1987; Helander & Zhang, 1997). The variations in perceptions of comfort across subjects could therefore be related to their anthropometric dimensions.

Comfort Measurement

Comfort may be measured using a variety of subjective and objective methods. Subjective measures are the only way to examine true subject preferences and feelings about chair design (Vergara & Page, 2002). The use of subjective measures is the most direct method to evaluate comfort, which is itself a "subjective state or feeling" (de Looze *et al.*, 2003). Helander and Mukund (1991) discussed the drawbacks of subjective qualitative methods as applying only to the comparison of different models of chairs by the same group of subjects. Furthermore, subjective measures rely on the abilities of subjects to accurately identify and rate their own levels of comfort, which may or may not be accurate. Subjective evaluations of variables such as comfort, however, can be the ultimate criterion of some users in a purchasing situation. As stated by Christiansen, "not anatomical or orthopedic aspects, body posture, task performance, but the users' subjective evaluation of seat comfort is *the* decisive criterion for the choice where to sit on or what chair to buy" (Christiansen, 1997; Shackel, Chidsey, & Shipley, 1969).

Comfort is measured in various ways in the literature. Subjective measures include the general comfort rating, body area [dis]comfort rating, chair feature checklist, method of adjustment, and personal comments (Christiansen, 1997). According to Christiansen (1997), however, no particular measurement method dominates. The overall reliability and validity of any comfort rating method varies greatly depending on the sample of subjects.

Subjective measures of comfort are often coupled with objective measures in research on comfort. Compared to subjective measures, objective measures are favored by most researchers because they can be quantified (Christiansen, 1997). Objective methods include posture analysis, electromyography, anthropometric fit assessment, pressure distribution, spinal load estimation, biomechanical analysis, physiological indicators, subject performance, and behavior analysis (Christiansen, 1997; de Looze *et al.,* 2003). The strengths and weaknesses of some of these measurement techniques explored in the literature review are discussed below, followed by the discussion of a new methodology.

Objective Measurement Techniques

Vergara and Page (2002) used a "rachimeter" to measure subject posture through the combined assessment of the lumbar and pelvic areas. This rachimeter contained a goniometer[1] and an inclinometer[2] which were attached to the spine of the subject; the amount of connection between three electrodes attached to the subject and the chair indicated the amount and type of contact of the subject with the chair's backrest. Although posture was of central interest in this study, lumbar support was also determined using this method. A major limitation of this technique is that the attachment of the rachimeter to the subject is invasive, may have been uncomfortable, and may have influenced subject seating behavior. Unfortunately, Vergara and Page (2002) did not evaluate these limitations in their study.

In 2003, de Looze et al. conducted a literature review of twenty-one ergonomics studies in which the subjective measure of comfort was supplemented with an objective measure. Of all the objective techniques utilized to assess comfort in these studies, pressure mapping appeared to have the clearest association with subjective ratings (de Looze *et al.,* 2003). In measuring interface pressure, past studies have used a variety of techniques. Eitzen (2004) utilized a pressure-mapping system to assess the pressure distribution on seat cushions. A thin sensor mat was placed between the subject and the chair seat to assess seat cushion prototypes. Similar pressure-mapping systems as used by Eitzen have been applied to assess pressure distribution on the backs of chairs as well. The use of such pressure-mapping systems, however, has limitations. Placement of the sensor mat between the subject and the chair may change the pressure distribution that would normally occur. Additionally, accuracy is influenced when the mat is placed on a surface that is not 'firm and even' (Eitzen, 2004). This drawback is significant as

[1] A goniometer is an instrument used to measure angles between body segments at joints
[2] An inclinometer is an instrument used to measure the angle of incline

chairs with flexible material backs would be difficult to assess using a pressure-mapping system. Moreover, the application of the mat onto the chair surface itself often results in greater inflexibility that is not characteristic of the actual chair back material. Essentially, the qualities of the chair flexible material back could be fundamentally changed by the addition of a pressure-mapping system.

Some newer technologies allow for the study of the body-seat interface without the use of the pressure-mapping system. Three dimensional (3D) methods exploring contact shape patterns in the chair include an ultrasonic contouring system, force-sensing probe system, and strain gauge system (Li & Aissaoui, 2004). Strengths of these techniques are grounded in the use of 3D technology and their visualization ability of contact shape patterns. While better than pressure-mapping methods, most of these 3D methods do not permit measurement of subjects in the sitting position (Li & Aissaoui, 2004). As an alternative method to evaluate wheelchair seats, Li and Aissaoui (2004) developed the shape sensing array (SSA) system. This system may be adapted to apply to the chair back in future studies. Similar issues nevertheless arise in the use of the SSA system as in the use of the pressure-mapping system used by Eitzen. In order to assess pressure or contour shape the experimenter is artificially adding an additional layer of surface onto the chair, therefore potentially changing its inherent characteristics.

The pressure-mapping system, as an objective measure to aid in assessing comfort and chair design, is a widely used technique in the ergonomics literature. Each variation upon this method, however, has similar limitations: the artificial addition of a sensor mat to the interface or the use of new equipment that may significantly influence the natural sitting behavior of the subject. Newer methods exploring the use of 3D technology have still not progressed to assessing the person-chair interaction without any physical contact. In the next section, I propose a new innovative 3D body scanning method that can assess the person-chair interface without inserting any external measuring equipment that could change the natural seating interaction.

The 3D Body Scanning System

The 3D body scanner (Human Solutions Vitus/Smart 3D Body Scanner) is a system developed as a tool for numerous applications including automotive and aircraft cockpit design, textile customization, virtual reality, and ergonomic and anthropometric research (Vitus, 2001) (Appendix A, Figure 1). The scanner uses eight cameras and four lasers to capture approximately 300,000 data points per scan (Explore Cornell, 2003). Special software (Polyworks IM Inspect & IM Edit) then allows the processed scans to be displayed in multiple ways and analyzed using cross sections, slice areas, surface areas, and volumes (Explore Cornell, 2003).

The use of a 3D body scanner is a new objective measure in looking at the interaction between a seated person and the chair back. Scans of the subject sitting upright and then leaning back into the chair are aligned, thus creating a ‘gap’ where the chair back deformed. Cross sections are then generated throughout the entire chair back from which volumetric change values are calculated. Unlike the methods discussed above, the 3D body scanner can evaluate the person-chair interface without adding anything either to the chair or the subject. This eliminates any influence on the subjects seating behavior and moreover, has no affect on the properties of the flexible material chair back itself.

Research Questions

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? From an ergonomics perspective, the design of the chair and its ability to provide proper lumbar support is crucial. Consideration of ergonomics in chair design may influence subject posture as well as have implications on lower back injury, pain, fatigue, and discomfort. The exploratory use of new 3D technology is significant in assessing chair design.

Second, how do anthropometric variations influence the way the chair back responds to the seated subject, and what implications does this have for the design of the chair? From an engineering/design perspective, it is important to determine what subject attributes cause deformation in the chair back.

Finally, how is deformation related to the perceived comfort ratings of the chair? Also, how are perceived overall back comfort ratings related to the perceived comfort of specific chair back attributes? From a marketing perspective, these questions examine how chair design influences comfort. Because comfort can be a criterion upon which final purchase decisions are made, the chair that provides the best sense of well-being and is rated highest aesthetically is most likely to be successful in the marketplace.

METHODS

Apparatus

Comparison was made between two ergonomic chairs: “Black” (Herman Miller Aeron chair) and “Green” (Humanscale Liberty Production model) (Appendix A, Figure 2a and 2b). Both ergonomically designed chairs have mesh fabric backs but provide lumbar support in different ways. The Green chair automatically adjusts to the user’s lumbar position and curve through the flexibility of the mesh material back. The Black chair provides lumbar support primarily through the rigid chair form. An additional lumbar support can be attached to the Black chair, however as a solid object, it would obscure the scanner’s ability to properly see the deformation of the chair back. Consequently, the additional lumbar support was not fitted to the Black chair in this study. Prior to testing, both the Black and Green chairs were secured with tape and string to limit seat rotation and reclining movement. Data were collected using the 3D body scanner in the same room for all 24 subjects, which eliminated confounding factors resulting from varying environmental conditions. Appropriate software (Polyworks IM Inspect and IM Edit) was then used to analyze the 3D body scans of each subject.

Subject anthropometric dimensions were also taken prior to scanning. The measurements of height, shoulder blade length, spine beginning, lumbar beginning, spine end, and shoulder width were all taken using the same meter stick for each subject. The anthropometric dimension of shoulder blade length was measured using a caliper.

Research Design

A repeated-measures research design was used for this study. Within-subjects testing has numerous advantages in data collection, sample size, and statistical power. In order to mitigate any practice and carry-over effects on the subjective ratings of comfort, subjects were randomly assigned to counterbalanced conditions of both chair (Black or Green) and scan condition (sitting with the back straight or leaning back into the chair).

Measures

Subject Attributes

Subject age, sex, height, shoulder width, spine length, lumbar length, and shoulder blade length were recorded before subject scanning began. All anthropometric dimensions were measured using a meter stick, except shoulder blade length which was measured using a caliper.

Perceived Comfort

The subjective rating of subject's perceived comfort following their sitting experience in each of the chairs was assessed through the use of a questionnaire (Appendix A, Figure 3). Questions on initial perceptions of comfort assessed both the chair back and the chair seat. For the chair seat, subjects were asked to rate their comfort level with the cushion support, seat length, seat width, seat height, seat contour, seat shape, and the seat overall. For the chair back, subjects were asked to rate their comfort level with the lumbar support, upper back support, back width, back height, and back overall. Subjects rated their "initial feelings of comfort" on a scale of 1 – 10, where 1 was extremely uncomfortable and 10 was extremely comfortable.[3]

The perceived comfort questionnaire was given to subjects following the completion of scans in one chair to provide ample time for subjects to form impressions of comfort. The second questionnaire was provided after all scans were completed in the second chair. Questionnaires for both chairs were not administered together after all scans were completed to prevent subjects from 'remembering' their initial perceptions of comfort for the first chair and to prevent comfort comparison ratings instead of individual chair assessments. Since the questionnaires were always provided following scanning completion of one chair, ratings should remain consistent according to subject experience. Counterbalancing of conditions further increased perceived comfort reliability.

Chair Back Volumetric Deformation

The main objective in this study was to assess the amount of deformation that occurred in the flexible, material backs of the Black and Green chairs. This amount was equivalent to the

[3] It may have been valuable to use standard subjective comfort measures previously used in the literature (e.g. Christiansen, 1997). However, the questionnaire used in this study had already been developed prior to my involvement and was based on a measure utilized by Marisol Barrero (2001).

volumetric change in the back material resulting from the subject leaning back from an upright position. Chair back deformation, which provided contoured support to the upper back, shoulders, lower back, and lumbar region, varied based on subject body dimensions and sitting characteristics. Assuming that these remain relatively stable, we can assume that the deformation values would remain consistent throughout all chair sitting experiences. Images illustrating the deformation gradient in both the Black and Green chair backs may be see in Appendix A (Figure 4a and 4b). Differences in the chair back design resulted in varying locations of peak deformation. Due to limitations in time and the intensive data editing process, multiple measures of deformation for each subject were not collected.

Subjects

Subjects (N=24) were recruited based on a convenience sample from a moderately sized, American university and all received monetary compensation ($10.00) for their participation. All subjects reported minimal health problems. In the sample of 14 females and 10 males, ages ranged from 18 to 53 with a mean age of 22.8. All 24 subjects were different in size and proportion; the mean height for females was 162.4 and that of males was 178.45 cm. Descriptive statistics of the subject group may be seen in Appendix B (Table 1).

Subjects were requested to limit loose-fitted clothing and to wear tank tops and shorts if possible. Clothing specifications aided in measurement of anthropometric dimensions and in visibility of the chair back. It also aided in the removal of the subject image from each 3D scan using the body scanner software. This research project protocol was reviewed and approved by the Cornell University Committee on Human Subjects.

Procedure

Subjects were randomly assigned to counterbalanced chair order and conditions. Upon arrival to the body scanner room, subjects were welcomed and immediately given a consent form and pay voucher to complete. Subjects were provided the opportunity to ask the experimenters any questions before the study began. They were then requested to remove their shoes and a variety of body dimension measurements were taken: height, shoulder blade length, spine beginning, lumbar beginning, spine end, and shoulder width. All anthropometrics were measured using the same instrument except for shoulder blade length, which was measured using a caliper. The body scanner was fully explained by the experimenter and the importance of remaining still was emphasized for proper data collection. As a ‘practice’ trial and to further emphasize remaining still, subjects were scanned standing on the platform with their arms out at a 45 degree angle. This initial scan was also conducted in case further anthropometric data was required following the completion of all data collection.

Prior to scanning, subjects were allowed to adjust the height of the chair until it felt the most comfortable. No guidance on appropriate chair adjustment was given. Subjects were requested to keep their feet flat on the floor and their knees close to 90 degrees. Each subject was then scanned in both conditions for each chair: sitting with the back straight and leaning back.

Chair 1 was placed onto the scanner platform and following initial adjustment, subjects were scanned both sitting upright and leaning back. Sitting and leaning scans were then repeated to ensure proper scanning and data collection. In the data editing phase of the study, the ‘better’ of the 2 scans for each condition were selected. This was determined visually and was based on comparisons of the amount of gaps in data collection of the scanned chair back. The scan that appeared the most complete was chosen to be analyzed. Following the completion of scans for Chair 1, subjects were given a brief questionnaire assessing perceived chair comfort on a scale of 1 to 10 (1 = extremely uncomfortable, 10 = extremely comfortable). Subjects were provided with adequate time to complete the questionnaire and were allowed to sit in Chair 1 again to verify their ratings. Chair 2 was then placed onto the scanner platform and the procedure was repeated. Subjects were thanked for their participation and allowed to leave with a copy of their pay voucher following the completion of all scans in both Chair 1 and 2.

Data Editing

Scanned subject files were processed and edited using Polyworks IM Inspect software. Examples of full 3D body scans, prior to editing, may be seen in Appendix A (Figure 5a and 5b). After selecting the best scan for each condition, images of subjects and excess portions of the chair were manually removed using the software in order to retain only the chair back image.

This removal required attention to all 3D angles of the scan and great care was necessary to ensure that none of the chair back was accidentally erased. Scans of subjects sitting upright and leaning back in the chair were then automatically aligned on top of one another using the software. 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 (Appendix A, Figure 6a and 6b). Scans with the generated cross sections curves were then imported into Polyworks IM Edit for further editing.

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 (Appendix A, Figure 7). Overlapping curves were deleted to ensure that only one cross section for every 12mm existed in the scan. Following the completion of these tasks, two segments were created to divide the chair back into upper and lower portions: segment 1 represented the upper back and shoulder area while segment 2 represented the lower back and lumbar region. The total data editing for each chair scan, with two chair scans per subject, took approximately 10 hours.

Volumetric Deformation Calculation

Data was then exported into an Excel file for final volume calculations from the individual areas for each closed curve. The series of closed curves in the chair back were analyzed as a group of conical frustums (Appendix A, Figure 8). Each conical frustum represents a horizontal cross sectional slice of the volume of deformation in the chair back. The volume for each individual conical frustum was $V = (1/3)*h*(A1 + A2 + \text{square root } (A1*A2))$ where h is equal to the height of the conical frustum, A1 is the area of the base circle, and A2 is the area of the top circle. The volume of each conical frustum was calculated using this formula. These conical frustums were aggregated into upper back (1) and lower back (2) regions. Total volume for segments 1 and 2 were equal to the sum of the distinct frustum volumes within each respective segment. The total volume values for each chair represent the total deformation that occurred in the chair back. Data analysis to analyze both volumetric and questionnaire data was performed using SPSS 13.

RESULTS

Volumetric Chair Deformation

Visible differences existed in the amount of deformation in the chair back that occurred when sitting in each of the chairs. Frequency distribution of deformation ranges can be seen in Appendix A, Figure 9a and 9b. The mean deformation of the lower segment of the Black chair was 268227.17 mm^3 compared to the mean deformation of the Green chair of 393116.14 mm^3. Differences in means of deformation values for the upper segment of the chair back were 951733.67 mm^3 for the Black chair and 986284.95 mm^3 for the Green chair (Appendix B, Table 2). Therefore, when looking only at the mean values, the Green chair back deformed to a greater extent than the Black chair back in reaction to the seated subjects. Differences in the mean values were greater in the lower lumbar than in the upper back portion of the chair.

A paired samples t-test of the deformation in the backs of both chairs indicated that the difference between the lower back deformation of the Black and Green chairs was statistically significant ($t = -5.394$, df 23, $p = 0.000$) (Appendix B, Table 3). Deformation values between the upper backs of both chairs, however, was not statistically significant ($t = -.749$, df 23, $p = .461$). Upper and lower deformation values were also added together to create a total deformation value for the Black and Green chairs. Differences in total deformation between both chairs were also found to be significant ($t = -3.494$, df 23, $p = .002$). Although the mean values of deformation indicated that the Green chair deformed more to the subject than the Black chair in both the upper and lower segments, the paired samples t-test determined that only the difference in the lower back deformation between both chairs was significant.

Chair Deformation and Subject Anthropometric Dimensions

Key Research Questions

- How are subject attributes related to one another?
- How well do subject attributes explain the amount of lower back and total deformation in both the Black and Green chairs?

A variety of subject characteristics was recorded prior to scanning, which included age, sex, height, spine length, lumbar length, shoulder width, and shoulder blade length. Since all these measures were likely to be highly correlated, a factor analysis was performed to examine higher level associations. Factor analysis of these attributes resulted in the extraction of two factors that explained 79.4% of the total variance (Appendix B, Table 4). Factors were then rotated using Varimax rotation.

Factor 1 had high loadings of subject height, shoulder blade length, spine length, and shoulder width. Lumbar length was also related to Factor 1 although to a lesser extent. This suggests that this factor is possibly related to the overall size of the person**.** Factor 2 was most related to subject age. This breakdown is logical since age in the range studied has no influence on the subject's anthropometric characteristics. While factor scores could be used in further analysis, it was decided to retain all the original variables (representing both factors) for ease of interpretability of the results.

Regression analysis was then conducted in order to assess how well subject attributes could explain the amount of lower back deformation for each chair. Subject characteristics of age, sex, height, spine length, lumbar length, shoulder width, and shoulder blade length were evaluated as potential causes of differences in deformation.

The Black chair regression model, with the subject characteristics listed above as predictors, had an R square value of .599 (Appendix B, Table 5). The Black chair regression model was therefore able to account for approximately 60% of the deformation that occurred in the lower segment of the chair back. The regression model for the Black chair was found to be significant ($F_{7, 15} = 3.203$, $p = .028$). Lower back deformation in the Black chair was significantly associated with spine length ($p = .009$) and shoulder width ($p = .055$). Both spine length (beta = -.837) and shoulder width (beta = .845) were comparable in relative importance; the standardized betas for both variables were almost equal.

Identical predictors were included in the regression model of the Green chair, which had an R square value of .486 (Appendix B, Table 6). Compared to the Black chair regression model's R value of 60%, the Green chair regression model was only able to account for approximately 49% of the deformation that occurred in the lower segment of the Green chair back. This indicates that the subject characteristics of age, sex, height, etc. do not explain the deformation as effectively in the Green chair as in the Black chair. Other factors, perhaps related to the differences in the design of the Green chair back, may better explain the deformation. Furthermore, the regression model for the Green chair was not significant ($F_{7,\ 15} = 2.029$, $p = .118$).

A regression analysis of the total deformation for each chair back (upper and lower back) was performed with identical predictors as those utilized above: age, sex, height, spine length, lumbar length, shoulder width, and shoulder blade length.

The regression model for the total deformation in the Black chair back had an R square value of .685; the model was able to account for approximately 69% of the total deformation that occurred in the chair back (Appendix B, Table 7). This regression model was found to be significant ($F_{7,\ 15} = 4.656$, $p = .006$). Of all the subject characteristics, shoulder width best explained the total deformation in the Black chair ($p = .058$) and had the highest relative importance (beta = .738).

The regression model for the Green chair had an R square value of .580; this model was therefore able to account for approximately 58% of the total deformation that occurs in the Green chair back (Appendix B, Table 8). Unlike the lower back deformation regression model for the Green chair, the total deformation regression model was significant ($F_{7,\ 15} = 2.956$, $p = .037$). Sex ($p = .038$) and shoulder width ($p = .032$) best explained the total deformation. Although shoulder width had a higher relative importance (beta = .981), sex also had a significant role (beta = .844).

For both the Black and Green chairs, the total deformation regression model was most associated with the anthropometric measurement of shoulder width. Overall, the total deformation models were also better explained by subject attributes than the lower back deformation models; the R square values were higher for both the Black and Green chairs. It is also not surprising that sex had a significant role in the total deformation model for the Green chair. All subject anthropometric measurements were correlated with men having higher mean values for each (Appendix B, Table 1 and 4).

Perceived Comfort and Perceived Chair Attributes

Key Research Questions

- Are perceived overall comfort ratings significantly different for the Black and Green chair?
- Which perceived chair attributes (such as back height, back contour, etc.) best explain the perceived overall back comfort in both the Black and Green chairs?

Questionnaires assessing perceived initial comfort were given to subjects following their experience in each chair. Descriptive statistics of the questionnaire responses for each chair may be seen in Table 9 of Appendix B. Histograms comparing the frequency distribution of perceived overall comfort ratings of both the Black and Green chair backs can be seen in Figure 10a and 10b of Appendix A. A paired sample t-test was conducted comparing the perceived comfort ratings between the Black and Green chairs (Appendix B, Table 10). Results indicated that there were no significant differences in the overall comfort ratings of the seats and backs of both chairs (seat: t = 1.446, df 23, p = .162, back: t = -6.32, df 23, p = .534).

Since in this study I focused on the chair back, a regression analysis was performed to explore which perceived chair attributes (as included in the questionnaire) best explained the perceived overall comfort ratings of the chair back.

The Black chair regression model had an R square value of .865, which explained approximately 86% of the variance in overall back comfort ratings (Appendix B, Table 11). This regression model was found to be significant ($F_{4,\,19}$ = 30.37, p = .000). More importantly, overall back comfort ratings of the Black chair were correlated with the perceived comfort of lumbar support (sig = .001) and the upper back support (sig = .001).

The Green chair regression model had an R square value similar to that of the Black chair, .899, which explained approximately 90% of the variance in overall back comfort ratings

(Appendix B, Table 12). This regression model was also significant ($F_{4, 19}$ = 42.36, p = .000). As in the Black chair regression model, overall back comfort of the Green chair was significantly correlated with the perceived comfort of the lumbar support (sig = .000).

The regression model of perceived comfort and perceived chair attributes confirms the crucial role of lumbar support in the perceived overall back comfort ratings in both the Black and Green chairs. If the lumbar support in the chair back is rated highly, it may be expected that overall chair comfort ratings would also be high. Since overall comfort is important in purchasing decisions in the marketplace, adequate lumbar support is essential.

Perceived Comfort and Subject Anthropometric Dimensions

Key Research Questions

- How does perceived overall back comfort of the Black and Green chairs relate to subject anthropometrics?

Regression analysis was then conducted to determine how the initial perceptions of comfort of the chair back related to subject anthropometrics. The chair back is the focus of interest for this paper, thus the comfort ratings for the chair seat were not included. The Black chair regression model, with the subject attributes as predictors and perceived comfort as the dependent variable, had an R square of .269 (Appendix B, Table 13). The model could therefore explain approximately 27% of the perceived comfort ratings. The regression model, however, was not found to be significant ($F_{7, 15}$ = .790, p = .607) and no subject attributes explained the variance.

The Green chair regression model relating comfort and anthropometrics was also not significant ($F_{7, 15}$ = 1.569, p = .219) and had an R square of .423 (Appendix B, Table 14). As in the Black chair regression model, none of the subject attributes significantly explained the perceived overall back comfort of the Green chair.

Both regression models for the Black and Green chairs were not significant and anthropometric dimensions were not significantly associated with comfort ratings. This may be the case since most of the subjects recruited were of average dimensions and the chairs were also average in size. Therefore, no extreme cases of poor person-chair fit occurred, which may have significantly influenced the perceived comfort ratings.

Perceived Comfort and Chair Deformation

Key Research Questions

- How does perceived overall back comfort relate to the amount of deformation in both the Black and Green chairs?

How is perceived comfort related to amount of deformation in the chair back? Although subject attributes were shown to have no effect, the amount of deformation in the chair back should also be explored in its relationship to perceived comfort ratings. Mean deformation values have shown that on average, the Green chair back deforms more to the seated subject than the Black chair back. Moreover, the difference in the amount of deformation in the lower backs of both chairs was significant (Appendix B, Table 2 and 3). The influence of this difference in deformation on perceived comfort was assessed using a regression analysis. Predictors of these regression models were the upper and lower back deformation in the chair back with the perceived overall back comfort rating as the dependent variable.

The Black chair regression model had an R square of .251; therefore, the chair deformation could explain approximately 25% of the variance in the perceived overall back comfort ratings (Appendix B, Table 15). This regression model was also found to be significant ($F_{2,\ 21}$ = 3.519, p = .048), and chair deformation was associated with the total lower back deformation in the Black chair (p = .020). Interestingly, lower back deformation was related negatively to overall back comfort ratings; as deformation decreased in the Black chair, comfort ratings increased. This may be a result of design of the Black chair, which depends primarily on the rigid chair form to provide proper back support. However correlation is not causation and other factors may be related to the relationship between deformation and overall perceived comfort of the chair back.

A similar regression model was conducted for the Green chair and this had an R square of .046, which only explained approximately 4.5% of the variance in the perceived overall back comfort (Appendix B, Table 16). Additionally, this regression model was not significant ($F_{2, 21}$ = .503, p = .612). Neither upper nor lower back deformation in the Green chair back were correlated with perceived comfort ratings. This finding was surprising; it was expected that the greater deformation in the Green chair back would be related to higher perceived comfort ratings when compared to the Black chair.

DISCUSSION

The first objective of this exploratory study was to explore the use of a new methodology to assess the person-chair interface. The use of a 3D body scanner to calculate volumetric deformation was used to evaluate the way in which two ergonomic chairs provided support to the upper and lower back regions of a seated person. Compared to alternate methods such as the pressure-mapping system, the 3D body scanner was the least invasive; deformation values were determined without altering or adding anything either to the chair or the subject. This new methodology therefore eliminated any influence on the subjects seating behavior and moreover, had no affect on the properties of the flexible material chair back itself.

Total chair back deformation was found to be significantly related to subject anthropometric dimensions. For both the Black and Green chairs, the total deformation regression models were best explained by the anthropometric measurement of shoulder width. Factor analysis of subject characteristics indicated that all anthropometric measurements were collinear and could be linked to subject size. Thus, total deformation in the Black and Green chairs is most likely also related to subject size. However, subject size may itself be a surrogate for subject body mass index (BMI). This corroborates with findings of previous literature utilizing pressure-mapping techniques. A study by Hostens, Papaioannou, Spaepen, and Ramon (2000) found that there was a linear relationship between increased pressure and increased subject BMI. Therefore, this provides some evidence that the objective measure of volumetric deformation may be a valid alternative to pressure-mapping methods.

The second objective of the study was to understand the drivers of perceived chair back comfort in terms of perceived comfort ratings, subject attributes, and objective chair deformation values.

Results indicated that overall back comfort ratings of the Black chair were best explained by the perceived comfort of lumbar support and upper back support. As with the Black chair model, overall back comfort of the Green chair was also best explained by the perceived comfort of lumbar support. These results reveal the importance of adequate lumbar support to the user in assessing overall chair back comfort. If the perceived comfort ratings of the chair’s lumbar support are high, then these results indicate that the entire chair back would also be perceived to be very comfortable. These results confirm research findings concluding that discomfort in the lumbar areas are primarily responsible for decreases in overall comfort ratings (Bishu *et al.,* 1991; Page *et al.,* 1994; Vergara & Page, 2002). Lumbar support is *the* most significant factor that drives perceptions of overall chair back comfort while seated. Furthermore, since comfort is the crucial determinant of consumer purchase decisions, proper lumbar support is a necessary component for successful chair design.

Perceived overall back comfort was not found to be related to the anthropometric measurements of subjects in this study. According to research by Helander et al. (1987), anthropometric measurements influenced subject preferences; subjects of a smaller stature disliked large chairs because the seat pan was too long and the lumbar support was too high, while subjects of larger statures disliked small chairs for the opposite reasons. Results from the present study may have been inconclusive because of the small sample size. Moreover, subjects in this sample were within mean anthropometric ranges and were neither very small nor very large. Both the Black and Green chair were also designed for the majority of the population, which accommodates subjects with average dimensions. No extreme cases of poor person-chair fit, which would influence perceived comfort ratings, occurred in this study. Subject sitting experiences were therefore generally comfortable; on a scale of 1-10, mean questionnaire ratings were never below the rating of 7 (Appendix B, Table 9). Furthermore, subjects in this study were seated in both chairs for a short duration. According to the study by Helander and Zhang (1997), feelings of discomfort in the chair increased with time. Therefore, further research can examine the perceptions of long term [dis]comfort and its relationship to volumetric deformation.

Most studies utilizing pressure-mapping systems to assess comfort relate discomfort to uneven pressure distribution (de Looze *et al.,* 2003). To the best of my knowledge, perceived back comfort has not been examined using chair back deformation. The findings show that in the Black chair, a significant negative correlation existed between total lower back deformation and perceived overall back comfort. This may appear to be counterintuitive as one may assume that lower deformation is related to higher pressure, and thus lower comfort. It should be noted, however, that the previous studies have examined pressure *distribution* of the chair back. Yun, Donges, and Freivalds (1992) found that an even distribution of pressure resulted in higher ratings of comfort. It is unknown what relationship exists between chair back deformation and pressure distribution. The findings in this study may be in line with previous research, and suggest that chair back deformation is an innovative new objective measure to assess chair comfort. This however, requires further investigation.

Perceived comfort was assessed using a questionnaire, which asked subjects to rate their "initial feelings of comfort" on a scale of 1 – 10. These questions focused on the physical aspects of the chair such as its lumbar support, upper back support, and back height (Appendix A, Figure 3). According to the literature, however, feelings of discomfort were a result of the physical dimensions of the chair while comfort was associated with feelings of well-being and positive aesthetic impressions of the chair (Helander & Zhang, 1997; Zhang, Helander, & Drury, 1996). Subjective measurement methods of comfort should therefore aim to include assessment of well-being and aesthetic impressions. In future research, the effect of visual appearance on perceived comfort may be mitigated by blindfolding subjects prior to their sitting experience in the chair. Blindfolding of subjects was not performed in this study due to the possible safety hazards resulting from getting into and out of a chair placed on the raised 3D body scanner platform.

The results of this study show that the 3D body scanner and chair back deformation can be used for assessment of the person-chair interface. However, additional research should be conducted exploring this method further. First, a larger sample size with a wider range of anthropometric dimensions should be utilized to better assess the influence of anthropometrics on perceived comfort and deformation. Second, to provide additional evidence of validity, multiple methods of assessment should be used such as the 3D body scanner, pressure-mapping systems, and contour shape analysis. Further investigation of the relationship between chair back deformation (using the 3D body scanner) and pressure distribution (using pressure-mapping systems) in future studies and their relationship to perceived comfort would be especially interesting. Pressure-mapping systems may be utilized on flexible, material chair backs while being scanned using 3D body scanning technology. This would allow the investigation of how the pressure-mapping system influences chair back deformation as well as perceived comfort ratings of subjects. Additionally, a more reliable measure for assessing comfort should be utilized in future studies that includes a question rating overall chair comfort of the seat and back. Subject attributes should also include subject weight and BMI. Finally, a wider range of chairs with varying fabrics and designs should be investigated using this new technique.

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APPENDIX A: Figures

Figure 1: Cornell University 3D Body Scanner

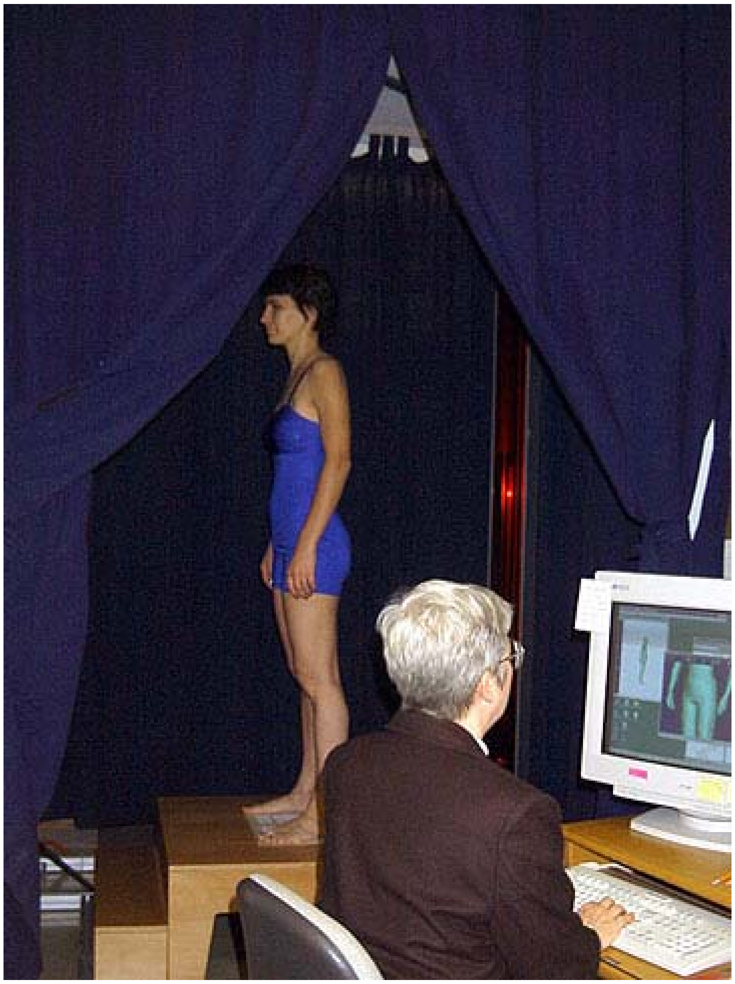


Figure 2: The Black and Green Chairs

2a: Black chair (Herman Miller Aeron chair)

2b: Green chair (Humanscale Liberty Production model)

Figure 3: Perceived Comfort Questionnaire

"Chair Study" Questionnaire

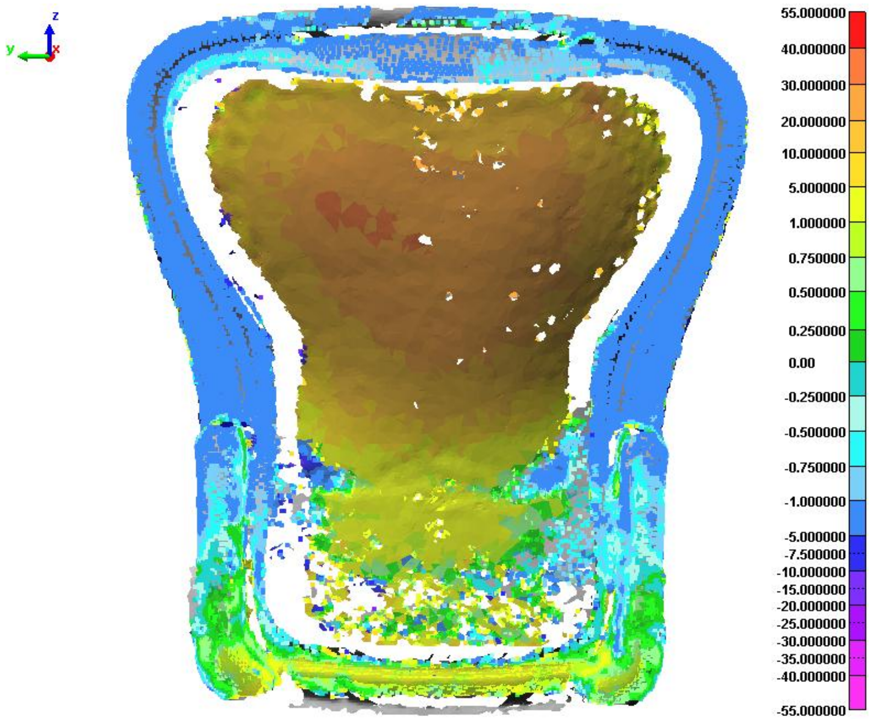
Participant # _____

Please rate your initial feelings of comfort on a scale of 1 – 10, where 1 is extremely uncomfortable and 10 is extremely comfortable.

Seat:	Cushion Support	1-2-3-4-5-6-7-8-9-10
	Seat Length	1-2-3-4-5-6-7-8-9-10
	Seat Width	1-2-3-4-5-6-7-8-9-10
	Seat Height	1-2-3-4-5-6-7-8-9-10
	Seat Contour	1-2-3-4-5-6-7-8-9-10
	Seat Shape	1-2-3-4-5-6-7-8-9-10
	Seat Overall	1-2-3-4-5-6-7-8-9-10
Back	Lumbar Support	1-2-3-4-5-6-7-8-9-10
	Upper Back Support	1-2-3-4-5-6-7-8-9-10
	Back Width	1-2-3-4-5-6-7-8-9-10
	Back Height	1-2-3-4-5-6-7-8-9-10
	Back Overall	1-2-3-4-5-6-7-8-9-10

Figure 4: Deformation Gradient in Black and Green Chair Backs

4a: Black Chair Deformation Gradient, Subject #20



4b: Green Chair Deformation Gradient, Subject #20

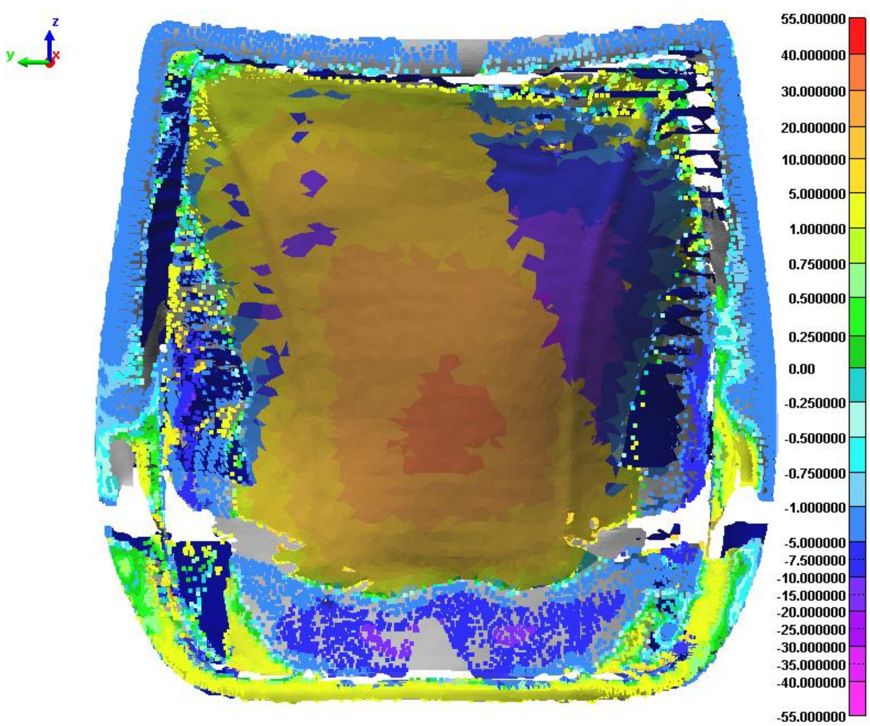


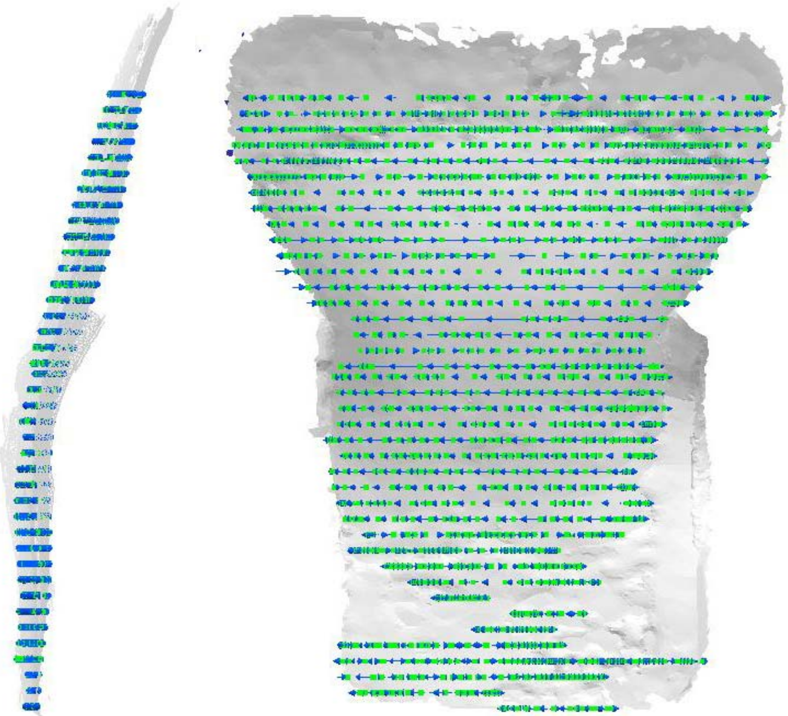
Figure 5: Full 3D Body Scan Images

5a: Black Chair 3D Body Scan, Subject #3

5b: Green Chair 3D Body Scan, Subject #3

Figure 6: Cross Sections Created in the Chair Backs

6a: Black chair, Side and Back view of Chair Back with Cross Sections, Subject #2



6b: Green chair, Side and Back view of Chair Back with Cross Sections, Subject #2

Figure 7: Manually Closed Cross Section Curve

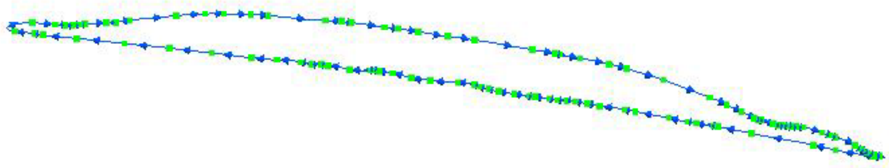


Figure 8: Conical Frustums in the Chair Back

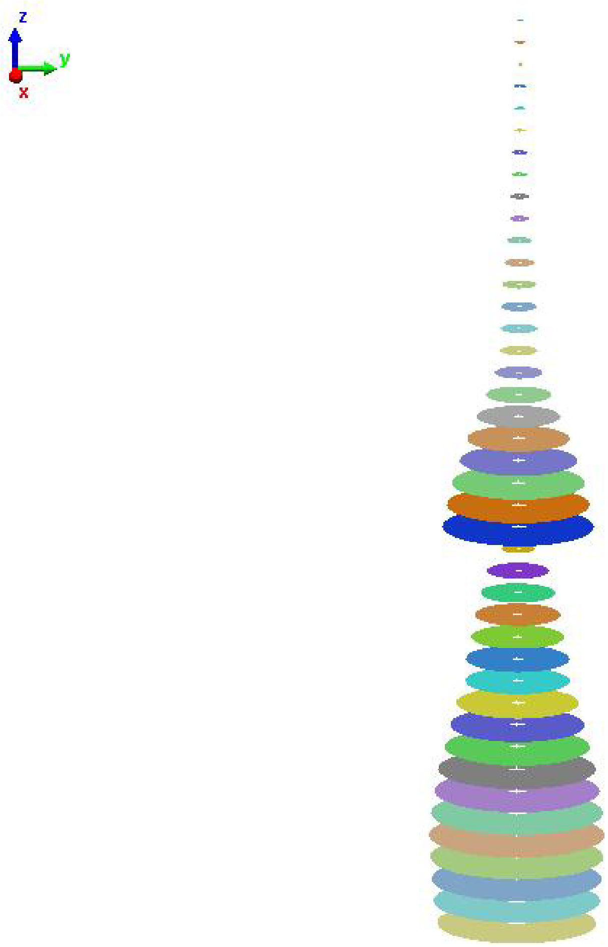
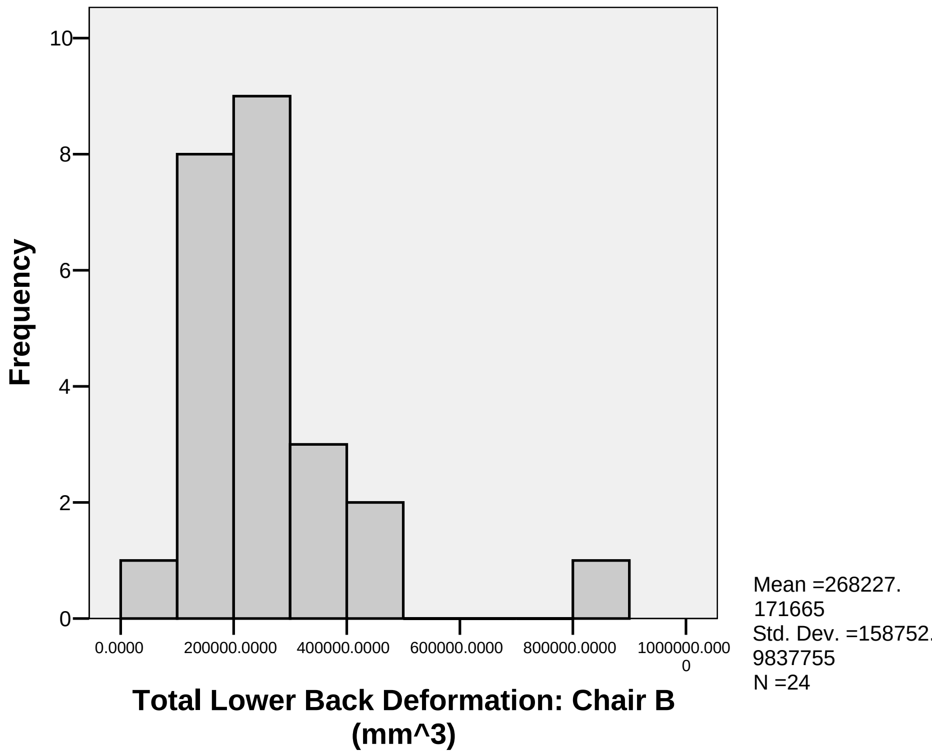


Figure 9: Frequency Histogram, Lower Lumbar Deformation

9a: Black Chair, Lower Lumbar Deformation



9b: Green Chair, Lower Lumbar Deformation

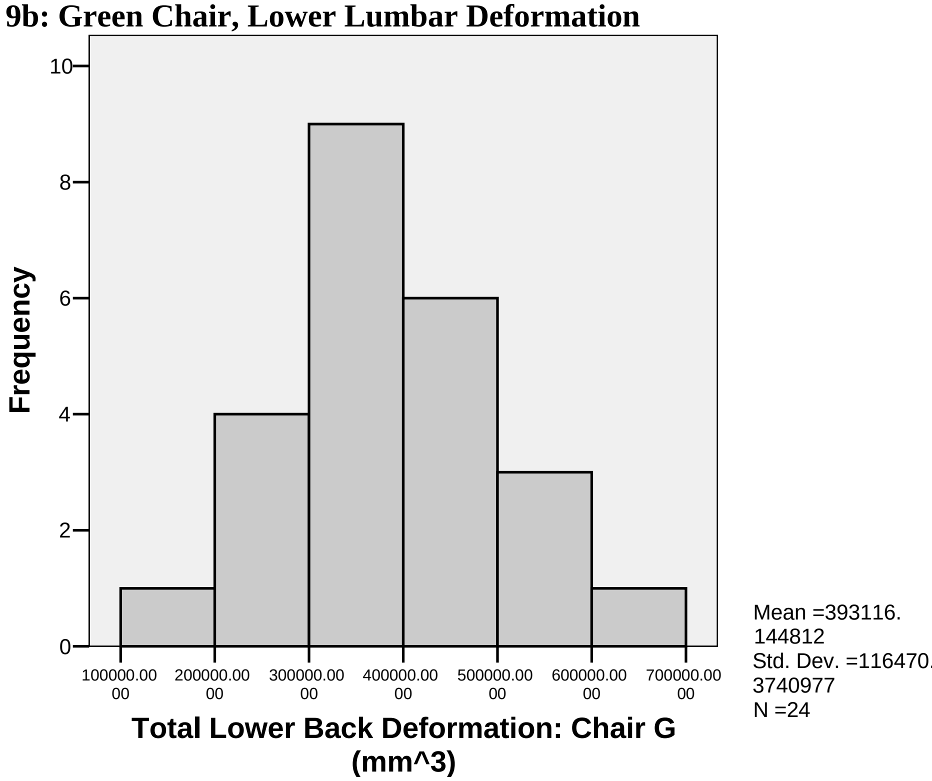
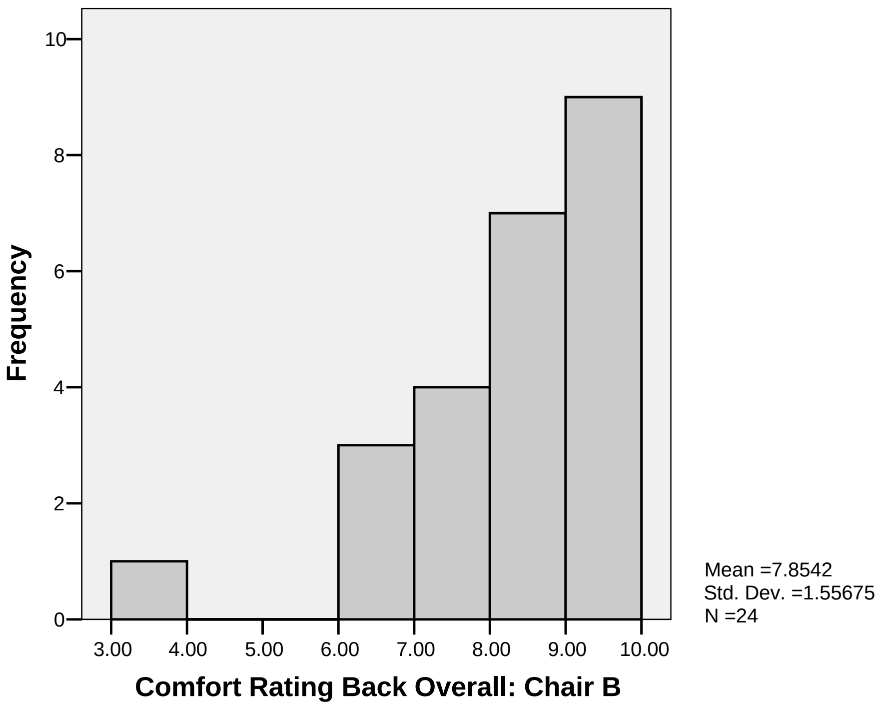
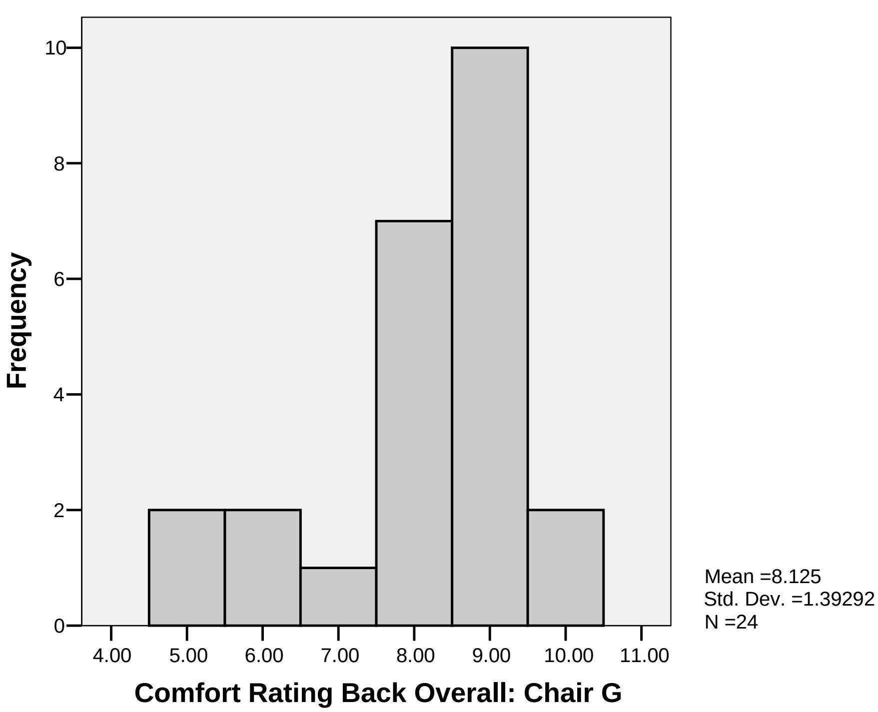


Figure 10: Frequency Histogram, Perceived Overall Back Comfort

10a: Black Chair, Perceived Overall Back Comfort



10b: Green Chair, Perceived Overall Back Comfort



APPENDIX B: Tables

Table 1: Descriptive Statistics, Subjects

Sex

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	10	41.7	41.7	41.7
	Female	14	58.3	58.3	100.0
	Total	24	100.0	100.0	

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	24	18.00	53.00	22.7917	7.07094
Subject Height (cm)	23	148.0	186.0	169.391	10.6728
Subject Shoulder Blade Length (mm)	24	95.50	127.00	114.2833	8.76682
Subject Spine Length (cm)	24	35.50	51.00	43.1458	4.59082
Subject Lumbar Length (cm)	24	3.00	17.50	10.7500	3.52321
Subject Shoulder Width (cm)	24	35.00	46.50	41.2083	3.39090
Valid N (listwise)	23				

Mean Anthropometric Subject Attributes, by Sex							
Sex	**N**	**Age**	**Height (cm)**	**Sh Bla L (mm)**	**Sp Length (cm)**	**Lum Len (cm)**	**Sh Width (cm)**
Females	N= 14	23.8	162.4	109.0	40.5	9.8	38.8
Males	N = 10	21.4	178.45	121.7	46.8	12.1	44.6

Table 2: Descriptive Statistics, Black and Green Chair Deformation

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Total Upper Back Deformation: Chair B (mm^3)	24	509835.3744	1520872.4051	951733.672042	277279.8962213
Total Lower Back Deformation: Chair B (mm^3)	24	98938.2351	856455.8943	268227.171665	158752.9837756
Total Upper Back Deformation: Chair G (mm^3)	24	654756.1151	1392477.8967	986284.947171	150285.2723514
Total Lower Back Deformation: Chair G (mm^3)	24	178066.7410	695742.4075	393116.144812	116470.3740977
Total Deformation Chair B (mm^3)	24	755691.78	1771358.40	1219960.8437	304435.96611
Total Deformation Chair G (mm^3)	24	1046721.70	1903480.20	1379401.0920	196301.72255
Valid N (listwise)	24				

Table 3: Paired Samples Test, Upper/Lower/Total Deformation

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Total Upper Back Deformation: Chair B (mm^3) - Total Upper Back Deformation: Chair G (mm^3)	-34551.2751291	225868.8105940	46105.2778971	-129927.3091314	60824.7588731	-.749	23	.461
Pair 2	Total Lower Back Deformation: Chair B (mm^3) - Total Lower Back Deformation: Chair G (mm^3)	-124888.9731473	113427.4951224	23153.2904877	-172785.2037209	-76992.7425738	-5.394	23	.000
Pair 3	Total Deformation Chair B (mm^3) - Total Deformation Chair G (mm^3)	-159440.24828	223581.89682	45638.46358	-253850.60328	-65029.89327	-3.494	23	.002

Table 4: Factor Analysis, Subject Attributes

Total Variance Explained

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.702	61.692	61.692	3.608	60.129	60.129
2	1.064	17.734	79.426	1.158	19.297	79.426
3	.711	11.853	91.279			
4	.289	4.824	96.103			
5	.213	3.547	99.650			
6	.021	.350	100.000			

Extraction Method: Principal Component Analysis.

Rotated Component Matrix(a)

	Component	
	1	2
Age		.961
Subject Height (cm)	.961	
Subject Shoulder Blade Length (mm)	.968	
Subject Spine Length (cm)	.814	-.333
Subject Lumbar Length (cm)	.529	-.340
Subject Shoulder Width (cm)	.897	

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 3 iterations.

Table 5: Regression Model, Black Chair Lower Lumbar Deformation as explained by Subject Attributes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.774[a]	.599	.412	124435.331

a.

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3E+011	7	4.959E+010	3.203	.028
	Residual	2E+011	15	1.548E+010		
	Total	6E+011	22			

b. Dependent Variable: Total Lower Back Deformation: Chair B (mm^3)

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-2079382	1054439		-1.972	.067
	Sex	174254.1	115932.9	.544	1.503	.154
	Age	3806.912	4120.809	.170	.924	.370
	Subject Height (cm)	12778.13	12816.15	.840	.997	.335
	Subject Shoulder Blade Length (mm)	-5792.263	15451.27	-.315	-.375	.713
	Subject Spine Length (cm)	-28946.4	9738.172	-.837	-2.972	.009
	Subject Lumbar Length (cm)	9573.019	8913.675	.212	1.074	.300
	Subject Shoulder Width (cm)	39597.28	18996.72	.845	2.084	.055

a. Dependent Variable: Total Lower Back Deformation: Chair B (mm^3)

Table 6: Regression Model, Green Chair Lower Lumbar Deformation as explained by Subject Attributes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.697(a)	.486	.247	103325.5460415

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2E+011	7	2.166E+010	2.029	.118
	Residual	2E+011	15	1.068E+010		
	Total	3E+011	22			

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-1712023	875559.5		-1.955	.069
	Sex	192660.1	96265.51	.820	2.001	.064
	Age	1064.950	3421.736	.065	.311	.760
	Subject Height (cm)	13785.16	10641.96	1.236	1.295	.215
	Subject Shoulder Blade Length (mm)	-11515.6	12830.04	-.853	-.898	.384
	Subject Spine Length (cm)	-9659.099	8086.143	-.381	-1.195	.251
	Subject Lumbar Length (cm)	17224.34	7401.518	.521	2.327	.034
	Subject Shoulder Width (cm)	24119.39	15774.03	.702	1.529	.147

a. Dependent Variable: Total Lower Back Deformation: Chair G (mm^3)

Table 7: Regression Model, Black Chair Total Deformation as explained by Subject Attributes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.828(a)	.685	.538	210222.84583

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3E+011	7	4.959E+010	3.203	.028
	Residual	2E+011	15	1.548E+010		
	Total	6E+011	22			

b. Dependent Variable: Total Lower Back Deformation: Chair B (mm^3)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2079382	1054439		-1.972	.067
	Sex	174254.1	115932.9	.544	1.503	.154
	Age	3806.912	4120.809	.170	.924	.370
	Subject Height (cm)	12778.13	12816.15	.840	.997	.335
	Subject Shoulder Blade Length (mm)	-5792.263	15451.27	-.315	-.375	.713
	Subject Spine Length (cm)	-28946.4	9738.172	-.837	-2.972	.009
	Subject Lumbar Length (cm)	9573.019	8913.675	.212	1.074	.300
	Subject Shoulder Width (cm)	39597.28	18996.72	.845	2.084	.055

a. Dependent Variable: Total Lower Back Deformation: Chair B (mm^3)

Table 8: Regression Model, Green Chair Total Deformation as explained by Subject Attributes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.761(a)	.580	.384	153563.70935

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5E+011	7	6.971E+010	2.956	.037[a]
	Residual	4E+011	15	2.358E+010		
	Total	8E+011	22			

a. Predictors: (Constant), Subject Shoulder Width (cm), Age, Subject Lumbar Length (cm), Subject Spine Length (cm), Subject Shoulder Blade Length (mm), Sex, Subject Height (cm)

b. Dependent Variable: Total Deformation Chair G (mm^3)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2904735	1301267		-2.232	.041
	Sex	325540.4	143071.0	.844	2.275	.038
	Age	5097.860	5085.427	.188	1.002	.332
	Subject Height (cm)	11998.60	15816.21	.655	.759	.460
	Subject Shoulder Blade Length (mm)	-9640.548	19068.17	-.435	-.506	.620
	Subject Spine Length (cm)	8347.004	12017.73	.200	.695	.498
	Subject Lumbar Length (cm)	7082.452	11000.23	.130	.644	.529
	Subject Shoulder Width (cm)	55425.66	23443.56	.981	2.364	.032

a. Dependent Variable: Total Deformation Chair G (mm^3)

Table 9: Descriptive Statistics, Perceived Comfort Questionnaire

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Comfort Rating Cushion Support: Chair B	24	4.000	10.000	7.58333	1.742479
Comfort Rating Seat Length: Chair B	24	4.00	10.00	7.3750	1.76469
Comfort Rating Seat Width: Chair B	24	6.00	10.00	8.1667	1.27404
Comfort Rating Seat Height: Chair B	24	2.00	10.00	7.0000	2.14679
Comfort Rating Seat Contour: Chair B	24	5.00	10.00	7.8333	1.46456
Comfort Rating Seat Shape: Chair B	24	5.00	10.00	7.8333	1.40393
Comfort Rating Seat Overall: Chair B	24	6.00	10.00	8.1250	1.11560
Comfort Rating Lumbar Support: Chair B	24	4.00	10.00	7.4583	1.76879
Comfort Rating Upper Back Support: Chair B	24	1.00	10.00	7.5417	2.26465
Comfort Rating Back Width: Chair B	24	5.00	10.00	8.2083	1.38247
Comfort Rating Back Height: Chair B	24	1.00	10.00	7.7917	2.10546
Comfort Rating Back Overall: Chair B	24	3.00	10.00	7.8542	1.55675
Comfort Rating Cushion Support: Chair G	24	5.00	10.00	8.2083	1.55980
Comfort Rating Seat Length: Chair G	24	4.00	10.00	7.2500	1.53934
Comfort Rating Seat Width: Chair G	24	4.00	10.00	7.7917	1.58743
Comfort Rating Seat Height: Chair G	24	4.00	10.00	7.5417	1.69344
Comfort Rating Seat Contour: Chair G	24	2.00	9.00	7.0833	2.04124
Comfort Rating Seat Shape: Chair G	24	2.00	10.00	7.5833	1.93181
Comfort Rating Seat Overall: Chair G	24	5.00	10.00	7.5417	1.55980
Comfort Rating Lumbar Support: Chair G	24	3.00	10.00	7.7917	2.12601
Comfort Rating Upper Back Support: Chair G	24	3.00	10.00	7.7083	1.80529
Comfort Rating Back Width: Chair G	24	6.00	10.00	8.1250	1.29590
Comfort Rating Back Height: Chair G	24	4.00	10.00	7.5000	1.71945
Comfort Rating Back Overall: Chair G	24	5.00	10.00	8.1250	1.39292
Valid N (listwise)	24				

Table 10: Paired Samples Test, Perceived Overall Seat and Back Comfort Ratings Black and Green Chairs

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Comfort Rating Seat Overall: Chair B - Comfort Rating Seat Overall: Chair G	.58333	1.97631	.40341	-.25119	1.41786	1.446	23	.162
Pair 2	Comfort Rating Back Overall: Chair B - Comfort Rating Back Overall: Chair G	-.27083	2.10062	.42879	-1.15785	.61618	-.632	23	.534

Table 11: Regression Model, Black Chair Overall Perceived Back Comfort as explained by Perceived Comfort of Chair Attributes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.930(a)	.865	.836	.62986

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	48.202	4	12.050	30.375	.000[a]
	Residual	7.538	19	.397		
	Total	55.740	23			

a. Predictors: (Constant), Comfort Rating Back Height: Chair B, Comfort Rating Lumbar Support: Chair B, Comfort Rating Upper Back Support: Chair B, Comfort Rating Back Width: Chair B

b. Dependent Variable: Comfort Rating Back Overall: Chair B

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.411	.863		1.634	.119
	Comfort Rating Lumbar Support: Chair B	.360	.097	.409	3.722	.001
	Comfort Rating Upper Back Support: Chair B	.315	.084	.458	3.753	.001
	Comfort Rating Back Width: Chair B	.016	.185	.014	.086	.932
	Comfort Rating Back Height: Chair B	.161	.123	.218	1.308	.206

a. Dependent Variable: Comfort Rating Back Overall: Chair B

Table 12: Regression Model, Green Chair Overall Perceived Back Comfort as explained by Perceived Comfort of Chair Attributes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.948(a)	.899	.878	.48663

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40.126	4	10.031	42.360	.000[a]
	Residual	4.499	19	.237		
	Total	44.625	23			

a. Predictors: (Constant), Comfort Rating Back Height: Chair G, Comfort Rating Upper Back Support: Chair G, Comfort Rating Lumbar Support: Chair G, Comfort Rating Back Width: Chair G

b. Dependent Variable: Comfort Rating Back Overall: Chair G

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.812	.696		2.604	.017
	Comfort Rating Lumbar Support: Chair G	.466	.065	.711	7.165	.000
	Comfort Rating Upper Back Support: Chair G	.087	.070	.113	1.240	.230
	Comfort Rating Back Width: Chair G	.095	.121	.088	.787	.441
	Comfort Rating Back Height: Chair G	.165	.101	.204	1.635	.118

a. Dependent Variable: Comfort Rating Back Overall: Chair G

Table 13: Regression Model, Black Chair Perceived Overall Back Comfort as explained by Subject Attributes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.519(a)	.269	-.072	1.62730

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.648	7	2.093	.790	.607[a]
	Residual	39.722	15	2.648		
	Total	54.370	22			

a. Predictors: (Constant), Subject Shoulder Width (cm), Age, Subject Lumbar Length (cm), Subject Spine Length (cm), Subject Shoulder Blade Length (mm), Sex, Subject Height (cm)

b. Dependent Variable: Comfort Rating Back Overall: Chair B

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	38.207	13.789		2.771	.014
	Sex	-2.705	1.516	-.872	-1.784	.095
	Age	.008	.054	.038	.155	.879
	Subject Height (cm)	-.214	.168	-1.453	-1.277	.221
	Subject Shoulder Blade Length (mm)	.223	.202	1.251	1.103	.287
	Subject Spine Length (cm)	.005	.127	.015	.041	.968
	Subject Lumbar Length (cm)	.020	.117	.046	.172	.866
	Subject Shoulder Width (cm)	-.390	.248	-.860	-1.572	.137

a. Dependent Variable: Comfort Rating Back Overall: Chair B

Table 14: Regression Model, Green Chair Perceived Overall Back Comfort as explained by Subject Attributes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.650(a)	.423	.153	1.29867

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.528	7	2.647	1.569	.219[a]
	Residual	25.298	15	1.687		
	Total	43.826	22			

a. Predictors: (Constant), Subject Shoulder Width (cm), Age, Subject Lumbar Length (cm), Subject Spine Length (cm), Subject Shoulder Blade Length (mm), Sex, Subject Height (cm)

b. Dependent Variable: Comfort Rating Back Overall: Chair G

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	5.763	11.005		.524	.608
	Sex	-1.595	1.210	-.573	-1.318	.207
	Age	.085	.043	.434	1.971	.067
	Subject Height (cm)	.225	.134	1.698	1.679	.114
	Subject Shoulder Blade Length (mm)	-.207	.161	-1.297	-1.286	.218
	Subject Spine Length (cm)	-.064	.102	-.212	-.627	.540
	Subject Lumbar Length (cm)	.021	.093	.053	.222	.827
	Subject Shoulder Width (cm)	-.215	.198	-.528	-1.084	.295

a. Dependent Variable: Comfort Rating Back Overall: Chair G

Table 15: Regression Model, Black Chair Perceived Overall Back Comfort as explained by Lower Back Deformation

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.501(a)	.251	.180	1.40995

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.992	2	6.996	3.519	.048[a]
	Residual	41.747	21	1.988		
	Total	55.740	23			

a. Predictors: (Constant), Total Lower Back Deformation: Chair B (mm^3), Total Upper Back Deformation: Chair B (mm^3)

b. Dependent Variable: Comfort Rating Back Overall: Chair B

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	8.503	1.213		7.011	.000
	Total Upper Back Deformation: Chair B (mm^3)	6.3E-007	.000	.113	.595	.558
	Total Lower Back Deformation: Chair B (mm^3)	-5E-006	.000	-.476	-2.507	.020

a. Dependent Variable: Comfort Rating Back Overall: Chair B

Table 16: Regression Model, Green Chair Perceived Overall Back Comfort as explained by Lower Back Deformation

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.214[a]	.046	-.045	1.42402

a. Predictors: (Constant), Total Lower Back Deformation: Chair G (mm^3), Total Upper Back Deformation: Chair G (mm^3)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.040	2	1.020	.503	.612[a]
	Residual	42.585	21	2.028		
	Total	44.625	23			

a. Predictors: (Constant), Total Lower Back Deformation: Chair G (mm^3), Total Upper Back Deformation: Chair G (mm^3)

b. Dependent Variable: Comfort Rating Back Overall: Chair G

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8.366	2.154		3.883	.001
	Total Upper Back Deformation: Chair G (mm^3)	7.30E-007	.000	.079	.368	.716
	Total Lower Back Deformation: Chair G (mm^3)	-2.4E-006	.000	-.204	-.956	.350

a. Dependent Variable: Comfort Rating Back Overall: Chair G