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PREDICTING AND QUANTIFYING SEATED COMFORT AND DISCOMFORT
USING OBJECTIVE AND SUBJECTIVE MEASURES

by
Scott David Openshaw

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Industrial Engineering
in the Graduate College of
The University of Iowa

May 2011

Thesis Supervisor: Associate Professor Thomas Schnell

ABSTRACT

Comfort is a sensation and state of being that many people seek when they are working in the office, driving in a car, flying on an airplane, or laying in a hospital bed. The literature identifies many definitions and interpretations for comfort and discomfort, and many different ways that researchers have tried to measure comfort and discomfort. de Looze proposed a model to explain the relationship between comfort and discomfort using three key components: (a) the human, (b) the product, and (c) the environment. This dissertation added a measurement component to the model.

In a repeated measures design, subjects (n=35) sat in three different office chairs for 60 minutes each on two different dates. Researchers collected subjective survey data and objective electronic data related to perceived sitting comfort and discomfort while participants completed office computer tasks. Data were analyzed to predict and quantify office worker seated comfort and discomfort using linear modeling and neural network modeling.

Correlation values from the linear regression model developed in this experiment were $R^2 < 0.70$, while the single hidden-layer neural network model predicted the comfort/discomfort responses with a higher correlation ($R^2=0.997$). The 35 subjects in the study perceived measurable comfort differences between the three chairs tested. Subjective questions that treated comfort and discomfort in a non-linear relationship discriminated chair differences better than questions using a linear relationship. There was no significant difference between male and female comfort/discomfort responses. Comfort ratings decreased over time, while discomfort increased over time; at least 45-minute comfort testing is needed to understand subjects' comfort/discomfort in a particular office chair.

Five common factors that were important to the model included: (a) fit of the product to the person, (b) the features of the product itself, (c) the time spent with the product, (d) the subjective questions, and (e) the objective pressure measurements.

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Date

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Thesis Supervisor: Associate Professor Thomas Schnell

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Graduate College
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CERTIFICATE OF APPROVAL

PH.D. THESIS

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has been approved by the Examining Committee
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To Dawnese, Randy, Thaniel, Olivia, and my family

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CHAPTER 1. INTRODUCTION

Whether they work in an office or factory, travel in a plane, car, or train, or sleep on a bed, humans want to feel comfortable. People want to be comfortable and not have signs of discomfort as they go about their daily tasks and routines. Comfort is usually also a criterion for purchasing a particular product or for promoting worker productivity in an office. The understanding is that if people purchase and use a comfortable product, then they will expect to be more productive and healthy throughout their day (Bhatnager, Drury, & Schiro, 1985).

Research that involves comfort evaluations exists in many industries: manufacturing (hand tools (Kuijt-Evers, Bosch, Huysmans, de Looze, & Vink, 2007)), medical (wheelchair patients (Crawford, Stinson, Walsh, & Porter-Armstrong, 2005)), automotive (driver), office (chairs (Groenesteijn, Vink, de Looze, & Krause, 2009)), bedding (mattresses (H. Lee & Park, 2006)), aerospace (jet pilot seats (Jackson, Emck, Hunston, & Jarvis, 2009)), and apparel (clothing (Barwood, Newton, & Tipton, 2009)).

The literature shows many definitions and interpretations for comfort and discomfort (Helander & Zhang, 1997). Researchers have tried many different ways to measure comfort and discomfort (Straker, 2003). Some measurement tools are based on objective outcomes using electronic equipment, while others are subjective and based on people's perception.

A sitting comfort review was conducted by de Looze et al. (2003), summarizing theories and research that focused on subjective and objective measures for sitting comfort. The review by de Looze also proposed a model to explain the relationship between comfort and discomfort and three key components that influenced comfort/discomfort: (a) the human, (b) the product, and (c) the environment. This dissertation discusses a brief history of comfort research and theories, then using existing literature, illustrates how others have tried to validate the model proposed by de Looze, et

al. It also discusses some of the shortcomings of the model and recommends areas of research that appear to be missing in the model, and other factors that could be added to the model. Finally, a specific investigation is conducted and the findings presented to further refine the parameters of determining Comfort/Discomfort.

1.1 Brief History of Comfort/Discomfort

Aviation researchers were looking for ways to make comfortable seats for military pilots who would spend 15 hours in seated flight (Hertzberg, 1958). Hertzberg postulated that comfort and discomfort are not two different states of consciousness, but “that there is only one, discomfort, and that ‘comfort’ is only the absence of discomfort”. With this same definition of comfort and discomfort Shackel et al. (1969) used a linear scale to select an appropriate office chair for workers. Richards (1980) also theorized that comfort and discomfort were two states that existed on different extremes of the same linear continuum.

Kamijo et al. (1982) postulated that comfort and discomfort were each influenced by its own set of variables and suggested that objective and subjective measures were needed to assess them both. The strongest research supporting a non-linear relationship between comfort and discomfort came from Zhang and Helander (1992) and Zhang et al. (1996). These two studies showed that there were different sets of descriptors that people used for comfort and discomfort, and they were based on independent factors. Comfort was associated with well-being while discomfort was associated with soreness, pain, and tiredness. A study was then conducted to verify the non-linear model of comfort and discomfort (Helander & Zhang, 1997). He observed in this study that discomfort has a dominant effect on comfort because when responses tended toward high discomfort, comfort ratings dropped quickly. An additional observation was that aesthetic design influenced the user’s perception of the product’s comfort (Helander & Zhang, 1997; Helander, 2003).

1.1.1 Further Discussion on Comfort vs. Discomfort

Part of the issue with understanding people's perception of comfort or discomfort is in the definitions and modeling of the two concepts. There has been a debate on the definitions of comfort and discomfort (Bishu, Hallbeck, Riley, & Stentz, 1991; Lueder, 1983; Richards, 1980; Vink, 2002; Zhang et al., 1996). Hertzberg defined comfort as the "absence of discomfort" (Hertzberg, 1958), suggesting that comfort was not present when someone felt discomfort. This definition seems to be a binary definition—one is either feeling comfort or feeling discomfort—it is either a "yes" or "no". Shackel et. al. (1969) added some gray area to this definition and stated that comfort and discomfort are on the same continuous scale with comfort on one end and discomfort at the other (Figure 1).

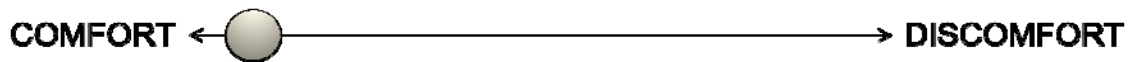


Figure 1. Linear definition showing comfort and discomfort on opposite extremes of the same spectrum.

These proponents argued that someone can feel various degrees of comfort or discomfort along a continuous scale. Unfortunately, this definition could not explain why people could feel comfortable and uncomfortable (discomfort) at the same time. Zhang et. al. (1996) and Helander and Zhang (1997) argued that comfort and discomfort are not on the same linear scale, but are different entities that are related non-linearly. This definition significantly changed the way people looked at comfort and discomfort.

Zhang's (1996) definition has become the most accepted model as his study showed significant differences between comfort and discomfort: "comfort is associated with feelings of relaxation and well-being...and aesthetic design" (p.388); "discomfort is

associated with biomechanical factors...that produce feelings of pain, soreness, numbness, stiffness, and so on” (p. 388).

According to Zhang, researchers must ask individuals to judge their comfort and discomfort separately using a set of questions that describe the sensation of comfort or discomfort. This type of evaluation allows an accurate depiction of what type of seat is comfortable or uncomfortable to the individual. Helander (2003) wrote a paper emphasizing the difference between comfort and discomfort, saying that comfort is primarily a perception, while discomfort is a secondary measure. Comfort is more of an emotional state, while discomfort is more of a physical state of being. He also argued that aesthetics of a seat’s appearance would influence the amount of comfort that a user would experience (Helander & Zhang, 1997; Helander, 2003). All of these definitions are important in understanding comfort and discomfort, but it is also important to understand how these two perceptions were measured.

1.1.2 de Looze Model

de Looze et al. (2003) introduced a comprehensive model illustrating the non-linear relationship between comfort and discomfort, as well as the dominant effect of discomfort in the model. They also specify three main influencers for comfort/discomfort assessment: (a) the human, (b) the product, and (c) the environment. The de Looze model is the most comprehensive model that exists thus far in the literature, accounting for human influencers of comfort/discomfort, as well as product and environmental factors.

In the de Looze model (Figure 2), discomfort (on left side of model) has a dominant effect on comfort (right side of model). The three categories of influencers are also shown. On the discomfort side, de Looze et al. suggested that the human’s physical capacity (endurance and weight) and physiological processes (skin temperature, muscle activation, and nerve conduction) can influence perceptions of discomfort. There may even be interactions between the physical capacity and the physical processes for the

user. On the comfort side, emotions and expectations will influence how the human perceives the comfort of the product. (i.e. the person is feeling happy [emotions] and sees a soft-looking seat—this should mean that the seat will be comfortable to him or her [expectations]).

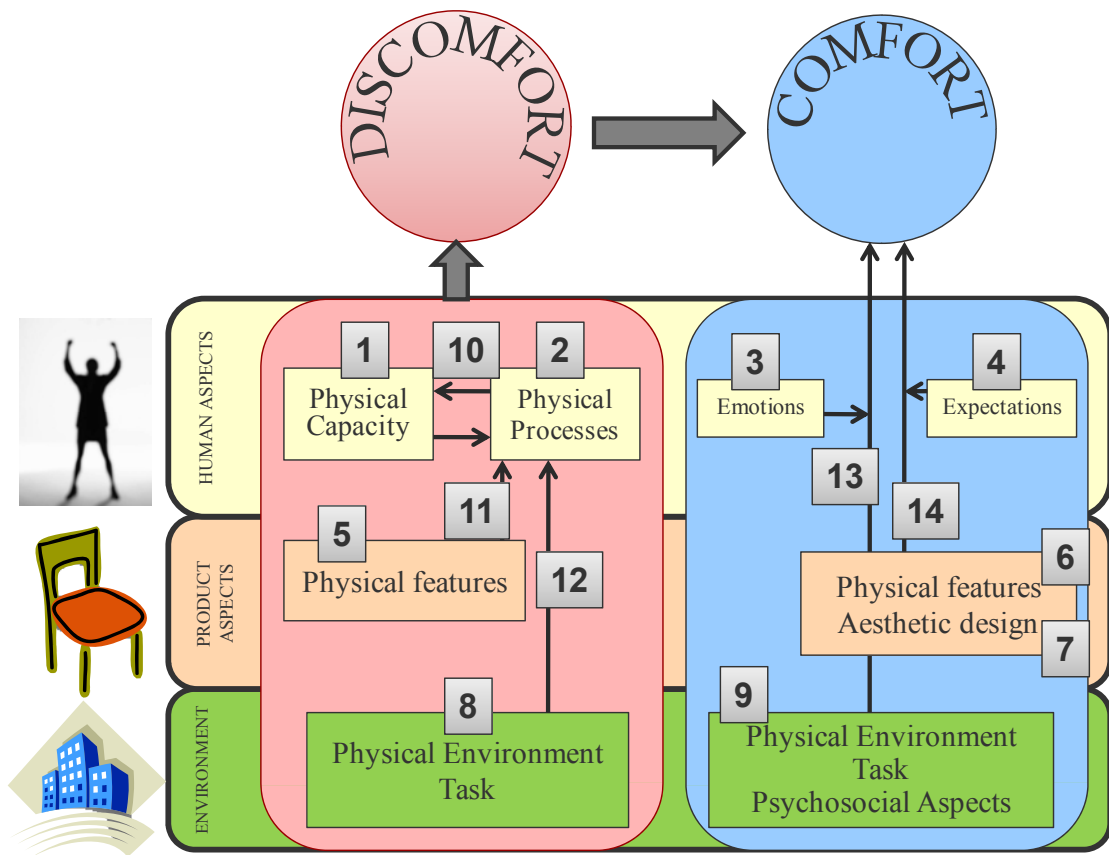


Figure 2. de Looze comfort model showing the 14 parts of the model and interactions. See Table 1 for specifics on each number in the diagram.

For the assessment of discomfort and comfort, the product can be influenced by its physical features: cushion thickness, contours, lumbar support, size and dimensions.

As noted by Helander (2003) and Kuijt-Evers et al. (2005) the aesthetic design of the product can influence the user's perception of comfort. Discomfort and comfort can be influenced by the physical environment (temperature, lighting) as well as the task being performed (typing, filing, and driving). Psychosocial aspects (job satisfaction, interactions with colleagues) can influence the user's perception of comfort.

The de Looze model shows interactions between physical human capacity and physiological processes (ability for muscles to endure long term sitting), product features and human physical processes (contour of seat alleviating pain on the buttocks), physical environment/task and human physical processes (warm room and body temperature discomfort), human emotions and physical environment/task/psychosocial aspects (user is not feeling well and does not enjoy working with his or her team), and human expectations and product features and aesthetics (user expects chair to feel good because it has an appealing design).

1.2 Review of Papers That Support the de Looze Model

A literature search was done using Pub Med, to see if there were documents that referenced the de Looze comfort model. A search for "de Looze comfort model" netted no results, but "de Looze comfort" returned a total of 6 references. A broader search was done for "comfort discomfort", which returned 941 articles that ranged from medical catheters to clothing to seating in offices and airplanes. Adding the word "sitting" narrowed the results to 33 with topics such as exercise balls, office chairs, wheelchairs, and airplanes. To eliminate the articles that were not relevant to the model in question, focus was given to documents that discussed either subjective or objective measures of comfort/discomfort in terms of humans, products, and environments in transportation, offices, and factories. Table 1 separates the 106 papers that were reviewed into each of the model's components.

Table 1. de Looze comfort model parts and related research articles.

de Looze Model Component	Number of Related Articles
1. Human [Physical Capacity] interactions for discomfort	9
2. Human [Physical Processes] interactions for discomfort	12
3. Human [Emotions]interactions for comfort	1
4. Human [Expectations] interactions for comfort	0
5. Product [Physical Features] interactions for discomfort	17
6. Product [Physical Features] interaction with comfort	3
7. Product [Aesthetic Design] interaction with comfort	4
8. Environment [Physical Environment + Task] interactions for discomfort	3
9. Environment [Physical Environment + Task Psychosocial Factors] interactions for comfort	6
10. Human Physical Capacity and Physical Processes for discomfort	4
11. Human Physical Processes and Product Physical Features for discomfort	38
12. Human Physical Processes and Physical Environment and Task for discomfort	9
13. Human Emotions and Physical Environment/Task/Psychosocial interactions for comfort	1
14. Human Expectations, Product Features and Aesthetics interactions for comfort	0

1.2.1 Overall Assessment of Literature

Seventy-one percent of the comfort/discomfort research that was reviewed deals with the interaction between the human and the physical features. Less than 2% of the papers looked at the human emotions and expectations related to comfort. Most of the papers did not distinguish between comfort and discomfort as separate concepts. Many times, they were used “interchangeably” as entities on different extremes of the same line. Some papers referred to “comfort” in the title, but actually measured “discomfort” (Park & Kim, 1997; Pint, Pelletiere, & Nguyen, 2003; Thomas, Congleton, Hutchingson,

Whiteley, & Rodrigues, 1991; Yun, Donges, & Freivalds, 1992). This made it a little difficult to separate the papers between the discomfort and comfort sides on the model, but most papers focused on measuring discomfort since it has the “dominant” effect as Helander and Zhang (1997) pointed out. The lack of research articles related to emotions, human expectations, and the interactions of those items with the aesthetics and physical features of the product points to possible research opportunities.

1.2.2 Human Aspects

One of every 4 papers reviewed was related to the human aspects of comfort or discomfort. The papers that discussed human physical capacity reviewed the forces on the buttocks (Goossens, 1998), time limits for sitting (Goossens, Kleinrensink, & Lechner, 2003; Reed & Massie, 1996), anthropometric accommodation (Kolich, 2003), and spinal postures (Faiks & Reinecke, 1998; Kee & Karwowski, 2001; Salewytsch & Callaghan, 1999). The papers discussing the physiological aspects of human processes and discomfort looked at blood flow (Habsburg & Middendorf, 1977), back muscles and posture (Andersson & Ortengren, 1974a; Andersson & Ortengren, 1974b; Andersson, Ortengren, Nachemson, & Elfstrom, 1974; Andersson, Ortengren, Nachemson, Elfstrom, & Broman, 1975), respiration and lumbar shape (Lin et al., 2006), low back pain (Pope, Rosen, Wilder, & Frymoyer, 1980), pressure under the ischial tuberosities (Branton, 1969; Goossens, Teeuw, & Snijders, 2005; Liu et al., 2006), and foot swelling (Winkel, 1986). Focus on most of these papers looked at comfort and discomfort on a linear scale. Researchers were trying to understand the physical and physiological limits of the human body as they relate to seated comfort.

One of the papers that related both human Physical Capacity and Physical Processes combined tests of sitting time and ischial tuberosity pressure (Thakurta, Koester, Bush, & Bachle, 1995) to measure endurance and comfort over time. Another study by Kolich (2003) illustrated how anthropometrics and occupant preferences

contradicted some of the published anthropometric recommendations for automotive seating. Kolich concluded that “automobile seat comfort is a unique science” and “ergonomic criteria...cannot be applied blindly” to ensure comfortable seats.

The single study found on emotions and comfort (Zenk, Franz, & Bubb, 2008) discussed how flash cards showing human emotion drawings could be used to help people judge their feelings while seated in a chair. The study also looked at aesthetics as an influence on how the user would perceive comfort. They covered the chairs with drapes during the first part of the experiment to get participants’ responses on the touch and feel of the product. During the second phase of the experiment, they uncovered the seats and asked the participants to judge their emotional response by only looking at the design of the seats. They found that there were gender differences in the area of design expectations, but not in the touch and feel of the seat comfort.

In the literature search, no research was found on user expectations. A search through design-related research may show some articles, but this appears to be an area where more comfort-related research can be performed. The ability to understand user expectations and how it relates to comfort may lead to products that are more intuitive, conform more naturally to the individual, or adapt to what the user may want.

1.2.3 Product Aspects

Another 25% of the papers reviewed discussed how the physical features and aesthetics of the products themselves influenced comfort. Many manufacturers and suppliers want to understand how a material will provide comfort to its users so that they can create a seat or another product that will meet comfort demands and influence productivity or health (de Looze et al., 2003). The papers that focused on discomfort and physical features of the product discussed product adjustments such as seat pan inclination angle (Bendix & Biering-Sorensen, 1983; Chen, Dennerlein, Chang, Chang, & Christiani, 2005; Coleman, Hull, & Ellitt, 1998; Congleton, Ayoub, & Smith, 1985;

Floyd & Roberts, 1958; Graf, 2004; Helander, Zhang, & Michel, 1995), pelvic support (Wu, Miyamoto, & Noro, 1998), and table and seat heights (Bendix, 1987). Others discussed the thickness of the foam construction (Crane et al., 2004; Crane, Holm, Hobson, Cooper, & Reed, 2007; Ragan, Kernozek, Bidar, & Matheson, 2002) or the materials used for the product's comfort (Congleton, Ayoub, & Smith, 1988; McGill, Kavcic, & Harvey, 2006). The research paper by Hertzberg (1972) explained how the United States Air Force was successful in looking at an optimized “average” contoured seat that experimentally passed as a comfortable seat for 15-hour long flights. The research from these papers discussed what material properties and adjustments influenced the comfort of users.

The three studies on product physical features that dealt with comfort were also related to foam construction (Jackson et al., 2009) and chair adjustments (Ebe & Griffin, 2001; Groenesteijn et al., 2009). The key research that suggested that aesthetics of a product can influence comfort (Helander, 2003) was discussed at the beginning of this paper. Other researchers in The Netherlands (Kuijt-Evers, Groenesteijn, de Looze, & Vink, 2004; Kuijt-Evers et al., 2005; Kuijt-Evers et al., 2007) took these concepts of aesthetic influences on comfort and applied their research to hand tools. They judged the comfort of different tools based on the look of their design. They found that aesthetics in hand tools was important in influencing comfort—just like it was important for Helander (2003) in seated comfort.

1.2.4 Environmental Aspects

The last category in the de Looze comfort model is the Environmental Aspects of comfort and discomfort. Fewer than 10% of all the papers reviewed fell in these categories, suggesting that there is a need to do more research in this area in the future to understand more about the physical environment and tasks related to comfort/discomfort. The papers that were reviewed in this area discussed workstation layout (Hutchinson,

2008; Konarska et al., 2005; Lindegard, Karlberg, Wigaeus Tornqvist, Toomingas, & Hagberg, 2005), work-rest schedules (Balci & Aghazadeh, 2003; Tucker & Knowles, 2008), and productivity (Bhatnager et al., 1985). Two of the studies looked at comfort in the environmental setting of a train (Branton & Grayson, 1967; Richards, 1980). The study by (Bhatnager et al., 1985) began to address the measurement of performance (or productivity) and postural discomfort. More research can be done related to comfort and productivity to show that people are more productive when they work comfortably. Sometimes the subjective conclusion is made that more comfort equals more work done, but it would be important to have empirical data that measurably substantiates these claims.

1.2.5 Interactions Between Parts of the de Looze Model

In the de Looze Comfort Model, there are interactions between different aspects of the model. For example, as discussed in the 1.2.2 Human Aspects section, the Human Capacity and Processes could interact to look at how time of sitting influences the muscle endurance under the ischial tuberosities. The interaction of Human Processes and Product Features had the most research papers of any category (35%) (Table 2). These papers mainly discussed how product features (seat material, seat contour, seat angle, pressure distribution, etc.) influenced the human response of discomfort or comfort. de Looze et al. analyzed many of these same papers, in their review, and saw that there was not a lot of coordination between the conclusions from one paper to the other. They used different definitions of comfort and discomfort and measured with different survey tools. Some measured only subjectively (Helander, Czaja, Drury, Cary, & Burri, 1987; Shackel et al., 1969). Some tried to measure both objectively and subjectively (Loslever & Lepoutre, 2004; Park, Lee, Nahm, Lee, & Kim, 1998). Other studies tried to predict comfort (Demontis & Giacoletto, 2002; Kamijo et al., 1982).

Table 2. Papers related to Human Processes (Physiology) and Product Physical Features.

Comfort/Discomfort Papers on Automotive	Comfort/Discomfort Papers on Office Chairs
(Blair, Milivojevich, Pageau, & van Heumen, 1999)	(Bush & Hubbard, 2008)
(Demontis & Giacoletto, 2002)	(Corlett, 2006)
(Ebe & Griffin, 2000b)	(van Dieen, de Looze, & Hermans, 2001)
(Frusti & Hoffman, 1994)	(Gadge & Innes, 2007)
(Gyi & Porter, 1999)	(Helander et al., 1987)
(Inagaki, Taguchi, Yasuda, & Izuka, 2000)	(Helander, Little, & Drury, 2000)
(Kamijo et al., 1982)	(Lengsfeld, Frank, van Deursen, & Griss, 2000)
(Katsuraki, Suwa, Murakami, & Nagashima, 1993)	(Loslever & Lepoutre, 2004)
(Katsuraki, Suwa, Murakami, & Nagashima, 1994)	(Occhipinti, Colombini, Molteni, & Grieco, 1993)
(J. Lee & Ferraiuolo, 1993)	(Shackel et al., 1969)
(J. Lee, Ferraiuolo, & Temming, 1993)	(Vergara & Page, 2000)
(Milivojevich, Stanciu, Russ, Blair, & van Heumen, 2000)	(Vergara & Page, 2002)
(Oudenhuijzen, Tan, & Morsch, 2003)	(Vlaovic, Bogner, & Grbac, 2008)
(Park & Kim, 1997)	(Vos, Congleton, Moore, Amendola, & Ringer, 2006)
(Park et al., 1998)	
(Porter, Gyi, & Tait, 2003)	
(Pywell, 1993)	
(Reed, Saito, Kakishima, Lee, & Schneider, 1991)	
(Runkle, 1994)	
(Shen & Vertiz, 1997)	
(Thomas et al., 1991)	
(Wijaya, Jonsson, & Johansson, 2003)	
(Yun et al., 1992)	

Fifteen of the papers focused on office work chair features and comfort/discomfort. Twenty-three papers focused on the automotive field and comfort in the driver's seat. One study (Pint et al., 2003) looked at comfort in a pilot ejection seat cushion.

There were also papers that discussed the interaction between the physical environment and the human physiology. The majority of these papers focused on postures in the office or automobile and how the user rated his/her comfort in the environment (Durkin, Harvey, Hughson, & Callaghan, 2006; Ebe & Griffin, 2000a; Falou et al., 2003; Haynes & Williams, 2008; Liao & Drury, 2000; Ziefle, 2003). Two of the papers investigated computational models of the automotive environment and tried to model comfort based on pressure maps and biomechanical models (Schmale et al., 2002; Verver, de Lange, van Hoof, & Wismans, 2005).

There was one paper that related the physical environment and tasks to human emotions (Paul, Helander, Morrow, & Zhang, 1997). This paper discussed the need to promote activity in the work setting with products so that people do not sit in sedentary positions. It discussed how nurturing and pampering workers can affect their emotions and well being.

1.3 de Looze Model Summary

Overall the de Looze Comfort Model does well at illustrating what factors can influence the comfort/discomfort of people as they use products. There are several research articles that explain parts of his model. As noted, there are also areas (such as comfort and aesthetics) that research has not focused on, but others' papers have improved the understanding of measuring comfort (Helander, 2003; Kuijt-Evers et al., 2005). The articles related to comfort and discomfort research have come from several industries: medical, aviation, office, automotive, industrial, etc. The assumption is not explicitly articulated among these research articles that the results in one field are

transferable to another. Most of the same methodologies and tools that measure comfort in the automotive field are used in the office environment. Assuming that a comfort measurement in an office chair study will apply directly to an automotive study may or may not be valid. More research needs to be done to understand if there is a transfer effect.

Additionally, Helander and Zhang (1997) suggested that it is important to measure both comfort and discomfort in the same study so that you can measure the effects of each independently. The de Looze model supports this conclusion, and one group of researchers has measured each independently in their studies (Kuijt-Evers et al., 2005; Kuijt-Evers et al., 2007). This is an important area that needs to be researched so that it can validate the assumptions made by Helander and Zhang.

In the measure of comfort and discomfort, many researchers have looked at both objective and subjective measures. The desire to focus on objective measures is that the human error or bias would be eliminated. Kolich, (2003) found that human bias actually showed that there was a discrepancy between theoretical fit [comfort] and actual comfort ratings.

Being able to find a correlation between the subjective and objective measures so that you can rely on just objective results can be important to product development teams so they can decrease development time. Part of understanding the correlation also includes finding the best tools that will measure what you are looking for. The review by de Looze discusses some of the best tools. A further analysis of the 38 articles found in that review could add more light to the de Looze conclusions.

One element that de Looze does not address in his model is how time affects comfort and discomfort. The literature discusses different time limits on people sitting in a chair to measure comfort. Some suggested it can be as little as 5 minutes (Jones & Hooper, 2005; Yuen & Garrett, 2001), others recommend more than 30 minutes (Thomas et al., 1991), and others even longer (Goossens et al., 2005). Helander (2003) argues that

a person will feel discomfort over time—not because the chair is designed poorly—but due to the physiological response of the body to sitting fatigue. Understanding how time can affect comfort can be important in creating a representative comfort model. In some cases, there may be a need to look at short-term comfort and long-term comfort separately.

The other element that would be important to include in the model is the demographics of the individual participant. Kuijt-Evers et al. (2007) found that there was a gender difference in judging comfort and aesthetics, but not with sitting and feeling comfort. Others see a difference in the way that comfort is measured based on gender. Hertzberg (Hertzberg, 1972) described how the muscles interact with the ischial tuberosities (IT), and that some people have different bone and muscle compositions that can induce pain quicker than others. If comfort is related to the physiological factors as discussed by de Looze, then it should be important to consider muscle mass in the buttocks and other parts of the body. Keeping an account of age (muscles can deteriorate with age), height, and weight can also help to understand some of the variability that may exist in the population as we assess comfort.

1.4 Literature Review Summary

This review discussed the history of comfort/discomfort research and explained how a model proposed by de Looze et al. is supported by over 100 research papers. There are areas in the de Looze model that need to be investigated further to validate and understand the model and how comfort can be assessed. Additionally, as research in this area progresses, it would be important to include demographics in the human aspects portion of the model to understand how gender, age, height, weight, and body composition may influence comfort.

Finally, it would also be important to understand how time plays a role in the comfort/discomfort assessment. Further research will continue in this field as scientists

try to understand how comfort can be measured objectively and reliably through all fields of interest. When we sit in a chair or car seat, we have the sensation of the backrest and seat pan touching our back and thighs. This sensation of touch is due to our nerves receiving signals and sending them to our brain (Coren, Ward, & Enns, 2004). As we sit in the chair, we may have different sensations occurring such as softness, pain, heat, moisture, or pressure adaptation. Our perception of these sensations can determine if we consider ourselves to be in a state of comfort or discomfort.

Over the years many researchers and designers have tried to understand the relationship between comfort and discomfort and apply that knowledge to the design and development of new materials and products for people to use (Bishu et al., 1991; Lueder, 1983; Richards, 1980; Vink, 2002; Zhang et al., 1996).

Researchers have primarily used subjective measures such as surveys or questionnaires to understand the perception of comfort or discomfort, but the subjectivity of the responses caused conflicts and discrepancies in drawing meaningful conclusions (de Looze et al., 2003; Kolich, 2003).

Others started to use objective measures to eliminate the subjectivity during experimentation, but they lost the human element that told them what the human psyche was sensing (de Looze et al., 2003; Milivojevich et al., 2000; Oudenhuijzen et al., 2003; Runkle, 1994; Thakurta et al., 1995; Vink, 2002).

In recent years, researchers have combined subjective and objective measures and tried to draw correlations between the different measures to find meaningful conclusions. Much of the literature from this combined approach shows promise, but there remains a need for solid answers about how to interpret people's perception of comfort and discomfort (Kolich, 2003).

1.5 Openshaw Additions to Comfort Model

Figure 3 shows the addition of a “Measurements” category with three new recommended components to the de Looze Comfort Model: Time, Objective Measures, and Subjective Measures. As discussed earlier, time has shown to affect the perceived comfort in some experiments, and therefore should be added as a part of this model. Secondly, researchers have also shown that both subjective and objective measures can be used to help describe comfort and discomfort. Part of this dissertation will explore how these three components play a role in creating a predictive comfort model.

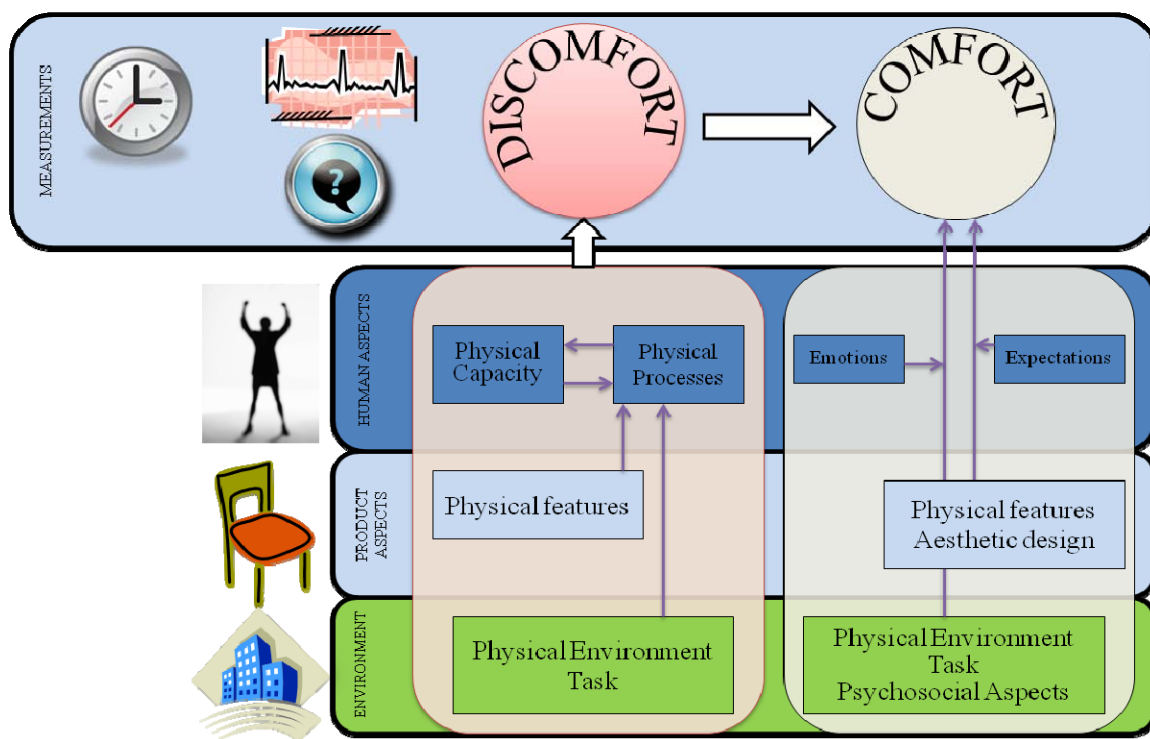


Figure 3. Openshaw's additions to de Looze Comfort Model

CHAPTER 2. EXPERIMENTAL DESIGN CONSIDERATIONS

2.1 Industries Interested in Comfort/Discomfort

Since the early 1950s, researchers have been studying comfort in the office (Bendix, Winkel, & Jessen, 1985; Bishu et al., 1991; Floyd & Roberts, 1958; Shackel et al., 1969), in transportation seats for cars, trains, and airplanes (Branton & Grayson, 1967; Demontis & Giacoletto, 2002; J. Lee et al., 1993; Pint et al., 2003; Pywell, 1993), and even in beds (H. Lee & Park, 2006) and hand tools (Kuijt-Evers et al., 2005). Researchers in each of these groups have tried to apply different methodologies to understand how comfort and discomfort play a role in their industries and how they can use their conclusions to improve designs and user satisfaction.

2.2 Measuring People

When working with people as subjects, there are many variables and considerations that must be reconciled in order to account for the variances that may be present. Here are some examples of the variations that can be seen when assessing comfort with people (Kolich, 2003):

- Gender (male or female)
- Anthropometry (height, weight, arm length, hand size, etc.)
- Age (young, old)
- Handedness (left or right handed)
- Education and prior experience of the user (may have used several office chairs, or never really ever sat in one)
- Strength (ability to get in and out of chair; sit for long periods of time; tolerate pain more easily)
- Cognition (ability to remember prior experiences)
- Aesthetic appeal (how the chair looks can influence how people perceive it and react toward it)

- Perceptions of softness/hardness and quality (what is considered too hard or too soft may differ; what is cheap or high quality may affect perception of comfort)

Information can be collected about the participants in a study and used in the analysis to understand how those factors might influence comfort or discomfort. Some of the studies that have previously been conducted on comfort or discomfort did not report the number of subjects tested, had low numbers of subjects, or the subjects were primarily young college students. Even the studies that focused on office comfort did not use subjects who were office workers (Bendix et al., 1985; Bush & Hubbard, 2008; Congleton et al., 1988; Oudenhuijzen et al., 2003; Tewari & Prasad, 2000; Uenishi, Fujihashi, & Imai, 2000).

Current statistics also show that office-type workers are made up of slightly more females than males (M = 47%, F = 53%) (US Department of Labor and Statistics, December 2010). Percentages for different office-worker age groups between 18 and 74 years old were determined by using current statistics from the US Census Bureau (August 2003). Office demographics, showing height and weight ranges of office workers are not readily available, but it is accepted practice to use the height and weight of the general United States population from the 1988 Anthropometric Survey of US Army Personnel (ANSUR) database (Gordon et al., 1989) to represent the office workforce (BIFMA International, 2002; Gordon et al., 1989; Human Factors and Ergonomics Society, 2007). Information from these data sources was used to create a balanced participant pool based on gender, age, height, and weight.

A lot of variability can be introduced when using humans as subjects, especially when assessing subjective topics such as comfort and discomfort (Helander, 2003). By using subjects who reflect the demographics and experience level of an office population, researchers should obtain results that are more representative of their subject pool. Using subjects who are familiar with office equipment, chairs, and tasks can also minimize the variability that might be introduced into the experiment (Helander et al., 1995).

2.3 Subjective Measures

Subjective measures attempt to gauge the user's degree of comfort/discomfort through questionnaires as they use a product (de Looze et al., 2003; Kuijt-Evers et al., 2007). These measures are influenced by the person's prior experience, current state of being, perceptions, opinions, and biases (Coren et al., 2004). Many times it is hard for a person answering subjective questions to be objective and unbiased. Yet, the subjectivity allows the researcher to understand what the person is feeling and perceiving, and thus have a better measure of the honest human interaction. Without the subjectivity, the human element can be lost.

Researchers who have focused on subjective measures have made important contributions to subjective data collection. Some of the subjective tools include Corlett's Body Part Discomfort (BPD) measure and Shackel's General Comfort Rating (Corlett, 2006; Helander et al., 1987; Shackel et al., 1969). With Corlett's BPD measure (Figure 4), the subject rates the amount of pain felt in different areas of the body on a scale of 1 to 10. This information is then used to assess the amount of discomfort that is being felt. If the discomfort is low, then it is assumed that the individual is experiencing comfort.

Body Part Discomfort



Figure 4. Body Part Discomfort diagram

Shackel's General Comfort Rating (GCR) is similar because it uses a linear scale from 1 to 11, with "most" discomfort equal to a 1 and "most" comfort being equal to a 10. This measure allows the subject to tell what degree of comfort is being felt (see Figure 5) (Shackel et al., 1969). For many years, researchers assessed comfort and discomfort based on a linear scale like Shackel used.

Rating	Description
1	I feel completely relaxed
2	I feel perfectly comfortable
3	I feel quite comfortable
4	I feel barely comfortable
5	I feel uncomfortable
6	I feel restless and fidgety
7	I feel cramped
8	I feel stiff
9	I feel numb (on pins and needles)
10	I feel sore and tender
11	I feel unbearable pain

Figure 5. General Comfort Rating (GCR) linear scale

In the 1990's researchers began to question the linearity of comfort/discomfort, wondering if it might be a non-linear relationship (Zhang & Helander, 1992; Zhang et al., 1996). Helander and Zhang (1997) began using two sets of questions, one for comfort and one for discomfort (Figure 6). The discomfort questions were related to biomechanical factors and soreness/pain. The comfort questions were related to relaxation, well-being, and design aesthetics. It was their opinion that these questions help to differentiate between comfort and discomfort and allow the subject to give a more accurate account of his or her perception while seated in a chair.

Discomfort Descriptors

1. I have sore muscles
2. I have heavy legs
3. I feel stiff
4. I feel tired
5. I feel pain
6. I feel numb
7. I feel uneven pressure
8. I feel cramped
9. I feel restless

Comfort Descriptors

10. I feel relaxed
11. I feel refreshed
12. I feel restful
13. Chair is spacious
14. Chair looks nice
15. Chair feels soft
16. I like the chair

Figure 6. Helander and Zhang's questions for comfort and discomfort assessment. (Helander, 2003).

Subjective measures are commonly calculated using a rating scale such as a numeric, cross modal matching (Reed et al., 1991), or continuous scale (Smith, Andrews, & Wawrow, 2006). Some of the numerical scales are based on 5-, 7-, 10-, or 11-point scales, measuring the degree of comfort, pain, or satisfaction from 0 or 1 as the “low” point to a “high” point represented by the highest number used for the scale. Other point scales center around 0 as the “Just Right” position, and then proceed in the negative direction for an “incorrect” rating (such as “seat is too hard”), or in the positive direction for an alternate “incorrect” rating (such as “seat too soft”) (Kolich, 1999).

Smith et al. (2006) created a Visual Analog Scale (VAS) survey for automotive seat comfort and reported on its effectiveness. The VAS allowed the participants to judge the comfort or discomfort of a seat feature by marking along a continuous scale that was

100mm long. de Looze et. al. (2003) reviewed many studies on comfort and discomfort, and noted that most researchers use a subjective scale, but no one has run experiments using Helander and Zhang's approach of evaluating comfort and discomfort on separate scales.

2.4 Objective Measures

To rely less on subjectivity, other researchers have been using objective measuring tools along with subjective tools to measure comfort or discomfort. Objective measures can provide data and evidence that is repeatable and not tainted by human opinion. Although objective tools can give numerical data on the subjects' state in a chair, they cannot give the human emotion or perception of what is being felt. Therefore, there is a need to have a coupling of the objective and the subjective data to relay the complete experience (de Looze et al., 2003; Milivojevich et al., 2000; Runkle, 1994; Thakurta et al., 1995; Vink, 2002).

There are a few challenges using objective data. First, researchers need to determine what measures are best to use. Some of the objective tools that have been used include: back and seat pressure distribution systems (Demontis & Giacoletto, 2002; Kamijo et al., 1982; J. Lee & Ferraiuolo, 1993; Park & Kim, 1997; Thakurta et al., 1995), electromyograms (EMGs) (K. S. Lee, Walker, & Wu, 1988), spinal position tools (Bishu et al., 1991; Eklund & Corlett, 1987; Eklund & Liew, 1991; Salewytch & Callaghan, 1999), in-seat movements (Fenety, Putnam, & Walker, 2000), and blood flow in the legs (Habsburg & Middendorf, 1977). Some additional tools that have not been used in any of the studies mentioned above include biometric readings such as skin temperature (ST), body and ambient heat flux (HF), and Galvanic Skin Response (GSR). These readings may show a correlation with the anxiety that is sometimes associated with discomfort or the relaxation that is associated with comfort. The tools that are used for a study depend on the types of measurements that need to be collected (i.e. a back comfort

study might use a spinal position, EMG, or pressure mapping system for objective tools). Other objective measures that may influence comfort/discomfort are room temperature, humidity, and lighting.

2.4.1 Pressure Mapping

Pressure mapping has been a common objective measuring tool in much of the literature dealing with comfort and discomfort (de Looze et al., 2003; Oudenhuijzen et al., 2003). Pressure pads (Figure 7) are electronic grids of transducers that measure interface pressure distribution between the user and the product (Figure 8).

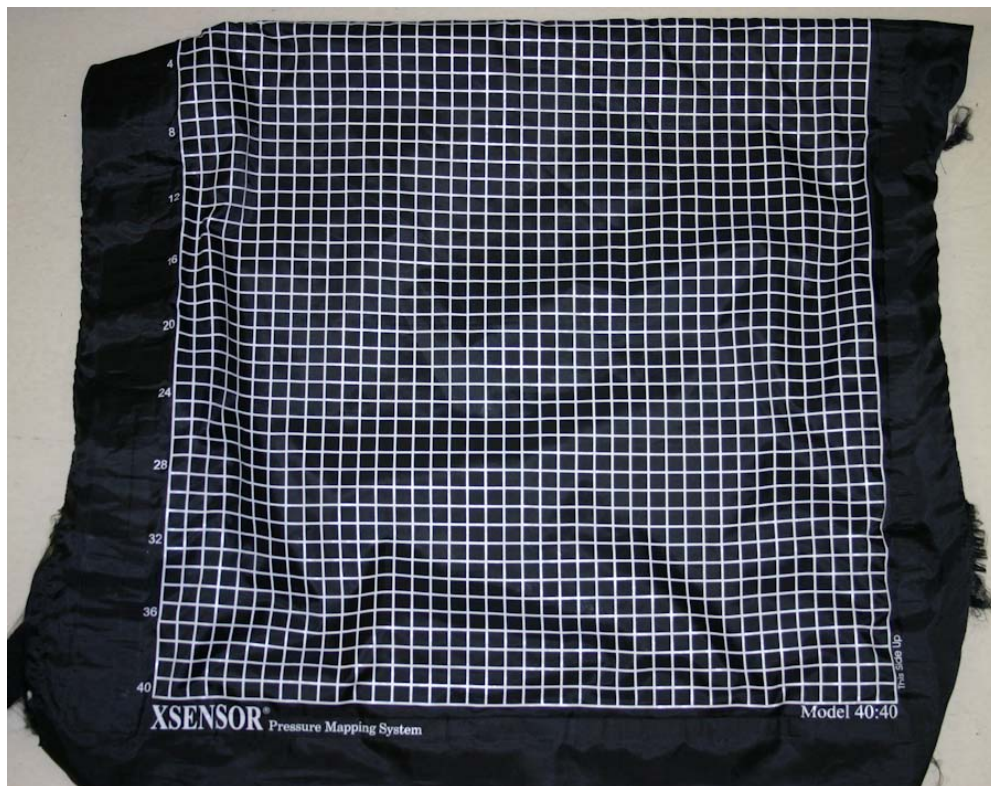


Figure 7. Xsensor 40x40 pressure mapping pad

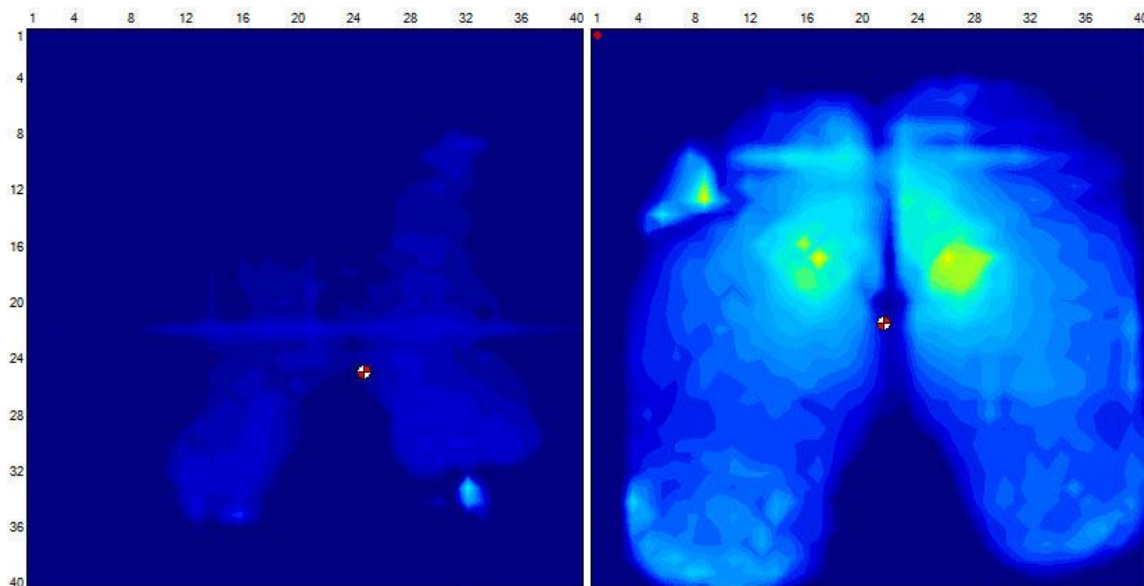


Figure 8. Image of a pressure map (back on left, seat on right)

The common measurements that are used when analyzing a pressure map are: Average Pressure (AP) (mean pressure on the pad during a certain time frame), Peak Pressure (PP) (highest pressure recorded on the pad during a certain time frame), and Contact Area (CA) (amount of contact area between the user and the product) (Gyi & Porter, 1999; Milivojevich et al., 2000).

Many researchers agree that the optimal pressure map has a larger contact area, lower average pressure and lower peak pressures (Congleton et al., 1988; Frusti & Hoffman, 1994; Porter et al., 2003). This scenario means that the forces of the thighs, buttocks, and back are spread out over a larger area, therefore decreasing the pressure felt by those tissues.

Some researchers have looked at different areas of the pressure map rather than just looking at the whole pressure map image (Demontis & Giacoletto, 2002; Frusti & Hoffman, 1994; Park & Kim, 1997). For example, they will focus on areas such as the

lumbar pressure or the shoulder pressure on the back. They may also look at the pressure points in the seat where the ischial tuberosities¹ are located, and the pressure around the popliteal area² (see Figure 9). These different zones will then be used in the analysis to break down the larger picture of the whole pressure map and see if the zones have a stronger correlation back to comfort or discomfort. Pressure mapping has been the most highly correlated measuring tool for assessing comfort (de Looze et al., 2003).

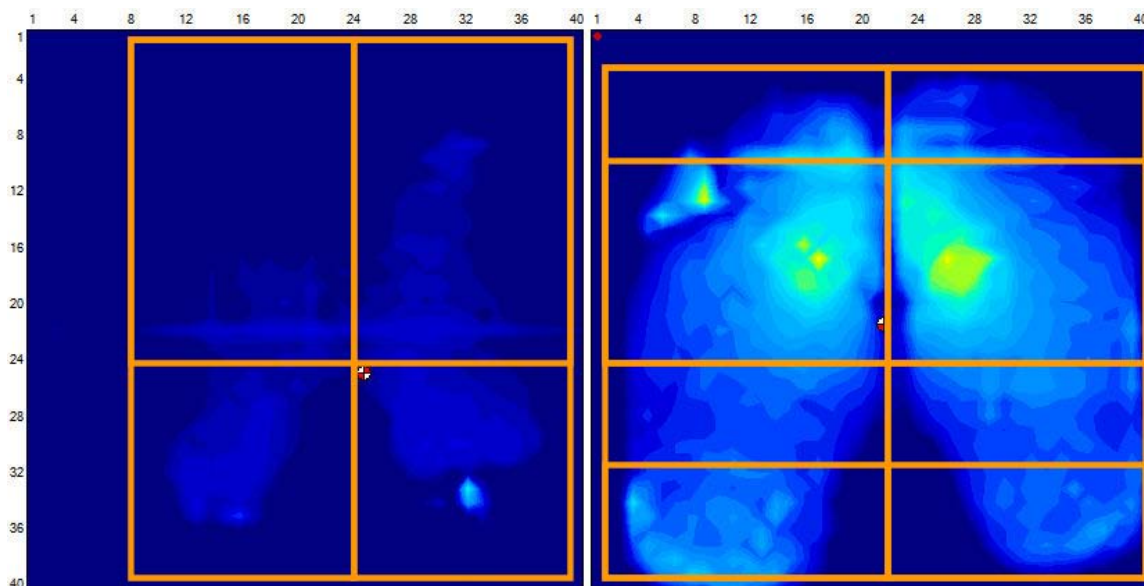


Figure 9. Pressure map showing different sub-regions (back on left, seat on right).

¹ Also commonly known as the sitting bones; part of the ischium

² Area behind the knee

2.4.2 Physiological Measurements

Physiological measurements help to understand how the body is reacting to different scenarios. A few researchers looked at physiological measurements while subjects were seated in wheelchairs and office seats (Lin et al., 2006; Winkel, 1986), but the majority used non-physiological data collection for comfort research. As technology improves, the tools used to collect this data become smaller and less intrusive. Some tools, such as the BodyMedia® SenseWear® (Pittsburgh, PA) (Figure 10) collect several measurements at one time without interfering with the user's movements and normal operations.



Figure 10. BodyMedia armband physiological data logger.

With a maximum sampling rate of 32 Hz, the sensors included in this device are:

- 2-axis accelerometer

- Heat flow
- Galvanic skin response
- Skin temperature
- Ambient temperature
- Heart rate receiver (needs additional heart rate transmitter)

The SenseWear device will calculate the following from the sensor data, which can be viewed on their proprietary software or exported to a spreadsheet (Appendix A.

BodyMedia SenseWear Output):

- Skin and near-body temperature
- Heat flux
- Galvanic skin response
- Energy expenditure
- Steps taken
- Resting or active states of the body
- Calorie expenditure
- Time and date of recording

Data can be collected on the device at different rates from 32 Hz to 1 data point every 10 minutes. The default collection rate for the device is 1 sample per minute. It was the researcher's opinion that this slower rate might cause some data points to be missed in the comfort evaluation, so for this experiment, data were collected at 10 Hz.

2.4.3 Environmental Meter

The office environment can affect comfort, discomfort, and productivity (Seppanen, Fisk, & Lei, 2006). Factors such as temperature, humidity, and lighting levels can be measured and used as inputs for modeling comfort and discomfort. The literature reviewed did not use environmental factors in their analysis to explain their influence on comfort and discomfort. Other researchers have shown that environmental conditions can

affect productivity (Seppanen et al., 2006; Wigo & Knez, 2005). A General Tools (formerly Mannix Tool) (New York, NY) DLAF-8000 Hygrometer, Anemometer, Light Meter, and Thermometer was used to collect environmental data during this experiment (Figure 11). The specifications for the device were not listed on their company website (General Tools, March 17, 2011). Recommended lighting levels for an office space should be between 200 and 500 lx (Human Factors and Ergonomics Society, 2007). Researchers have shown that a temperature range of 21-22°C is optimal, but offices may range from 21°C to 25°C (Hedge & Gaygen, October 2009; Seppanen et al., 2006). Humidity levels in an office can vary depending on the regional climate and season of the year, one study observed relative humidity levels in the New York City area in the range of 7-40% (Hedge & Gaygen, October 2009).



Figure 11. Environmental meter used to collect humidity, temperature, and lighting values.

2.5 Office Equipment and Tasks

In order to simulate an office environment during experimentation, it is helpful to replicate office equipment and work during data collection. This will allow for a better representation of human interaction with the office space as subjects assess their sitting comfort and discomfort. Most of the automotive comfort studies looked at postures while driving in a simulator. Having office workers perform normal office tasks in an office setting will help understand comfort as people work.

Some aspects to consider with sitting comfort include the time that a person sits in a chair. Sometimes a person may test a chair out and sit in it for a few minutes to see if it is comfortable. This is referred to as a short-term comfort test. It does not involve doing tasks while assessing the comfort of the product. A short-term comfort test entails sitting in the chair, making adjustments, looking at the chair, and assessing if it is comfortable or not to the user. This is actually the way that many seating products are purchased—based on a short-term sit (Thakurta et al., 1995).

When people work in their offices, they sit for about 30-60 minutes at a time before taking a break of some type (walk to the printer, grab a drink, talk to a co-worker, or attend a meeting). This longer sitting period is called the long-term sit. During this sitting time period, workers may experience different pressures, sensations, and pains that may not have been manifested during the short-term sit test. The long-term sit gives a better assessment of the comfort of a chair because some materials (foam, fabric, plastics, mesh, etc.) may react differently with the worker over time. For example, the foam in a seat cushion may feel comfortable at first because it is billowy, but over time, the foam will compress and a worker may sink into the foam so much that their ischial tuberosities feel extra pressure against the seat board underneath the foam (Congleton et al., 1988; Corlett, 2006).

For these reasons, it is helpful to assess comfort based on a short- and long-term basis. Researchers have taken this approach in assessing office and automotive comfort (Goossens et al., 2003; Inagaki et al., 2000; Thakurta et al., 1995; Thomas et al., 1991).

2.5.1 Chair Adjustments

Understanding the adjustments on a chair (Figure 12) and their ergonomic benefits can also increase the comfort for office workers (BIFMA International, 2002; Helander et al., 1987; Human Factors and Ergonomics Society, 2007). When testing participants with office chairs, researchers can either allow the subjects to figure out on their own how to adjust their chair properly (which most people do not know how to do correctly) (Helander et al., 1995); or the researchers could show the subjects each adjustment, teach them how to fit it properly, and then verify that it is correct. Either strategy can bias the data collection process. If the first option is elected, then participants will probably have the chair misadjusted and sit in an uncomfortable position throughout the test, causing the comfort-discomfort data to be inaccurate because of improper understanding of ergonomics. If the second option is chosen, then the subjects are fit in the chair better than had they not been instructed, and therefore will be answering the questions differently because of this bias.

Since the goal of this research is to create a model for comfort, the choice was made to bias the subjects by educating them on ergonomic fit and adjustments. By doing this, all of the subjects begin the comfort testing with the same understanding of chair adjustments and office ergonomics. This removes the error and variability that could exist if each individual were to adjust the chair without any instruction.

Most office chairs today are equipped with the following adjustments:

- Seat height
- Seat depth
- Backrest and/or lumbar adjustments

- Armrest height, width, and depth

Seat Height

Chairs usually have a lever on the right side of the chair that adjusts the vertical height of the seat. An appropriate seat height, with the feet supported on solid surface (floor or footrest) would allow the user to have his or her hips and knees at a near-horizontal position. This will ensure that pressure on the thighs and buttocks is distributed evenly while seated.



Figure 12. Typical office chair

Seat Depth

The seat depth adjustment is usually unknown to the typical office worker, but it is an adjustment that moves the seat cushion in and out so that the user can have more or less support under his or her buttocks and thighs. The seat depth adjustment also ensures that users do not feel undue pressure against their popliteal area. It is recommended to have two to three fingers of clearance between the front edge of the seat and the popliteal area of the leg so that users don't experience pressure in this area.

Backrest and/or Lumbar Adjustments

Most chairs have some type of back adjustment to fit the chair backrest to the user's spinal curvature. There are many ways these adjustments are presented, but they usually involve the movement of the backrest or materials in the lumbar area. The amount of support and curvature needed depends on each individual. The user should feel that his or her back is supported by the chair backrest.

Armrest Adjustments

After the seat height adjustment, armrests are probably the most used adjustment by the office worker because the armrests allow a more intimate fit of the chair to the user. Most armrests will adjust in height so that the user can rest his or her forearm on the padded surface and relieve the load of the arms from the person's shoulder and trapezius muscles (Delisle, Larivière, Plamondon, & Imbeau, 2006). The armrests should not be so high that the shoulders become elevated, nor so low that the shoulders droop. Some chairs have armrests that adjust fore and aft (allowing the user to get closer to the worksurface or more support under the forearm). Other armrests also adjust laterally so that the width between the armrests can accommodate a wider or narrower frame sitting in the chair.

The use of armrests by an office worker can vary—some prefer not to use them while others use them to rest their arms and shoulders. Alternatively, some office workers

use the worksurface to rest their arms. When workers support their arms on a worksurface or armrest, the load recorded by a pressure map is less because the weight of the arms and shoulders is being redirected to a different surface.

In this experiment, general notations were made if the subject rested his/her arms on the worksurface or armrest, but it was not used as a factor in the comfort model because postures and arm support positions changed throughout the testing period.

2.5.2 Chair Materials

Materials used in the construction of chair seats and backrests vary. Common seats and backrests in the market today are made with polyurethane foam and fabric upholstery, polymer materials, wood substrate, or mesh weaves. For long-term comfort, especially while working at a workstation for the majority of the day, most workers want a material that will cushion their body weight and movements as they sit and work (Congleton et al., 1988). Foam or mesh has an interaction with the body that gives more cushioning than a hard substrate like wood or plastic (polymer), and it would be expected that workers will feel more comfortable sitting in the foam- or mesh-type construction. Upholstery materials may also have an effect on the comfort. A tighter knit fabric that does not have as much give may feel firmer and therefore cause more discomfort over time, in a manner similar to the foam vs. wood scenario.

A material that is commonly used to prototype seating contours is high-density polyurethane fixture board. This is a hard, clay-like material that can be shaped with common machining tools in a model shop (Freeman Supply, March 7, 2011). The contour of foam seat geometry can be machined into this surface so it can be compared to the foam construction.

In this experiment, a RenShape™ board was machined like the contour shape of the foam seat, and used as the seat material for the “least comfortable” chair.

Additionally, a plastic production backrest was used on the “least comfortable” and

“semi-comfortable” chairs, while a mesh material back was used on the “most comfortable” chair. The expectation was that the mesh back-foam seat would be more comfortable than a plastic back-foam seat and a plastic back-RenShape seat (Figure 13).



Figure 13. Variation of materials used in office chairs

2.5.3 Typing

Typing is one of the common tasks performed in the office environment since most offices are equipped with personal computers or laptops. There are different ways that people type. Some workers are touch typists who do not need to look at the keys as they type. Others type with two fingers, while others may do some combination of those two methods. Straker et. al. (2009) used a typing test to simulate office work while collecting data from office workers. They calculated the syllabic intensity of each typing

test so the mean syllables per word were similar between tests. A similar strategy was used in this experiment (see Appendix B. Typing Test).

Software exists to collect typing data and statistics (words per minute, errors per minute, etc.) TypingMasterPro (Helsinki, Finland) was chosen by Straker et. al. because it had different texts to choose from and collected typing data in an efficient manner. Appendix B displays a sample report and results from this software.

2.5.4 Mousing

Using a computer mouse is a second common computer activity that office workers engage in during the day (Dennerlein & Johnson, 2006). Mousing involves primarily using the computer mouse to move the cursor around the screen to perform different tasks. For this experiment, six different clip art images from Microsoft® Office® (Figure 14) were used as samples that participants were instructed to replicate using Microsoft Paint. This portion of the testing allowed for the user to interact primarily with the mouse and assume a posture that workers would have when only doing mousing work.

The clip art images were chosen so that they would be challenging for the participants and take about 10-15 minutes to complete. A pretrial test was conducted to ensure that each picture took the expected time. Samples of images created by all subjects can be found in Appendix C. Images drawn by each participant.

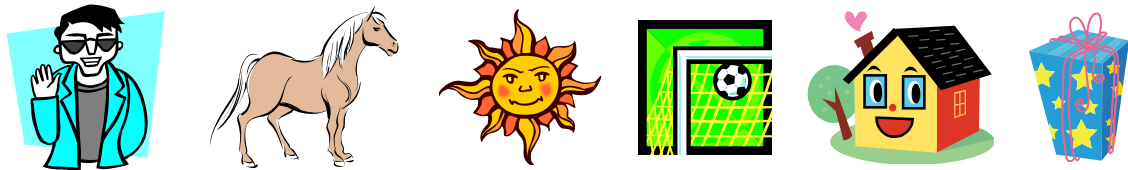


Figure 14. Six clipart images that were used for the mousing (paint) exercise

2.5.5 Typing and Mousing

Many times office workers will use the mouse to browse the web for information and then type results in a report. The combination of mousing and typing creates different postures and movements that are common in the office workday. The final task that was chosen for participants to complete in this experiment involved a combination of keyboarding and mousing. For this particular task, participants were given specific topics to research on the Internet and then create a presentation of four to five slides on their findings. Appendix D: Research Topics lists the instructions and research topics that were given in this experiment.

2.5.6 Randomization and Assignment of Tasks

In this experiment, tasks were chosen to simulate office work rather than to measure productivity or assess the effect of the tasks on comfort. To minimize an order effect of the tasks, or fatigue because of the order of tasks, each of the three tasks (mousing, typing, and research) were randomized using JMP 9.0 Software (SAS, Cary, NC) for each subject, each chair, and each day. Future studies could investigate the effect of tasks on comfort. Understanding if certain tasks allow people to feel more comfortable or if a more comfortable chair will help to make someone more productive at typing and doing office work could provide some important data.

2.6 Correlating Objective and Subjective Measures

After identifying the appropriate measures to use in a comfort/discomfort study, the next challenge is finding a correlation between the objective and subjective inputs. This task has proven to be challenging for researchers because some measures correlate better with comfort or discomfort than others, and it has been difficult to determine the best objective tools.

Other studies done on comfort and discomfort have been small, pilot-type, or poorly designed studies that have not shown significant correlations between subjective measures of comfort/discomfort and objective measures (Oudenhuijzen et al., 2003). For example, Bishu et. al. (1991) looked at spinal shape and discomfort, but did not use enough subjects and was not consistent in his experimental protocol.

Other studies seem to contradict each other: Lee et. al. (1988) used 12 subjects and showed any significance in back EMG fatigue and user discomfort, but Salewytsh and Callaghan (1999) had a study with 14 subjects that did not show any significance with EMG and spinal position.

Some researchers using objective measures have shown correlations that are statistically significant, while most have not. Lee et. al. (1988) showed a significant correlation between EMG and comfort, while Thakurta et. al. (1995) and Demontis and Giacoletto (2002) showed a correlation between seat pressure and comfort.

Some studies were thorough in their protocol and used several subjects to collect data. Frusti and Hoffman (1994) used 140 subjects and Park et. al. (1998) used 75 participants. These researchers were able to show simple linear models that predicted automotive comfort based on ratios of pressures in the seat and back.

Past subjective-objective measurement studies have only looked at one or two objective measures at one time. If more objective tools were used in the same study, there may be a better chance to understand the correlations between subjective-objective-comfort-discomfort (de Looze et al., 2003).

Additionally, regarding subjective measures, the literature reviewed does not show any researcher who has reported results that follow Zhang's model of asking both comfort and discomfort questions. Most have used a linear model of comfort and discomfort to assess people's feedback.

2.7 Models and Neural Networks

Neural network (NN) models are based on a model of the activity in the human brain. We have neurons that connect to each other—some neurons have multiple connections to other neurons (Figure 15). These neurons communicate with each other and begin to learn patterns that are similar or distinct and create forecasts or predictions of future events. Neurons allow us to remember past events and apply knowledge to current experiences. Computationally, artificial neurons are connected to other neurons in layers. The first layer is called the input layer. These input neurons receive information from the outside world and are usually interconnected to at least one hidden layer of neurons. This interconnection provides for the learning and non-linearity that occurs in artificial intelligence. The neurons that output predictions or forecasts are called the output layer (Engelbrecht, 2007).

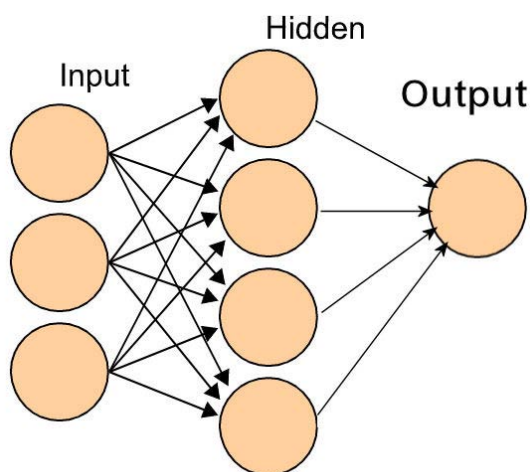


Figure 15. Visual model of a neural network.

A few researchers have used computational intelligence to predict seated comfort or discomfort (Kolich, 2004; Loslever & Lepoutre, 2004). Kolich used a neural network to predict comfort using both subjective surveys and objective measures (pressure mapping, anthropometry, and demographic variables.) Loslever used fuzzy logic coding to find correlations between objective and subjective measures of participants in a seated posture.

Using pressure mapping and chair height as example input neurons (variables), connections can be made in the neural network to weight the contribution that each has to a comfortable chair. As these contributions are computed, a hidden layer can be added to account for the non-linearity of comfort. As the output is computed as “comfortable”, the NN will learn this pattern (what settings and interactions on the pressure map and chair height contributed to the output.) The NN will continue to learn as more and more data is added to the model, and comfort is predicted.

Using NN can help to combine objective and subjective measures in a way that is efficient, creative, and more realistic. It has promises to be a better tool than iterative surveying of participants on comfort or discomfort (Kolich, 1999). At this point, NN has only been used with automotive seating, and researchers have not used it to combine objective and subjective measures to predict comfort.

CHAPTER 3. DISSERTATION AND HYPOTHESIS

Given that comfort and discomfort are important concepts for designers, engineers, ergonomists, manufacturers, and consumers, understanding how to measure them can benefit many people. Research has been realized on many separate measures, but has not looked at using a neural network to combine objective and subjective data in predicting comfort in an office setting. Additionally, subjective surveys of comfort and discomfort have had conflicting reviews, yet no one has looked at measuring both comfort and discomfort subjectively at the same time, and combine results with objective measures to predict a comfort model.

This research will attempt to show that a neural network can be created to predict comfort and discomfort using both objective and subjective measures for a participant using an office chair. The solution will ask both comfort and discomfort questions, look at anthropometry and physiological measures of the participants, record settings on the chair, and measure seat and back pressure.

3.1 Scope of the Dissertation

This dissertation will be evaluating a predictive model for office chair comfort using neural networks, and subjective and objective measures. It will not be comparing the office chair to the car seat, but the data and understanding gained may help to drive a future comfort-discomfort model that will account for any type of seat. The measures used will be both objective and subjective. We are not analyzing all of the parameters of the design in a chair that could affect comfort. There are many. We are choosing certain ones that we feel were pertinent to the scope of the problem to find a model that is able to predict comfort and discomfort. Further refining is expected to be done to the model later, adding more variables into the calculations.

Additionally, the research in this dissertation is not looking at how comfort and workload affects productivity in an office. High workload may make comfort irrelevant

for perception but not for productivity. Studies and conclusions related to comfort, workload, and productivity can be investigated in the future.

3.2 Main Hypothesis:

A neural network model will be able to accurately predict comfort and discomfort levels by assessing subjective and objective measures. A linear model will not predict comfort and discomfort levels as accurately.

3.2.1 Sub-Hypotheses:

1. Comfortable chairs will be rated higher than uncomfortable ones
2. Non-linear questions will correlate better than linear questions
3. There will not be a significant comfort rating difference between genders
4. Comfort will disappear over time and discomfort will increase

This dissertation will test these hypotheses through the methodology explained in detail below.

CHAPTER 4. METHODOLOGY

4.1 Experimental Setup

Three modified Allsteel Relate® office chairs were used to assess seated office comfort and discomfort. The chairs were identified as Chair B, Chair P, and Chair R.



Figure 16. Three experimental chairs with pressure mapping pads. From left to right, Chair B, Chair P, and Chair R.

Each chair was chosen to have characteristics that created a condition of comfort or discomfort for the user. Chair B was designated as the “most comfortable” chair with all of the adjustments and materials that should elicit as comfortable a response as possible. Chair P was designated as a “semi-comfortable” chair that had some good elements and adjustments that would elicit comfortable responses, but it also had elements and adjustments that are supposed to achieve a less than comfortable response.

Chair R was chosen to have the fewest adjustments and specific materials that were expected to create an uncomfortable situation for most users.

Table 3. Features on experimental chairs

Feature	Chair B	Chair P	Chair R
Seat height adjustment	Yes	Yes	Yes
Armrest height adjustment	Yes	Yes	Yes
Backrest movement	Pivoting with lumbar adjustment	Pivoting, no lumbar adjustment	No pivot, no lumbar adjustment
Backrest material	Mesh	Plastic	Plastic
Seat material	Upholstered	Upholstered	RenShape ³

Data for different chair parameters were taken for each seated subject at the start and end of each chair comfort test. The information collected on each chair included: seat height, seat depth, armrest height, and whether the recline was locked or unlocked. These adjustments allowed each chair to be fitted for each participant's anthropometry and were used in the computation comfort model.

Prior to beginning data collection, permission was obtained from the University of Iowa Human Subjects Office/Institutional Review Board (IRB) to conduct research using human subjects (IRB ID# 201011724, Approved 12/02/2010). Data were collected at Allsteel headquarters, in Muscatine, Iowa on individuals who had varying levels of office experience, were between the ages of 18 and 65, and had a mixture of heights, and weights. Height, weight, gender, and a calculated value of Body Mass Index (BMI) were

³ Brand name for CNC tooling board manufactured by Freeman Manufacturing, Avon, Ohio(Freeman Supply, March 7, 2011).

used as inputs into the comfort models. Informed Consent forms approved by the IRB were provided to subjects and signed prior to starting data collection (see Appendix E. Informed Consent Forms).

Physiological measurements of each individual were taken at 10 Hz using the BodyMedia® SenseWear® Pro armband (Figure 10) while participants worked in each chair. The data collected included: skin temperature, near body temperature, galvanic skin response (GSR), heat flux, and arm acceleration (longitudinal and transverse).

X2 Pressure Mapping pads from Xsensor Technologies (Calgary, Canada) were placed on the backrest and the seat of each chair to measure the pressure distribution while participants sat and worked. Each pad had a total of 1600 sensors, with one every 0.5" on a 20"x20" grid. Before testing began, each pad was calibrated according to Xsensor calibration procedures (Xsensor Technologies, 2004).

The pads were placed in a consistent location on each chair for repeatable and comparable pressure measurements. Data were measured at 2 Hz for a maximum of 60 minutes, or 7200 frames. The pressure range for the pads was 10 – 220 mmHg, which is a normal range for seated measurements (Xsensor Technologies, 2004). The parameters that were used as inputs into the computational models included:

- Peak Pressure (PP) for seat and back (SPP, BPP)
- Average Pressure (AP) for the seat and back (SAP, BAP)
- Center of Pressure (COP) for the seat and back (SCOP, BCOP)
- Contact Area (CA) for the seat and back (SCA, BCA)

Additionally, the seat and back pressure maps were sub-divided into different regions as other researchers had done previously (Demontis & Giacoletto, 2002; Frusti & Hoffman, 1994).

The backrest was divided into four areas:

1. Upper back (UB)
2. Lower back (lumbar) (LoB)

3. Right back (RB)
4. Left back (LfB)

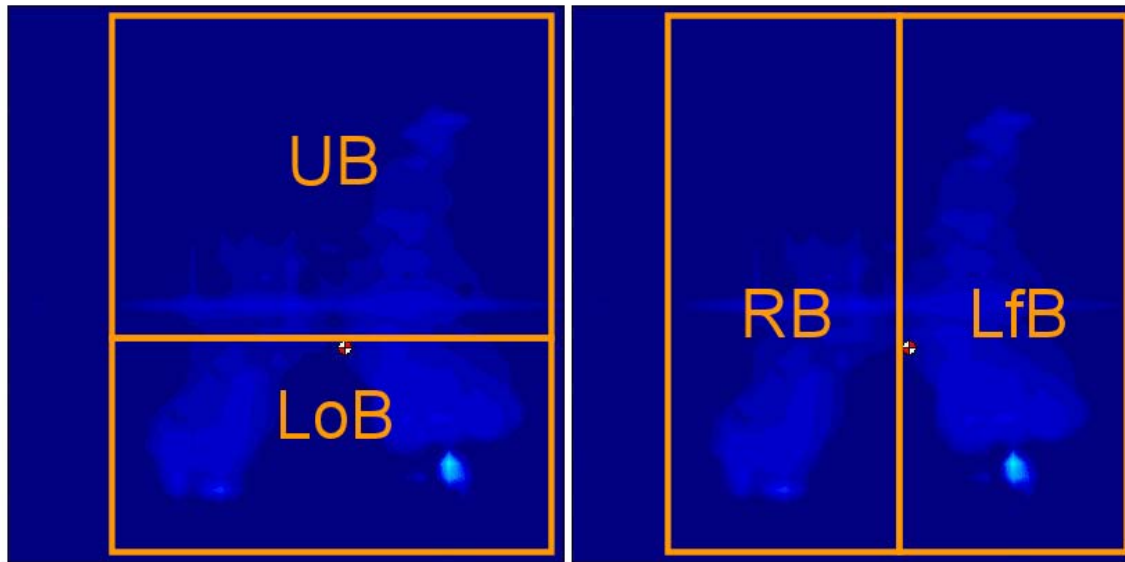
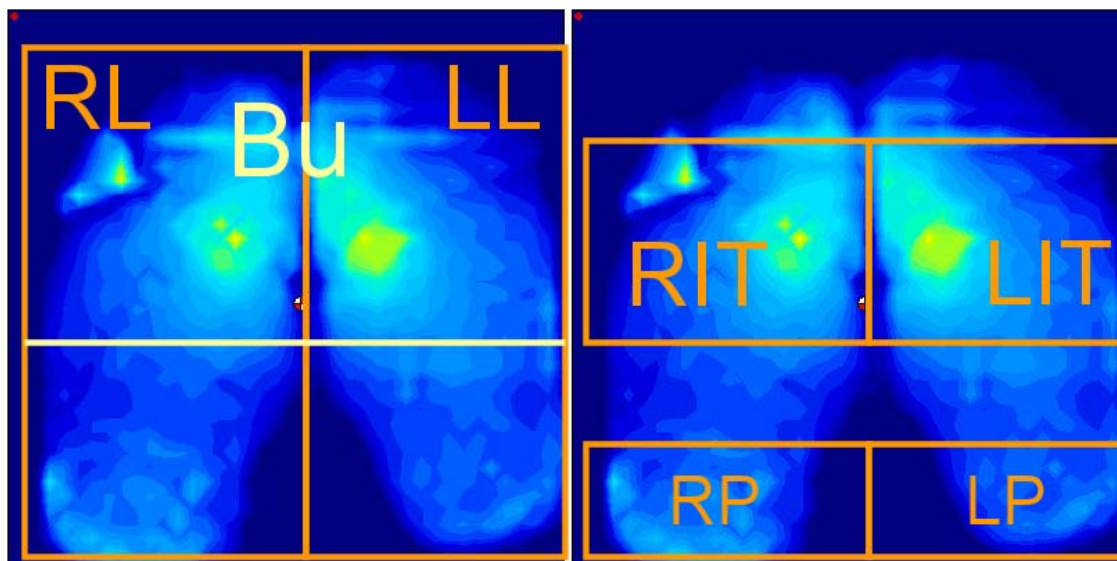


Figure 17. Four sub-regions for the back pressure map.

The seat was divided into seven different areas:

1. Right leg (RL)
2. Left leg (LL)
3. Buttocks (Bu)
4. Right ischial tuberosity (RIT)
5. Left IT (LIT)
6. Right popliteal (RP)
7. Left popliteal (LP)



NOTE: Left image shows the three larger divisions for sub-regions of the seat. Right image shows the four smaller sub-regions. RL/LL = right/left leg, Bu = buttocks, RIT/LIT = right/left ischial tuberosity, RP/LP = right/left popliteal.

Figure 18. Seven sub-regions for the seat pressure map.

The same measures (PP, AP, and CA) were used with these subdivisions to model comfort. The COP measurement was calculated for the whole seat and whole back, not for the individual sub-regions.

Subjective measures were collected by using two different surveys. One survey was the non-linear questionnaire proposed by Helander and Zhang (1997), combining comfort and discomfort questions on a 9-point scale (Figure 6). The other survey was the GCR scale (Figure 5), suggesting a linear relationship between comfort and discomfort as proposed by Shackel et. al. (1969). The researcher added a 9-point scale to each of the GCR questions to gauge the intensity of the participants' comfort or discomfort. Since the questions are on a linear scale, it would be expected that while sitting in the "most comfortable" chair (Chair B), subjects would rate the "I feel comfortable" question near

the higher values (7-8-9) of the spectrum, and the “I feel uncomfortable” question in the lower values (3-2-1). For the “least comfortable” chair (Chair R), the values should be switched, and for the “okay” chair (Chair P), they should be in the middle. Adding this Likert scale will allow researchers to see the correlation between the linear responses and understand if some of the questions in the GCR are irrelevant when assessing comfort and discomfort.

Additional questions were also asked about the participants’ rating of the fit and comfort of the seat, backrest, armrests, and the chair overall (Appendix F. Comfort Survey). These questions were used to assess if the chair was adjusted properly for the subject and to see if additional comfort ratings would correlate with the linear and non-linear models by Shackel and Helander.

Surveys were created with Microsoft SharePoint® software and hosted on an Intranet site accessible at the computer as participants sat in the test chair. Participants filled the comfort surveys twice for each chair test—at the beginning of testing and at the end.

Two workstations were setup to run two subjects simultaneously. Each workstation had an experimental chair, the pressure mapping and BodyMedia equipment, as well as a computer, monitor, keyboard, and mouse. An additional computer was used by the researcher to collect the pressure mapping data and record observations (Figure 19).

4.2 Data Collection

Data were collected on 36 participants in a controlled office environment. Eleven of the participants were employed by the company who funded this study (Allsteel) or its sister company HON. The other 25 participants were recruited by the researcher. Participants were selected based on their heights, weights, and ages to give a distribution

similar to current United States demographics; gender distributions were similar to the office worker population (US Department of Labor and Statistics, December 2010).



Figure 19. Workstation setup with participant, chair, computer, monitor, keyboard, and researcher computer.

After being briefed on the experimental details and signing the necessary IRB forms, subjects were shown how to adjust their chair properly for an ergonomic fit so that each subject would be sitting in the optimal posture and chair settings that fit them. This removes errors that may occur if the chair is adjusted incorrectly during the testing and the individual is uncomfortable because of maladjustment and not fatigue or chair

materials. They were then introduced to their workstation, adjusted their chair to fit their body, and shown how to fill out the electronic SharePoint survey using the Demonstration Survey (see Appendix G. Demonstration Survey). Participants then placed the BodyMedia SenseWear armband on their arm, and began answering the Demographics Survey (see Appendix H. Demographics survey). At this same time, the researcher also filled out the Researcher Survey to collect environmental and chair adjustment data (see Appendix I: Researcher Data Entry).

After completing the Demographics Survey, the pressure mapping data were started and participants were instructed to begin with the initial, or short-term, Comfort Survey (see Appendix F. Comfort Survey). The initial survey recorded the user's first impression and experience with the chair's comfort and would be used to compare to the same survey given at the end of the chair testing.

After completing the survey, they were given their three office-related tasks which were randomly ordered: typing test, paint task, and research task. The typing test was timed for 10 minutes. The paint and research tasks were each allotted a maximum of 15 minutes to complete. Files for each task were saved to a hard drive to compare productivity results by chair and task at a later date, since productivity is not directly related to this dissertation (Appendix B. Typing Test).

After completing the three tasks, the participant completed the Comfort Survey for their long-term sitting test. The researcher completed the final Researcher Survey at the same time and measured the environmental and chair parameters after the 45 minutes of testing—to record if they had changed.

The participant was given a 10 minute break to stand and walk around. During this time the researcher switched the experimental chair according to the randomized order and prepared the workstation for the next test sequence. After the break, the participant was instructed to adjust the chair to his/her ergonomic preference and then complete the initial, or short-term, Comfort Survey.

The researcher completed the initial Researcher Survey at the same time. The same procedures done with the first chair were repeated for the second and third chairs. Once users completed the final Comfort Survey for the third chair, they were paid a \$50 American Express gift card for their participation and dismissed for Day 1 of testing. Participants who were Allsteel or HON Company employees were not compensated with a gift card, but were paid their normal wage because they were at work during the testing.

The user returned a day (or more) later and completed the same procedure as Day 1 in a randomized order, and received the same compensation. Pictures and video were taken to record postures, interactions with the chairs, and other pertinent information. Notes were also recorded to document postures, unique situations, or anomalies.

CHAPTER 5. RESULTS

5.1 Incorrect Calibration Files Assigned

After data were collected on the 36 subjects over a four-week period, the researcher realized that the calibration settings for the pressure pads on Chair B in one of the two workstations had been incorrectly set in the software. For the subjects that used that particular workstation, the pressure pads on Chair B recorded data with the wrong calibration files, so pressure values were invalid for analysis. After discussing options with Xsensor Technologies, the pressure system manufacturer, the only way to remedy the data collection error was to bring the affected participants back to re-record their tests for that chair.

A few other pressure pad readings on the other chairs were also identified as having unusable data, totaling 23 different readings that needed to be re-recorded (16 for Chair B, 5 for Chair P, and 2 for Chair R). A total of 16 subjects were asked to return, and 14 were able to redo the testing. Due to time constraints and schedules of participants, only the affected chairs were retested, rather than re-running every chair.

The same testing methodology and procedure was used for retesting, including the original order in which the subjects performed their office tasks. Participants were compensated with two free movie tickets upon completing their retesting. Pressure mapping data were not compared between the first round of testing and the retesting to show the differences because there was no way to compare the invalid data to the new set.

5.2 Averaging Blank Pressure Mapping Cells

Occasionally during recording of pressure mapping data, particular rows or columns failed to record the pressures in their cells, and a resultant dark blue line would show up in the pressure map image (Figure 20). The cause of this recording anomaly was due to an electrical short in the pressure mapping cables that connect to the computer.

Leaving the dark lines in the data analysis would affect calculation of the regions in the affected seat and back. After discussing the issue with Xsensor Technologies, they stated that a common practice when this occurs is to average the values from the line above and below the affected row. The averaging would allow the missing values to be inserted so that they would give a better representation of the pressure map.

A Visual Basic for Applications (VBA) program was written to read each pressure mapping file, search for rows that were blank and then replace the affected cells with the average of the row above and below (Appendix J. Code for Data Processing). The modified file was then saved and ready for data analysis. Figure 21 shows the result of averaging row 28 on the backrest and row 24 on the seat of Figure 20. The modified file correctly displays a fluid pressure map. 1.8% of the approximately 99 million combined rows in all the pressure mapping files were modified.

There were also a few cells with missing values (where most of the row was recorded correctly) in some of the files. The same program in Appendix J was used to find an individual cell that was blank and surrounded by other cells with values. If a “hole” was found, the program would average the cell above and below that “hole”. Less than 0.04% of all the cells were affected by this anomaly.

5.3 Top Corner of Backrest Pressure Map

In order to keep the backrest pressure map in place, it was draped over the backrest using a sleeve that was sewn to the fabric edges of the pressure pad. This sleeve made it easy to position the pad on the backrest without having to tape or pin it in place. When people sit against a pressure pad on the backrest, sometimes their weight pulls the pad downward toward the seat.

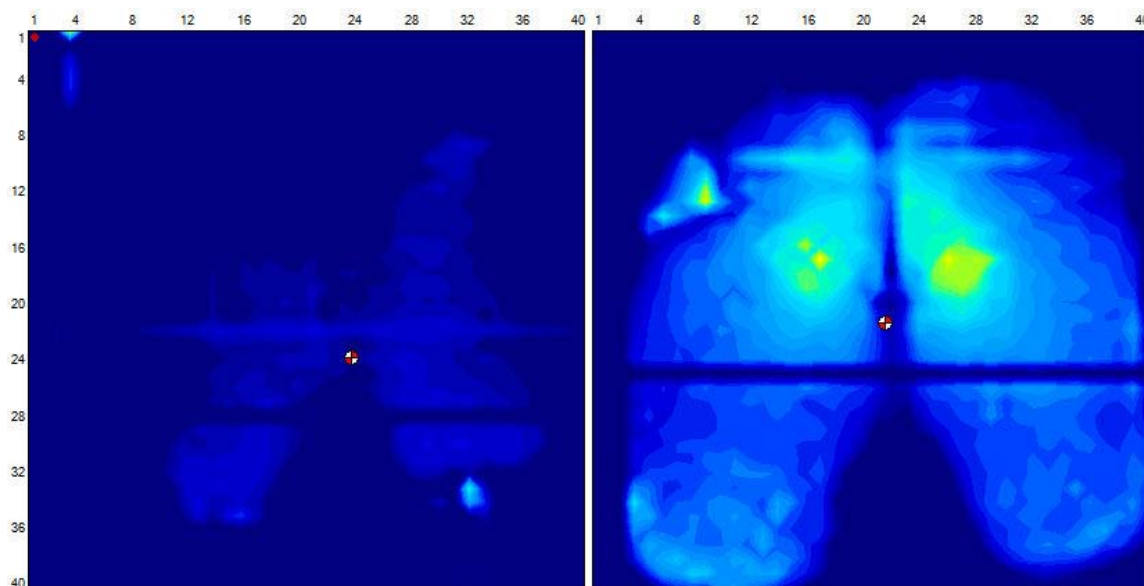


Figure 20. Pressure map with empty rows and non test-related pressure values

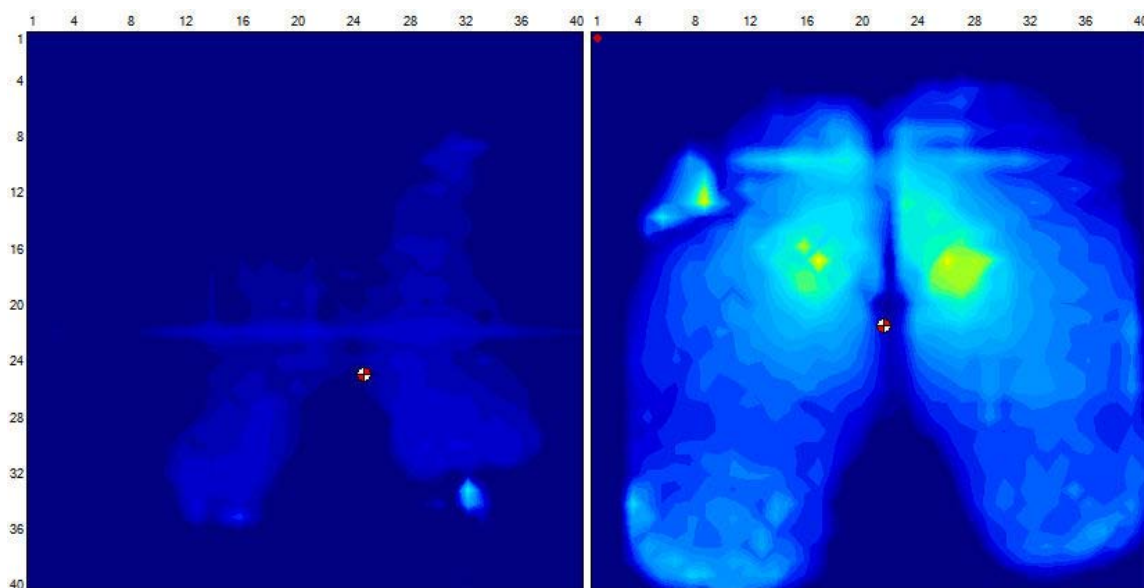


Figure 21. Pressure map after data cleanup

When the backrest pad is pulled downwards during sitting, some of the cell arrays in the top corner of the pad show pressure readings from the interface between the backrest's top corner and the pad. These readings are not related to the pressure the person is putting on the backrest and can alter the pressure map calculations if not fixed. Having a high extra pressure in the top corner, away from the participant's back will cause the backrest's center of pressure calculation to be skewed toward that corner. If the extraneous pressure is removed, then the correct COP will be calculated, as well as average and peak pressures.

To remove the non-related corner pressures, a visual inspection of each pressure pad was done to determine the presence and size of the corner array. The coordinates were then read into a VBA script that read the pressure mapping text file and remove the area based on the coordinates. All 209 pads had values that were removed from the top corner. Figure 20 shows an array of pressure reading in the top left corner of the backrest pad. After the VBA script is run, the pressure readings are gone from the map (Figure 21).

The calculated computer processing time to rectify the pressure map data files with the averaging of rows and holes, and eliminating the non-related corner pressures took a total of 7.13 days, but because the task was divided up over 4 computers, it took an average of 49 minutes per file and completed in 42 hours.

5.3 Demographics

Data on 35 (M=15, F=20) subjects (43% M, 57% F) are reported in the results. Subject 14, a male, had only one chair dataset that recorded correctly, and because he was unable to rerecord the other five chairs, his data were excluded from the analysis. The following graphs show distribution of height, weight, and age for all genders combined. Distribution of demographics by gender can be seen in Appendix J. Code for Data Processing.

Table 4. Age ranges, genders combined

Age	Count	Probability
18-24	7	0.20000
25-34	6	0.17143
35-44	9	0.25714
45-54	7	0.20000
55-64	4	0.11429
65-74	2	0.05714
Total	35	1.00000

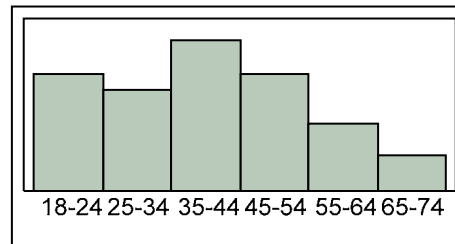


Table 5. Height ranges, genders combined

Height	Count	Probability
Below 5'	1	0.02857
5' to 5'2"	3	0.08571
5'3" to 5'5"	7	0.20000
5'6" to 5'8"	10	0.28571
5'9" to 5'11"	6	0.17143
6' to 6'2"	5	0.14286
Above 6'2"	3	0.08571
Total	35	1.00000

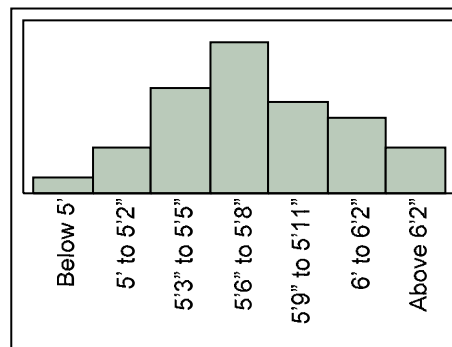


Table 6. Weight distributions, combined genders

Weight	Count	Probability
100 to 115	2	0.05714
116 to 130	1	0.02857
131 to 145	4	0.11429
146 to 160	5	0.14286
161 to 175	2	0.05714
176 to 190	4	0.11429
191 to 205	5	0.14286
206 to 220	4	0.11429
221 to 235	4	0.11429
236 to 250	2	0.05714
Above 250	2	0.05714
Total	35	1.00000

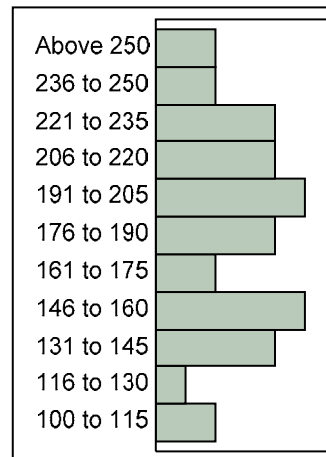
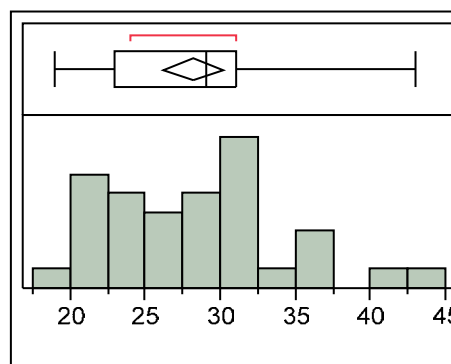


Table 7. Estimated BMI, both genders

Estimated BMI	
Median	29
Mean	28.142857
Std Dev	5.7810179
Std Err Mean	0.9771704



5.4 General Observations

Participants took 47.4 minutes ($SD=6.24$) on average to complete each chair test. The initial survey and final survey took 3.5 minutes ($SD=1.26$) and 3.3 minutes ($SD=1.18$), respectively to complete, or about 14% of the total testing time. Table 8 shows the details for the time it took for subjects to complete each chair test, office task, and comfort survey.

Table 8. Average times to complete testing and tasks

TASK	Frames	Time (min)	SD Time (min)	Min Time (min)	Max Time (min)
FULL TEST	5683	47.4	6.24	29.0	57.7
INITIAL SURVEY	420	3.5	1.26	0.0	6.7
PAINT TASKS	1613	13.4	2.24	9.0	16.9
RESEARCH TASKS	1712	14.3	2.24	7.6	17.7
TYPING TASKS	1220	10.2	0.73	5.0	11.8
FINAL SURVEY	391	3.3	1.18	1.4	8.1

There was no significant difference between those participants who were employees of Allsteel, and those who were recruited separately ($p > 0.05$). In general, office furniture company employees rated Chair B higher in comfort and Chair R lower in comfort than non-employees, but the differences were not significant.

Participants sat in many different postures, but there were a few that were common (Figure 22). While taking the start and end surveys, participants were more relaxed and only used the mouse to navigate. The other hand was either resting on the worksurface or under their chin. During the typing task most sat more upright and rested

their wrists and forearms on the end edge of the worksurface. In the paint task, some were relaxed and reclined as they worked, while others perched forward and leaned toward the screen. Most used the mouse during this task, and not the keyboard. While working on the research task, participants would vary their posture depending on whether they were researching information on the Internet or typing text for their presentation. Postures during Internet research were either more relaxed and reclined or perched and leaning forward, only using the mouse. When they typed, postures changed to be more upright and less relaxed. Additional images of postures can be found in Appendix L. Images of Subjects and Postures.



Figure 22. Common seated postures during testing

5.5 Environmental Variables

Measurements were taken in the winter of 2010, so ambient temperatures were relatively warmer in the building, but still within the typical temperature range of an office. Humidity and lighting values also fluctuated depending on the weather outside (relatively higher humidity values on days that it snowed, and lower lighting value readings when it was overcast). The two workstations were not near open windows and only received indirect lighting from the outside. Average, minimum, and maximum values for environmental variables by day are listed in Table 9.

Table 9. Environmental variables

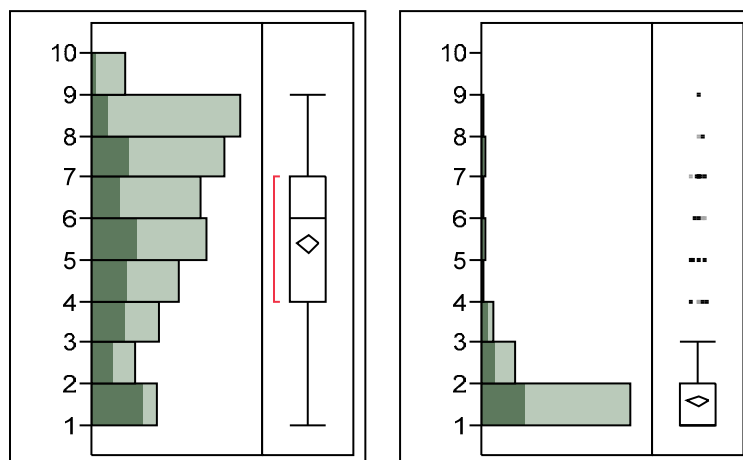
Environmental Variable	Day	Min	Max	Mean	SE
Temperature (°C)	1	22.5	25.5	23.7	0.035
	2	22.7	24.5	23.6	0.022
Lighting (lx)	1	136	218	175.5	1.413
	2	132	228	176.9	1.535
Relative Humidity (%)	1	2.0	30.8	11.1	0.376
	2	1.5	29.0	12.6	0.409

5.6 Subjective Results

5.6.1 Alpha values and GCR Results

A total of 38 subjective questions were asked in the initial and final surveys for use as responses in the comfort models. During data analysis, it was apparent that not all responses were different between chair tests. A number of responses showed distributions

that were skewed toward one side of the nine-point scale, regardless of the chair being tested. Other questions displayed a wide range of answers, as was expected (Figure 23).



Note: Left image: “I feel perfectly comfortable” Right image: “I feel unbearable pain”. Responses based on a nine-point scale. Darker shading represents the frequency of responses for Chair R. The lighter shading is for Chairs B & P.

Figure 23. Distributions for GCR questions #2 (left) and #11 (right)

A one way ANOVA tested the statistical difference for each of the 38 subjective responses by chair (3 levels), day (2 levels), survey time (2 levels), and gender (2 levels). Using an alpha = 0.0001, results indicate significance for Chair and Initial-Final factors, but not Day or Gender (Table 10). All Day values (day 1 vs. day 2) had $p > 0.13$. For Gender, only questions 4 and 11 had $0.05 < p < 0.0001$; all others $p > 0.05$. Five of the eleven questions did not give significant results to assess comfort/discomfort.

The reason for choosing an alpha value of 0.0001 is illustrated in Figure 24. Since our data set included $3 \times 2 \times 2 \times 35$ or 420 lines, responses such as GCR question #11 show statistical significance ($p = 0.0049$), even though visually (Figure 23) the distribution was

Table 10. Statistical significance of responses for GCR questions

Question	Chair	Initial-Final	Gender
I feel completely relaxed*	$F(2,409) = 16.13$ $p < 0.0001^*$	$F(1,410) = 19.9$ $p < 0.0001^*$	$F(1,410) = 1.83$ $p = 0.1769$
I feel perfectly comfortable*	$F(2,409) = 35.84$ $p < 0.0001^*$	$F(1,410) = 13.53$ $p = 0.0003$	$F(1,410) = 1.04$ $p = 0.308$
I feel quite comfortable*	$F(2,409) = 31.48$ $p < 0.0001^*$	$F(1,410) = 14.53$ $p = 0.0002$	$F(1,410) = 1.27$ $p = 0.2609$
I feel barely comfortable	$F(2,400) = 9.12$ $p = 0.0001^*$	$F(1,401) = 5.24$ $p = 0.0226$	$F(1,401) = 11.98$ $p = 0.0006$
I feel uncomfortable*	$F(2,406) = 32.91$ $p < 0.0001^*$	$F(1,407) = 18.11$ $p < 0.0001^*$	$F(1,407) = 0.18$ $p = 0.6693$
I feel restless and fidgety*	$F(2,407) = 14.9$ $p < 0.0001^*$	$F(1,408) = 10.59$ $p = 0.0012$	$F(1,408) = 1.18$ $p = 0.2772$
I feel cramped	$F(2,409) = 6.55$ $p = 0.0016$	$F(1,410) = 9.35$ $p = 0.0024$	$F(1,410) = 0.46$ $p = 0.4993$
I feel stiff*	$F(2,407) = 12.9$ $p < 0.0001^*$	$F(1,408) = 20.47$ $p < 0.0001^*$	$F(1,408) = 0.51$ $p = 0.4766$
I feel numb (on pins and needles)	$F(2,409) = 5.46$ $p = 0.0046$	$F(1,410) = 10.32$ $p = 0.0014$	$F(1,410) = 1.69$ $p = 0.1948$
I feel sore and tender	$F(2,409) = 8.18$ $p = 0.0003$	$F(1,410) = 15.06$ $p = 0.0001^*$	$F(1,410) = 1.17$ $p = 0.2805$
I feel unbearable pain	$F(2,405) = 5.38$ $p = 0.0049$	$F(1,406) = 3.32$ $p = 0.069$	$F(1,406) = 5.57$ $p = 0.0187$

NOTE: * indicates statistical significance at $\alpha = 0.0001$

heavily skewed to the left. When plotting the differences of the means in the ANOVA, it was visually apparent (Figure 24) that there was a difference when the significance was p

< 0.0001 (Question 2), but not as visually apparent with $0.05 < p < 0.0001$ (Question 11). This alpha level was applied throughout the process of choosing significant subjective measures.

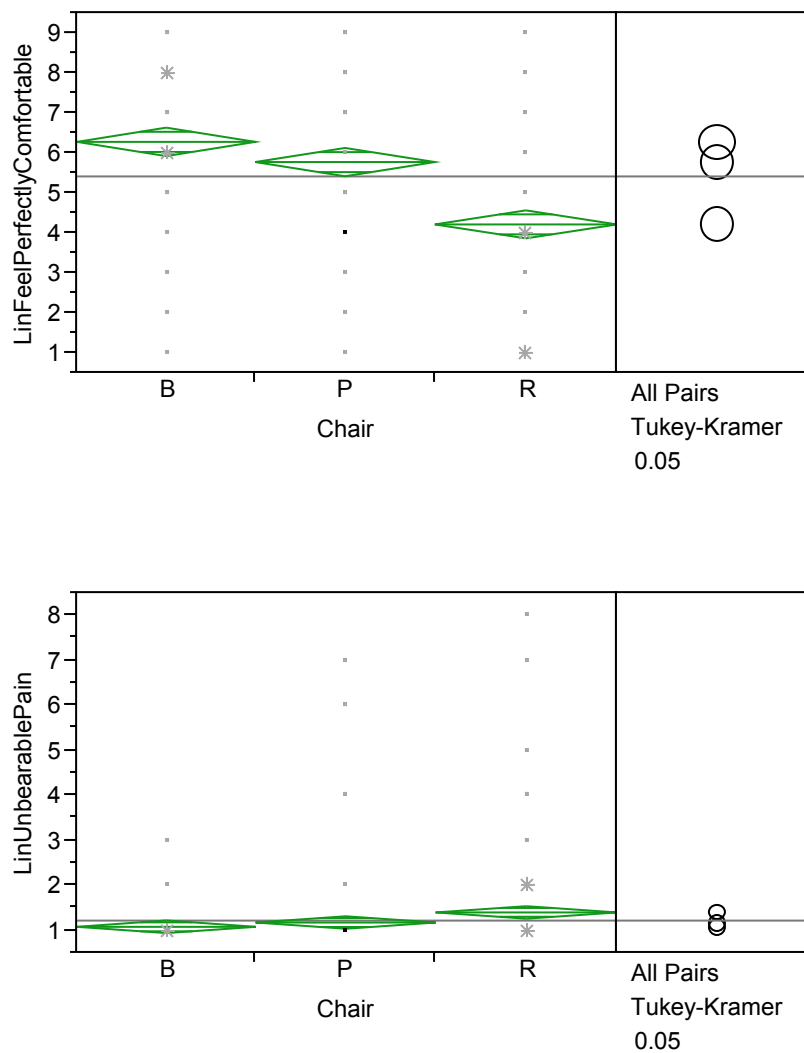


Figure 24. ANOVA for GCR questions #2 (top) and #11 (bottom)

5.6.2 Non-linear question results

The same methodology for choosing the significant responses with the GCR questions were applied to the Helander questions (Figure 6). One-way ANOVA results showed statistical significance with Chair and Initial-Final responses, but not with Day and Gender. (Table 11)

Table 11. Statistical significance of Helander discomfort-related questions

Helander Discomfort Questions	Chair	Initial-Final	Gender
I have sore muscles	$F(2,410) = 3.89$ $p = 0.0213$	$F(1,411) = 9.16$ $p = 0.0026$	$F(1,411) = 12.49$ $p = 0.0005$
I have heavy legs	$F(2,411) = 4.74$ $p = 0.0092$	$F(1,412) = 14.24$ $p = 0.0002$	$F(1,412) = 1.06$ $p = 0.3048$
I feel stiff*	$F(2,411) = 11.24$ $p < 0.0001^*$	$F(1,412) = 23.15$ $p < 0.0001^*$	$F(1,412) = 3.51$ $p = 0.0617$
I feel tired	$F(2,410) = 3.61$ $p = 0.0279$	$F(1,411) = 5.31$ $p = 0.0217$	$F(1,411) = 6.34$ $p = 0.0122$
I feel pain*	$F(2,411) = 9.18$ $p = 0.0001^*$	$F(1,412) = 27.28$ $p < 0.0001^*$	$F(1,412) = 1.55$ $p = 0.2144$
I feel numb	$F(2,407) = 2.47$ $p = 0.0861$	$F(1,408) = 10.74$ $p = 0.0011$	$F(1,408) = 2.98$ $p = 0.0852$
I feel uneven pressure*	$F(2,411) = 16.27$ $p < 0.0001^*$	$F(1,412) = 14.83$ $p = 0.0001^*$	$F(1,412) = 0.19$ $p = 0.6612$
I feel cramped	$F(2,410) = 2.92$ $p = 0.0549$	$F(1,411) = 7.39$ $p = 0.0069$	$F(1,411) = 4.54$ $p = 0.0337$
I feel restless	$F(2,409) = 5.89$ $p = 0.003$	$F(1,410) = 12.95$ $p = 0.0004$	$F(1,410) = 4.64$ $p = 0.0318$

NOTE: * indicates statistical significance at $\alpha = 0.0001$

Three out of the nine discomfort descriptors from Helander were statistically significant, and five out of the seven Helander comfort descriptors were significant responses (Table 12). The other two comfort descriptors were not expected to be significantly different. As expected, the question “Chair is spacious” elicited a similar response ($p = 0.3367$) because all three chairs had the same width and “spaciousness” to them. Secondly, the question “Chair looks nice” was not assessed by allowing participants to look at the aesthetics of the chair. It would have been too difficult to remove the pressure maps and reposition them during the testing in order to answer this question, so subjects answered this question without looking beneath the pressure pads. The data show $p = 0.0024$ for this response with Chair as a factor. Post hoc analysis with Tukey-Kramer showed a significant mean difference between Chair B ($M=6.69$ $p < 0.0001$), Chair P ($M=5.93$ $p < 0.0001$), and Chair R ($M=3.22$ $p = 0.0087$).

Despite the fact that all three chairs looked the same with the pressure pads on them (Figure 16), subjects were judging their perceived aesthetics based on their comfort or discomfort assessment. This was not really expected because it is different than was Helander found when looking at chair aesthetics (Helander, 2003). He saw that looks of a chair would elicit a response from subjects about its comfort (if it looked nice, people said it was more comfortable). In these results, subjects stated that the perceived aesthetics of the more comfortable chair were better than the chairs that were uncomfortable—without even seeing the chair’s design.

Through this elimination process, 22 out of the 38 subjective responses were chosen as significant contributors to assess comfort and discomfort between the three chairs.

Post hoc analysis using Tukey-Kramer HSD of the Chair and Initial-Final factors reflected the expected results. Comfort decreased from Chair B to Chair P to Chair R, but increased in discomfort from Chair B to Chair P to Chair R. For example with the response “I feel comfortable”, Chair B had the highest mean ($M=6.69$), followed by Chair

Table 12. Statistical significance of Helander comfort-related questions

Helander Discomfort Questions	Chair	Initial-Final	Chair
I feel relaxed*	$F(2,409) = 25.29$ $p < 0.0001^*$	$F(1,410) = 17.43$ $p < 0.0001^*$	$F(1,410) = 0.95$ $p = 0.3304$
I feel refreshed*	$F(2,405) = 21.19$ $p < 0.0001^*$	$F(1,406) = 29.9$ $p < 0.0001^*$	$F(1,406) = 2.61$ $p = 0.1068$
I feel restful*	$F(2,403) = 24.97$ $p < 0.0001^*$	$F(1,404) = 21.46$ $p < 0.0001^*$	$F(1,404) = 1.75$ $p = 0.1871$
Chair is spacious	$F(2,406) = 1.09$ $p = 0.3367$	$F(1,407) = 1.78$ $p = 0.1832$	$F(1,407) = 0.98$ $p = 0.3223$
Chair looks nice	$F(2,402) = 6.13$ $p = 0.0024$	$F(1,403) = 1.06$ $p = 0.3044$	$F(1,403) = 0$ $p = 0.9533$
Chair feels soft*	$F(2,403) = 246.14$ $p < 0.0001^*$	$F(1,404) = 0.88$ $p = 0.35$	$F(1,404) = 0.03$ $p = 0.8563$
I like the chair*	$F(2,408) = 102.79$ $p < 0.0001^*$	$F(1,409) = 3.03$ $p = 0.0825$	$F(1,409) = 0.06$ $p = 0.8116$
I feel comfortable*†	$F(2,403) = 96.49$ $p < 0.0001^*$	$F(1,404) = 10.24$ $p = 0.0015$	$F(1,404) = 0$ $p = 0.9594$
I feel uncomfortable*†	$F(2,409) = 80.92$ $p < 0.0001^*$	$F(1,410) = 11.19$ $p = 0.0009$	$F(1,410) = 0.46$ $p = 0.4999$

NOTE: * indicates statistical significance at $\alpha = 0.0001$; † questions not part of Helander's comfort-related questions, but added to this study for validation purposes

P ($M=5.94$), and Chair R ($M=3.33$) had the lowest comfort ratings (pairwise: B vs. R and P vs. R, $p < 0.0001$; B vs. P, $p = 0.0108$). For the "I feel uncomfortable" rating, Chair R had the highest mean ($M=5.25$), followed by Chair P ($M=2.60$) and then Chair B ($M=1.94$) (pairwise: R vs. B and R vs. P, $p < 0.0001$, P vs. B $p = 0.0475$) (Figure 25).

The subjective responses showed a significant difference between the initial sit test and the long-term sit test. Similar to the Chair responses, discomfort increased over time while comfort decreased (Figure 26). Initial responses for comfort/discomfort were similar to final responses for Chairs P & R ($R^2 > 0.70$), but not necessarily for Chair B.

Some subjects liked Chair B at first, but then did not rate it high at the end, while others rated it lower at the start than at the end. Correlation values for Chair B were $R^2=0.495$.

Data showed that there were no significant differences between the subjective responses given on Day 1 vs. Day 2. There also were no significant differences in responses due to gender.

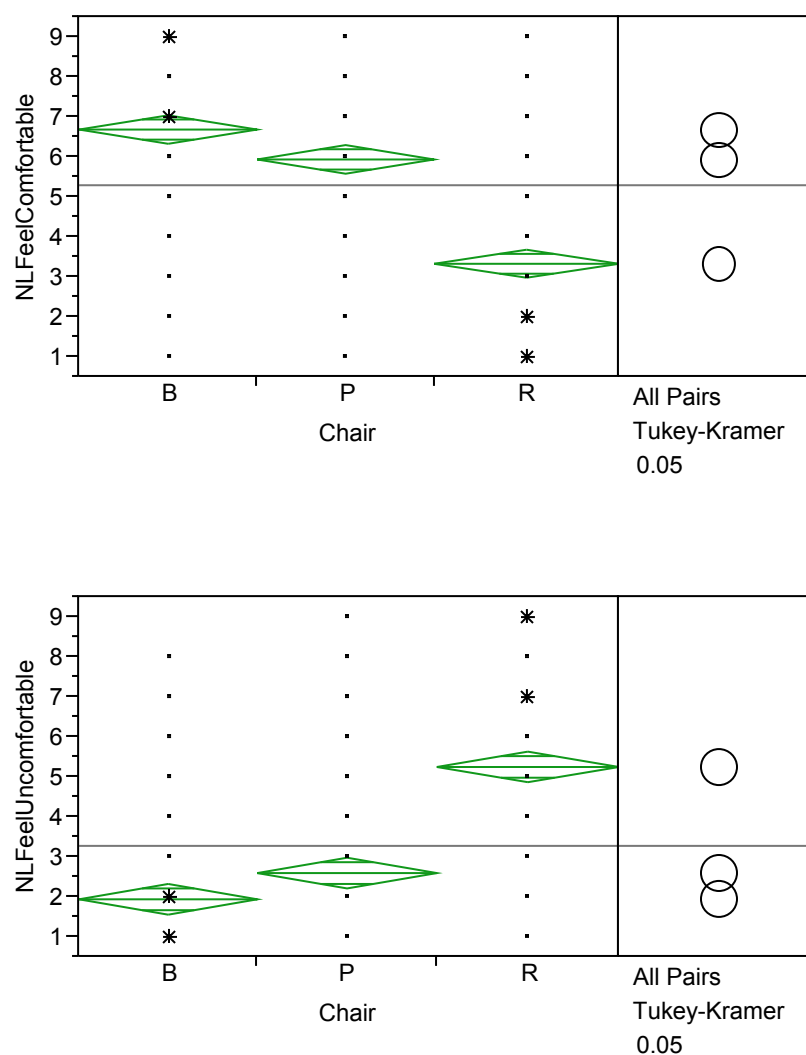


Figure 25. Differences between chairs in subjective responses

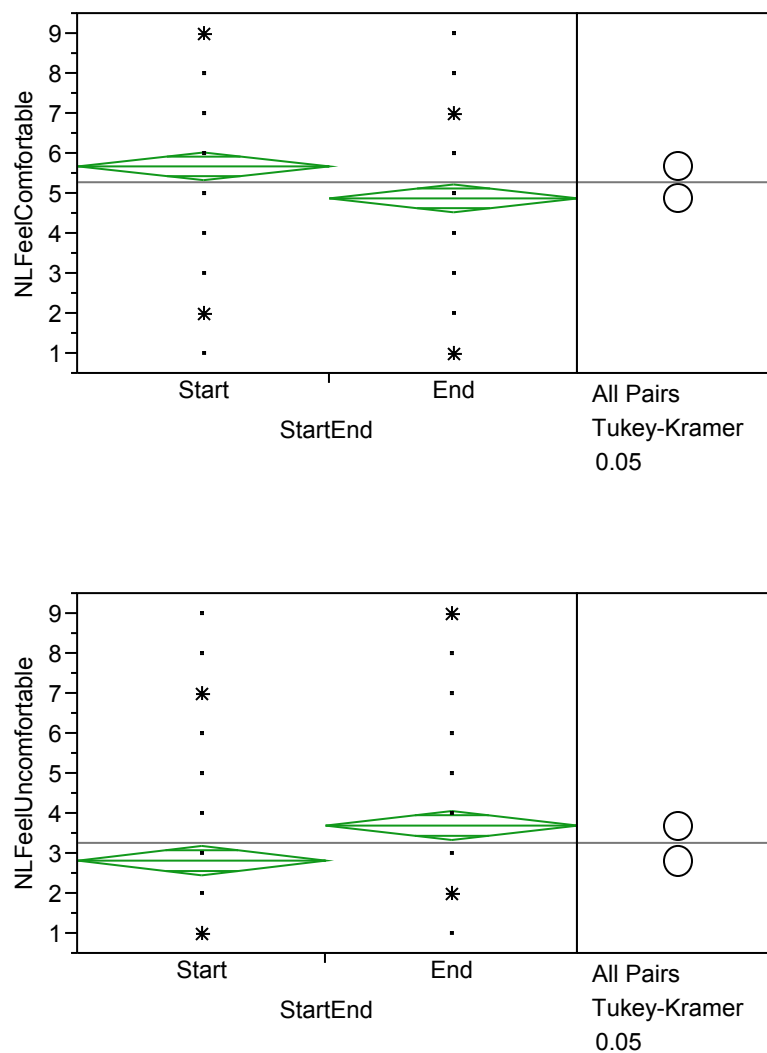


Figure 26. Subjective responses for short-term and long-term tests

5.7 Objective Results

A total of 132 different objective measures and calculations were collected in this experiment. Over 90% of those calculations were related to pressure mapping, while the other 10% were related to physiological measures. A one-way ANOVA was used with

the objective measures, just like it was used for discovering the most significant responses to the factors Chair, Day, Initial-Final, and Gender.

5.7.1 Pressure Mapping

In general, the pressure mapping results showed a significant difference with Chair and Initial-Final, an occasional difference due to subject body weight, but no significance with Day. There were a few categories where the Initial-Final factor was not significant. Gender was not significant, but weight was used as a factor for pressure mapping responses. When the seat or back was statistically significant, the corresponding sub regions for that chair part were also significantly different.

Figure 27 illustrates the difference between each pad (vertically from top to bottom, Chair B, P, and R) and the difference between the short- and long-term sits (left side is Initial, right side is Final). Additional images can be seen in Appendix M: Sample Pressure Mapping Images.

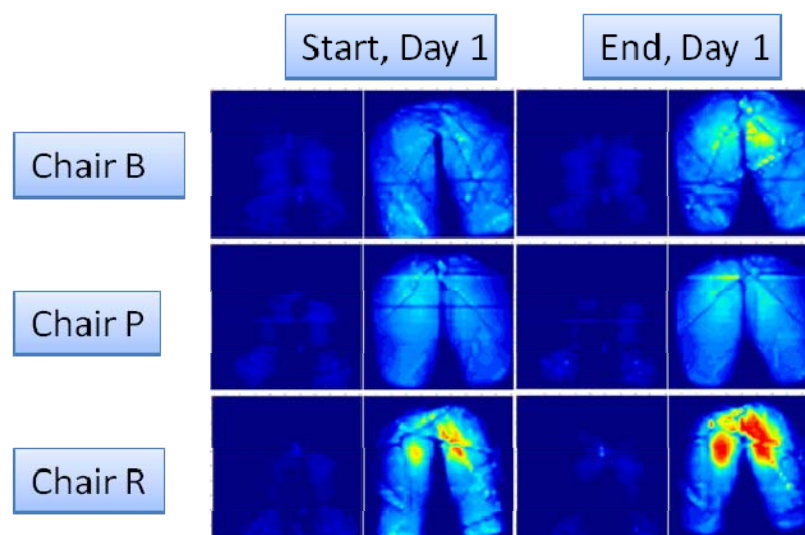


Figure 27. Pressure maps of Subject 28

Seat average pressure was significantly different between the factors Chair and Initial-Final, but was not significant for the backrest average pressure. The significance of the sub regions corresponding to the seat and backrest mimicked the general area (Table 13).

Figure 28 graphs the means for the Seat Average Pressure by Chair. Chair P has a significantly lower average pressure than Chair B and Chair R. Weight showed an upward trend, but weak correlation ($r = 0.15$) with seating average pressure Figure 29.

The rate of change of average pressure over each frame did not show statistical significance for any of the factors ($p = 0.6301$, Figure 30).

Maximum, or peak pressure, differed between chairs and also between the start and finish of the testing for the seat, but not the back. In a post hoc analysis, the significance shows that Chair P had less maximum pressure values than Chair B, and Chair R had the highest maximum pressure. There was not a significant difference between chairs for the Minimum Average Pressure condition. Table 14 displays the average pressures and pairwise comparison for each chair in the minimum and maximum conditions for the left ischial tuberosity sub-region.

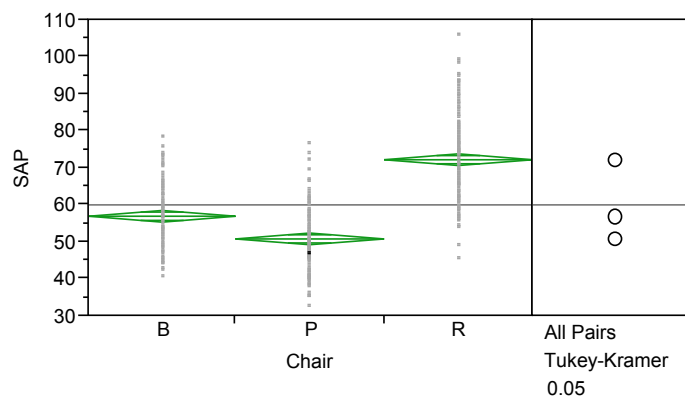


Figure 28. Average pressure (mmHg) for the seat, by Chair

Table 13. Statistical significance of average pressure

Pressure Map	Chair	Initial-Final	Weight	BMI
BAP	$F(2,415) = 8.7$ $p = 0.0002$	$F(1,416) = 0.91$ $p = 0.3411$	$F(1,416) = 0.36$ $p = 0.5494$	$F(1,416) = 5.44$ $p = 0.0202$
SAP*	$F(2,415) = 190.13$ $p < 0.0001^*$	$F(1,416) = 81.3$ $p < 0.0001^*$	$F(1,416) = 73.28$ $p < 0.0001^*$	$F(1,416) = 44.51$ $p < 0.0001^*$
LITA*	$F(2,415) = 312.42$ $p < 0.0001^*$	$F(1,416) = 55.19$ $p < 0.0001^*$	$F(1,416) = 24.23$ $p < 0.0001^*$	$F(1,416) = 5.88$ $p = 0.0158$
RITA*	$F(2,415) = 140.56$ $p < 0.0001^*$	$F(1,416) = 67.38$ $p < 0.0001^*$	$F(1,416) = 34.46$ $p < 0.0001^*$	$F(1,416) = 5.17$ $p = 0.0235$
BuA*	$F(2,415) = 266.93$ $p < 0.0001^*$	$F(1,416) = 69.72$ $p < 0.0001^*$	$F(1,416) = 31.73$ $p < 0.0001^*$	$F(1,416) = 8.04$ $p = 0.0048$
LLA*	$F(2,415) = 250.99$ $p < 0.0001^*$	$F(1,416) = 66.96$ $p < 0.0001^*$	$F(1,416) = 57.73$ $p < 0.0001^*$	$F(1,416) = 38.05$ $p < 0.0001^*$
RLA*	$F(2,415) = 106.34$ $p < 0.0001^*$	$F(1,416) = 83.23$ $p < 0.0001^*$	$F(1,416) = 79.42$ $p < 0.0001^*$	$F(1,416) = 44.55$ $p < 0.0001^*$
LPA*	$F(2,415) = 47.33$ $p < 0.0001^*$	$F(1,416) = 23.54$ $p < 0.0001^*$	$F(1,416) = 70.97$ $p < 0.0001^*$	$F(1,416) = 62.58$ $p < 0.0001^*$
RPA*	$F(2,415) = 32.21$ $p < 0.0001^*$	$F(1,416) = 23.8$ $p < 0.0001^*$	$F(1,416) = 44.47$ $p < 0.0001^*$	$F(1,416) = 40.4$ $p < 0.0001^*$
LoBA	$F(2,415) = 0.43$ $p = 0.6512$	$F(1,416) = 0.13$ $p = 0.7143$	$F(1,416) = 5.23$ $p = 0.0227$	$F(1,416) = 3.93$ $p = 0.0481$
UBA*	$F(2,415) = 9.4$ $p = 0.0001$	$F(1,416) = 0.37$ $p = 0.5437$	$F(1,416) = 1.32$ $p = 0.2519$	$F(1,416) = 1.77$ $p = 0.1836$
LfBA	$F(2,415) = 5.86$ $p = 0.0031$	$F(1,416) = 0.91$ $p = 0.3394$	$F(1,416) = 0.09$ $p = 0.77$	$F(1,416) = 2.31$ $p = 0.129$
RBA	$F(2,415) = 5.06$ $p = 0.0067$	$F(1,416) = 0$ $p = 0.9446$	$F(1,416) = 0.77$ $p = 0.3795$	$F(1,416) = 5.35$ $p = 0.0212$

NOTE: * indicates statistical significance at $\alpha = 0.0001$. Average Pressure (AP or A), Upper back (UB), Lower back/lumbar (LoB), Right back (RB), Left back (LfB), Right leg (RL), Left leg (LL), Buttocks (Bu), Right ischial tuberosity (RIT), Left IT (LIT), Right popliteal (RP), Left popliteal (LP)

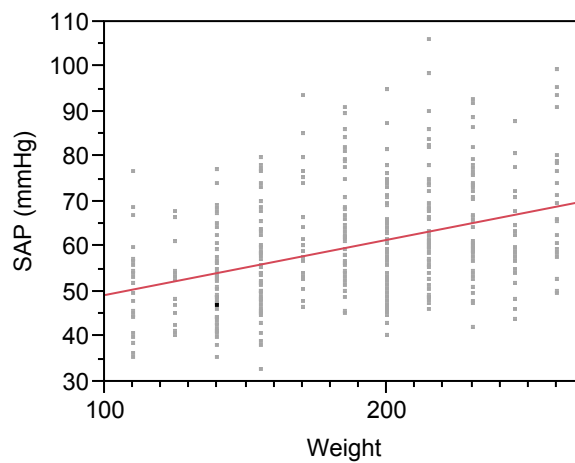


Figure 29. Average pressure (mmHg) for the seat by weight of subjects

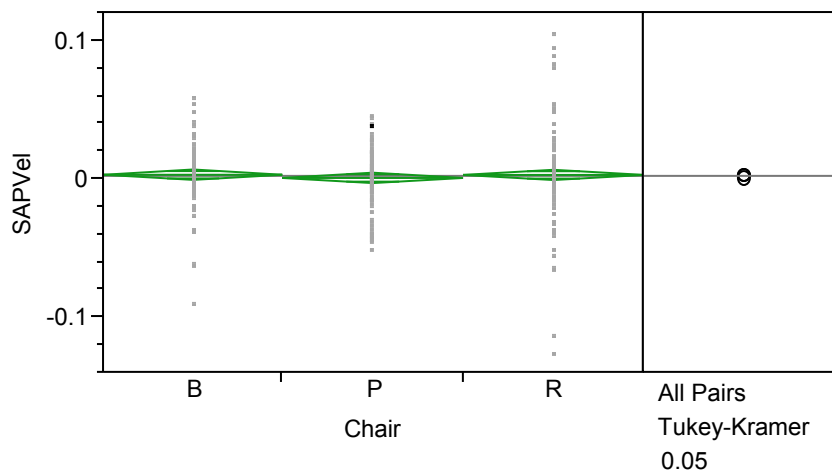


Figure 30. One-way ANOVA of Chair vs. seating pressure rate change

Table 14. Maximum and minimum pressures for the Left IT (LIT)

Chair	LIT Maximum Pressure (mmHg)	Pairwise Comparison	LIT Minimum Pressure (mmHg)	Pairwise Comparison
B	159.3	A	10.7	A
P	119.4	B	10.6	A
R	199.2	C	10.5	A

NOTE: LIT = Left Ischial Tuberosity. For pairwise comparison column a different letter means there were statistical differences between the levels of Chair. Same letters means there were no statistical differences,

Contact area between the subjects' backs and the chair's backrest, or the subjects' buttocks and thighs and the chair's backrest shows statistical differences between Chair and Weight, but not Initial-Final. The Chair pairwise comparison for the Seat Contact Area (cm²) states that Chair B ($M = 1619$) is significantly different from Chair P ($M = 1555$) and Chair R ($M = 1286$). Chairs B and P are statistically different from Chair R ($p < 0.0001$), but Chairs B and P are not different ($p = 0.0615$). Table 15 shows the one-way ANOVA results for Contact Area.

Movement in the chair was measured as the "center of position" or COP, by row (forward and back movements) and column (side-to-side movements). The Seat COP rows was significantly different between chairs ($p < 0.0001$), with subjects sitting in Chair R sitting further forward in the chair than when sitting in both Chairs B and P. There was a significant difference ($p < 0.0001$) for side-to-side position (COP columns) of subjects in Chair R from the other two chairs. Table 16 gives the means and pairwise comparison results.

After analysis of the significance of each pressure mapping variable, the list of 120 variables was decreased by 53% to 57 variables.

Table 15. Statistical significance of contact area

Contact Area	Chair	Initial-Final	Weight	BMI
BCA*	$F(2,415) = 47.16$ $p < 0.0001^*$	$F(1,416) = 0.48$ $p = 0.4911$	$F(1,416) = 77.05$ $p < 0.0001^*$	$F(1,416) = 67.28$ $p < 0.0001^*$
SCA*	$F(2,415) = 78.6$ $p < 0.0001^*$	$F(1,416) = 0.03$ $p = 0.8529$	$F(1,416) = 271.82$ $p < 0.0001^*$	$F(1,416) = 265.29$ $p < 0.0001^*$
LITC*A	$F(2,415) = 15.66$ $p < 0.0001^*$	$F(1,416) = 0.42$ $p = 0.5189$	$F(1,416) = 197.48$ $p < 0.0001^*$	$F(1,416) = 177.93$ $p < 0.0001^*$
RITCA*	$F(2,415) = 18.12$ $p < 0.0001^*$	$F(1,416) = 0.03$ $p = 0.8618$	$F(1,416) = 214.63$ $p < 0.0001^*$	$F(1,416) = 209.64$ $p < 0.0001^*$
BuCA*	$F(2,415) = 19.21$ $p < 0.0001^*$	$F(1,416) = 0.12$ $p = 0.7247$	$F(1,416) = 241.94$ $p < 0.0001^*$	$F(1,416) = 196.18$ $p < 0.0001^*$
LLCA*	$F(2,415) = 70.9$ $p < 0.0001^*$	$F(1,416) = 0.27$ $p = 0.6068$	$F(1,416) = 246.21$ $p < 0.0001^*$	$F(1,416) = 227.14$ $p < 0.0001^*$
RLCA*	$F(2,415) = 69.45$ $p < 0.0001^*$	$F(1,416) = 0.04$ $p = 0.8391$	$F(1,416) = 250.34$ $p < 0.0001^*$	$F(1,416) = 255.63$ $p < 0.0001^*$
LPCA*	$F(2,415) = 35.48$ $p < 0.0001^*$	$F(1,416) = 0.05$ $p = 0.8204$	$F(1,416) = 73.63$ $p < 0.0001^*$	$F(1,416) = 96.52$ $p < 0.0001^*$
RPCA*	$F(2,415) = 31.76$ $p < 0.0001^*$	$F(1,416) = 0.47$ $p = 0.4924$	$F(1,416) = 124.39$ $p < 0.0001^*$	$F(1,416) = 147.72$ $p < 0.0001^*$
LoBCA*	$F(2,415) = 30.68$ $p < 0.0001^*$	$F(1,416) = 2.48$ $p = 0.1159$	$F(1,416) = 59.41$ $p < 0.0001^*$	$F(1,416) = 82.97$ $p < 0.0001^*$
UBCA*	$F(2,415) = 24.8$ $p < 0.0001^*$	$F(1,416) = 0.32$ $p = 0.5716$	$F(1,416) = 26.59$ $p < 0.0001^*$	$F(1,416) = 11.61$ $p = 0.0007$
LfBCA*	$F(2,415) = 31.01$ $p < 0.0001^*$	$F(1,416) = 0.1$ $p = 0.7553$	$F(1,416) = 84.92$ $p < 0.0001^*$	$F(1,416) = 75.2$ $p < 0.0001^*$
RBCA*	$F(2,415) = 48.79$ $p < 0.0001^*$	$F(1,416) = 2.39$ $p = 0.123$	$F(1,416) = 45.98$ $p < 0.0001^*$	$F(1,416) = 38.16$ $p < 0.0001^*$

NOTE: * indicates statistical significance at $\alpha = 0.0001$. Contact Area (CA), Upper back (UB), Lower back/lumbar (LoB), Right back (RB), Left back (LfB), Right leg (RL), Left leg (LL), Buttocks (Bu), Right ischial tuberosity (RIT), Left IT (LIT), Right popliteal (RP), Left popliteal (LP)

Table 16. Location for the Center of Pressure in the seat, by Chair

Chair	Center of Position, rows	Pairwise Comparison	Center of Position, columns	Pairwise Comparison
B	23.2	A	21.6	A
P	23.1	A	21.3	A
R	21.8	B	20.9	B

NOTE: The pressure pad is a 40x40 array; values for the rows and columns are based on a range from 1 to 40. For pairwise comparison column a different letter means there were statistical differences between the levels of Chair. Same letters mean there were no statistical differences,

5.7.2 Physiological

The physiological measures used for data analysis were averaged like the pressure mapping variables. A two minute span of data was averaged at the end of the initial sit, and then a two minute span of data was averaged at the beginning of the final sit survey. The physiological data had a lot of variation and did not appear to be consistent in its measurement. Figure 31 shows data output from two separate subjects during their full testing of three chairs. The output is approximately 180 minutes. The temperature values are the two highest lines in both graphs. There is a gradually and consistently increasing slope through both tests— independent of the chairs being tested. Data showed a significant increase in temperature from Initial to Final test, but the data suggest that the increase is not related to the chair. There was no significance with Chair and temperature.

In the one-way ANOVA for physiological measures, the two temperature measures of body and near-body temperature, as well as galvanic skin response in the Initial-Final factor were statistically significant. Because of the unreliability of accurate measures and lack of significant differences with more than one factor on the physiological data, we did not to include it in the comfort model analysis.



NOTE: Top image, Subject 35, Day 2, Chairs P, R, then B; bottom image, Subject 36, Day 2, Chairs B, P, then R.

Figure 31. Physiological data from two subjects

Table 17. Statistical results for physiological measurements

Physiological Measure	Chair	Initial-Final	Gender
Near body temperature	$F(2,391) = 0.84$ $p = 0.4325$	$F(1,392) = 23.27$ $p < 0.0001^*$	$F(1,392) = 34.04$ $p < 0.0001^*$
Average skin temperature	$F(2,397) = 0.7$ $p = 0.4958$	$F(1,398) = 24.26$ $p < 0.0001^*$	$F(1,398) = 36.44$ $p < 0.0001^*$
Average low heat flux	$F(2,405) = 0.87$ $p = 0.4201$	$F(1,406) = 0.75$ $p = 0.3877$	$F(1,406) = 9.42$ $p = 0.0023$
Average high heat flux	$F(2,405) = 1.04$ $p = 0.3561$	$F(1,406) = 0.82$ $p = 0.3663$	$F(1,406) = 9.06$ $p = 0.0028$
Average heat flux	$F(2,405) = 1.03$ $p = 0.3562$	$F(1,406) = 0.82$ $p = 0.3663$	$F(1,406) = 9.06$ $p = 0.0028$
Average longitudinal accelerometer	$F(2,397) = 0.38$ $p = 0.6851$	$F(1,398) = 0.15$ $p = 0.7005$	$F(1,398) = 1.72$ $p = 0.1899$
Average transverse accelerometer	$F(2,397) = 0.06$ $p = 0.9406$	$F(1,398) = 0.12$ $p = 0.7321$	$F(1,398) = 17.13$ $p < 0.0001^*$
Average low GSR	$F(2,391) = 0.65$ $p = 0.5251$	$F(1,392) = 22.73$ $p < 0.0001^*$	$F(1,392) = 6.98$ $p = 0.0086$
Average high GSR	$F(2,391) = 0.72$ $p = 0.4856$	$F(1,392) = 22.57$ $p < 0.0001^*$	$F(1,392) = 7.01$ $p = 0.0084$
Average GSR	$F(2,405) = 0.51$ $p = 0.6004$	$F(1,406) = 23.44$ $p < 0.0001^*$	$F(1,406) = 4.39$ $p = 0.0368$

5.8 Linear Model of Comfort

A correlation matrix was created with the 101 factors (57 from pressure mapping, 22 subjective, and 22 from other survey responses and demographics) to be used in the comfort model. Table 18 displays the ten strongest positive and negative correlations. All of the positive correlations are related to objective pressure mapping variables, while the inverse correlations are related to subjective measures and the question “I feel

uncomfortable.” The comfort-related correlations have to do with comfort, look, likeability, and softness of the chair.

To create the linear model, all 22 subjective variables were used as responses, while the other 79 variables were included as effects. Using JMP 9.0 statistical software (Cary, North Carolina, USA), a stepwise function was used with a minimum Bayesian Information Criterion (BIC) to choose the best model for each subjective response.

Results for each the stepwise regression response were not the same—some had larger correlations than others (Appendix N: Linear Model). Since some of the correlations were as low as $R^2=0.2029$, it was decided to focus on the top six responses that had $R^2 > 0.50$ to build the comfort model. Five of the top six response correlations were related to comfort, and one was related to discomfort (Table 19). Each of these six responses had individual parameters from the 79 factors that were originally used in the model. The number of parameters that were significant ($p > 0.05$) for each response is also listed in Table 19.

Appendix N shows a table with the parameters that were statistically significant, along with the response they are associated with. The parameters related to “NL Feel Soft” and “NL Like Chair” were related to factors like Chair, Fit of the chair features to their body, and pressure regions in the popliteal and lower back areas. Seat and Overall comfort parameters were Chair, Fit of chair features, and pressure regions in the lower back and popliteal areas. “NL Feel Comfortable” was influenced by Chair, but also by the Start-End of each test (or time sitting in the chair). Fit of the features was also an important parameter. The “NL Feel Uncomfortable” parameter, Chair and Start-End were part of the model, but also were parameters dealing with the Upper Backrest (minimum, maximum, and contact area).

Scatter plots showing relationships between the “I Feel Uncomfortable” and two of its model parameters (Fit Seat Contour and Left Leg Average Pressure) can be seen in Figure 32 and Figure 33.

Table 18. Top twenty variable correlations

Variable	By Variable	Correlation (r^2)	Category
Left Leg Max	Left IT Maximum	0.9931	Objective
Right Back Contact %	Right Back Contact Average	0.9834	Objective
Buttocks Maximum	Seat Peak Pressure	0.9822	Objective
Left Back Contact %	Left Back Contact Area	0.9714	Objective
Left Leg Session Mean	Seat Session Mean	0.9687	Objective
Left Leg Average	Seat Average Pressure	0.9674	Objective
Left Leg Contact Area	Seat Contact Area	0.9671	Objective
Right Leg Contact Area	Seat Contact Area	0.9634	Objective
Buttocks Session Mean	Left IT Session Mean	0.9599	Objective
Buttocks Average	Left IT Average	0.9594	Objective
NL I feel uncomfortable	Seat Contour fits me	-0.5825	Subjective
Linear I feel uncomfortable	NL I like the chair	-0.5884	Subjective
NL I feel uncomfortable	5-point Back Comfort	-0.5905	Subjective
Linear I feel uncomfortable	NL I feel comfortable	-0.6378	Subjective
NL I feel uncomfortable	NL Chair feels soft	-0.6759	Subjective
NL I feel uncomfortable	5-point Seat Comfort	-0.7120	Subjective
NL I feel uncomfortable	5-point Overall Comfort	-0.7185	Subjective
NL I feel uncomfortable	NL I like the chair	-0.7275	Subjective
NL I feel uncomfortable	NL I feel comfortable	-0.7674	Subjective

Table 19. Top six subjective R² stepwise correlations

Subjective Response	DFE	RMSE	R ²	R ² Adj	p	BIC
NL Feel Soft	364.00	1.6461	0.6530	0.6435	11	1497.98
Seat Comfort	369.00	0.9226	0.5899	0.5766	13	1092.51
Overall Comfort	371.00	0.8567	0.5517	0.5396	11	1026.08
NL Feel Uncomfortable	370.00	1.8324	0.5419	0.5295	11	1602.89
NL Feel Comfortable	365.00	1.7545	0.5311	0.5195	10	1540.89
NL Like Chair	371.00	1.7852	0.5217	0.5127	8	1560.20

NOTE: NL = Non-linear, BIC = Bayesian information Criterion, R² Adj = adjusts R² to compare to other models better, DFE = degrees of freedom, RMSE = root mean square error, p = number of parameters in the model.

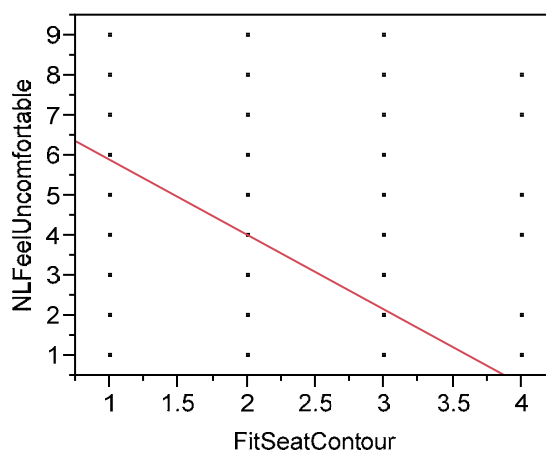


Figure 32. Scatter plot of Seat Contour Fit to “I Feel Uncomfortable”

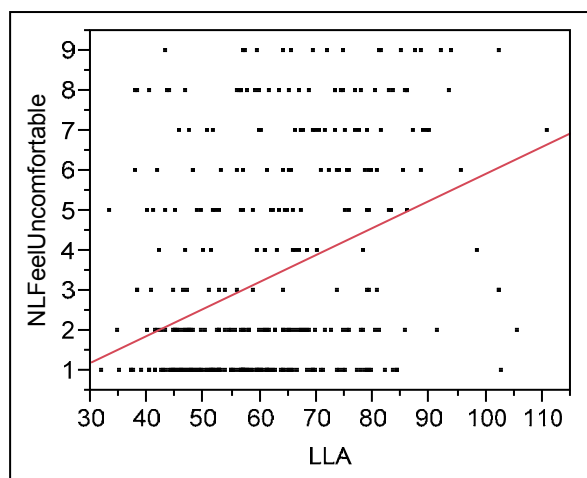


Figure 33. Scatter plot for Left Leg average pressure and "I Feel Uncomfortable"

Below is a summary table of all the R^2 values for each subjective response. Summaries, ANOVA tables, and coefficients for each model can be found in Appendix N. The highest correlation ($R^2=0.636$) model resulted with the response to "Feels Soft", while the lowest correlation ($R^2=0.512$) of the six responses was "Feel Uncomfortable".

Table 20. Model predictor summary related to each subjective variable

Subjective Response	R^2	R^2 Adj	RMSE
Feels Soft	0.636	0.628	1.692
Seat Comfort	0.596	0.583	0.917
Overall Comfort	0.559	0.548	0.857
Like Chair	0.522	0.512	1.809
Feel Comfortable	0.518	0.507	1.796
Feel Uncomfortable	0.512	0.501	1.909

5.9 Neural Network Model of Comfort

After creating a linear model to predict the six subjective comfort-discomfort related responses, a neural network model was created to see if it could provide a more accurate prediction model.

The same variables (22 responses and 79 effects) that were used for the linear model were inserted into the neural network, using JMP 9.0 neural network module (Figure 34). The neural model in JMP uses one layer of hidden nodes to create non-linear activation functions for the 79 inputs, and then transforms a linear combination of the inputs into a linear output. The simple JMP model also allows the user to control the amount of data used for training the neural network and the amount to validate the model (holdback data). It does not allow users to run a test dataset to confirm the validation. Table 21 summarizes the different R^2 values for each of the four different datasets that were tested with different holdback percentages and different numbers of hidden nodes. Other NN models were run, adding a second hidden layer, but results were not as high as the one-hidden layer models.

The 25% holdback with five nodes gave the best training and validation model based on R^2 values for the neural network, but after performing a paired-t test, the individual response values were only statistically different for the training dataset ($p = 0.0121$). Statistical significance was also found between the linear model group and (a) the training groups for 3-25% ($p = 0.0032$) and (b) both training and validation groups for 3-20% group ($p = 0.0008$ and $p = 0.0143$). The generalized R^2 values for the neural network model indicate that its model has a high correlation for both the training and the validation data. Additional statistical details for the model can be found in Appendix N.

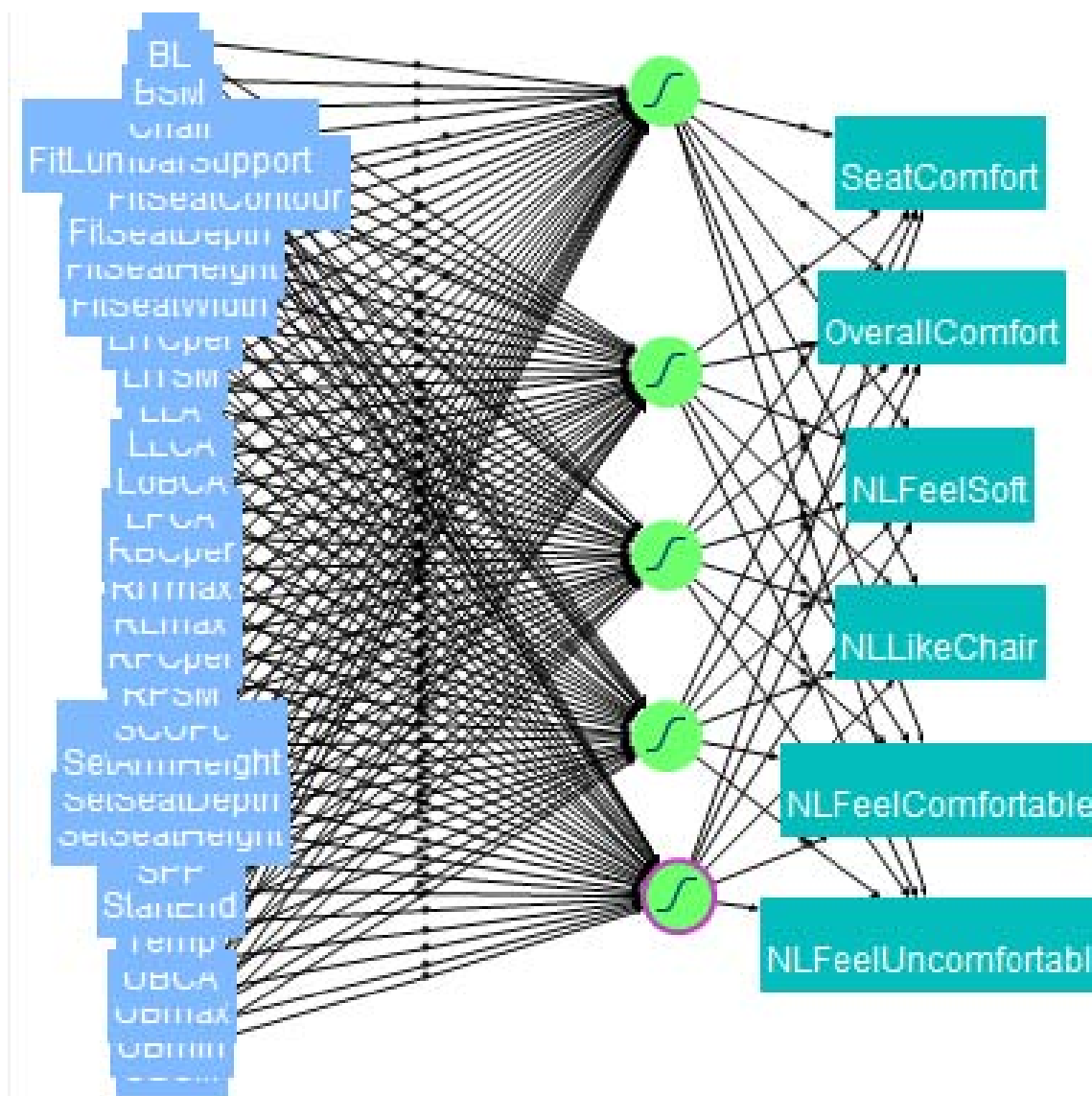


Figure 34. Comfort-Discomfort neural network model

Table 21. R² values from Neural Network models

Subjective Response		33% Holdback 3 Nodes	25% Holdback 3 Nodes	20% Holdback 3 Nodes	25% Holdback 5 Nodes
Generalized R² for all Responses	Training	.9947	.9991	.9984	.9966
	Validation	.9932	.9858	.9780	.9929
NL Feel Soft	Training	.6423	.7065	.7290	.6715
	Validation	.6550	.5276	.4979	.6662
Seat Comfort	Training	.6357	.7075	.6569	.6432
	Validation	.5564	.5712	.5150	.5759
Overall Comfort	Training	.5963	.6988	.6289	.6231
	Validation	.5500	.5405	.4960	.5064
NL Like Chair	Training	.5534	.7229	.6546	.6113
	Validation	.5580	.4455	.4483	.5455
NL Feel Comfortable	Training	.5323	.6841	.6644	.5737
	Validation	.5541	.4976	.3512	.5778
NL Feel Uncomfortable	Training	.5148	.5859	.5929	.5323
	Validation	.4964	.4541	.4989	.4742

NOTE: Holdback refers to the percentage of data that was used for the validation of the model. Nodes are specified by the user in the software and are used to fit the data.

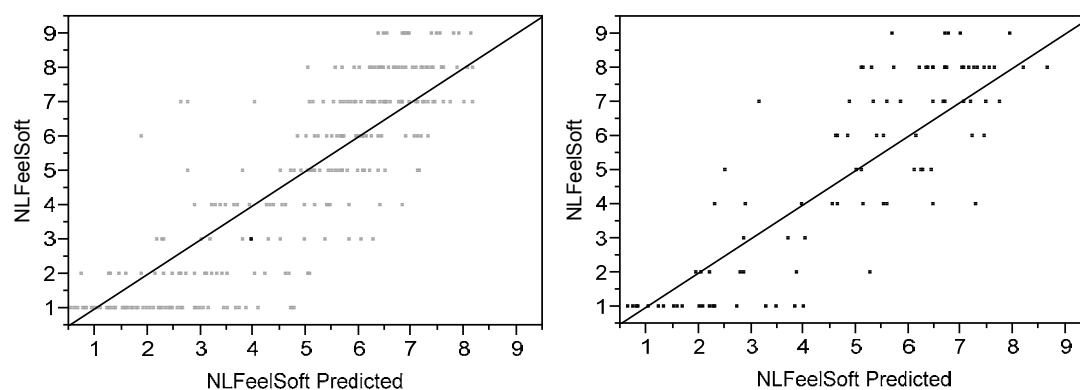


Figure 35. Correlation of Actual vs. Predicted Non-Linear Feel Soft. Training data (R²=0.6715) is on the left, validation data (R²=0.6662) is on the right.

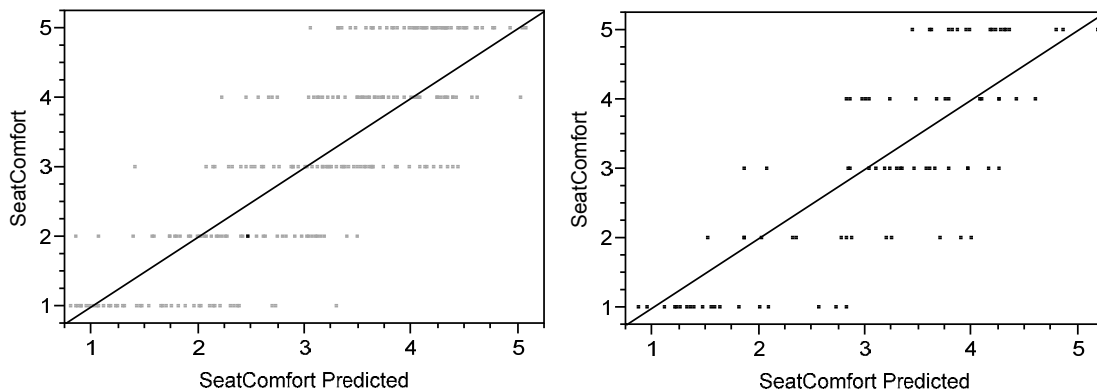


Figure 36. Correlation of Actual vs. Predicted Seat Comfort. Training data ($R^2=0.6432$) is on the left, validation data ($R^2=0.5759$) is on the right.

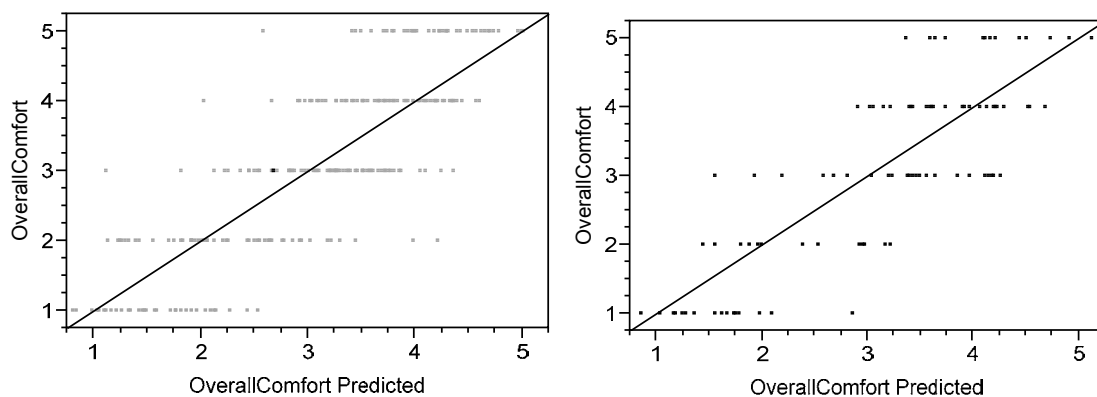


Figure 37. Correlation of Actual vs. Predicted Overall Comfort. Training data ($R^2=0.6231$) is on the left, validation data ($R^2=0.5064$) is on the right.

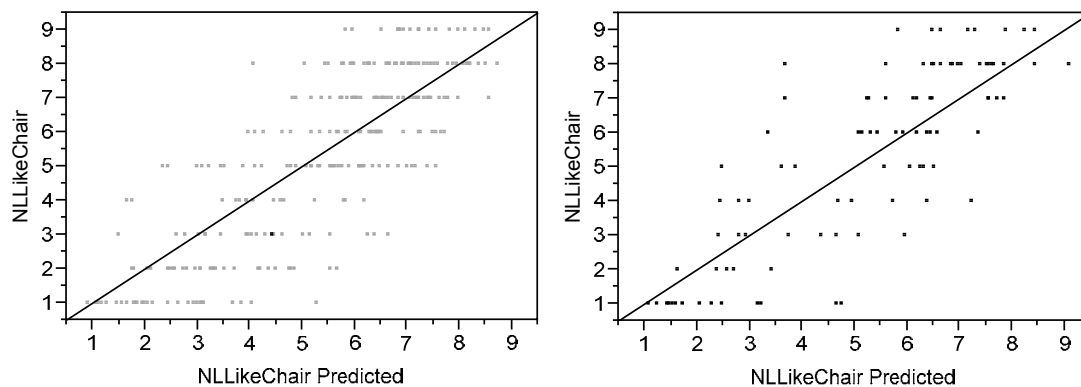


Figure 38. Correlation of Actual vs. Predicted Non-Linear I Like Chair. Training data ($R^2=0.6113$) is on the left, validation data ($R^2=0.5455$) is on the right.

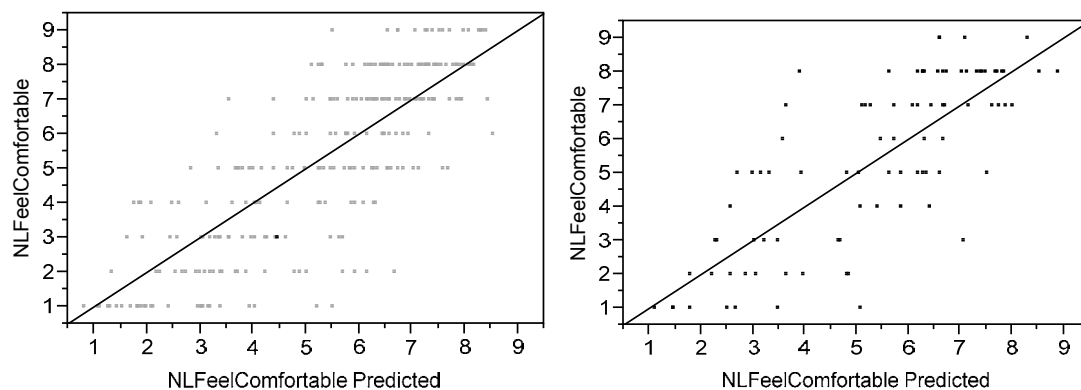


Figure 39. Correlation of Actual vs. Predicted Non-Linear I Feel Comfortable. Training data ($R^2=0.5737$) is on the left, validation data ($R^2=0.5778$) is on the right.

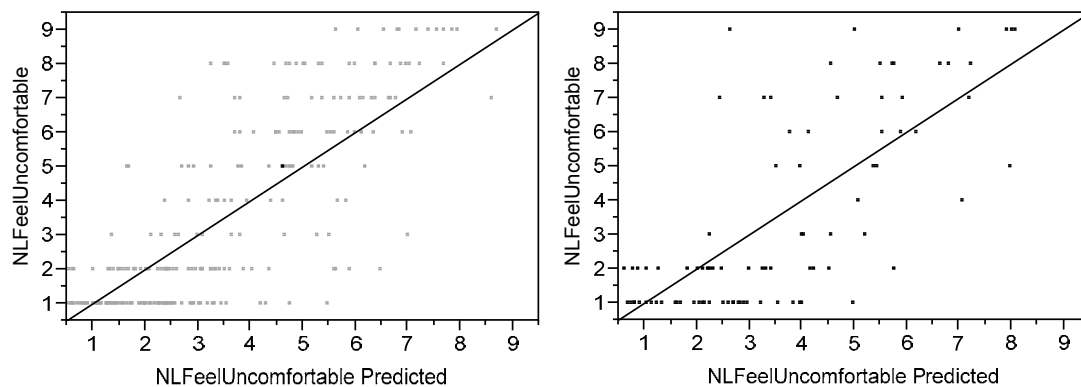


Figure 40. Correlation of Actual vs. Predicted Non-Linear I Feel Uncomfortable. Training data ($R^2=0.5323$) is on the left, validation data ($R^2=0.4742$) is on the right.

CHAPTER 6. DISCUSSION

Comfort and discomfort were measured during this experiment to discover ways to improve the testing, modeling, and prediction of these human emotions. The expectations of this experiment were to measure physiological signals, objective pressure mappings, demographics, and subjective data to facilitate the analysis of the model. Through this experiment, new principles can be added to future development in comfort research.

6.1 Model for Testing Comfort

The current comfort models that have been developed discuss different aspects to comfort (de Looze et al., 2003). de Looze discusses human, product, and environmental aspects that relate to comfort and discomfort. This particular investigation looked primarily at the human and product aspects, attempting to maintain environmental variables constant while testing people in office chairs.

The objective measures positively correlated highly with each other and the subjective measures had relatively high negative correlations with each other. There were only a few strong correlations between subjective and objective measures, and some of those were actually negative correlations. For example, when the average pressure on the buttocks increases, people will rate “the chair feels soft” lower. Creating the linear and neural network models helped find some of the hidden relationships between variables and remove others that were noise in the model.

The linear regression model developed in this experiment had correlation values less than 0.70 (Table 20), and the simple neural network model was able to predict the comfort responses with a higher correlation. Also, the general model R^2 for all of the six responses was greater than 0.9800. This particular model should be able to accurately predict comfort based on the different parameters in the model. The neural network model was more accurate at predicting comfort than the linear model.

6.2 Sub-hypotheses

6.2.1 Comfort-Discomfort Correlation

It was expected that subjects would say that they were more comfortable in Chair B, than Chair P, than Chair R. It was also expected that the pressure mapping data, as well as physiological data, would have trends that could correlate to the subjective opinions of the subjects.

Data showed that the 35 subjects did perceive Chair B to be the most comfortable, Chair P to be the middle ground, and Chair R to be the least comfortable (Figure 24). There were comfort differences designed into the three chairs to hopefully attain these responses (Table 3). One difference between Chairs B and P upholstery fabric on the seat cushions; Chair B had looser weave fabric than Chair P. The hypothesis was that the softer fabric would be more comfortable and give a better pressure reading than the tighter fabric that made Chair P's seat slightly firmer.

Pressure mapping values for Chair B did not give the expected results. Pressure values were actually lowest with Chair P, slightly higher with Chair B, and significantly higher with Chair R (Appendix M: Sample Pressure Mapping Images). The only apparent difference between the two seats of Chairs B and P is the fabric, so this must be adding variability to the measurement in an unexpected way. It appears that the looser weave of fabric allows the individual to settle more into the foam and increase their seat pressure. The tighter fabric must give enough firmness to the foam that the individual does not sink into the foam enough to increase their pressure readings like Chair B. Further investigation also shows that because subjects sitting in Chair R had less contact area in the seat than when sitting in the upholstered chairs, subjects did not sink into the harder seat. The bolster effect of foam did not happen with Chair R and apparently Chair P also, to some degree (Figure 27).

There are a few ways to apply this knowledge. First, when testing chairs, it is important to keep them in the same upholstery fabric so the material does not add variability to the model. Second, it opens the door for future research into the response of pressure maps to different fabrics. Would there be a way to specify how different fabrics will react to people sitting in them? What causes some of the fabrics to increase the pressure map, while others do not? Is there a way to categorize different weaves into pressure ratings or grades for easier design or specification of upholstery materials?

Throughout the experiment, Chair R received high discomfort scores and low comfort scores. Figure 41 has five comfort-related responses at the bottom, and the sixth response is a discomfort one. The responses are inverted on the last question of the graph, indicating that when subjects sat in Chair R (lowest line), it received lower comfort ratings and higher discomfort ratings.

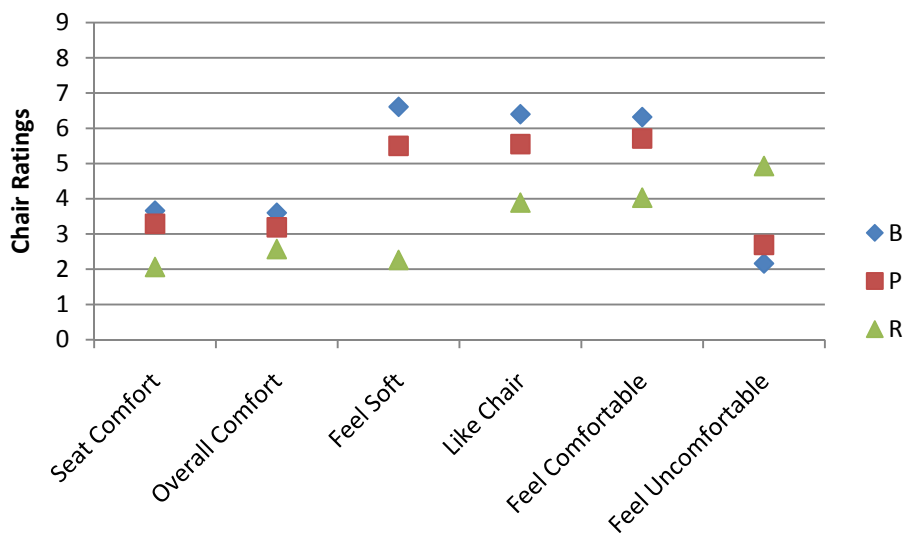


Figure 41. Inverse relationship with comfort and discomfort

6.2.2 Comfort-Discomfort Questions

de Looze et. al. recommended that comfort future research needed to ask participants both sets of questions related to Shackel's linear model of comfort-discomfort and Helander and Zhang's non-linear comfort-discomfort theory. This may be the first study that presented both questionnaires in the same study to see which set is a better correlation for comfort assessment.

Our data showed that there were higher correlations in responses to the non-linear questions than with Shackel's GCR questions. What was also important is that the subjective data outcomes from this experiment indicate that not all of the questions recommended by Helander and Zhang (1997) or Shackel (1969) are necessary. Data showed that the 35 participants in this study were unable to articulate differences between certain questions when sitting in opposite comfort-style chairs. For example, Figure 23 illustrates that subjects did not answer the question "I feel unbearable pain" differently between chairs. 88% of the responses to this question were "Not at all" or a "1", even while some of the participants were sitting in the uncomfortable chair (Chair R). Of Shackel's 11 degrees between the most comfortable and least comfortable sensations, five show statistical significance in this study. Figure 42 shows the non-significant Shackel GCR questions marked out.

From Helander and Zhang's descriptors, most people related to the comfort-focused questions, and did not have a lot of spread in their answers on the discomfort descriptors (Figure 43).

Although the list of separate descriptors for comfort and discomfort may be helpful in describing differences between people's sensations (Zhang et al., 1996), the intent of the descriptors may not be conveyed well when reading the question. As was observed with a few of the 35 subjects in this study, respondents may not understand what "I have heavy legs" means and decide not to answer the question as was intended.

Additionally, some of the language may be outdated for today's society and refreshing the list of words or descriptors may help for future studies.

Rating	Description
1	I feel completely relaxed
2	I feel perfectly comfortable
3	I feel quite comfortable
4	I feel barely comfortable
5	I feel uncomfortable
6	I feel restless and fidgety
7	I feel cramped
8	I feel stiff
9	I feel numb (on pins and needles)
10	I feel sore and tender
11	I feel unbearable pain

Figure 42. General Comfort Rating (GCR) questions that did not show variances

Discomfort Descriptors

- ~~1. I have sore muscles~~
- ~~2. I have heavy legs~~
3. I feel stiff
- ~~4. I feel tired~~
- ~~5. I feel pain~~
- ~~6. I feel numb~~
7. I feel uneven pressure
- ~~8. I feel cramped~~
- ~~9. I feel restless~~

Comfort Descriptors

1. I feel relaxed
2. I feel refreshed
3. I feel restful
4. Chair is spacious
5. Chair looks nice
6. Chair feels soft
7. I like the chair

Figure 43. Helander and Zhang's questions that were not differentiating

Two other challenges with the questions are that people may not be able to discern the difference between two questions that seem “identical”. For example, some may wonder what the difference is between “I feel completely relaxed” and “I feel perfectly comfortable”. Secondly, the number of questions asked to assess comfort or discomfort can be simplified. When assessing comfort, taking a long survey may affect the answers given on the survey because the subject is fidgety and restless. Kolich (1999) validated a comfort survey for the automotive industry that asks 11 questions, but only half of them are direct comfort questions. Similar refinement could be done with the comfort questions currently available.

6.2.3 Gender and Comfort

Throughout the data analysis, there was no significant difference between the responses of males and females. Similar proportions of male to female office workers were used in this experiment. The genders were also spread well across different ages, heights, and weights (Appendix K: Statistics).

Since there was no significant difference between males and females, future researchers in the field of comfort can assume that each gender will give similar answers regarding comfort and discomfort. This equal response may change if the product being tested fits one group better than the other, so correct sampling and ergonomic fitting prior to data collection will be important.

6.2.4 Increase in Discomfort over Time

As mentioned earlier in this paper, some researchers have discussed the effects of time on pressure mapping comfort. Some researchers have used short-term sit tests to assess comfort (Yuen & Garrett, 2001), while others have used long-term tests greater than an hour (Goossens et al., 2005). Data from this study indicated that there was a difference between people’s assessment of comfort and discomfort at the start and end of

the 45 minutes of testing. As time elapsed, people gave lower comfort scores and higher discomfort scores (Figure 26).

Human subjects need time to be able to assess comfort and discomfort differences, and that cannot always come with a short-term test. An individual may be able to assess the difference between a Chair B and Chair R in a short term test, but they will probably need longer to assess the difference between a Chair B and Chair P. In this experiment, a 45-minute sit test with subjects performing office-related tasks allowed the researchers to see statistical differences between chairs and create a model to predict comfort.

6.3 Comfort Parameters

When creating the stepwise regression models, researchers looked for similar effects or variables that existed in all 22 models. The initial search showed the following factors were significant ($p < 0.05$) and common in many of the models (the number in parentheses indicates how many models used the parameter):

- Seat Contour Fits Me (22)
- Seat Width Fits Me (16)
- Seat Depth Fits Me (12)
- Chair (10)
- Initial and Final Survey (9)

What is interesting is that these five common factors are centered on (a) fit of the product to the person, (b) the product itself, and (c) the time spent using the product. As part of the protocol, the researcher taught the 35 subjects how to adjust their chair and workspace properly. This allowed the subjects to be in a comfortable orientation from the start of the testing, and eliminated fit as a potential variable. Observing that the variables related to fit were significantly present in so many of the regression models points to the importance of fitting products to the individuals for comfort.

CHAPTER 7. CONCLUSION

This dissertation has discussed many of the variables that can be used to test comfort and discomfort in an office setting. A discussion reviewed the history of comfort and discomfort research and the differences between current models by de Looze, Helander, and Shackel.

Through the data collection and analysis, it was possible to correlate comfort and discomfort to objective and subjective measures. A neural network model was better than a linear model at predicting comfort and can be further refined in future research to give designers and engineers specific parameters that will optimize the human experience in office seating. Responses by males and females were not different and therefore allows for assessments to not be concerned about gender response differences. Additionally, ensuring that testing is done for at least a 45-minute period will help people discern chair differences that they would not sense during a short-term sit.

Chair manufacturers can use the short and long term sit tests during product development with several different subjects. The trends they see with comfort ratings at the start and end will enlighten them on how their customers should feel when they briefly test the product before purchasing.

The results of this experiment can be generalized for procedures in testing office comfort, but not specific seating products. The methodology for testing a poor, medium, and good office chair used in this experiment was to understand the differences that are perceived between different degrees of comfort. A more refined study design and survey tools will be necessary to find significant differences between products that are not far from each other on the comfort spectrum.

Some parameters, such as physiological data, were not recorded in this experiment as planned. Recent researchers have not used physiological measures during their comfort experiments. Including this data in the model may enhance the

predictability of the models. Additionally, the current physiological tools are smaller, wireless, and unobtrusive, making it easy to use in human comfort research.

Future work can look at comfort and productivity to see how workers' performance changes with different levels of comfortable chairs. Understanding more about fabrics and their effect on pressure readings can also help in product development, fabric classification, and enhancing comfort.

Automotive and wheelchair designers have looked at comfort for many years. Some models have been developed to predict automotive sitting comfort. In the future, comfort researchers should find ways to apply comfort theories learned by different industries so that they can be used effectively by others. Other industries that can benefit from this type of research could also include aviation and the military. Additionally, as indicated by de Looze, there are opportunities to conduct research in other areas of his model such as environmental or physical factors or product aesthetics. Working in these other areas will either validate or continue to refine the comfort models that exist.

APPENDIX A. BODYMEDIA SENSEWEAR OUTPUT

Software from BodyMedia displays the layout of each sensor measurement and calculation of energy expenditure and physical activity. The calculations done by the software are calibrated for a data collection rate of 1 sample per minute, so the data we collected did not show detection for these calculations. Raw data from the sensor was exported and analyzed with Microsoft Excel® and JMP® 9.0.

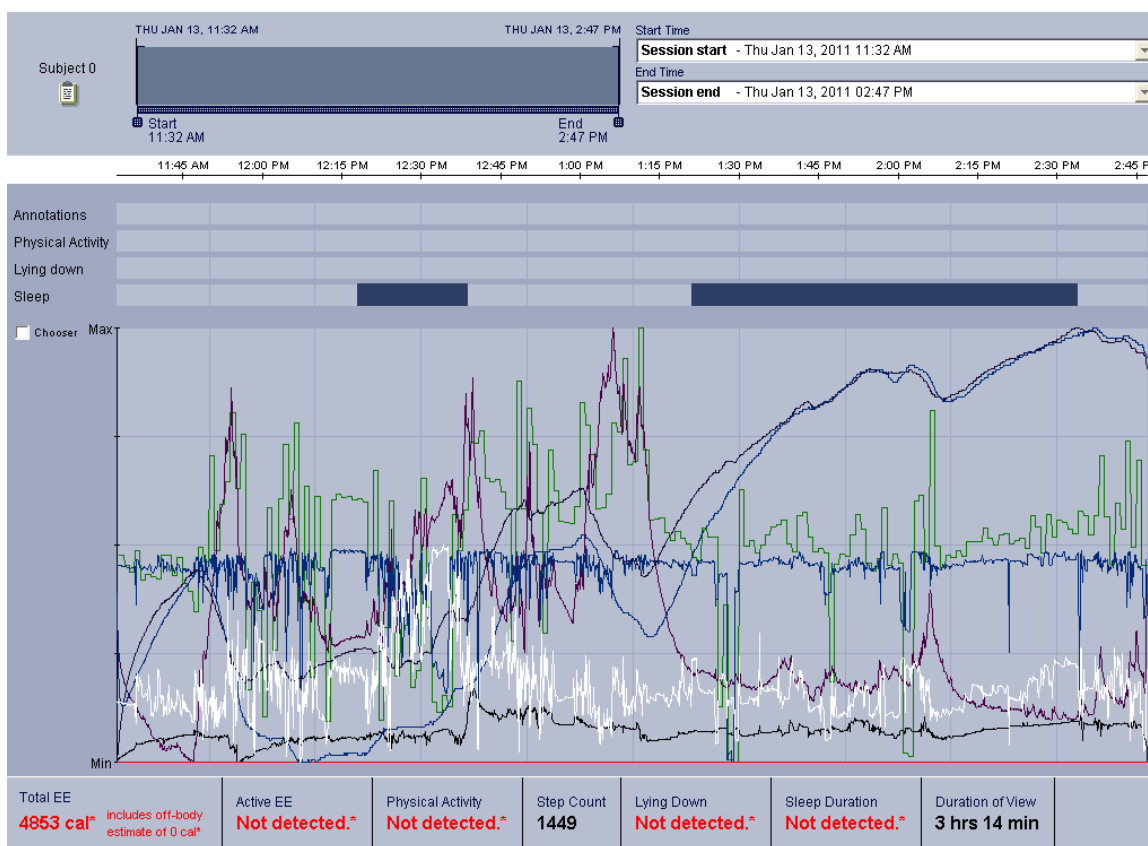


Figure A-1. Sample BodyMedia software graphical display

APPENDIX B. TYPING TEST

B.1 Example

Typing Test completed | 12/4/2010 | TypingMaster

Page 1

TYPING TEST - PASSED

User: Subject 1
Test name: Thoughts of Benjamin Franklin
Date: 12/4/2010 5:47 PM

TEST RESULTS

Duration:	10.00 min. of total 10.00 min.		
Gross speed:	49 wpm	Gross strokes:	2495
Accuracy:	98%	Error hits:	45 (9 errors * 5)
Net speed:	48 wpm	Net strokes:	2450

TEST TEXT

Benjamin Franklin was not only one of the Founding Fathers of Colonial America, but he was one of the wisest thinkers and statesmen of that time. It is interesting, therefore, to take a look at some of ~~this~~ ~~his~~ thoughts and opinions -- in his ~~own~~ words: God works and their reward. -- For my own part, when I am employed in serving others, I do not look upon myself as conferring favors, but as paying debts. In my travels, and since my settlement, I have received much kindness from men, to whom I shall never have any opportunity of making the least direct return, and numberless services from God, who is infinitely above being benefitted by our services. These kindnesses from men, I can therefore only return on their fellow men; and I can only show ~~my~~ gratitude for these services from God, by a readiness to help his other children and my brethren. For I ~~am~~ ~~do~~ not ~~thing~~ ~~think~~ that thanks and compliments, though repeated weekly, can discharge our real obligations to each other, and much less those to our Creator.

Figure B-1. Sample typing test summary for Subject 1, Day 1

B.2 Typing Test Results

Six typing tests were chosen from the 19 possible options in TypingMaster Pro software (Helsinki, Finland). For each day, three tests typing tests were taken, one for each chair. To make sure that the tests were similar in difficulty and verbal content, they were ranked based on syllabic intensity or “mean syllables per word” (Straker et al., 2009). Table B-1 shows the information for each of the six tests that was chosen.

Table B-1. Typing test word and syllable counts

Document	Sentence Count	Word Count	Syllable Count	Character Count (alphanumeric)	Mean characters per word	Mean syllables per word
Movie Credits	153	1,738	2,300	7,873	4.53	1.32
Netiquette	196	1,622	2,148	7,233	4.46	1.32
Benjamin Franklin	113	1,578	2,106	6,922	4.39	1.33
Astronauts	179	1,861	2,695	8,787	4.72	1.45
Father of Computing	115	1,563	2,270	7,518	4.81	1.45
Yosemite National Park	150	1,651	2,466	8,295	5.02	1.49

APPENDIX C. IMAGES DRAWN BY EACH PARTICIPANT



Figure C-1. Images of man clipart that participants recreated in their mousing activity.

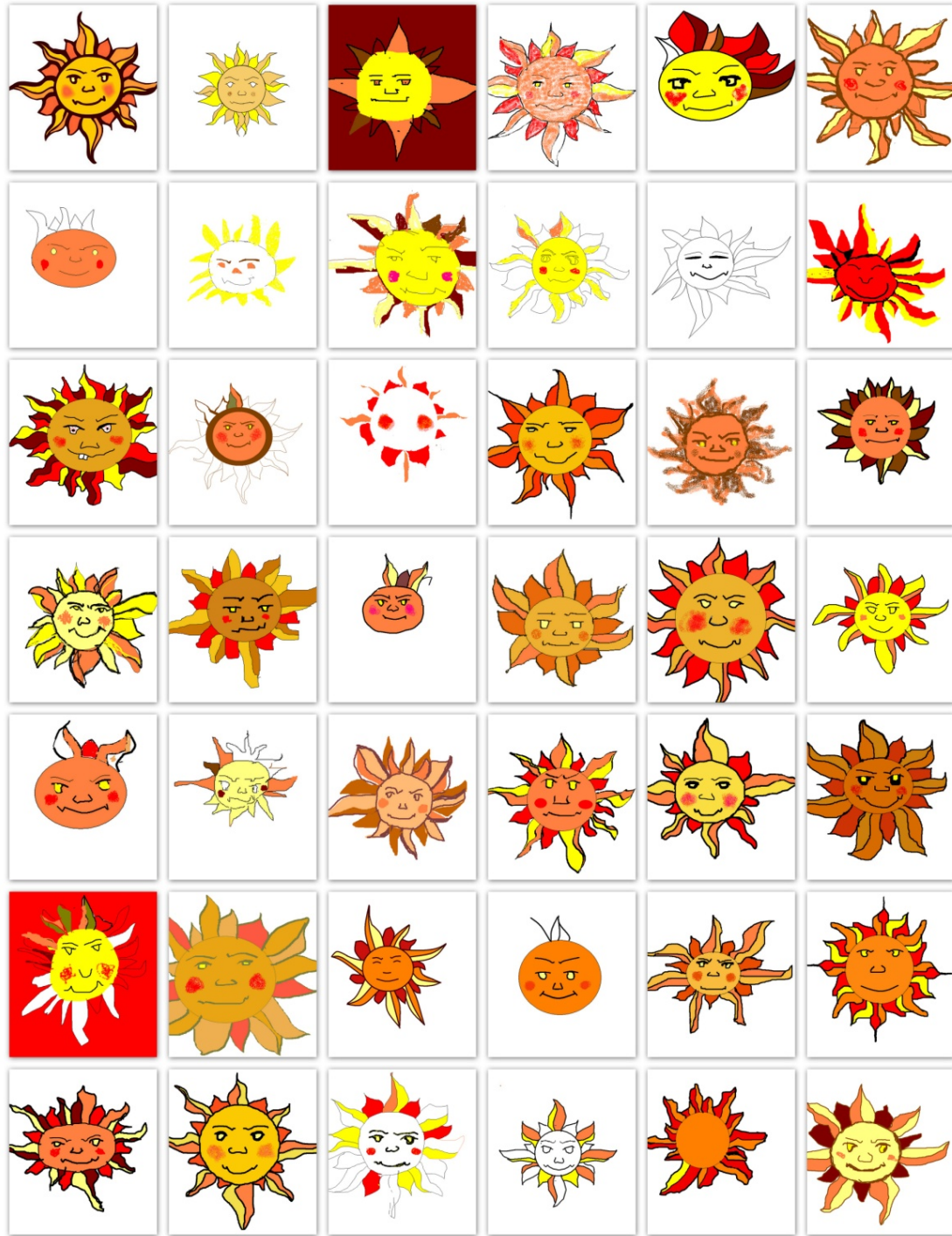


Figure C-2. Images of sun clipart that participants recreated in their mousing activity.



Figure C-3. Images of house clipart that participants recreated in their mousing activity.

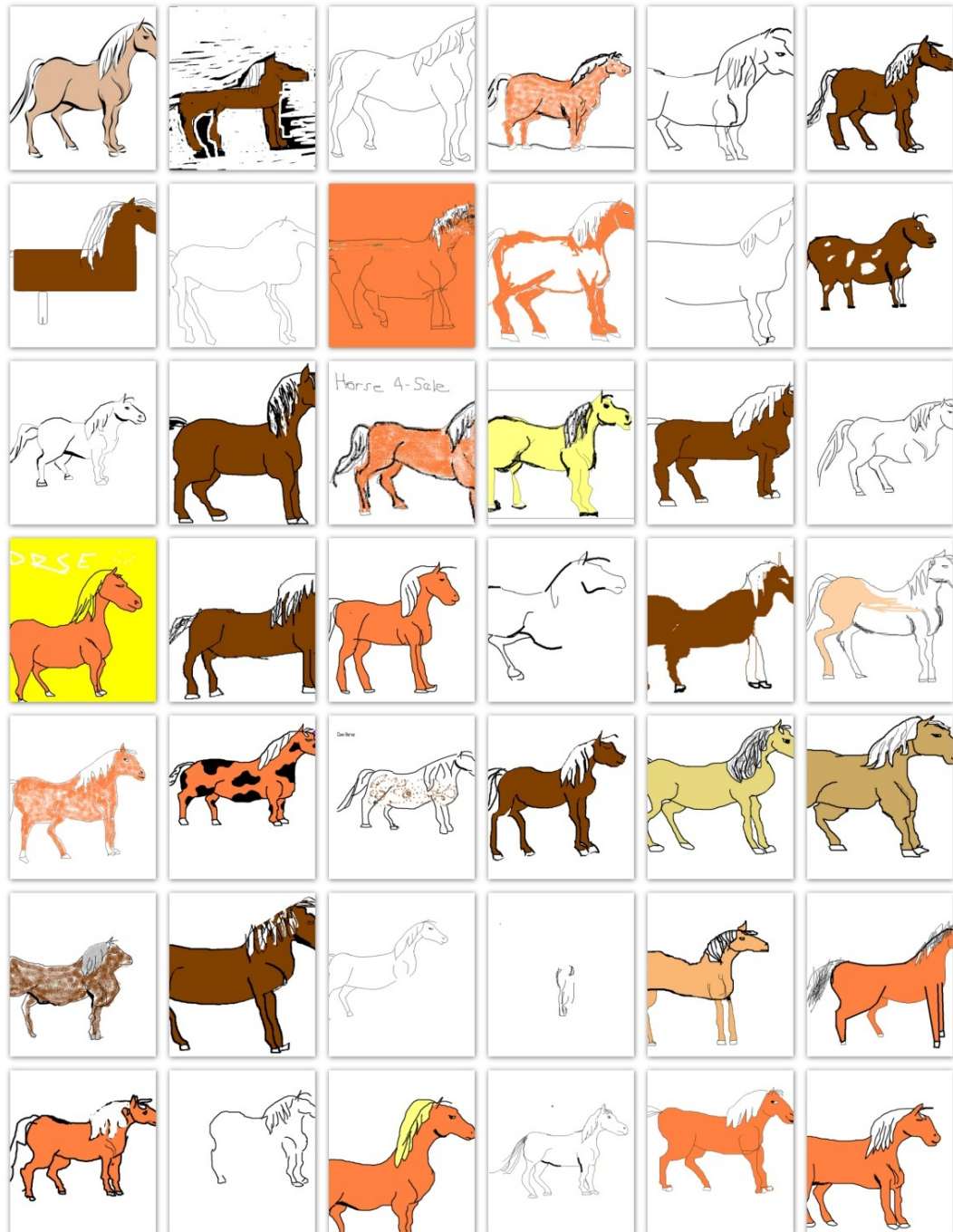


Figure C-4. Images of horse clipart that participants recreated in their mousing activity.

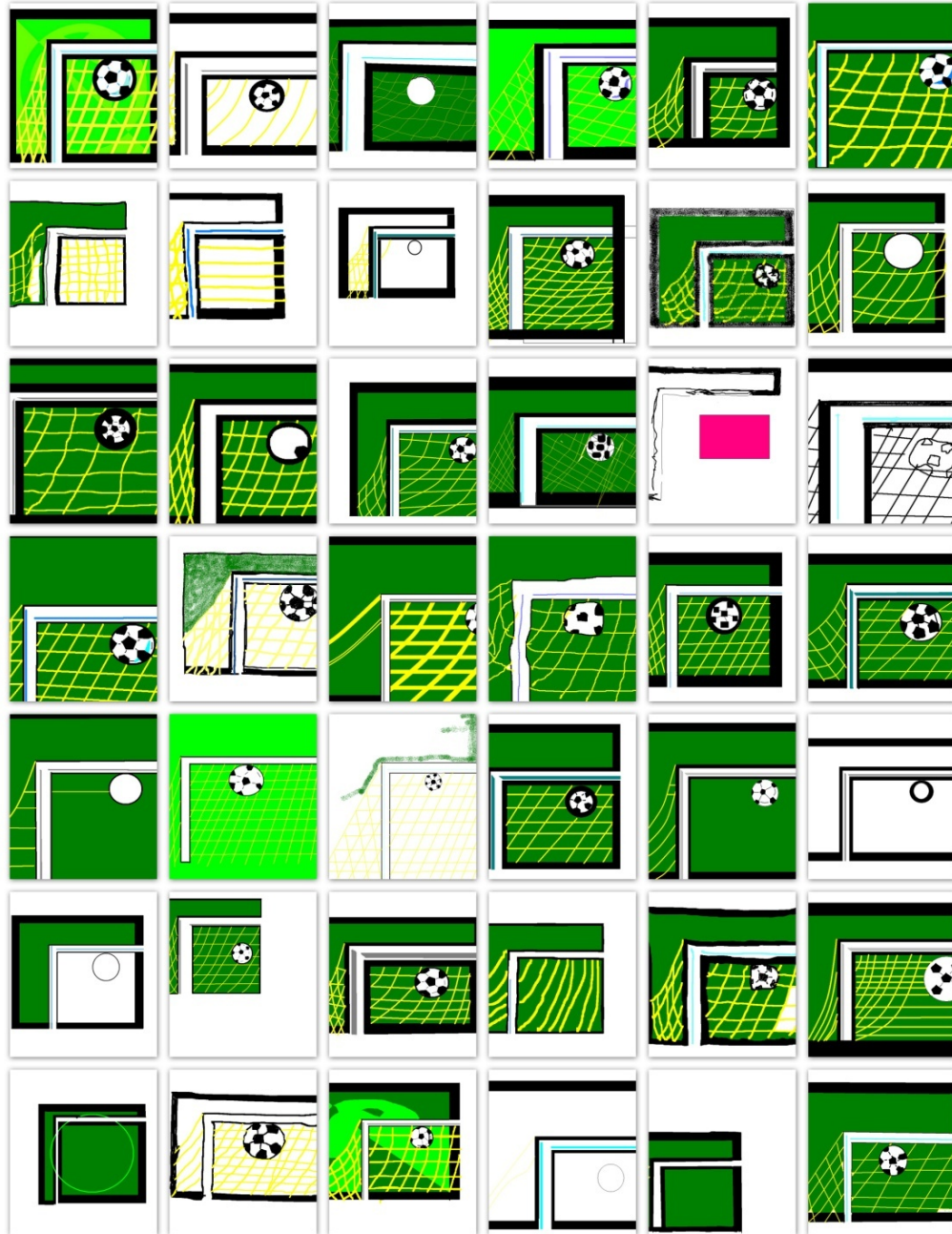


Figure C-5. Images of soccer goal clipart that participants recreated in their mousing activity.

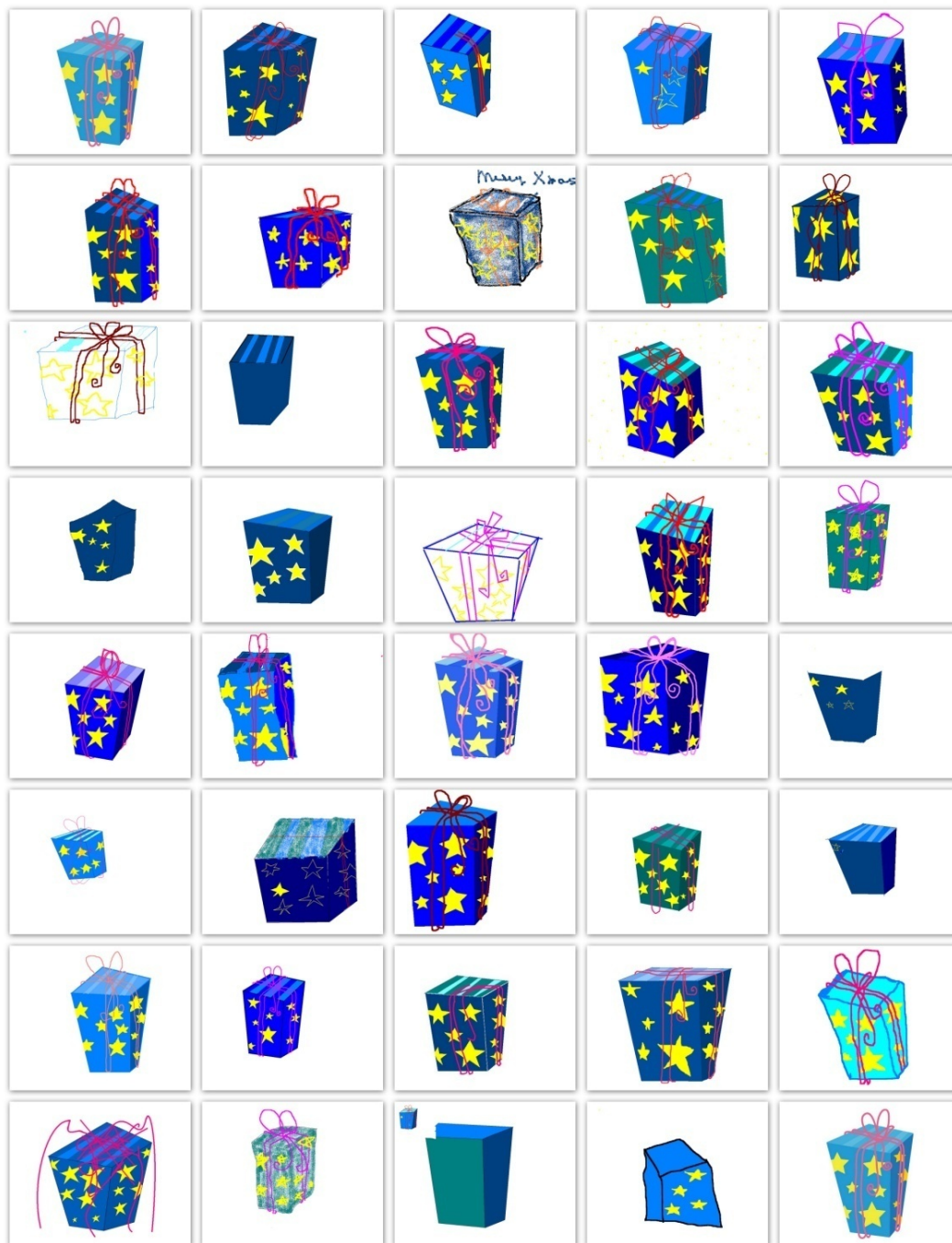


Figure C-6. Images of gift clipart that participants recreated in their mousing activity.

APPENDIX D: RESEARCH TOPICS

The following research topics and instructions were given to each subject during the testing of each chair. These research topics were used to simulate keyboarding and mousing at the same time, a common task in the office environment. Participants were instructed to research the given topic on the Internet and create a PowerPoint presentation of 3-5 slides in a 10-15 minute time period.

Use the Internet to search for information and then create a slide show (using PowerPoint) with 3-5 slides about the following topic. The topic is broad, so you can use your creativity and imagination as you put your PowerPoint slides together.

1. What are some of the new trends or problems of Ergonomics in the Office Environment?
2. What are some of the ergonomic issues or considerations for the educational environment (university, high school, middle school, or elementary school)?
3. What are some of the new technologies that are being used in the office environment?
4. What are the best ways to work comfortably when you are traveling (on a plane, in a hotel, at a coffee shop, etc.)?
5. What are some of the postures and ways that people work in a collaborative/non-traditional work environment?
6. What are some of the trends with Aging and Obesity in our society?

APPENDIX E. INFORMED CONSENT FORMS

The following form was used for subjects who were employed at Allsteel Inc. or The HON Company.

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INFORMED CONSENT DOCUMENT

Project Title: PREDICTING AND QUANTIFYING SEATED COMFORT AND DISCOMFORT USING OBJECTIVE AND SUBJECTIVE MEASURES

Principal Investigator: Scott Openshaw, MS, CPE

Research Team Contact: Scott Openshaw, 2210 Second Ave, Muscatine, IA 52761; 563-272-4879 or 563-299-4336

This consent form describes the research study to help you decide if you want to participate. This form provides important information about what you will be asked to do during the study, about the risks and benefits of the study, and about your rights as a research subject.

- If you have any questions about or do not understand something in this form, you should ask the research team for more information.
- You should discuss your participation with anyone you choose such as family or friends.
- Do not agree to participate in this study unless the research team has answered your questions and you decide that you want to be part of this study.

WHAT IS THE PURPOSE OF THIS STUDY?

This is a research study. You are being asked to participate in this research study because you are an adult who has indicated that you are able to sit for up to 4 hours, that you do not have back or leg injuries which would interfere with your assessments, that you have experience doing office work, and because you match a certain demographic included in the study population. The purpose of this research study is to assess the comfort and discomfort of different office chairs. We will measure individual personal feelings of comfort (subjective observations) as well as make electronic recordings (objective observations) of body positions while seated and working in an office setting. This data will be used to create a model that will allow researchers to predict comfort. The data and conclusions from this study may be published in professional journals, industry news, and used in future Allsteel product development.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 40 people will take part in this study conducted by a researcher from the University of Iowa at Allsteel Headquarters in Muscatine, Iowa.

HOW LONG WILL I BE IN THIS STUDY?

If you agree to take part in this study, your involvement will last for 2 days, up to 4 hours each day. The follow-up/second visit can be scheduled on consecutive days or as soon as possible after your first visit. The researcher can give you some alternative dates and times to schedule the second visit.

WHAT WILL HAPPEN DURING THIS STUDY?

During each visit, you will be asked to sit in 3 different office chairs for 1 hour each. You will be

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performing different office-related tasks while sitting and answering surveys about your comfort/discomfort. You will be asked to perform a typing task, a drawing task, and a net search task on a computer. We will keep the results of each task completed; for the typing task we will keep a report of results of the task as computed by the program used for the task; for the drawing task we will keep the image produced; and for the internet search task we will keep the file you create from the data collected.

We will record the pressure of your body on the chair seat and backrest as well as your skin temperature and breathing rate and movements using electronic equipment. To record the chair pressures we will place a pressure sensing pad on the seat and back of the chairs you will use for the study. These pads will collect information while you sit and work and send the information to a computer where it will be saved. To record your skin temperature, breathing rate, and acceleration and velocity of your arm movements, we will place a small electronic sensor around your upper arm using a cloth band with hook and loop closures. The sensor will collect the information while you are seated and working and will send the information to a computer where it will be saved. We will take photographs and make video recordings during your completion of the study tasks to record postures and interactions.

You will be asked to answer questionnaires presented on a computer. You will be asked to provide information about yourself including your age group, height range, weight range, gender, occupation/department, work experience, the amount of time you spend in a task chair each day, your handedness, typing skill level, percent of time in different sitting positions, and rate your current emotional state. You will also be asked to answer a questionnaire before, during, and after each experiment that asks about your level of comfort/discomfort and for an assessment of the chair. You have the right to skip any of the questions that you would like. We encourage you to ask questions.

Study Schedule:

DAY	Chair	Chair	Chair
1	C	A	B
	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey • 15 min break/rest 	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey • 15 min break/rest 	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey
2	D	C	A
	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey • 15 min break/rest 	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey • 15 min break/rest 	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey

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Video Recording or Photographs

One aspect of this study involves taking photographs of your posture and seated position or making video recordings while you are completing the study tasks. This will help to analyze the relationship between posture and comfort. Only the researcher will have access to the photographs and video recordings. If either is used to present results in reports, the images will be blurred so that you are not personally identified.

If you prefer not to be photographed or videotaped, you can still participate in the study. Please indicate your choice by placing your initials next to your choice below.

[_____] Yes [_____] No I give you permission to make video recordings of me during this study.

[_____] Yes [_____] No I give you permission to make photographs of me during this study.

WHAT ARE THE RISKS OF THIS STUDY?

You may experience one or more of the risks indicated below from being in this study. In addition to these, there may be other unknown risks, or risks that we did not anticipate, associated with being in this study.

- It is possible that you may feel some discomfort as you are sitting in the chair over time. You will be given time during the session to stand and move around. You may ask for a break if needed at any time.
- If you experience discomfort that continues beyond the experiment or if you have any concern about discomfort you have, contact Scott Openshaw at (563) 272-4879 or OpenshawS@allsteeloffice.com.
- You may be concerned that your decision whether or not to be in the study or your performance on the study tasks will affect your status with your employer or that the information will be used to make employment decisions. We will not share your responses with your employer and your employer will not have access to identified research information. We will report the results of the study in group numbers and if any images are used in the reporting of study results identifying features will be blocked or blurred on the images.

WHAT ARE THE BENEFITS OF THIS STUDY?

You will not benefit directly from being in this study. However, we hope that, in the future, other people might benefit from this study because it will help to determine an effective model for seated office comfort.

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WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not have any costs for being in this research study. Allsteel and HON/HNI members will be paid your regular wages during the time you are excused for participation in the study.

WILL I BE PAID FOR PARTICIPATING?

You will be paid your regular wage/salary from Allsteel/HNI for being in this research study. You will not receive additional payments for your participation.

WHO IS FUNDING THIS STUDY?

Allsteel is providing funds to support this research study. This means that the researcher is receiving payments from Allsteel to support the activities that are required to conduct the study. No one on the research team will receive a direct payment or increase in salary from Allsteel for conducting this study.

WHAT ABOUT CONFIDENTIALITY?

We will keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people such as those indicated below may become aware of your participation in this study and may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

- federal government regulatory agencies,
- auditing departments of the University of Iowa, and
- the University of Iowa Institutional Review Board (a committee that reviews and approves research studies)

To help protect your confidentiality, we will identify your study information by a subject number and not your name. The subject number assigned to you will be linked to your name on a master list that is stored in a separate location from the study data and which is accessible only to the researcher on this project. This signed consent document will be stored in a separate location from your study data. All paper or hard copy research materials will be stored in locked filing cabinets and storage areas and all electronic research materials will be stored in password protected computer files. If we write a report or article about this study or share the study data set with others, we will do so in such a way that you cannot be directly identified.

IS BEING IN THIS STUDY VOLUNTARY?

Taking part in this research study is completely voluntary. You may choose not to take part at all. If you decide to be in this study, you may stop participating at any time. If you decide not to be in this study, or if you stop participating at any time, you won't be penalized or lose any benefits for which you otherwise qualify.

WHAT IF I HAVE QUESTIONS?

We encourage you to ask questions. If you have any questions about the research study itself, please

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 APPROVAL DATE: 12/02/10
 EXPIRATION DATE: 12/02/11

contact: Scott Openshaw at OpenshawS@allsteeloffice.com or 563-272-4879. If you experience a research-related injury, please contact Scott or Thomas Schnell, Thomas-schnell@uiowa.edu.

If you have questions, concerns, or complaints about your rights as a research subject or about research related injury, please contact the Human Subjects Office, 105 Hardin Library for the Health Sciences, 600 Newton Rd, The University of Iowa, Iowa City, IA 52242-1098, (319) 335-6564, or e-mail irb@uiowa.edu. General information about being a research subject can be found by clicking "Info for Public" on the Human Subjects Office web site, <http://research.uiowa.edu/hso>. To offer input about your experiences as a research subject or to speak to someone other than the research staff, call the Human Subjects Office at the number above.

This Informed Consent Document is not a contract. It is a written explanation of what will happen during the study if you decide to participate. You are not waiving any legal rights by signing this Informed Consent Document. Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subject's Name (printed): _____

Do not sign this form if today's date is on or after EXPIRATION DATE: 12/02/11.

 (Signature of Subject)

 (Date)

Statement of Person Who Obtained Consent

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative. It is my opinion that the subject understands the risks, benefits, and procedures involved with participation in this research study.

 (Signature of Person who Obtained Consent)

 (Date)

The following form was used for subjects who were recruited outside of the furniture companies in Muscatine, Iowa.

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INFORMED CONSENT DOCUMENT

Project Title: PREDICTING AND QUANTIFYING SEATED COMFORT AND DISCOMFORT USING OBJECTIVE AND SUBJECTIVE MEASURES

Principal Investigator: Scott Openshaw, MS, CPE

Research Team Contact: Scott Openshaw, 2210 Second Ave, Muscatine, IA 52761; 563 272 4879 or 563-299-4336

This consent form describes the research study to help you decide if you want to participate. This form provides important information about what you will be asked to do during the study, about the risks and benefits of the study, and about your rights as a research subject.

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- You should discuss your participation with anyone you choose such as family or friends.
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This is a research study. You are being asked to participate in this research study because you are an adult who has indicated that you are able to sit for up to 4 hours, that you do not have back or leg injuries which would interfere with your assessments, that you have experience doing office work, and because you match a certain demographic included in the study population. The purpose of this research study is to assess the comfort and discomfort of different office chairs. We will measure individual personal feelings of comfort (subjective observations) as well as make electronic recordings (objective observations) of body positions while seated and working in an office setting. This data will be used to create a model that will allow researchers to predict comfort. The data and conclusions from this study may be published in professional journals, industry news, and used in future Allsteel product development.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 40 people will take part in this study conducted by a researcher from the University of Iowa at Allsteel Headquarters in Muscatine, Iowa.

HOW LONG WILL I BE IN THIS STUDY?

If you agree to take part in this study, your involvement will last for 2 days, up to 4 hours each day. The follow-up/second visit can be scheduled on consecutive days or as soon as possible after your first visit. The researcher can give you some alternative dates and times to schedule the second visit.

WHAT WILL HAPPEN DURING THIS STUDY?

Because you are a visitor at Allsteel headquarters, you will be asked to sign a non-disclosure agreement form to agree to keep things you see and hear while here at Allsteel confidential (as outlined in the

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document). The researcher will give you that document to sign. Please ask any questions you may have.

During each study visit, you will be asked to sit in 3 different office chairs for 1 hour each. You will be performing different office-related tasks while sitting and answering surveys about your comfort/discomfort. You will be asked to perform a typing task, a drawing task, and a net search task on a computer. We will keep the results of each task completed; for the typing task we will keep a report of results of the task as computed by the program used for the task; for the drawing task we will keep the image produced; and for the internet search task we will keep the file you create from the data collected.

We will record the pressure of your body on the chair seat and backrest as well as your skin temperature and breathing rate and movements using electronic equipment. To record the chair pressures we will place a pressure sensing pad on the seat and back of the chairs you will use for the study. These pads will collect information while you sit and work and send the information to a computer where it will be saved. To record your skin temperature, breathing rate, and acceleration and velocity of your arm movements, we will place a small electronic sensor around your upper arm using a cloth band with hook and loop closures. The sensor will collect the information while you sit and work and will send the information to a computer where it will be saved. We will take photographs and make video recordings during your completion of the study tasks to record postures and interactions.

You will be asked to answer questionnaires presented on a computer. You will be asked to provide information about yourself including your age group, height range, weight range, gender, occupation/department, work experience, the amount of time you spend in a task chair each day, your handedness, typing skill level, percent of time in different sitting positions, and rate your current emotional state. You will also be asked to answer a questionnaire before, during, and after each experiment that asks about your level of comfort/discomfort and for an assessment of the chair. You have the right to skip any of the questions that you would like. We encourage you to ask questions.

Study Schedule:

DAY	Chair	Chair	Chair
1	C	A	B
	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey • 15 min break/rest 	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey • 15 min break/rest 	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey
2	B	C	A
	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey • 15 min break/rest 	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey • 15 min break/rest 	<ul style="list-style-type: none"> • Initial Survey • 15 min Typing task • 15 min Research task • 15 min Mousing task • Final Survey

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--

Video Recording or Photographs

One aspect of this study involves taking photographs of your posture and seated position or making video recordings while you are completing the study tasks. This will help to analyze the relationship between posture and comfort. Only the researcher will have access to the photographs and video recordings. If either is used to present results in reports, the images will be blurred so that you are not personally identified.

If you prefer not to be photographed or videotaped, you can still participate in the study. Please indicate your choice by placing your initials next to your choice below.

[_____] Yes [_____] No I give you permission to make **video recordings** of me during this study.

[_____] Yes [_____] No I give you permission to make **photographs** of me during this study.

WHAT ARE THE RISKS OF THIS STUDY?

You may experience one or more of the risks indicated below from being in this study. In addition to these, there may be other unknown risks, or risks that we did not anticipate, associated with being in this study

- It is possible that you may feel some discomfort as you are sitting in the chair over time. You will be given time during the session to stand and move around. You may ask for a break if needed at any time.
- If you experience discomfort that continues beyond the experiment or if you have any concern about discomfort you have, contact Scott Openshaw at (563) 272-4879 or OpenshawS@allsteeloffice.com.
- You may be concerned that your decision whether or not to be in the study or your performance on the study tasks will affect your status with your employer or that the information will be used to make employment decisions. We will not share your responses with your employer and your employer will not have access to identified research information. We will report the results of the study in group numbers and if any images are used in the reporting of study results identifying features will be blocked or blurred on the images.

WHAT ARE THE BENEFITS OF THIS STUDY?

You will not benefit directly from being in this study. However, we hope that, in the future, other people might benefit from this study because it will help to determine an effective model for seated office comfort.

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WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not have any costs for being in this research study

WILL I BE PAID FOR PARTICIPATING?

You will receive a \$50 American Express gift card for each day that you complete the study. If you decide to withdraw before the end of the study session, you will receive a \$25 gift card for completion of a partial study session. You will be asked to provide your name and the name of your employer in order to receive the study payment. This information will be used for account reconciliation. The information will then be destroyed after 1 year of retention.

WHO IS FUNDING THIS STUDY?

Allsteel is providing funds to support this research study. This means that the researcher is receiving payments from Allsteel to support the activities that are required to conduct the study. No one on the research team will receive a direct payment or increase in salary from Allsteel for conducting this study.

WHAT ABOUT CONFIDENTIALITY?

We will keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people such as those indicated below may become aware of your participation in this study and may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

- federal government regulatory agencies,
- auditing departments of the University of Iowa, and
- the University of Iowa Institutional Review Board (a committee that reviews and approves research studies)

To help protect your confidentiality, we will identify your study information by a subject number and not your name. The subject number will be linked to your name on a master list that is stored in a separate location from the study data and which is accessible only to the researcher on this project. This signed consent document will be stored separately from your study data. All paper or hard copy research materials will be stored in locked filing cabinets and storage areas and all electronic research materials will be stored in password-protected computer files. If we write a report or article about this study or share the study data set with others, we will do so in such a way that you cannot be directly identified.

IS BEING IN THIS STUDY VOLUNTARY?

Taking part in this research study is completely voluntary. You may choose not to take part at all. If you decide to be in this study, you may stop participating at any time. If you decide not to be in this study, or if you stop participating at any time, you won't be penalized or lose any benefits for which you otherwise qualify.

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WHAT IF I HAVE QUESTIONS?

We encourage you to ask questions. If you have any questions about the research study itself, please contact: Scott Openshaw at OpenshawS@allsteeloffice.com or 563-272-4879. If you experience a research-related injury, please contact Scott or Thomas Schnell, Thomas-schnell@uiowa.edu.

If you have questions, concerns, or complaints about your rights as a research subject or about research related injury, please contact the Human Subjects Office, 105 Hardin Library for the Health Sciences, 600 Newton Rd, The University of Iowa, Iowa City, IA 52242-1098, (319) 335-6564, or e-mail irb@uiowa.edu. General information about being a research subject can be found by clicking "Info for Public" on the Human Subjects Office web site, <http://research.uiowa.edu/hso>. To offer input about your experiences as a research subject or to speak to someone other than the research staff, call the Human Subjects Office at the number above.

This Informed Consent Document is not a contract. It is a written explanation of what will happen during the study if you decide to participate. You are not waiving any legal rights by signing this Informed Consent Document. Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subject's Name (printed): _____

Do not sign this form if today's date is on or after EXPIRATION DATE: 12/02/11 .

(Signature of Subject)

(Date)

Statement of Person Who Obtained Consent

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative. It is my opinion that the subject understands the risks, benefits, and procedures involved with participation in this research study.


(Signature of Person who Obtained Consent)

(Date)

APPENDIX F. COMFORT SURVEY

The following questions were asked to each participant at the beginning and end of testing.

Date and Time



What is your subject number?

Which Test Chair are you sitting in?

B

P

R

Is this Day 1 of testing or Day 2 of testing for you?

Day 1

Day 2

Redo Day 1

Redo Day 2

Is this the start of the test or end of the test for the chair?

Start

End

Figure F-1. Page 1 of the Comfort Survey

Please rate (on a scale of 1-5) the location of pain that you feel right now in different parts of your body

	No pain		Moderate pain		Severe pain
	1	2	3	4	5
Head/neck	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Shoulders	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Arms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Wrists/hands	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Back	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Chest	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Hips/buttocks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Upper legs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lower legs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ankles/feet	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Body Part Discomfort



Figure F-2. Page 2 of the Comfort Survey

Next Save Cancel

Please rate your level of general comfort in each category on a scale of 1-9.

	Not at all				Moderately		Extremely		
	1	2	3	4	5	6	7	8	9
I feel completely relaxed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel perfectly comfortable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel quite comfortable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel barely comfortable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel uncomfortable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel restless and fidgety	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel cramped	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel stiff	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel numb (or pins and needles)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel sore and tender	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel unbearable pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Created at 3/2/2011 4:18 PM by Openshaw, Scott (Allsteel)
Last modified at 3/2/2011 4:22 PM by Openshaw, Scott (Allsteel)

Next Save Cancel

Figure F-3. Page 3 of the Comfort Survey

Next Save Cancel

Please rate the following on a scale of 1-9.

	Not at all				Moderately		Extremely		
	1	2	3	4	5	6	7	8	9
I have sore muscles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I have heavy legs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel stiff	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel tired	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel numb	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel uneven pressure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel cramped	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel restless	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel relaxed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel refreshed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel restful	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Chair is spacious	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Chair looks nice	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Chair feels soft	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I like the chair	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel comfortable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel uncomfortable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure F-4. Page 4 of the Comfort Survey

The seat depth for the chair is...					
	Too deep 1	2	Perfect 3	4	Too shallow 5
Seat depth	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

The seat width for the chair is...					
	Too narrow 1	2	Perfect 3	4	Too wide 5
Seat Width	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

The seat height for this chair is...					
	Too low 1	2	Perfect 3	4	Too high 5
Seat Height	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

The contour of the seat in this chair is...					
	Not enough 1	2	Perfect 3	4	Too much 5
Seat Contour	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Rate the back of the chair...					
	Too low 1	2	Perfect 3	4	Too high 5
Backrest Height	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lumbar Support	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Rate the comfort of the...					
	Uncomfortable 1	2	Average 3	4	Comfortable 5
Seat	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Back	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Chair overall	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Add any comments you have about this chair:

Figure F-5. Page 5 of the Comfort Survey

APPENDIX G. DEMONSTRATION SURVEY

The following survey was given to each participant to familiarize them with the procedure of filling out a SharePoint survey online.

This is a text field to enter information. Enter a number between 1 and 10

This is a choice field. Enter your choice by selecting one of the radio buttons on the left of the question

Enter Choice #1
 Enter Choice #2
 Enter Choice #3

This is a multiple-answer example. You can select the checkboxes to answer the items that are with 1 or more responses.

Enter Choice #1
 Enter Choice #2
 Enter Choice #3
 Enter Choice #4

This is a rating scale. For each item, select the ranking that is applicable.

	Cold		Warm		Hot
	1	2	3	4	5
Weather Outside	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Now that you are done with this page, you can choose the "NEXT" button at the bottom of the page to continue the survey. If you press the "SAVE" button, it will save your work and kick you out of the survey.

Figure G-1. Page 1 of the Demonstration Survey

This question is a drop down box. Select the drop down arrow and then the appropriate value.

Now that you are done with the tutorial, please ask any questions before you are ready to begin.

Press FINISH to submit and save your survey answers.

Figure G-2. Page 2 of the Demonstration Survey

APPENDIX H. DEMOGRAPHICS SURVEY

The following survey was given at the start of the experiment to obtain general demographics and comfort information from each participant.

Date and Time Started

What is your subject number?

What is your gender?

Male

Female

What is your age range?

18-24

25-34

35-44

45-54

55-64

65-74

What is your height range?

Below 5'

5' to 5'2"

5'3" to 5'5"

5'6" to 5'8"

5'9" to 5'11"

6' to 6'2"

Above 6'2"

What is your weight range?

Below 100

100 to 115

116 to 130

131 to 145

146 to 160

161 to 175

176 to 190

191 to 205

206 to 220

221 to 235

236 to 250

Above 250

Figure H-1. Page 1 of the Demographics Survey

How many years of work experience do you have in the office environment?

- 0 to 5 years
- 6 to 10 years
- 11 to 15 years
- 16 to 20 years
- 21 to 25 years
- More than 26 years

What type of department do you work in currently?

- Accounting/Finance
- Administration
- Engineering
- Human Resources
- Management
- Marketing
- Product Development
- Sales
- Specify your own value:

What is your "handedness"?

- Right Handed
- Left Handed
- Ambidextrous (either)

How do you type on a keyboard? (Check all that apply)

- Type with two fingers
 - Type with all my fingers
 - Almost always look at the keys when typing
 - Sometimes look at the keys when typing
 - Almost never look at the keys when typing
-

Figure H-2. Page 2 of the Demographics Survey

How many hours do you spend sitting in a task chair each day?

What percentage of the time do you sit in the following postures when working?

	10%		50%						100%		N/A
	1	2	3	4	5	6	7	8	9	10	
Upright	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reclined	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Perched	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Common Seated Postures

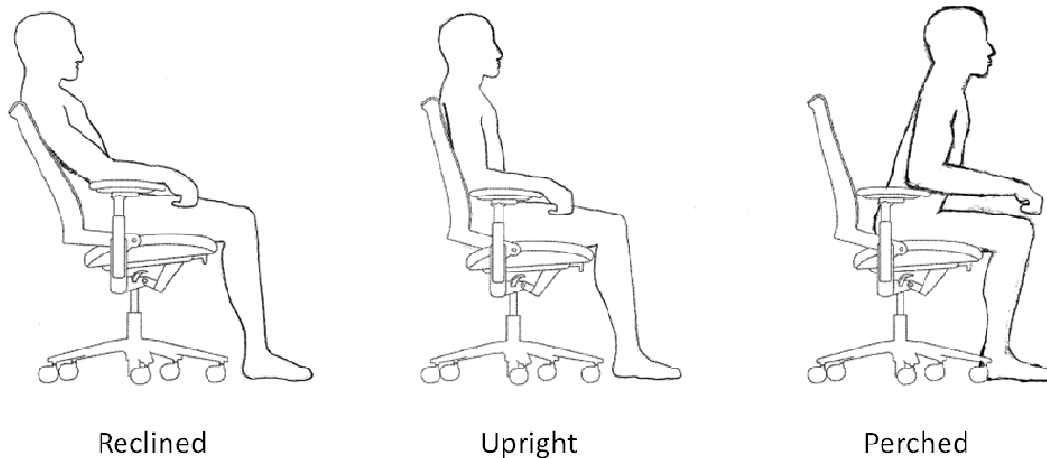


Figure H-3. Page 3 of the Demographics Survey. Image used to illustrate seated positions.

Choose your current emotional state

- 1. Intense Neutral
- 2. Intense Pleasant
- 3. Average Pleasant
- 4. Calm Pleasant
- 5. Calm Average
- 6. Calm Unpleasant
- 7. Average Unpleasant
- 8. Intense Unpleasant

Current Emotional State

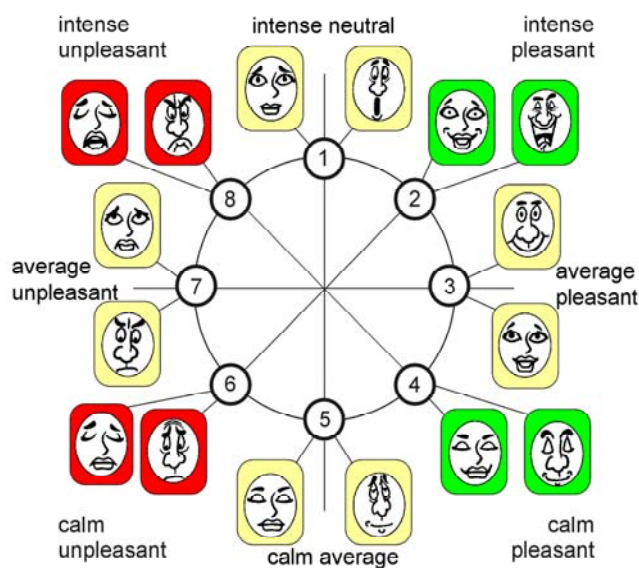


Figure H-4. Page 4 of the Demographics Survey. Image used to illustrate current emotional state (Desmet, Overbeeke, & Tax, 2001).

APPENDIX I: RESEARCHER DATA ENTRY

The following information was entered at the start and end of each chair that was tested.

Subject Number

Workstation

Kelly

Brandon

Shop

Clothes subject is wearing

Shirt

Pants

Skirt

Dress

Socks

Hose

Sweater

Jacket

Dress Shoes

Tennis Shoes

High Heels

Flip Flops

Specify your own value:

Trial Day

First Visit

Second Visit

Redo 1

Redo 2


Test Sequence

Start

End

Figure I-1. First set of questions for the researcher to enter on each trial

Date and Time Started



Temperature in the room

Humidity value in the room

Lighting value in the room

Chair Tested

B
 P
 R

Arm Height setting

Seat Height value

Seat Depth value

Recline setting

Locked
 Unlocked

Figure I-2. Second set of questions for the researcher to enter on each chair trial

APPENDIX J. CODE FOR DATA PROCESSING

J.1 Pressure Map Data Processing

The following Visual Basic for Applications (VBA) code was created to fix pressure mapping data that had three issues:

1. Extra pressure readings in the top corner of the backrest came from the pad being pulled over the top right corner of the chair. These pressure readings were not related to the subject's back pressure map and needed to be eliminated for correct calculations.
2. Complete lines (rows or columns) of pressure mapping data were missing because the pressure mapping wires had a short in them during the recording. Most "blank" lines were horizontal, but there were some that were vertical.
3. Missing data "holes" on the pressure map where a short line of cells did not record, but others around them did.

```
Sub openExports()

Dim f, p As Integer
Dim fname As String
Dim lastRow As Long
Dim fPath As String
Dim block, r1, r2, c1, c2 As Integer

Dim writeFile As String
Dim ch As Long
Dim msgWrite As String
Dim filePath As String
Dim txtFileNum As Integer
Dim startTime
Dim startDate
Dim macroTime
Dim macroDate

startTime = Time
startDate = Date
Dim ztable As String
Dim pmapfilep(210) As String

pmapfilep(0) = "F:\Data\AllPMapTogether\AllExport\Sub01ChBD1.txt"
' ... name other files
ztable = "F:\Data\AllPMapTogether\TopZeroTable.xlsx"

' open topzerotable file
ChDir "F:\Data\AllPMapTogether"
Workbooks.Open Filename:=ztable

lastRow = Range("A" & Rows.Count).End(xlUp).Row
```

```

f = 2      ' start with second row since first row are headings

Do While (f <= 210) = True

    ' pull information for filename
    macroTime = Time
    macroDate = Date
    fname = Range("A" & f)
    p = f - 2
    Debug.Print "Now Processing Row: " & f
    Debug.Print fname
    Debug.Print pmapfilep(p)

    ' determine how many blocks
    block = Cells(f, 2)

    ' pull information for blocks
    If block = 2 Then
        r1 = Cells(f, 3)
        c1 = Cells(f, 4)
        r2 = Cells(f, 5)
        c2 = Cells(f, 6)

    Else
        r1 = Cells(f, 3)
        c1 = Cells(f, 4)
        r2 = 0
        c2 = 0

    End If

    ' open PMap text file
    ChDir "F:\Data\AllPMapTogether\AllExport"

Workbooks.OpenText Filename:=pmapfilep(p), Origin:=437, StartRow:=1,
DataType:=xlDelimited, TextQualifier:=xlDoubleQuote, ConsecutiveDelimiter:=False,
Tab:=True, Semicolon:=False, Comma:=False, Space:=False, Other:=False, OtherChar:="x",
FieldInfo:=Array(Array(1, 1), Array(2, 1), Array(3, 1), Array(4, 1), Array(5, 1),
Array(6, 1), Array(7, 1), Array(8, 1), Array(9, 1), Array(10, 1), Array(11, 1), Array(12,
1), Array(13, 1), Array(14, 1), Array(15, 1), Array(16, 1), Array(17, 1), Array(18, 1),
Array(19, 1), Array(20, 1), Array(21, 1), Array(22, 1), Array(23, 1), Array(24, 1),
Array(25, 1), Array(26, 1), Array(27, 1), Array(28, 1), Array(29, 1), Array(30, 1),
Array(31, 1), Array(32, 1), Array(33, 1), Array(34, 1), Array(35, 1), Array(36, 1),
Array(37, 1), Array(38, 1), Array(39, 1), Array(40, 1)), TrailingMinusNumbers:=True

    ' run macros
    ' topZero
    Call CleanZeroTopLeft((block), (r1), (c1), (r2), (c2))

    ' zeroRows
    Call CleanZeroLines

    ' zeroHoles
    Call CleanZeroHoles

    ' write data to files (done in each function call above)

    ' save PMaptxt file
    ChDir "F:\Data\UpdatedPMapTxt"
    Application.DisplayAlerts = False
ActiveWorkbook.SaveAs Filename:="F:\Data\UpdatedPMapTxt\Upd" & fname, FileFormat:=xlText,
CreateBackup:=False
    Application.DisplayAlerts = True

    ' write changes to a data file
    writeFile = "blocks.txt"
    filePath = "F:\Data\UpdatedPMapTxt\" & writeFile
    txtFileNum = FreeFile()
    Open filePath For Append As #txtFileNum

```

```

Print #txtFileNum, "File: " & writeFile & " STARTED: " & startDate & " " & startTime
Print #txtFileNum, "File Process STARTED " & macroDate & " "; macroTime
Print #txtFileNum, "File Process COMPLETED " & Date & " "; Time()

    If block = 2 Then
Print #txtFileNum, "File: " & fname & " Block: " & block & " R1xC1: " & r1 & "x" & c1 & "
R2xC2: " & r2 & "x" & c2

    Else
Print #txtFileNum, "File: " & fname & " Block: " & block & " R1xC1: " & r1 & "x" & c1
    End If
    Close #txtFileNum ' close blocks.txt file

'close current PMap text file to move on to the next one
Application.DisplayAlerts = False
ActiveWorkbook.Close
Application.DisplayAlerts = True

f = f + 1
Loop
End Sub

Sub CleanZeroLines()
' Scott Openshaw and Miguel Morales
' 2/18/2011

' finds the lines with ALL zero values and averages the lines above and below
' used for Xsensor txt files

Dim lastRow As Long ' last row value on the sheet
Dim i As Long ' row value
Dim sumPrev As Long ' previous row's range
Dim sumNext As Long ' next row's range
Dim sumCurr As Long ' current row's range
Dim sumNext2 As Long
Dim strCurr As String
Dim strNext As String
Dim strPrev As String
Dim strNext2 As String
Dim rngCurr As Range
Dim rngNext As Range
Dim rngPrev As Range
Dim rngNext2 As Range
Dim totalChanges As Long

Dim c As Integer ' column value
Dim frame As Long
Dim pad As Long
Dim line As Long
Dim output(300000) As String
Dim writeFile As String
Dim ch As Long
Dim msgWrite As String
Dim filePath As String
Dim txtFileNum As Integer

Dim col(40) As String
Dim colrow1 As Long
Dim colrow40 As Long
Dim sumcPrev As Long
Dim sumcCurr As Long
Dim sumcnext As Long
Dim strcPrev As String
Dim strcCurr As String
Dim strcNext As String
Dim rngcPrev As Range
Dim rngcCurr As Range
Dim rngcNext As Range
Dim cOnetime As Boolean

```



```

Dim onlyPad1 As Boolean
Dim onlyPad2 As Boolean

` define columns col(i) from A to AN

Dim startTime
Dim startDate

startTime = Time
startDate = Date

lastRow = Range("A" & Rows.Count).End(xlUp).Row
i = 1
c = 1
totalChanges = 0
pad = 2
line = 0
writeFile = Sheets(1).Name & "zeroRows.txt"
filePath = "F:\Data\UpdatedPMapTxt\" & writeFile
ch = 0
cOnetime = False
onlyPad1 = False
onlyPad2 = False

Do While i <= lastRow = True
  If (Cells(i, 1) = "FRAME:") Then
    frame = Cells(i, 2)
  End If
  If (Cells(i, 1) = "PAD:" And pad = 2) Then
    pad = 1 ' assign pad 1
    line = 0 ' reset the line numbering after 40
    cOnetime = True
    onlyPad1 = True
    onlyPad2 = False
  Else
    If (Cells(i, 1) = "PAD:" And pad = 1) Then
      pad = 2 ' assign pad 2
      line = 0 ' reset the line numbering after 40
      cOnetime = True
      onlyPad1 = False
      onlyPad2 = True
    End If
  End If
  If ((Cells(i, c) <> "") And (IsNumeric(Cells(i, c)))) Then ' make sure line is
    numeric and not blank
    line = line + 1 ' Create line number for each pad
    colrow1 = i
    colrow40 = i + 39

    'check columns to see if they are all zeros and need to be averaged
    c = 2 ' start with 2nd column so you have a next and prev...
    Do While (cOnetime = True) And (c < 41) = True

      ' set ranges and calculate sums for columns
      strcCurr = col(c - 1) & colrow1 & ":" & col(c - 1) & colrow40
      Set rngcCurr = Range(strcCurr)
      sumcCurr = Application.WorksheetFunction.Sum(rngcCurr)

      If (sumcCurr = 0) Then
        strcPrev = col(c - 2) & colrow1 & ":" & col(c - 2) &
colrow40
        Set rngcPrev = Range(strcPrev)
        sumcPrev = Application.WorksheetFunction.Sum(rngcPrev)
        strcNext = col(c) & colrow1 & ":" & col(c) & colrow40
        Set rngcNext = Range(strcNext)
        sumcNext = Application.WorksheetFunction.Sum(rngcNext)

        If ((sumcCurr = 0) And (sumcPrev > 0) And (sumcNext > 0))
Then

```

```

Cells(colrow1, c).FormulaR1C1 = "=average(RC[-1],RC[1])"
strcCurr = col(c - 1) & colrow1 & ":" & col(c - 1) & colrow40
                Set rngcCurr = Range(strcCurr)
Cells(colrow1, c).AutoFill Destination:=rngcCurr, Type:=xlFillDefault

                ' record information when changes are made
                output(totalChanges) = "Change " & totalChanges + 1
& ": Excel Row - " & i & ": Frame - " & frame & "; Pad - " & pad & "; Column - " & c
                totalChanges = totalChanges + 1 ' count the number
of changes that have been made

                End If
            End If
            c = c + 1
        Loop
        cOnetime = False ' reset the trigger for doing column check 1 time
        c = 1 ' reset column to 1 for rest of the program

        ' setup for eliminating full rows of zeros
        strCurr = "A" & i & ":AN" & i ' create string for the current line
        Set rngCurr = Range(strCurr) ' set range for current string
        sumCurr = Application.WorksheetFunction.Sum(rngCurr) ' sum the current
range

        If ((Cells(i - 1, 1) <> "") And (IsNumeric(Cells(i - 1, 1))) And ((Cells(i
+ 1, 1) <> "") And (IsNumeric(Cells(i + 1, 1)))))) Then
            strPrev = "A" & i - 1 & ":AN" & i - 1 ' create string for the
previous row line
            Set rngPrev = Range(strPrev) ' create range for the
previous row string
            sumPrev = Application.WorksheetFunction.Sum(rngPrev) ' sum the
previous row range
            strNext = "A" & i + 1 & ":AN" & i + 1 ' create string for the
next row line
            Set rngNext = Range(strNext) ' create range for the
next row range
            sumNext = Application.WorksheetFunction.Sum(rngNext) ' sum the next
row range

            ' if 2 whole rows are zeros
            If ((onlyPad2 = True) And (sumCurr = 0) And (sumPrev > 0) And
(sumNext = 0) And (Cells(i + 2, 1) <> "") And (IsNumeric(Cells(i + 2, 1)))) Then
                strNext2 = "A" & i + 2 & ":AN" & i + 2 ' create string
for the next2 row line
                Set rngNext2 = Range(strNext2) '
create range for the next2 row range
                sumNext2 = Application.WorksheetFunction.Sum(rngNext2)
                ' sum the next2 row range
                If (sumNext2 > 0) Then

                    ' average the prev and 2nd next into current
                    Cells(i, 1).FormulaR1C1 = "=Average(R[-1]C,R[2]C)"
                    strcCurr = "A" & i & ":AN" & i
                    Set rngcCurr = Range(strcCurr)
                    Cells(i, 1).AutoFill Destination:=rngcCurr,
Type:=xlFillDefault 'autofill to the end of row

                    'record information when chages are made
                    output(totalChanges) = "Change " & totalChanges + 1
& ": Excel Row - " & i & ": Frame - " & frame & "; Pad - " & pad & "; Line - " & line
                    totalChanges = totalChanges + 1 ' count the number
of changes that have been made

                    ' average prev and next2 into next
                    Cells(i + 1, 1).FormulaR1C1 = "=Average(R[-
2]C,R[1]C)"

                    strNext = "A" & i + 1 & ":AN" & i + 1
                    Set rngNext = Range(strNext)
                    Cells(i + 1, 1).AutoFill Destination:=rngNext,
Type:=xlFillDefault 'autofill to the end of row

```

```

'record information when chages are made
output(totalChanges) = "Change " & totalChanges + 1
& ": Excel Row - " & i + 1 & ": Frame - " & frame & "; Pad - " & pad & "; Line - " & line
+ 1
totalChanges = totalChanges + 1 ' count the number
of changes that have been made
End If
End If

' if whole row is zeros and next and prev are non zero
If ((sumCurr = 0) And (sumPrev > 0) And (sumNext > 0)) Then ' make
sure prev and next are nonzero
Cells(i, 1).FormulaR1C1 = "=Average(R[-1]C,R[1]C)" '
average prev and next in current
strCurr = "A" & i & ":AN" & i
Set rngCurr = Range(strCurr)
Cells(i, 1).AutoFill Destination:=rngCurr,
Type:=xlFillDefault 'autofill to the end of row

'record information when chages are made
output(totalChanges) = "Change " & totalChanges + 1 & ":
Excel Row - " & i & ": Frame - " & frame & "; Pad - " & pad & "; Line - " & line
totalChanges = totalChanges + 1 ' count the number of
changes that have been made
End If
End If
End If
i = i + 1 ' increment the row
Loop

' write changes to a data file
txtFileNum = FreeFile()
Open filePath For Append As #txtFileNum
Print #txtFileNum, "File: " & writeFile
Print #txtFileNum, "Macro STARTED " & startDate & " "; startTime
Print #txtFileNum, "FILE STARTED " & Date & " "; Time()
Print #txtFileNum, "You had a total of " & totalChanges & " 'Zero Row' changes in this
worksheet"
For ch = 0 To totalChanges
Print #txtFileNum, output(ch)
Next ch
Close #txtFileNum

End Sub

Sub CleanZeroTopLeft(zblock As Integer, zrow1 As Integer, zcol1 As Integer, _
zrow2 As Integer, zcol2 As Integer)
' Scott Openshaw
' 2/22/2011

' asks the user for area (row and column) that needs to be zeroed out
' in the top left of the pressure map; used for Xsensor txt files

Dim lastRow As Long ' last row value on the sheet
Dim i As Long ' row value
Dim totalChanges As Long

Dim c As Integer ' column value
Dim frame As Long
Dim pad As Long
Dim line As Long
Dim output(300000) As String
Dim writeFile As String
Dim ch As Long
Dim msgWrite As String
Dim filePath As String
Dim txtFileNum As Integer

Dim col(40) As String
Dim onlyPad1 As Boolean

```

```

Dim onlyPad2 As Boolean

Dim combinations As Integer
Dim zeroRows As Integer
Dim zeroColumns As Integer
Dim zeroRows2 As Integer
Dim zeroColumns2 As Integer

Dim r As Range
Dim r2 As Range

` define columns col(i) from A to AN

Dim startTime
Dim startDate

startTime = Time
startDate = Date

lastRow = Range("A" & Rows.Count).End(xlUp).Row
i = 1
c = 1
totalChanges = 0
pad = 2
line = 0
writeFile = Sheets(1).Name & "topZero.txt"
filePath = "F:\Data\UpdatedPMapTxt\" & writeFile
ch = 0
cOnetime = False
onlyPad1 = False
onlyPad2 = False

'combinations = InputBox("How many blocks will be zeroed? 1 or 2?", "Blocks to Zero")
'If combinations = 2 Then
'    zeroRows = InputBox("How many rows need to be zeroed in your first block?", "Block
1 # Rows")
'    zeroColumns = InputBox("How many columns need to be zeroed in your first block?",
"Block 1 # Columns")
'    zeroRows2 = InputBox("How many rows need to be zeroed in your second block?",
"Block 2 # Rows")
'    zeroColumns2 = InputBox("How many columns need to be zeroed in your second
block?", "Block 2 # Columns")
'Else
'    zeroRows = InputBox("How many rows need to be zeroed?", "Number of Rows")
'    zeroColumns = InputBox("How many columns need to be zeroed?", "Number of Columns")
'End If

Do While i <= lastRow = True
    If (Cells(i, 1) = "FRAME:") Then
        frame = Cells(i, 2)
    End If
    If (Cells(i, 1) = "PAD:" And pad = 2) Then
        pad = 1 ' assign pad 1
        line = 0 ' reset the line numbering after 40
        onlyPad1 = True
        onlyPad2 = False
    Else
        If (Cells(i, 1) = "PAD:" And pad = 1) Then
            pad = 2 ' assign pad 2
            line = 0 ' reset the line numbering after 40
            onlyPad1 = False
            onlyPad2 = True
        End If
    End If
    If ((Cells(i, c) <> "") And (IsNumeric(Cells(i, c)))) Then ' make sure line is
numeric and not blank
        line = line + 1 ' Create line number for each pad
        If (onlyPad1 = True) Then

```

```

        If block = 2 Then

            ' fill in the first cell with a 0
            Cells(i, c).FormulaR1C1 = "0"
            Set r = Range(col(c - 1) & i)

            ' autofill the first column of cells with 0's BLOCK 1
            r.AutoFill Destination:=Range(col(c - 1) & i &
            ":" & col(c - 1) & i + zrow1 - 1), Type:=xlFillDefault

            ' autofill the rest of the columns with 0's BLOCK 1
            Set r = Range(col(c - 1) & i & ":" & col(c - 1) & i + zrow1
            - 1)
            r.AutoFill Destination:=Range(col(c - 1) & i &
            ":" & col(zcol1 - 1) & i + zrow1 - 1), Type:=xlFillDefault

            Cells(i, c).FormulaR1C1 = "0"
            Set r2 = Range(col(c - 1) & i)

            ' autofill the first column of cells with 0's BLOCK 2
            r2.AutoFill Destination:=Range(col(c - 1) & i &
            ":" & col(c - 1) & i + zrow2 - 1), Type:=xlFillDefault

            ' autofill the rest of the columns with 0's BLOCK 2
            Set r2 = Range(col(c - 1) & i & ":" & col(c - 1) & i +
            zrow2 - 1)
            r2.AutoFill Destination:=Range(col(c - 1) & i &
            ":" & col(zcol2 - 1) & i + zrow2 - 1), Type:=xlFillDefault

            'record information when chages are made
            output(totalChanges) = "(Zeroed) Change " & totalChanges +
            frame & "; Pad - " & pad
            totalChanges = totalChanges + 1 ' count the number of
            changes that have been made

        Else

            ' fill in the first cell with a 0
            Cells(i, c).FormulaR1C1 = "0"
            Set r = Range(col(c - 1) & i)

            ' autofill the first column with 0's
            r.AutoFill Destination:=Range(col(c - 1) & i &
            ":" & col(c - 1) & i + zrow1 - 1), Type:=xlFillDefault

            ' autofill the rest of the columns with 0's
            Set r = Range(col(c - 1) & i & ":" & col(c - 1) & i + zrow1
            - 1)
            r.AutoFill Destination:=Range(col(c - 1) & i &
            ":" & col(zcol1 - 1) & (i + zrow1 - 1)), Type:=xlFillDefault

            'record information when chages are made
            output(totalChanges) = "(Zeroed) Change " & totalChanges +
            frame & "; Pad - " & pad
            totalChanges = totalChanges + 1 ' count the number of
            changes that have been made

        End If

        ' reset the counters
        onlyPad1 = False

    End If

    End If
    i = i + 1 ' increment the row
Loop

' write changes to a data file
txtFileNum = FreeFile()
Open filePath For Append As #txtFileNum
Print #txtFileNum, "File: " & writeFile
Print #txtFileNum, "Macro STARTED " & startDate & " "; startTime

```

```

Print #txtFileNum, "FILE STARTED " & Date & " "; Time()
Print #txtFileNum, "You had a total of " & totalChanges & " 'Top Left Zero' changes in
this worksheet"
Print #txtFileNum, "Zeroed out BLOCK 1: " & zrow1 & " Rows by " & zcol1 & " Columns"
Print #txtFileNum, "Zeroed out BLOCK 2: " & zrow2 & " Rows by " & zcol2 & " Columns"
For ch = 0 To totalChanges
    Print #txtFileNum, output(ch)
Next ch
Close #txtFileNum

End Sub

Sub CleanZeroHoles()
' Scott Openshaw and Miguel Morales
' 2/18/2011

' finds the lines with ALL zero values and averages the lines above and below
' used for Xsensor txt files

Dim lastRow As Long          ' last row value on the sheet
Dim i As Long                ' row value
Dim sumPrev As Long         ' previous row's range
Dim sumNext As Long         ' next row's range
Dim sumCurr As Long         ' current row's range
Dim sumNext2 As Long
Dim strCurr As String
Dim strNext As String
Dim strPrev As String
Dim strNext2 As String
Dim rngCurr As Range
Dim rngNext As Range
Dim rngPrev As Range
Dim rngNext2 As Range
Dim totalChanges As Long

Dim c As Integer            ' column value
Dim frame As Long
Dim pad As Long
Dim line As Long
Dim output(300000) As String
Dim writeFile As String
Dim ch As Long
Dim msgWrite As String
Dim filePath As String
Dim txtFileNum As Integer

Dim col(40) As String
Dim colrow1 As Long
Dim colrow40 As Long
Dim sumcPrev As Long
Dim sumcCurr As Long
Dim sumcnext As Long
Dim strcPrev As String
Dim strcCurr As String
Dim strcNext As String
Dim rngcPrev As Range
Dim rngcCurr As Range
Dim rngcNext As Range
Dim cOnetime As Boolean
Dim onlyPad1 As Boolean
Dim onlyPad2 As Boolean

' define columns col(i) from A to AN

Dim startTime
Dim startDate

startTime = Time
startDate = Date

lastRow = Range("A" & Rows.Count).End(xlUp).Row

```

```

i = 1
c = 1
totalChanges = 0
pad = 2
line = 0
writeFile = Sheets(1).Name & "zeroHoles.txt"
filePath = "F:\Data\UpdatedPMapTxt\" & writeFile
ch = 0
cOnetime = False
onlyPad1 = False
onlyPad2 = False

Do While i <= lastRow = True
  If (Cells(i, 1) = "FRAME:") Then
    frame = Cells(i, 2)
  End If

  If (Cells(i, 1) = "PAD:" And pad = 2) Then
    pad = 1 ' assign pad 1
    line = 0 ' reset the line numbering after 40
    cOnetime = True
    onlyPad1 = True
    onlyPad2 = False
  Else
    If (Cells(i, 1) = "PAD:" And pad = 1) Then
      pad = 2 ' assign pad 2
      line = 0 ' reset the line numbering after 40
      cOnetime = True
      onlyPad1 = False
      onlyPad2 = True
    End If
  End If

  If ((Cells(i, c) <> "") And (IsNumeric(Cells(i, c)))) Then ' make sure line is
numeric and not blank
    line = line + 1 ' Create line number for each pad

    strCurr = "A" & i & ":AN" & i ' create string for the current line
    Set rngCurr = Range(strCurr) ' set range for current string
    sumCurr = Application.WorksheetFunction.Sum(rngCurr) ' sum the current
range
    If ((Cells(i - 1, 1) <> "") And (IsNumeric(Cells(i - 1, 1))) And ((Cells(i
+ 1, 1) <> "") And (IsNumeric(Cells(i + 1, 1))))) Then
      strPrev = "A" & i - 1 & ":AN" & i - 1 ' create string for the
previous row line
      Set rngPrev = Range(strPrev) ' create range for the
previous row string
      sumPrev = Application.WorksheetFunction.Sum(rngPrev) ' sum the
previous row range
      strNext = "A" & i + 1 & ":AN" & i + 1 ' create string for the
next row line
      Set rngNext = Range(strNext) ' create range for the
next row range
      sumNext = Application.WorksheetFunction.Sum(rngNext) ' sum the next
row range

      ' check to see if some values are zeros and then average them
      If ((onlyPad2 = True) And (sumCurr > 0) And (sumPrev > 0) And
(sumNext > 0)) Then ' fix zero cells if not all are zeros
        Do While c < 39 = True

          ' check if current is a zero and next/prev are
greater than zero
          If (Cells(i, c) = 0) And (Cells(i - 1, c)) > 0 And
(Cells(i + 1, c) > 0) Then
            Cells(i, c).FormulaR1C1 = "=Average(R[-1]C,R[1]C)"
          ' average prev and next in current

          ' record information when changes are made

```

```

                                output(totalChanges) = "Change " & totalChanges + 1
& ": Excel Row - " & i & ": Frame - " & frame & "; Pad - " & pad & "; Line - " & line & "
; Column - " & c
                                totalChanges = totalChanges + 1 ' count the number
of changes that have been made
                                c = c + 1
                                Else
                                c = c + 1
                                End If
                                Loop
                                End If
                                c = 1
                                End If
                                End If
                                i = i + 1 ' increment the row
Loop
' write changes to a data file
txtFileNum = FreeFile()
Open filePath For Append As #txtFileNum
Print #txtFileNum, "File: " & writeFile
Print #txtFileNum, "Macro STARTED " & startDate & " "; startTime
Print #txtFileNum, "FILE STARTED " & Date & " "; Time()
Print #txtFileNum, "You had a total of " & totalChanges & " 'zero holes' changes in this
worksheets"
For ch = 0 To totalChanges
    Print #txtFileNum, output(ch)
Next ch
Close #txtFileNum
End Sub

```

J.2 Code to Extract Start and End Pressure Data

The following code averaged the 3m:00s to 4m:00s of pressure mapping data for each of the participants, corresponding to the time that they were taking their initial survey. It also averaged the last 3m:45s to 2m:45s of their testing, corresponding to the time they were taking their final survey.

```

Sub CleanXSNstartend()
'
' CleanXSNstartend Macro
' Create XLSX file that has all subjects' start and end averaged pressure map data
'
' Declare variables

Dim fname(209), fpath As String
Dim lRow, sRow, seRow, eRow, eeRow As Long
Dim i, r As Integer

' define fname(i) for all files in your folder

r = 2 ' starting row is 2 and then will be increased on each pass

```



```

fpath = "F:\Data\UpdatedPMapTxt\xsnV6\AllStatSensSimpleEachFr\"

For i = 0 To 208

    ChDir fpath
    Workbooks.Open fileName:=fpath & fname(i) & ".xlsx"

    If fname(i) = "SSS03ChRD2" Then
        sRow = 2
    ElseIf fname(i) = "SSS08ChBD1" Then
        sRow = 122
    ElseIf fname(i) = "SSS13ChRD1" Then
        sRow = 202
    ElseIf fname(i) = "SSS20ChBD1" Then
        sRow = 122
    Else
        sRow = 362
    End If

    seRow = sRow + 120 ' end of the start row averages
    lRow = Range("A" & Rows.Count).End(xlUp).Row ' last row in sheet
    eRow = lRow - 450 ' start of the end row
    eeRow = eRow + 120 ' end of the end row averages

    Debug.Print fname(i) & ": Start (" & sRow & "-" & seRow & ") | ROW: " & r

    ' copy the start average values into the Excel spreadsheet file
    Windows("CleanXSNStartEnd.xlsx").Activate
    Range("A" & r).Select
    ActiveCell.FormulaR1C1 = "360"
    Range("B" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C2"
    Range("C" & r).Select
    ActiveCell.FormulaR1C1 = "Start"
    Range("D" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C4"
    Range("E" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C5"
    Range("F" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C6"
    Range("G" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C7"
    Range("K" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C11"
    Range("L" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C12"

    Range("M" & r).Select
    ActiveCell.FormulaR1C1 = "=AVERAGE(" & fname(i) & ".xlsx!R" & sRow & "C:R" & seRow &
"C)"
    Range("M" & r).Select
    Selection.AutoFill Destination:=Range("M" & r & ":EN" & r), Type:=xlFillDefault
    Range("M" & r & ":EN" & r).Select

    ' fix text fields
    Range("AI" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
    Range("AS" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
    Range("BC" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
    Range("BM" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
    Range("BW" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
    Range("CG" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
    Range("CQ" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
    Range("DA" & r).Select
    ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"

```

```

Range("DK" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
Range("DU" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"
Range("EE" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & sRow & "C"

r = r + 1 ' move to the next row
Range("A" & r).Select

Debug.Print fname(i) & ": End (" & eRow & "-" & eeRow & ") | ROW: " & r

' Calculate the end average fields
Range("A" & r).Select
ActiveCell.FormulaR1C1 = "450"
Range("B" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C2"
Range("C" & r).Select
ActiveCell.FormulaR1C1 = "End"
Range("D" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C4"
Range("E" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C5"
Range("F" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C6"
Range("G" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C7"
Range("K" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C11"
Range("L" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C12"

Range("M" & r).Select
ActiveCell.FormulaR1C1 = "=AVERAGE(" & fname(i) & ".xlsx!R" & eRow & "C:R" & eeRow &
"C)"
Range("M" & r).Select
Selection.AutoFill Destination:=Range("M" & r & ":EN" & r), Type:=xlFillDefault
Range("M" & r & ":EN" & r).Select

' rename text fields
Range("EE" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("DU" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("DK" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("DA" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("CQ" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("CG" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("BW" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("BM" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("BC" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("AS" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"
Range("AI" & r).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & ".xlsx!R" & eRow & "C"

' move to the next row
r = r + 1
Range("A" & r).Select

' close the file and repeat the process with the next file

```

```

Windows(fname(i) & ".xlsx").Activate
Application.DisplayAlerts = False
ActiveWindow.Close
Application.DisplayAlerts = True

Next i

End Sub

```

J.3 Code for Extracting Start and End Average

Physiological Data

The following code averaged the 3m:00s to 4m:00s of physiological data for each of the participants, corresponding to the time that they were taking their initial survey. It also averaged the last 3m:45s to 2m:45s of their testing, corresponding to the time they were taking their final survey.

```

Sub BMseAvg()

Dim cCell, fname(70) As String
Dim lastRow, sRow, seRow, eRow, eeRow, r, writeR As Long
Dim n As Integer
r = 2
n = 0

' declare filename (fname(i) here

fpath = "F:\Data\AllBodyMedia\"

writeR = 2      ' start writing on the 2nd row of the XLSX sheet

For i = 0 To 69

    ' open file
    ' ChDir fpath
    Workbooks.Open fileName:=fpath & fname(i)
    lastRow = Range("A" & Rows.Count).End(xlUp).Row
    r = 2

    Do While r <= lastRow + 1

        If n < 4 Then
            cCell = Cells(r, 13)
            If cCell = "" Or cCell = "eof" Then
                ' do nothing
            ElseIf cCell = "sRow" Then
                sRow = Cells(r, 13).Row
                n = n + 1
            ElseIf cCell = "seRow" Then
                seRow = Cells(r, 13).Row
                n = n + 1
            ElseIf cCell = "eRow" Then
                eRow = Cells(r, 13).Row
                n = n + 1
            ElseIf cCell = "eeRow" Then
                eeRow = Cells(r, 13).Row
                n = n + 1
        End If
    End Do

```

```

Else
    Debug.Print "FILE: " & fname(i) & " error, ROW: " & r & " CELL: " & cCell
End If
r = r + 1
Else

' n is = 4 so do the calculations for start and end averages
Debug.Print fname(i) & ": START ROWS = (" & sRow & "-" & seRow; ") | END ROWS =
(" & eRow & "-" & eeRow & ")"

' calculate average of start
Windows("CleanBMAvgse.xlsx").Activate

Range("A" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C1" ' subject
Range("B" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C2" ' age
Range("C" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C3" ' height
Range("D" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C4" ' weight
Range("E" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C5" ' gender
Range("F" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C6" '
Handedness
Range("G" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C7" ' smoker
Range("H" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C8" ' serial
number
Range("I" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C9" ' subject
Range("J" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C10" ' day
Range("K" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C11" ' chair
order
Range("L" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C12" ' chair
Range("M" & writeR).Select
ActiveCell.FormulaR1C1 = "Start" ' start/end
Range("P" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & sRow & "C16" ' Time

Range("Q" & writeR).Select
ActiveCell.FormulaR1C1 = "=AVERAGE('[" & fname(i) & "]Data"!R" & sRow & "C:R" &
seRow & "C)"
Range("Q" & writeR).Select
Selection.AutoFill Destination:=Range("Q" & writeR & ":AH" & writeR),
Type:=xlFillDefault
Range("Q" & writeR & ":AH" & writeR).Select
writeR = writeR + 1 ' move to the next row for the END calculation
Range("A" & writeR).Select

' calculate average of end
Range("A" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & eRow & "C1" ' subject
Range("B" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & eRow & "C2" ' age
Range("C" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & eRow & "C3" ' height
Range("D" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & eRow & "C4" ' weight
Range("E" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & eRow & "C5" ' gender
Range("F" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data"!R" & eRow & "C6" '
Handedness
Range("G" & writeR).Select

```

```

ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data!R" & eRow & "C7" ' smoker
Range("H" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data!R" & eRow & "C8" ' serial
number
Range("I" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data!R" & eRow & "C9" ' subject
Range("J" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data!R" & eRow & "C10" ' day
Range("K" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data!R" & eRow & "C11" ' chair
order
Range("L" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data!R" & eRow & "C12" ' chair
Range("M" & writeR).Select
ActiveCell.FormulaR1C1 = "End" ' start/end
Range("P" & writeR).Select
ActiveCell.FormulaR1C1 = "=" & fname(i) & "]Data!R" & eRow & "C16" ' Time

Range("Q" & writeR).Select
ActiveCell.FormulaR1C1 = "=AVERAGE('[" & fname(i) & "]Data!R" & eRow & "C:R" &
eeRow & "C)"
Range("Q" & writeR).Select
Selection.AutoFill Destination:=Range("Q" & writeR & ":AH" & writeR),
Type:=xlFillDefault
Range("Q" & writeR & ":AH" & writeR).Select

writeR = writeR + 1 ' move to the next row for the START calculation
Range("A" & writeR).Select

' reset counter and variables, increase row
n = 0
sRow = 0
seRow = 0
eRow = 0
eeRow = 0
r = r + 1
Windows(fname(i)).Activate ' go back to the file to count rows
End If

Loop

'close the BM file and move on to the next one
Windows(fname(i)).Activate
Application.DisplayAlerts = False
ActiveWindow.Close
Application.DisplayAlerts = True

Next i

End Sub

```

APPENDIX K: STATISTICS

K.1 Demographics

Age, height, and weight distributions of each gender are shown in the tables below.

Table K-1. Age range distribution, female subjects

Female Age	Count	Probability
18-24	4	0.20000
25-34	3	0.15000
35-44	7	0.35000
45-54	3	0.15000
55-64	2	0.10000
65-74	1	0.05000
Total	20	1.00000

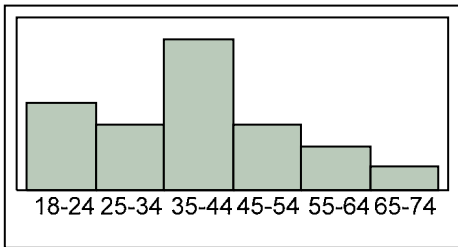


Table K-2. Height range, female subjects

Height	Count	Probability
Below 5'	1	0.05000
5' to 5'2"	3	0.15000
5'3" to 5'5"	7	0.35000
5'6" to 5'8"	7	0.35000
5'9" to 5'11"	1	0.05000
6' to 6'2"	1	0.05000
Total	20	1.00000

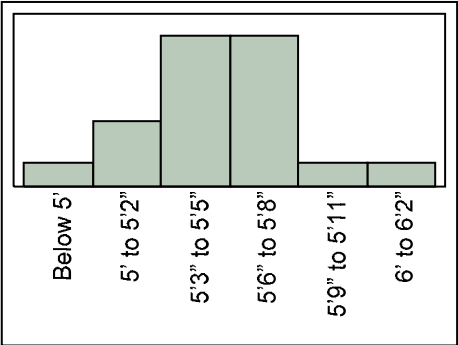


Table K-3. Weight range, female subjects

Weight	Count	Probability
100 to 115	2	0.10000
116 to 130	1	0.05000
131 to 145	4	0.20000
146 to 160	2	0.10000
161 to 175	1	0.05000
176 to 190	1	0.05000
191 to 205	4	0.20000
206 to 220	2	0.10000
221 to 235	2	0.10000
Above 250	1	0.05000
Total	20	1.00000

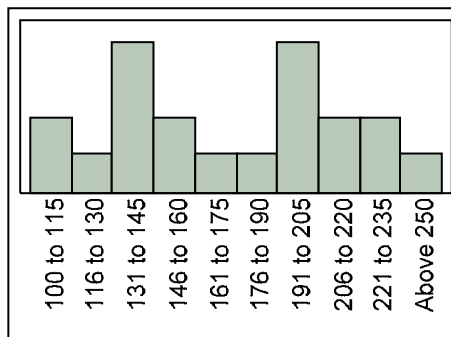


Table K-4. Age range, male subjects

Age	Count	Probability
18-24	3	0.20000
25-34	3	0.20000
35-44	2	0.13333
45-54	4	0.26667
55-64	2	0.13333
65-74	1	0.06667
Total	15	1.00000

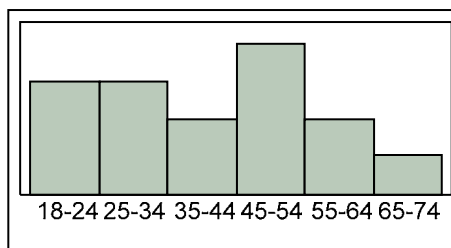


Table K-5. Height range, male subjects

Height	Count	Probability
5'6" to 5'8"	3	0.20000
5'9" to 5'11"	5	0.33333
6' to 6'2"	4	0.26667
Above 6'2"	3	0.20000
Total	15	1.00000

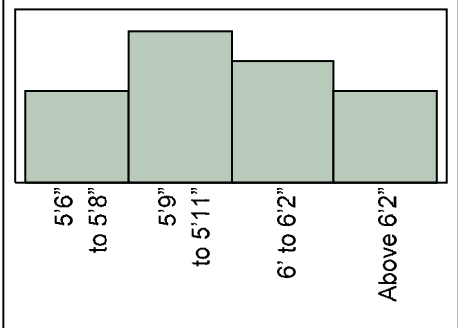


Table K-6. Weight range, male subjects

Weight	Count	Probability
146 to 160	3	0.20000
161 to 175	1	0.06667
176 to 190	3	0.20000
191 to 205	1	0.06667
206 to 220	2	0.13333
221 to 235	2	0.13333
236 to 250	2	0.13333
Above 250	1	0.06667
Total	15	1.00000

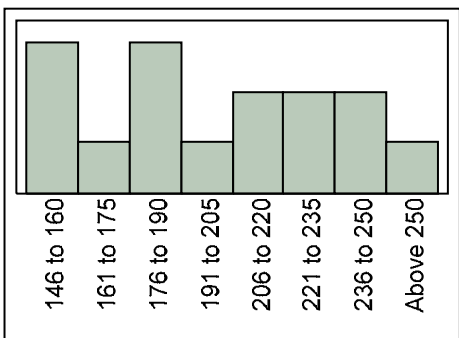


Table K-7. Estimated BMI, female subjects

Female Estimated BMI	
Median	27.5
Mean	28.35
Std Dev	6.9606034
Std Err Mean	1.5564382
Upper 95% Mean	31.607663
Lower 95% Mean	25.092337
N	20

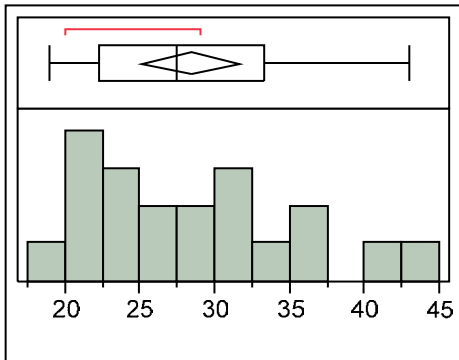
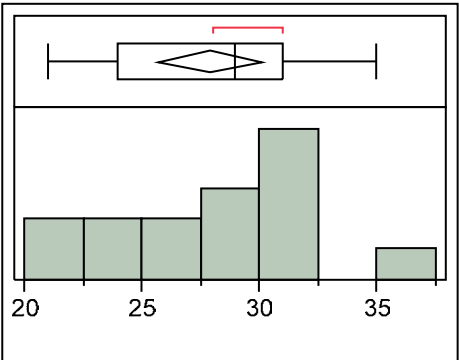


Table K-8. Estimated BMI, male subjects

Estimated Male BMI	
Median	29
Mean	27.866667
Std Dev	3.9072582
Std Err Mean	1.0088497
Upper 95% Mean	30.030434
Lower 95% Mean	25.702899
N	15



The following table was used to estimate BMI from participants' ranges of heights and weights.

Table K-9. BMI ranges based on height and weight ranges

	Weight Ranges											
	99	100-115	116-130	131-145	146-160	161-175	176-190	191-205	206-220	221-235	236-250	251
75	12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-27	28-29	29-31	31
72-74	13-13	13-16	15-18	17-20	19-22	21-24	23-26	25-28	26-30	28-32	30-34	32-34
69-71	14-15	14-17	16-19	18-21	20-24	22-26	25-28	27-30	29-32	31-35	33-37	35-37
66-68	15-16	15-19	18-21	20-23	22-26	24-28	27-31	29-33	31-36	34-38	36-40	38-41
63-65	16-18	17-20	19-23	22-26	24-28	27-31	29-34	32-36	34-39	37-42	39-44	42-44
60-62	18-19	18-22	21-25	24-28	27-31	29-34	32-37	35-40	38-43	40-46	43-49	46-49
59	20	20-23	23-26	26-29	29-32	33-35	36-38	39-41	42-44	45-47	48-50	51

Table K-10. Estimated BMI values based on average range values from Table K-9

Average Height Range Values	Average Weight Range Values											
	99	108	123	138	153	168	183	198	213	228	243	251
75	12	13	15	17	19	21	23	25	27	28	30	31
73	13	14	16	18	20	22	24	26	28	30	32	33
70	14	15	18	20	22	24	26	28	31	33	35	36
67	16	17	19	22	24	26	29	31	33	36	38	39
64	17	18	21	24	26	29	31	34	37	39	42	43
61	19	20	23	26	29	32	35	37	40	43	46	47
59	20	22	25	28	31	34	37	40	43	46	49	51

K.2 General Observations

The following tables illustrate the responses by all subjects regarding their office work experience and mannerisms.

Table K-11. Years of office experience, all subjects

Years of Office Experience	Count	Probability
0 to 5 years	15	0.42857
6 to 10 years	5	0.14286
11 to 15 years	5	0.14286
16 to 20 years	3	0.08571
21 to 25 years	1	0.02857
More than 26 years	6	0.17143
Total	35	1.00000

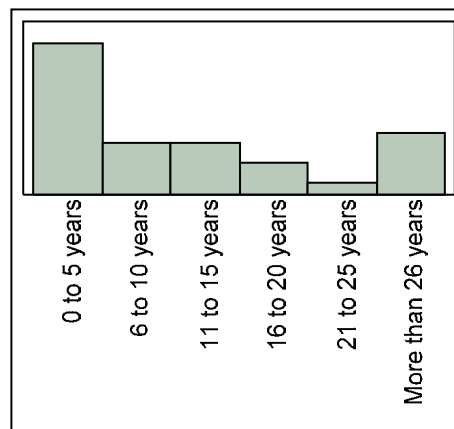


Table K-12. Amount of hours all subjects sit during the day

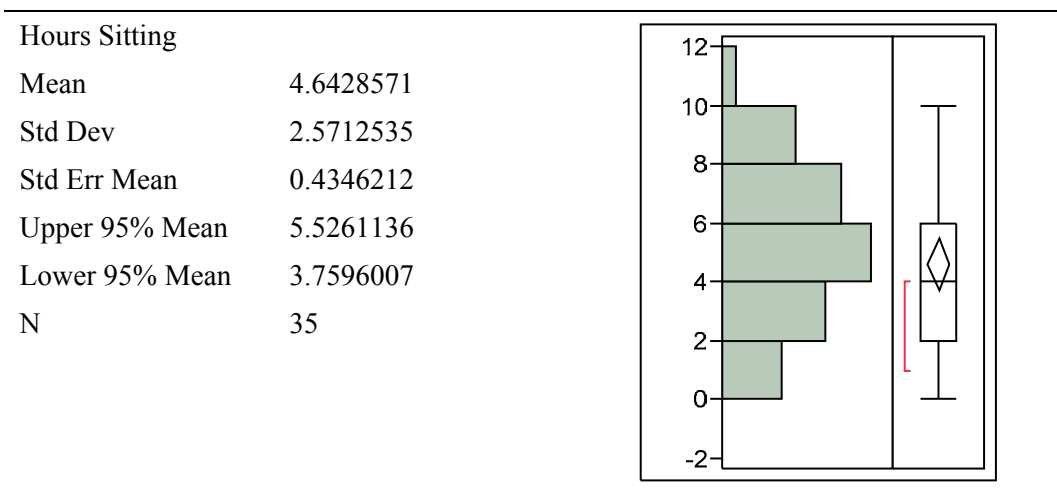


Table K-13. Typing habits, all subjects

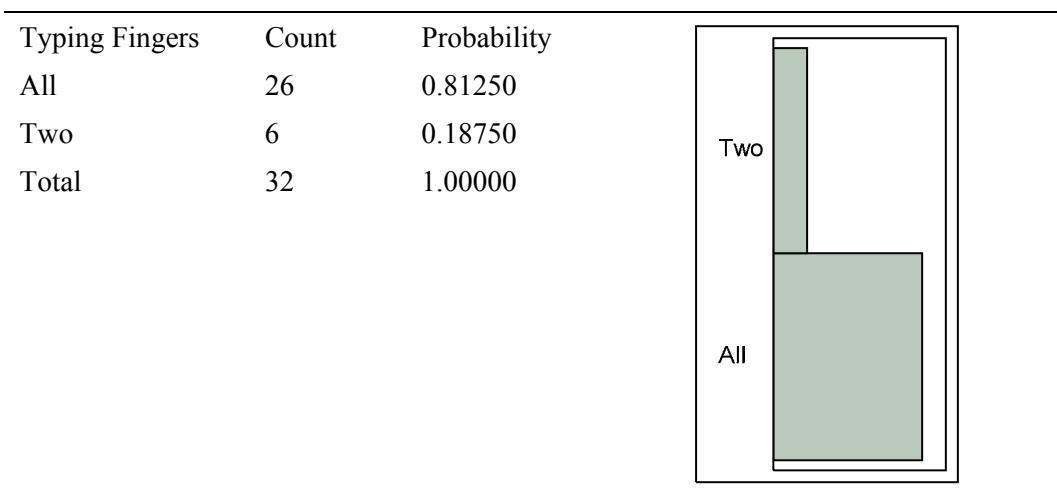


Table K-14. Typing and looking at the keys, all subjects

Typing Look	Count	Probability
Almost Never	8	0.28571
Sometimes	14	0.50000
Almost Always	6	0.21429
Total	28	1.00000

A horizontal bar chart with three bars. The top bar is labeled 'Almost Always' and has a length of 6. The middle bar is labeled 'Sometimes' and has a length of 14. The bottom bar is labeled 'Almost Never' and has a length of 8. The bars are light green with black outlines.

Table K-15. Handedness, all subjects

Handedness	Count	Probability
Ambidextrous (either)	1	0.02941
Left Handed	4	0.11765
Right Handed	29	0.85294
Total	34	1.00000

A horizontal bar chart with three bars. The top bar is labeled 'Right Handed' and has a length of 29. The middle bar is labeled 'Left Handed' and has a length of 4. The bottom bar is labeled 'Ambidextrous (either)' and has a length of 1. The bars are light green with black outlines.

Table K-16. Armrest height settings for all chairs

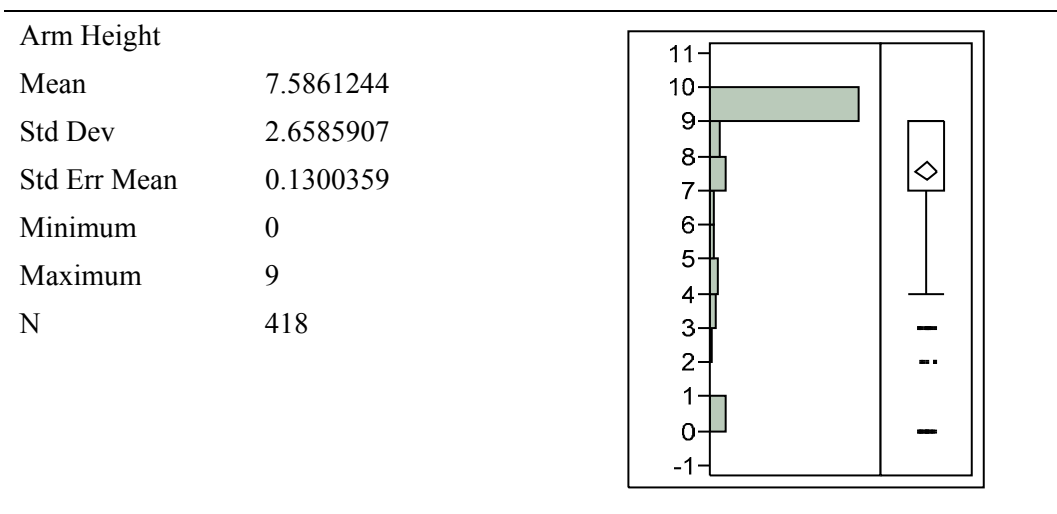


Table K-17. Seat height settings, all chairs

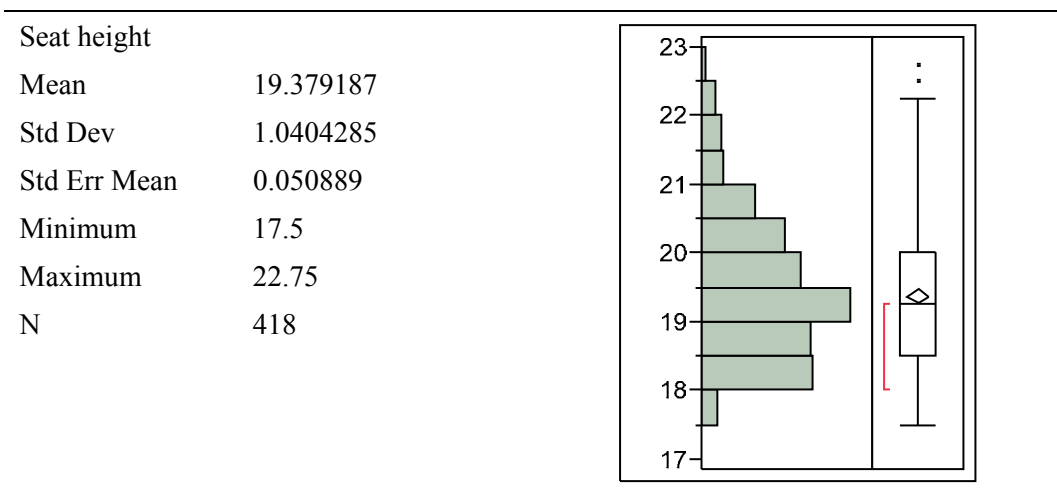


Table K-18. Seat depth setting, all chairs

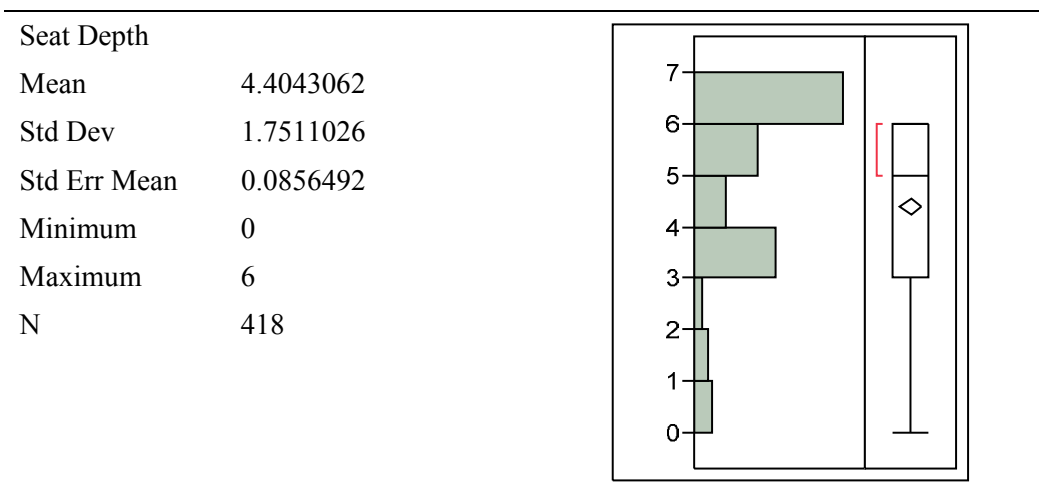


Table K-19. Chair recline setting, all chairs

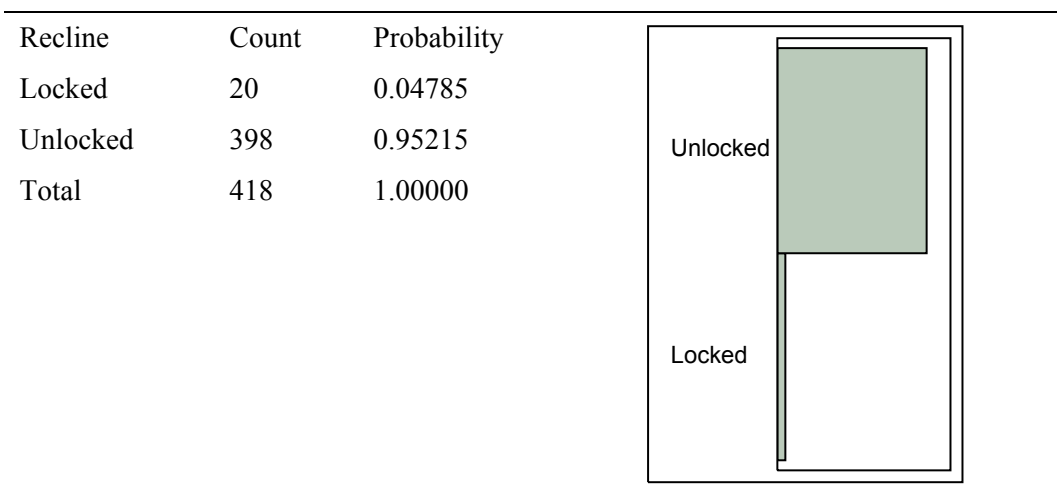
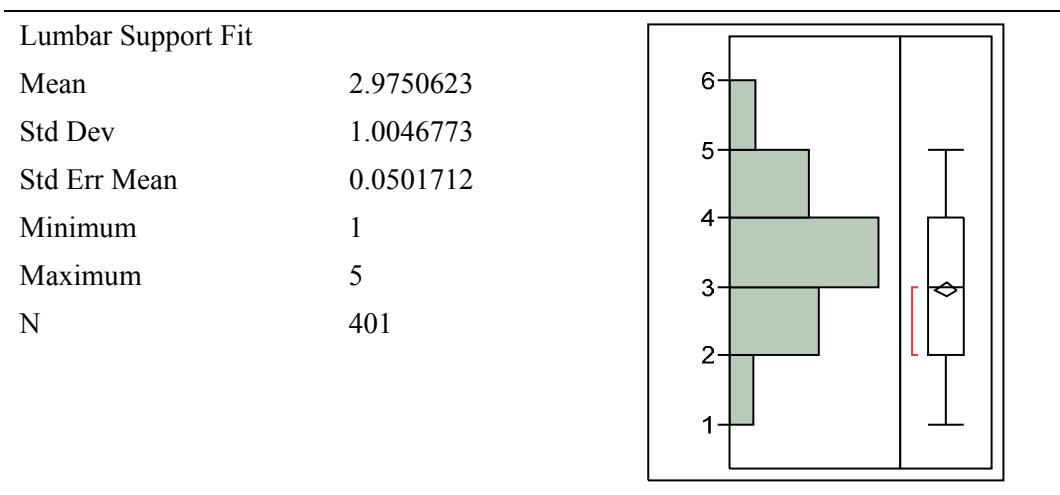
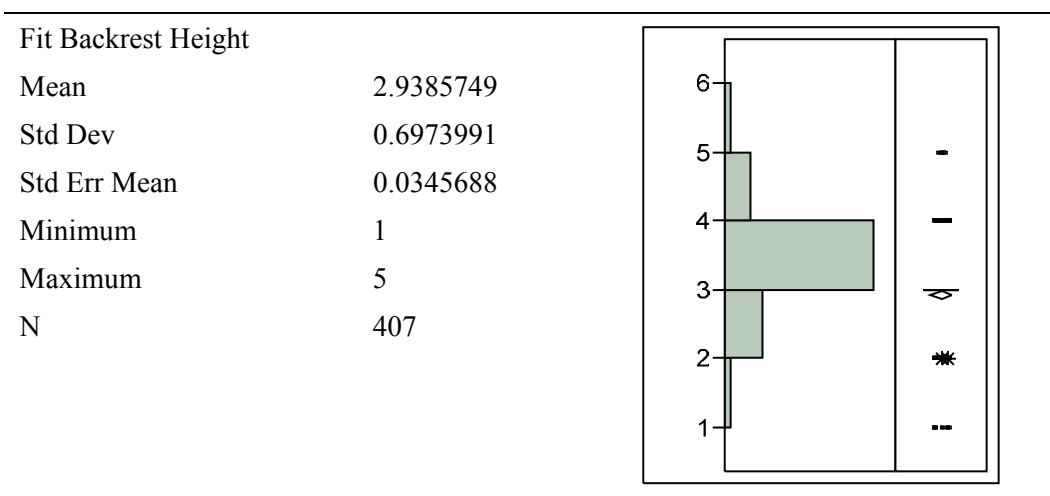


Table K-20. Lumbar support fit rating, all subjects



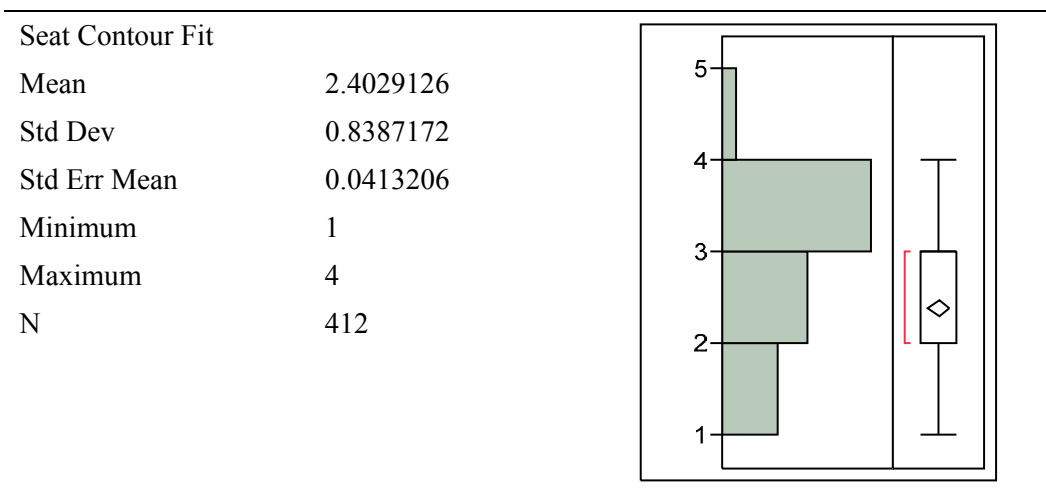
NOTE: 1=Too low, 3=Perfect, 5=Too high

Table K-21. Backrest height fit, all subjects



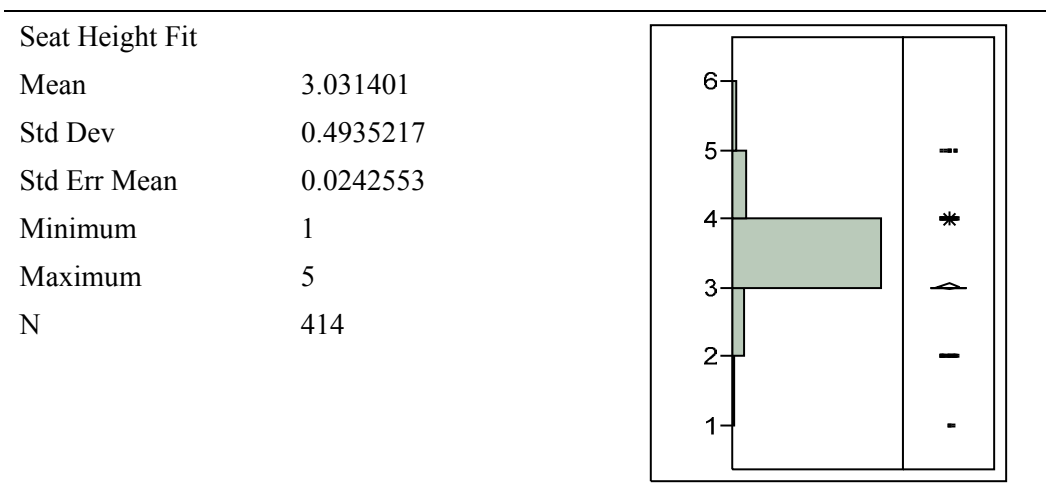
NOTE: 1=Too low, 3=Perfect, 5=Too high

Table K-22. Seat shape rating, all subjects



NOTE: 1=Not enough, 3=Perfect, 5=Too much

Table K-23. Seat height rating, all subjects



NOTE: 1=Too low, 3=Perfect, 5=Too high

Table K-24. Seat width rating, all subjects

Seat Width Fit	
Mean	3.1557178
Std Dev	0.5227368
Std Err Mean	0.0257847
Minimum	2
Maximum	5
N	411

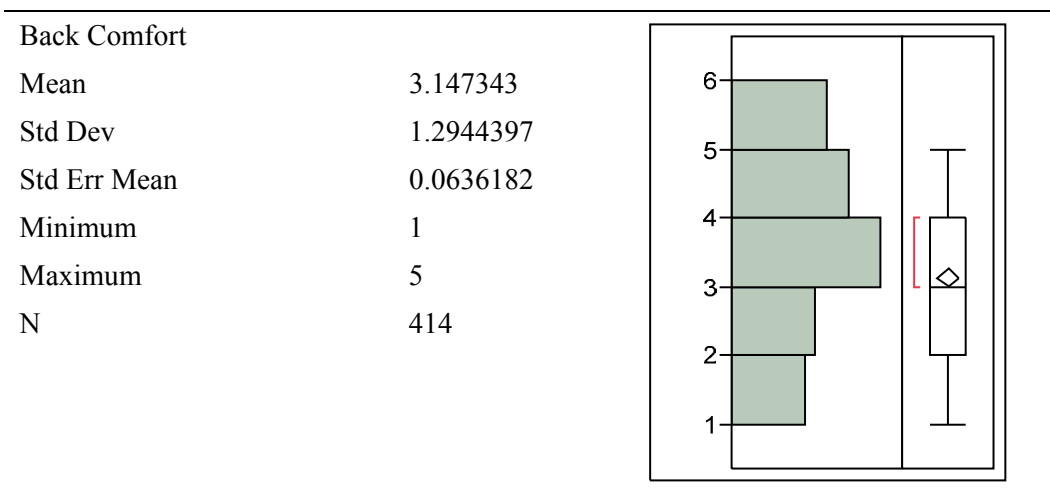
NOTE: 1=Too narrow, 3=Perfect, 5=Too wide

Table K-25. Seat depth rating, all subjects

Seat Depth Fit	
Mean	3.0120482
Std Dev	0.6647432
Std Err Mean	0.032631
Minimum	1
Maximum	5
N	415

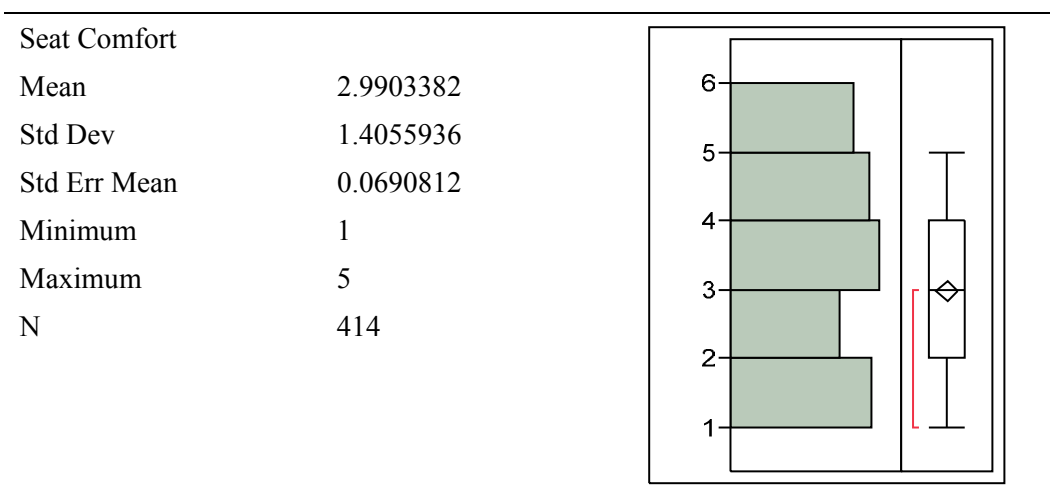
NOTE: 1=Too deep, 3=Perfect, 5=Too shallow

Table K-26. Linear assessment of back comfort, all subjects



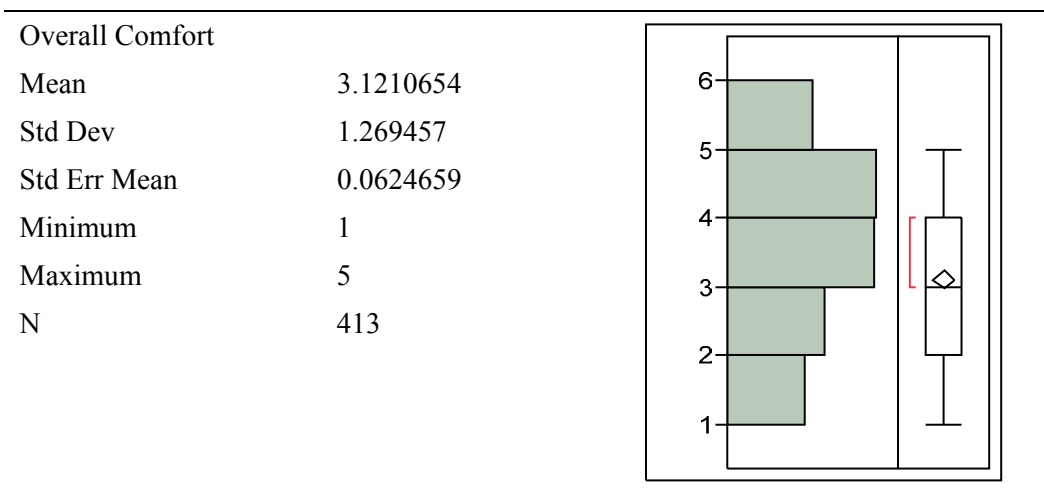
NOTE: 1=Uncomfortable, 3=Average, 5=Comfortable

Table K-27. Linear assessment of seat comfort, all subjects



NOTE: 1=Uncomfortable, 3=Average, 5=Comfortable

Table K-28. Linear assessment of overall chair comfort, all subjects

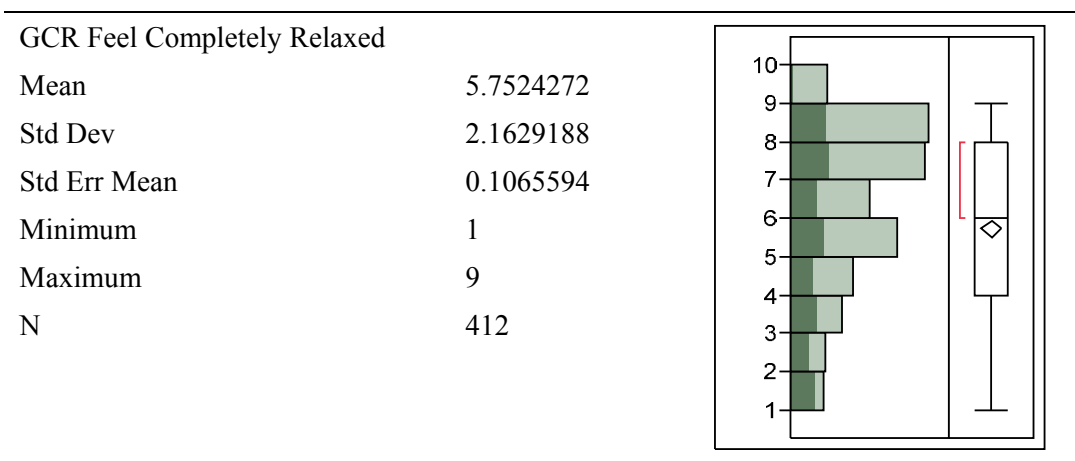


NOTE: 1=Uncomfortable, 3=Average, 5=Comfortable

K.3 Subjective Results

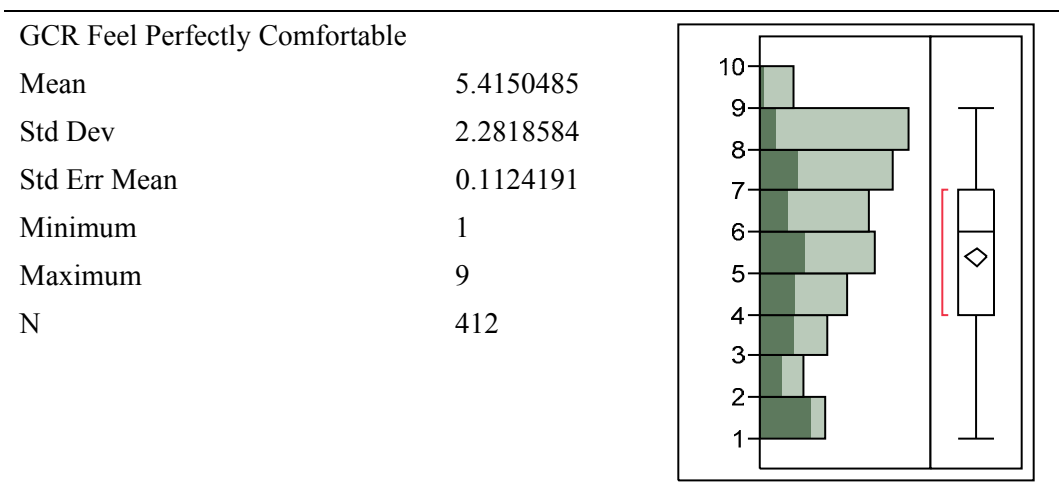
K.3.1 GCR Distributions

Table K-29. GCR “Feel Completely Relaxed” responses, all subjects



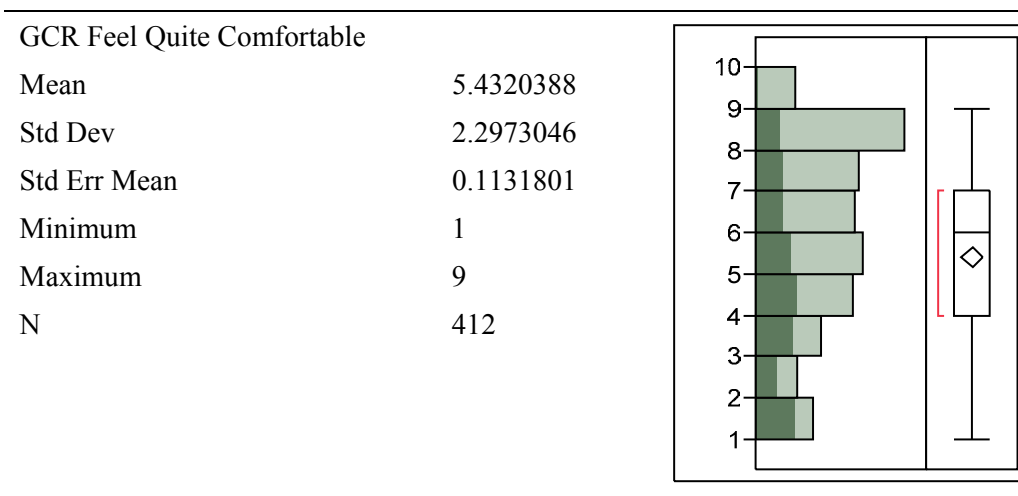
NOTE: The dark green shading represents values for Chair R.

Table K-30. GCR “Feel Perfectly Comfortable” responses, all subjects



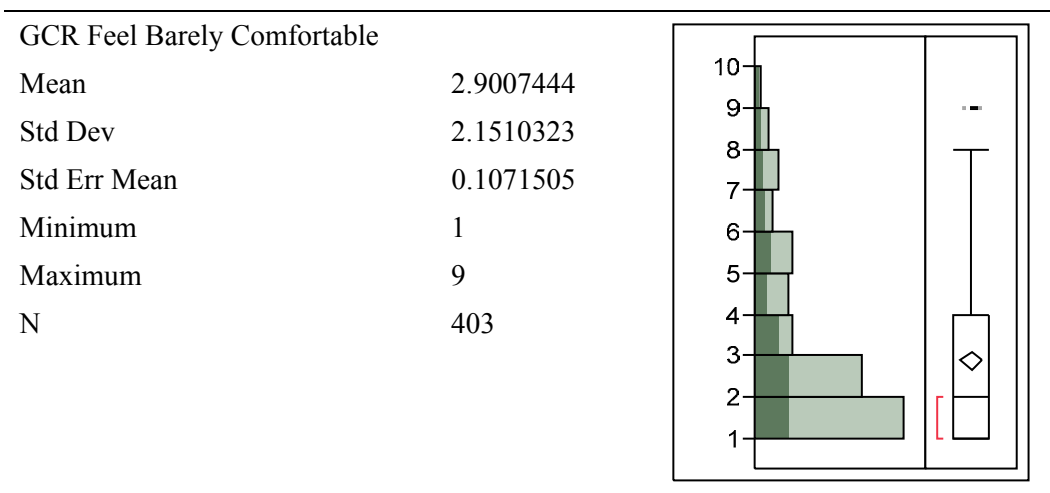
NOTE: The dark green shading represents values for Chair R.

Table K-31. GCR “Feel Quite Comfortable” responses, all subjects



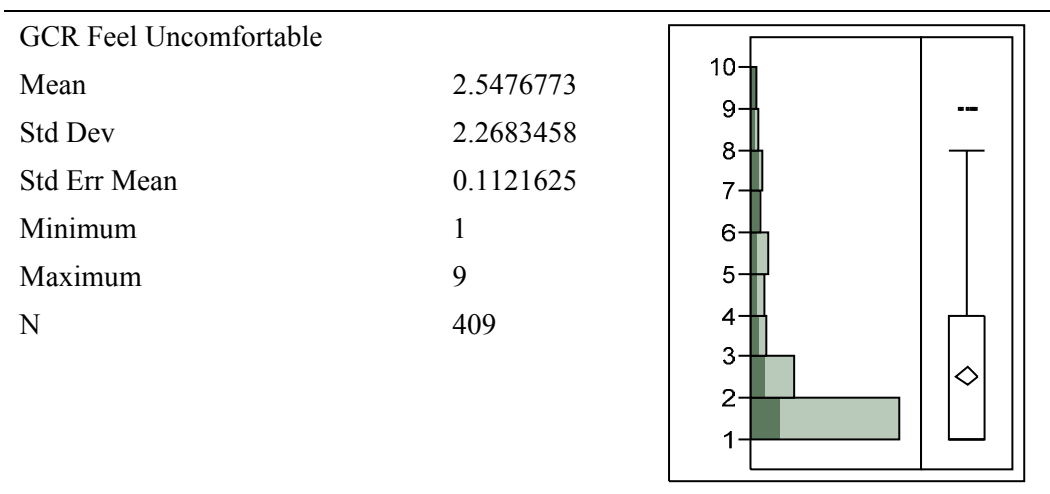
NOTE: The dark green shading represents values for Chair R.

Table K-32. GCR “Feel Barely Comfortable” responses, all subjects



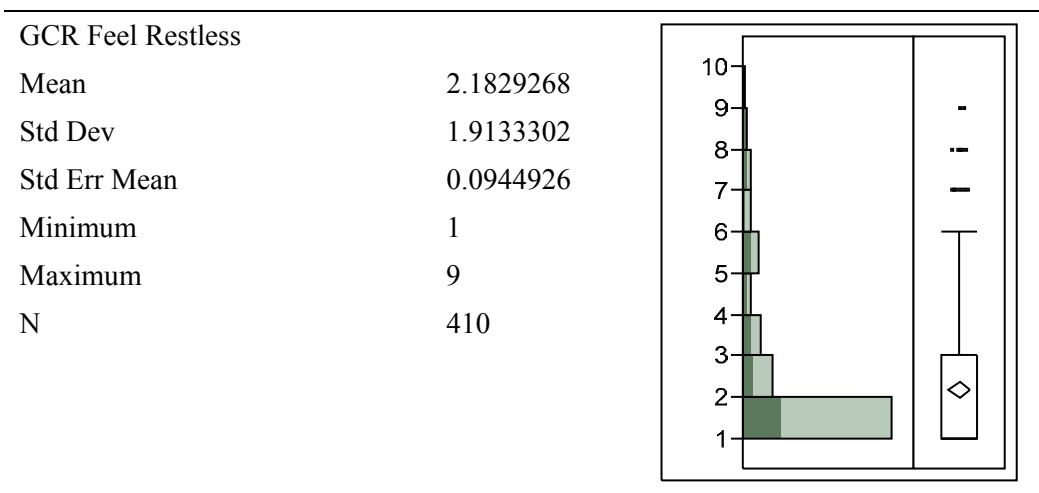
NOTE: The dark green shading represents values for Chair R.

Table K-33. GCR “Feel Uncomfortable” responses, all subjects



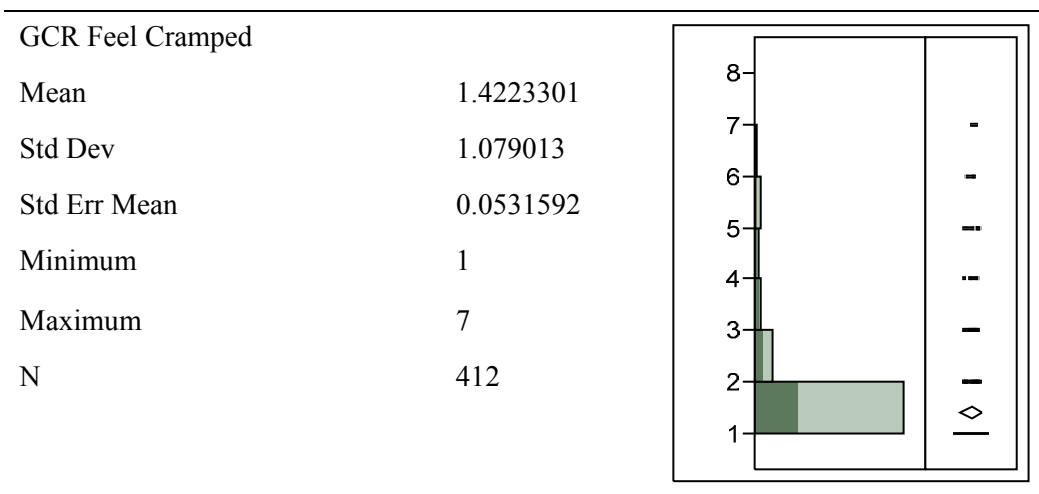
NOTE: The dark green shading represents values for Chair R.

Table K-34. GCR “Feel Restless” responses, all subjects



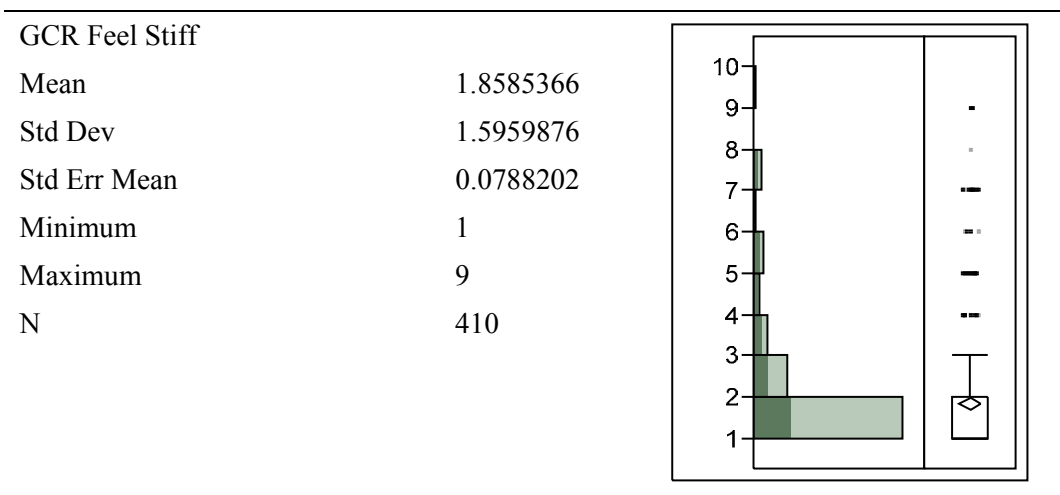
NOTE: The dark green shading represents values for Chair R.

Table K-35. GCR “Feel Cramped” responses, all subjects



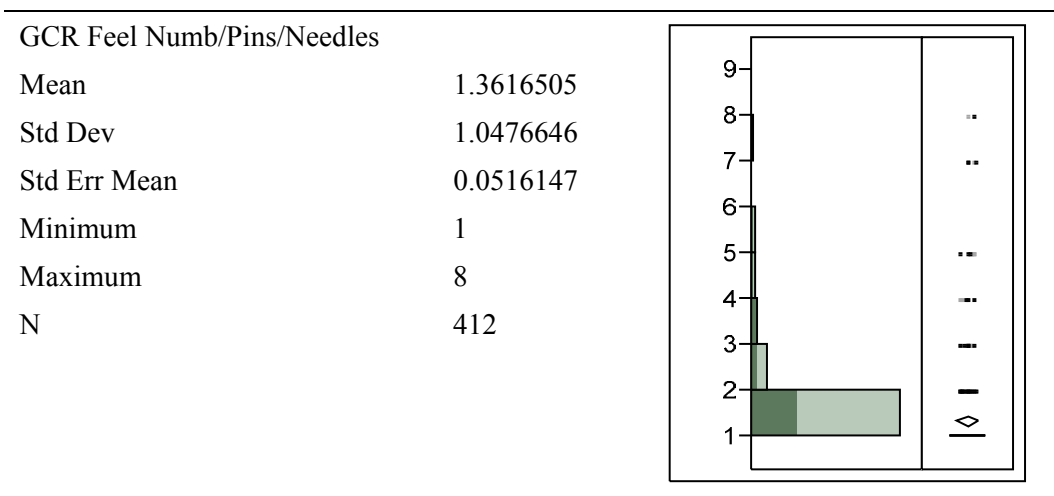
NOTE: The dark green shading represents values for Chair R.

Table K-36. GCR “Feel Stiff” responses, all subjects



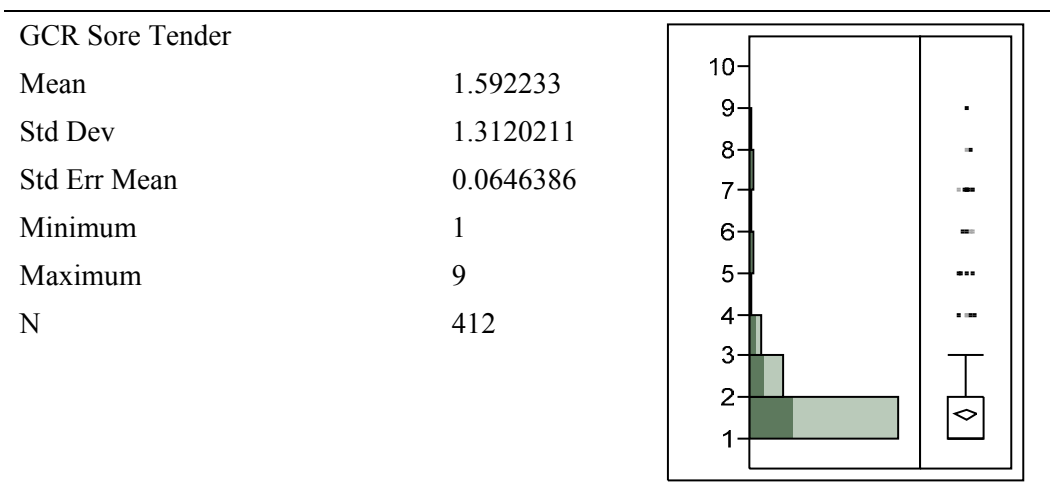
NOTE: The dark green shading represents values for Chair R.

Table K-37. GCR “Feel Numb (on pins and needles)” responses, all subjects



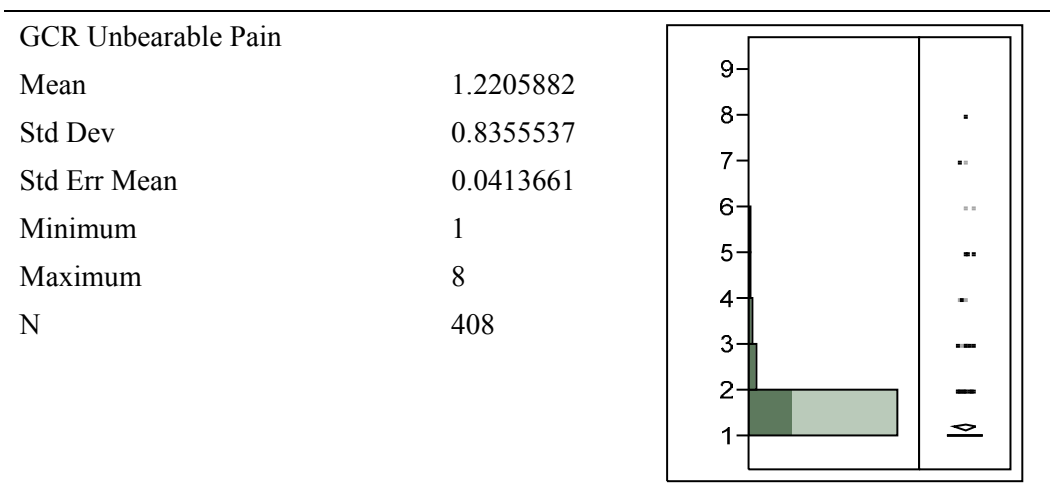
NOTE: The dark green shading represents values for Chair R.

Table K-38. GCR “Feel Sore and Tender” responses, all subjects



NOTE: The dark green shading represents values for Chair R.

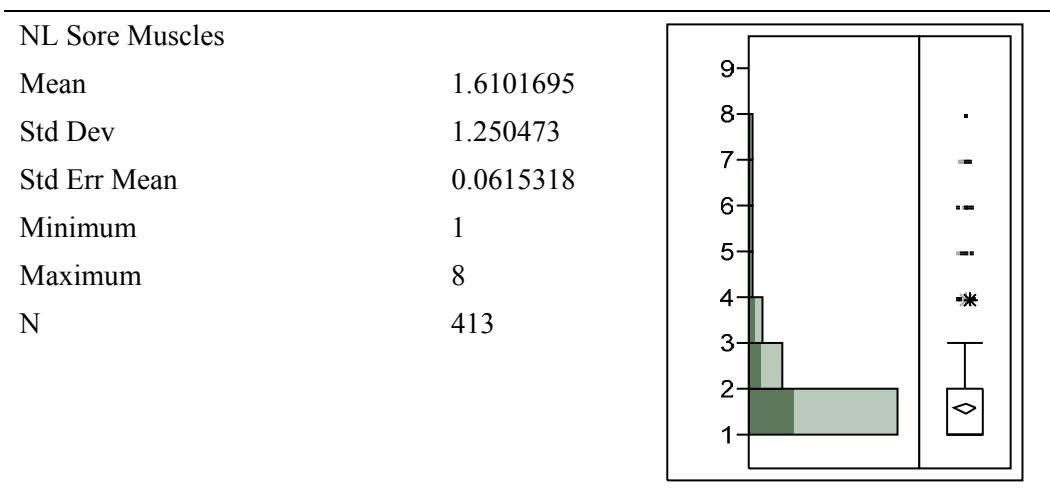
Table K-39. GCR “Feel Unbearable Pain” responses, all subjects



NOTE: The dark green shading represents values for Chair R.

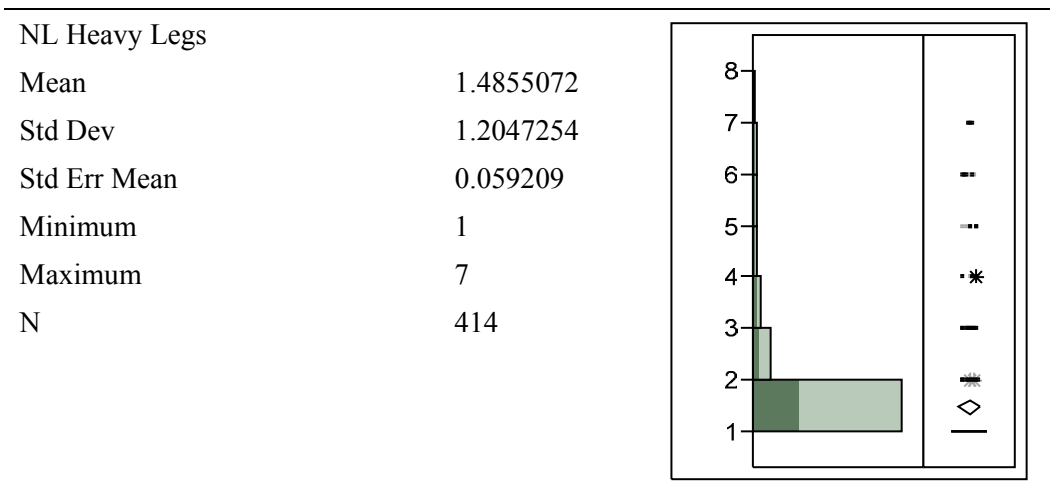
K.3.2 Non-linear Comfort/Discomfort Distributions

Table K-40. Non-linear “Sore Muscles” responses, all subjects



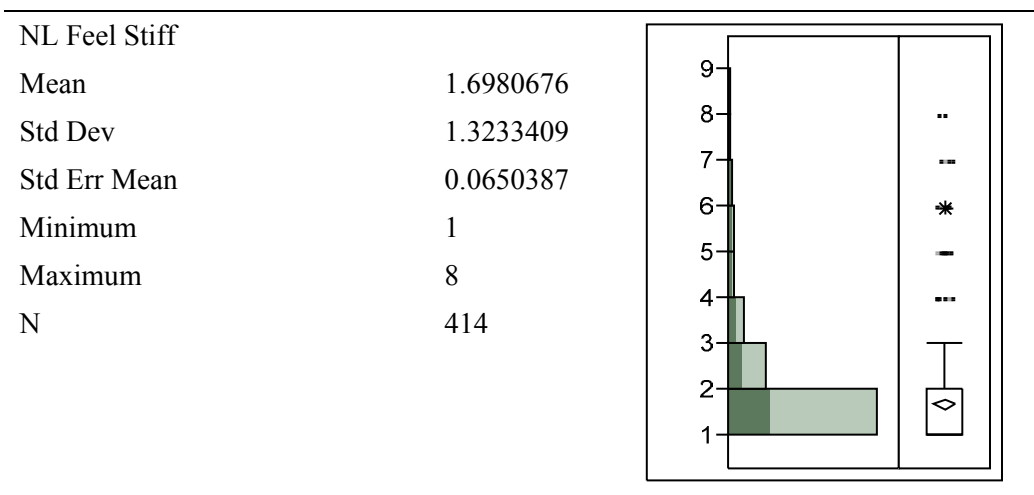
NOTE: The dark green shading represents values for Chair R.

Table K-41. Non-linear “Heavy Legs” responses, all subjects



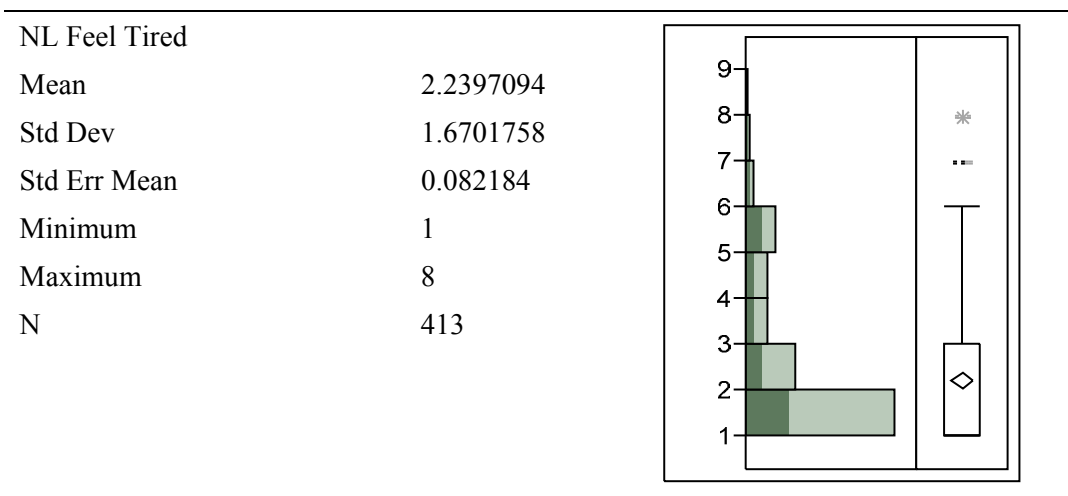
NOTE: The dark green shading represents values for Chair R.

Table K-42. Non-linear “Feel Stiff” responses, all subjects



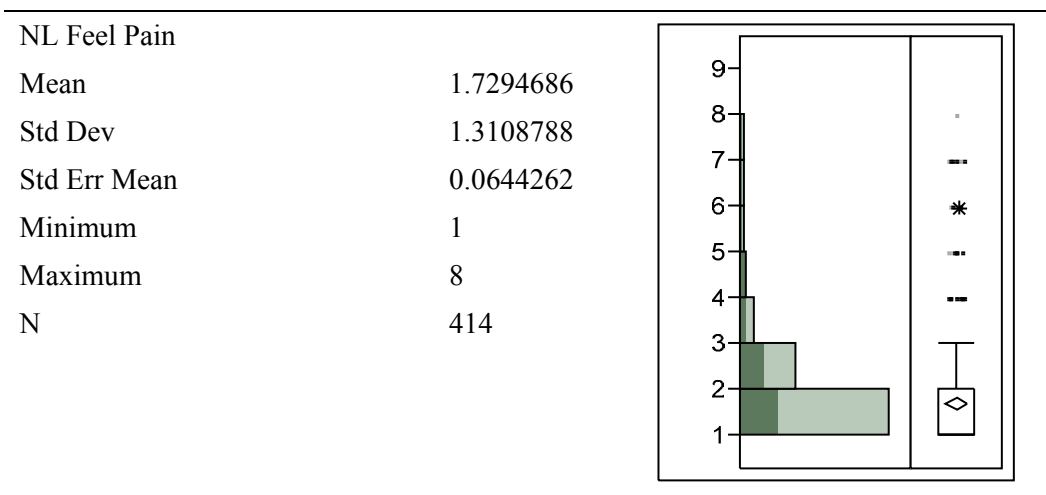
NOTE: The dark green shading represents values for Chair R.

Table K-43. Non-linear “Feel Tired” responses, all subjects



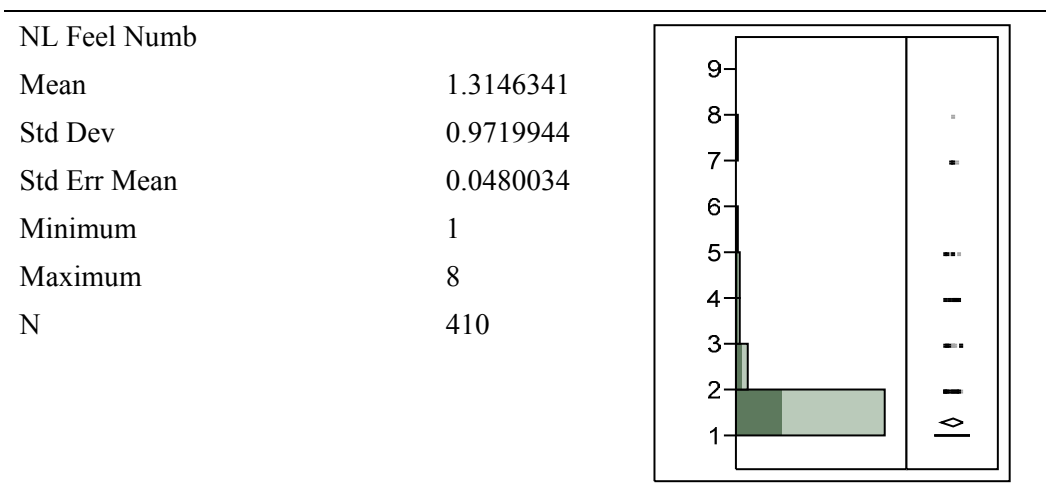
NOTE: The dark green shading represents values for Chair R.

Table K-44. Non-linear “Feel Pain” responses, all subjects



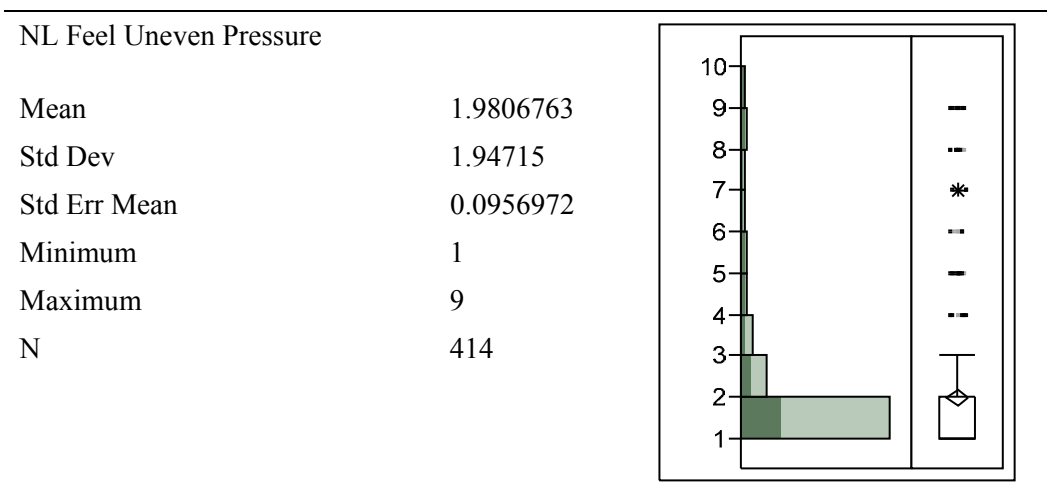
NOTE: The dark green shading represents values for Chair R.

Table K-45. Non-linear “Feel Numb” responses, all subjects



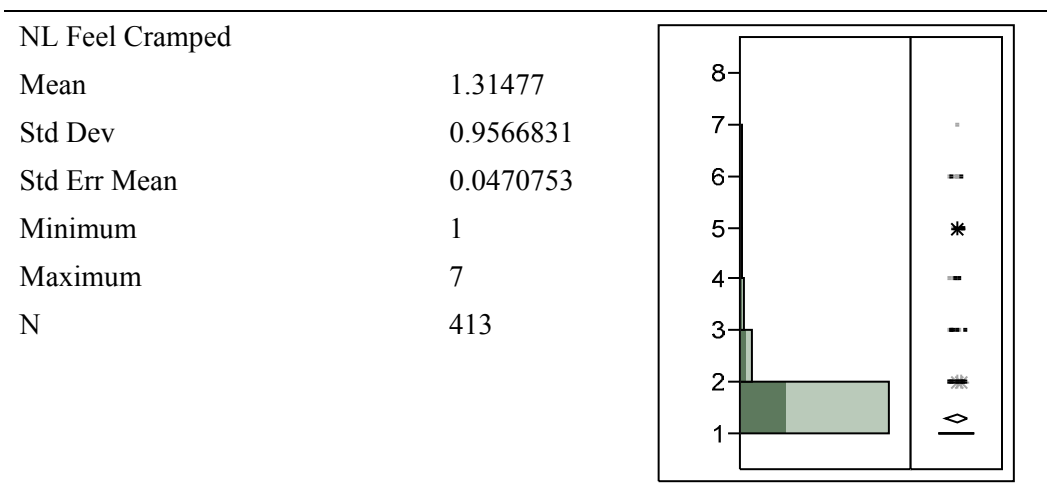
NOTE: The dark green shading represents values for Chair R.

Table K-46. Non-linear “Uneven Pressure” responses, all subjects



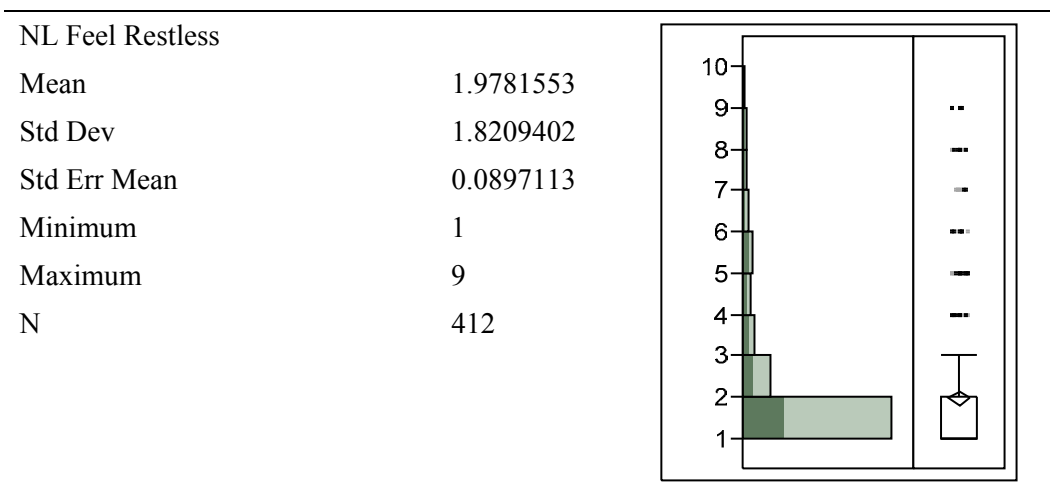
NOTE: The dark green shading represents values for Chair R.

Table K-47. Non-linear “Feel Cramped” responses, all subjects



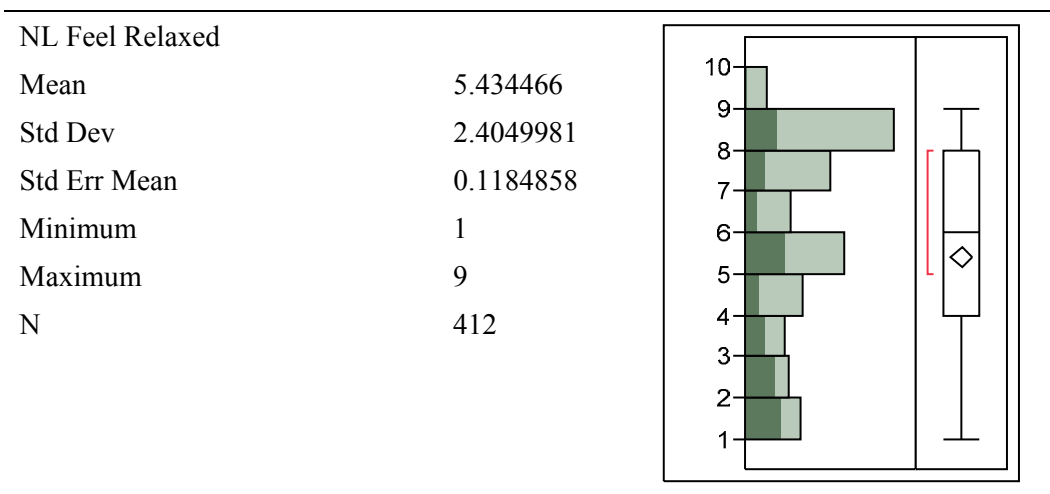
NOTE: The dark green shading represents values for Chair R.

Table K-48. Non-linear “Feel Restless” responses, all subjects



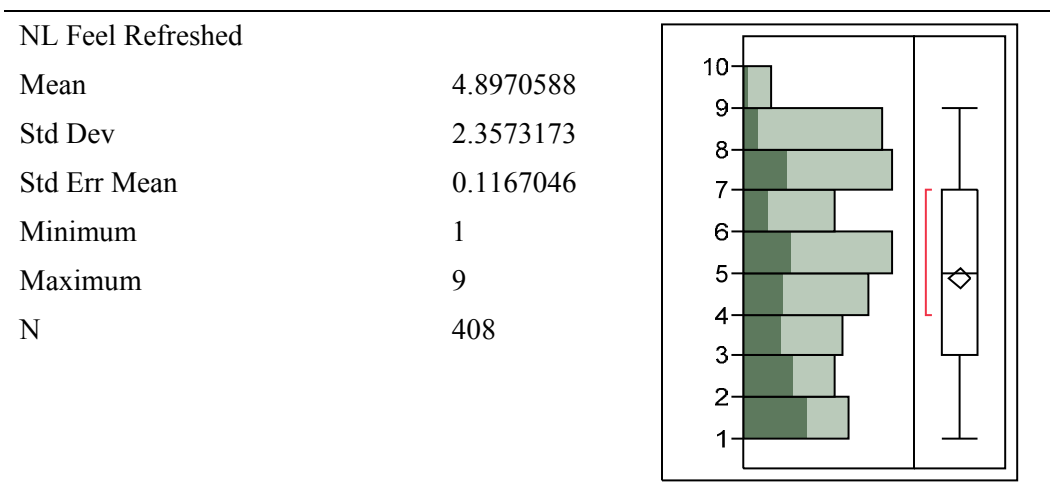
NOTE: The dark green shading represents values for Chair R.

Table K-49. Non-linear “Feel Relaxed” responses, all subjects



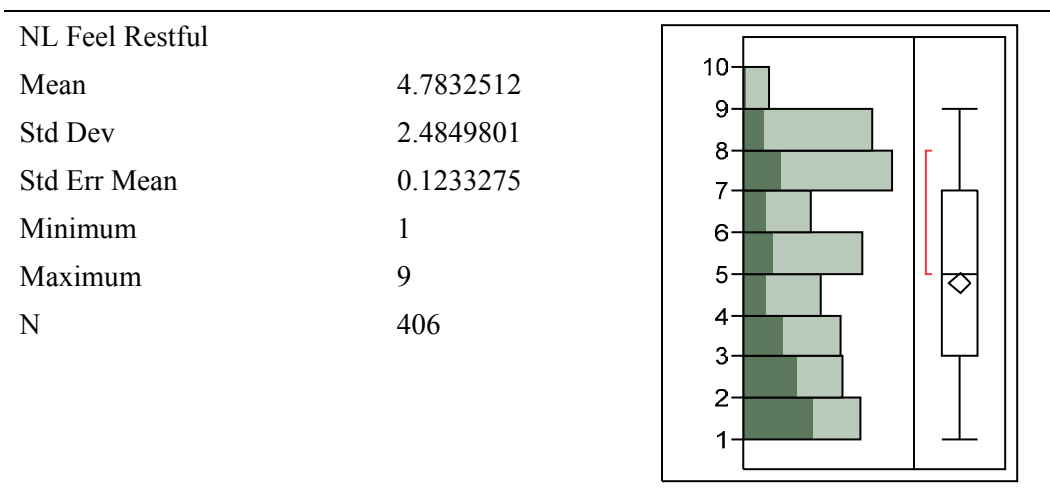
NOTE: The dark green shading represents values for Chair R.

Table K-50. Non-linear “Feel Refreshed” responses, all subjects



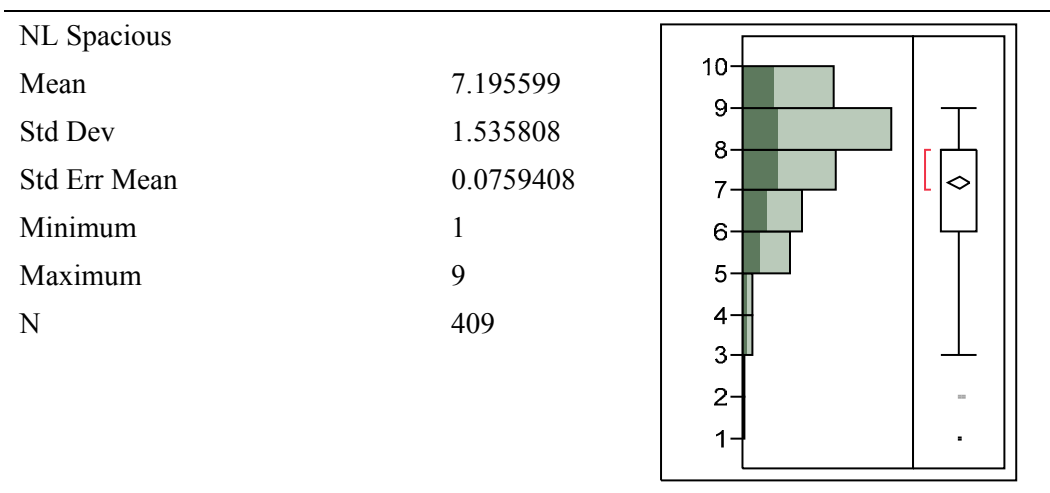
NOTE: The dark green shading represents values for Chair R.

Table K-51. Non-linear “Feel Restful” responses, all subjects



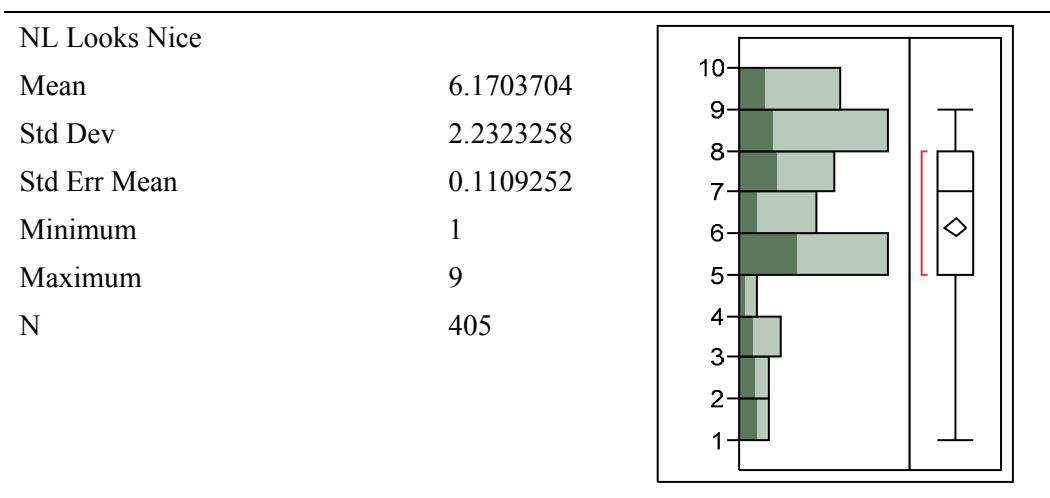
NOTE: The dark green shading represents values for Chair R.

Table K-52. Non-linear “Spacious” responses, all subjects



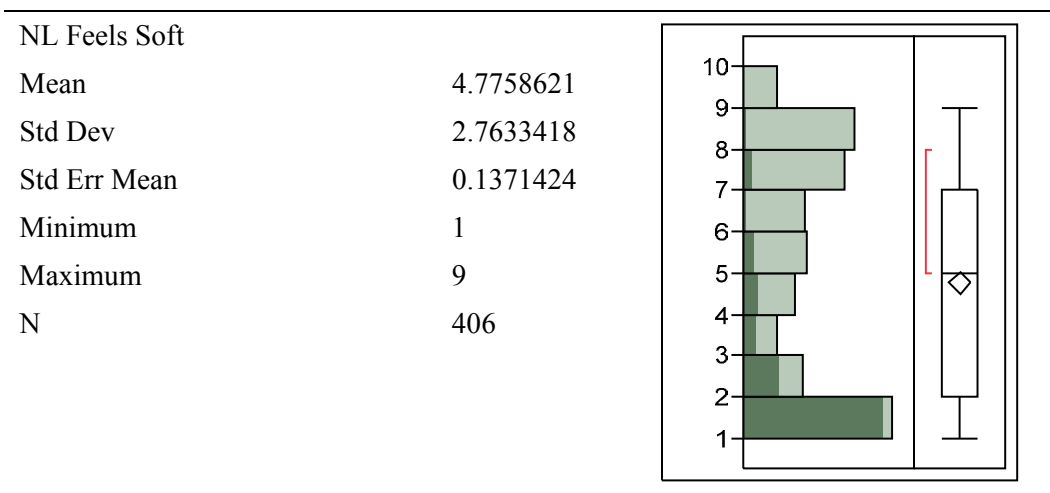
NOTE: The dark green shading represents values for Chair R.

Table K-53. Non-linear “Looks Nice” responses, all subjects



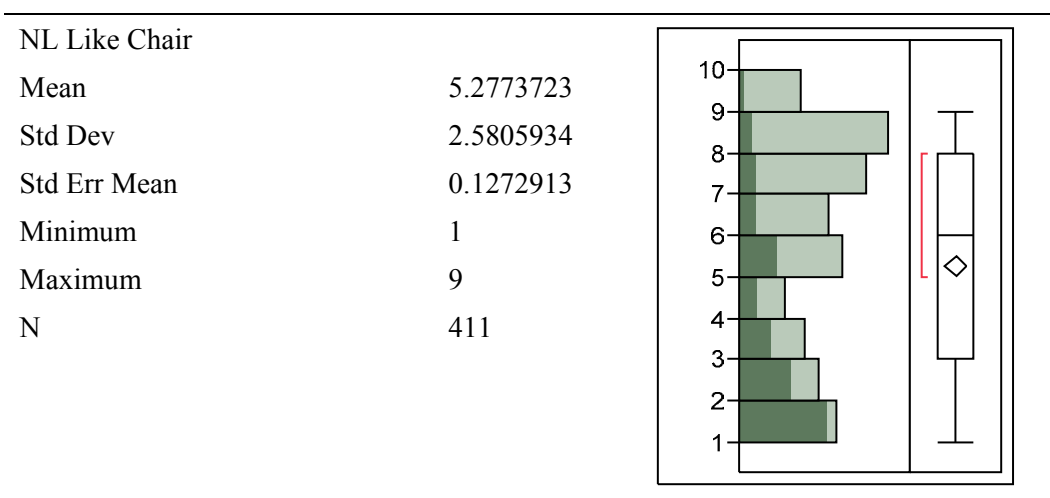
NOTE: The dark green shading represents values for Chair R.

Table K-54. Non-linear “Feels Soft” responses, all subjects



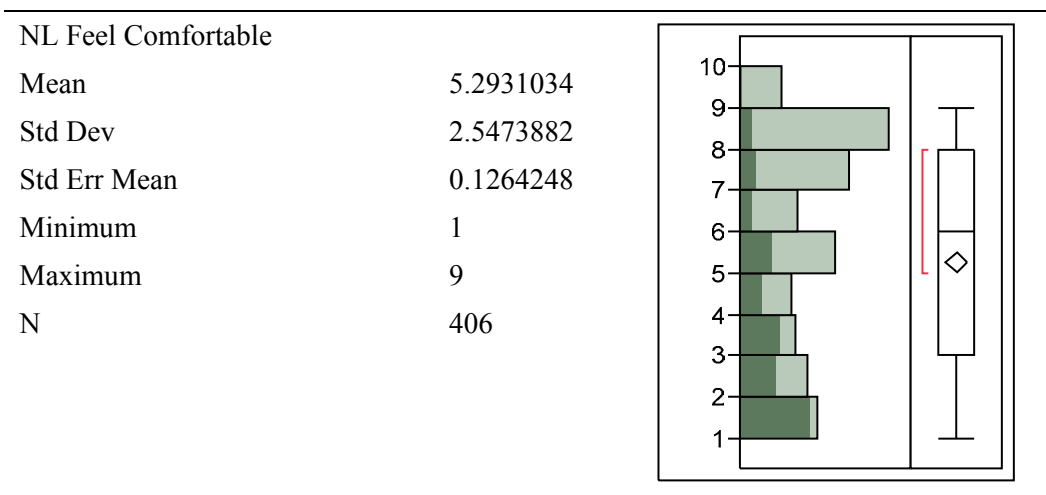
NOTE: The dark green shading represents values for Chair R.

Table K-55. Non-linear “Like Chair” responses, all subjects



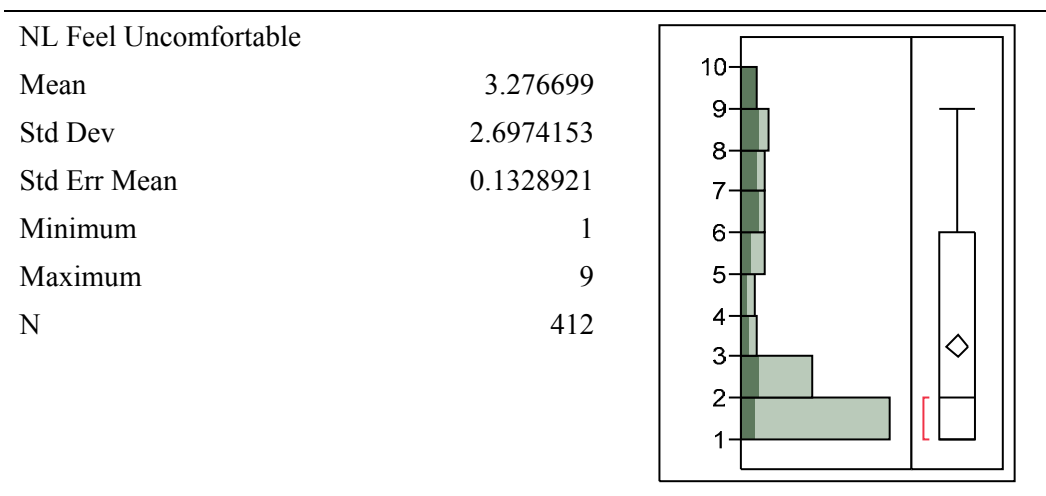
NOTE: The dark green shading represents values for Chair R.

Table K-56. “Feel Comfortable” responses, all subjects



NOTE: The dark green shading represents values for Chair R.

Table K-57. “Feel Uncomfortable” responses, all subjects



NOTE: The dark green shading represents values for Chair R.

APPENDIX L. IMAGES OF SUBJECTS AND POSTURES

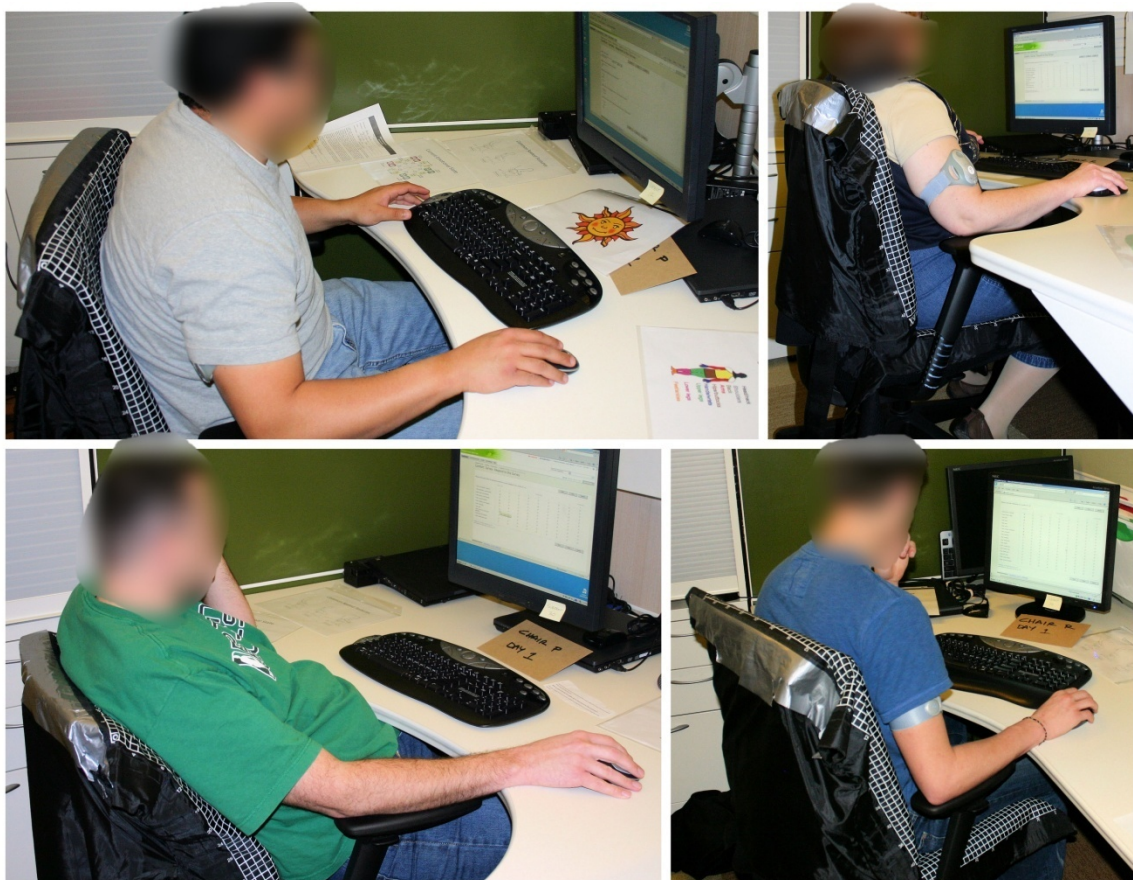


Figure L-1. Postures while taking the surveys



Figure L-2. Postures while working

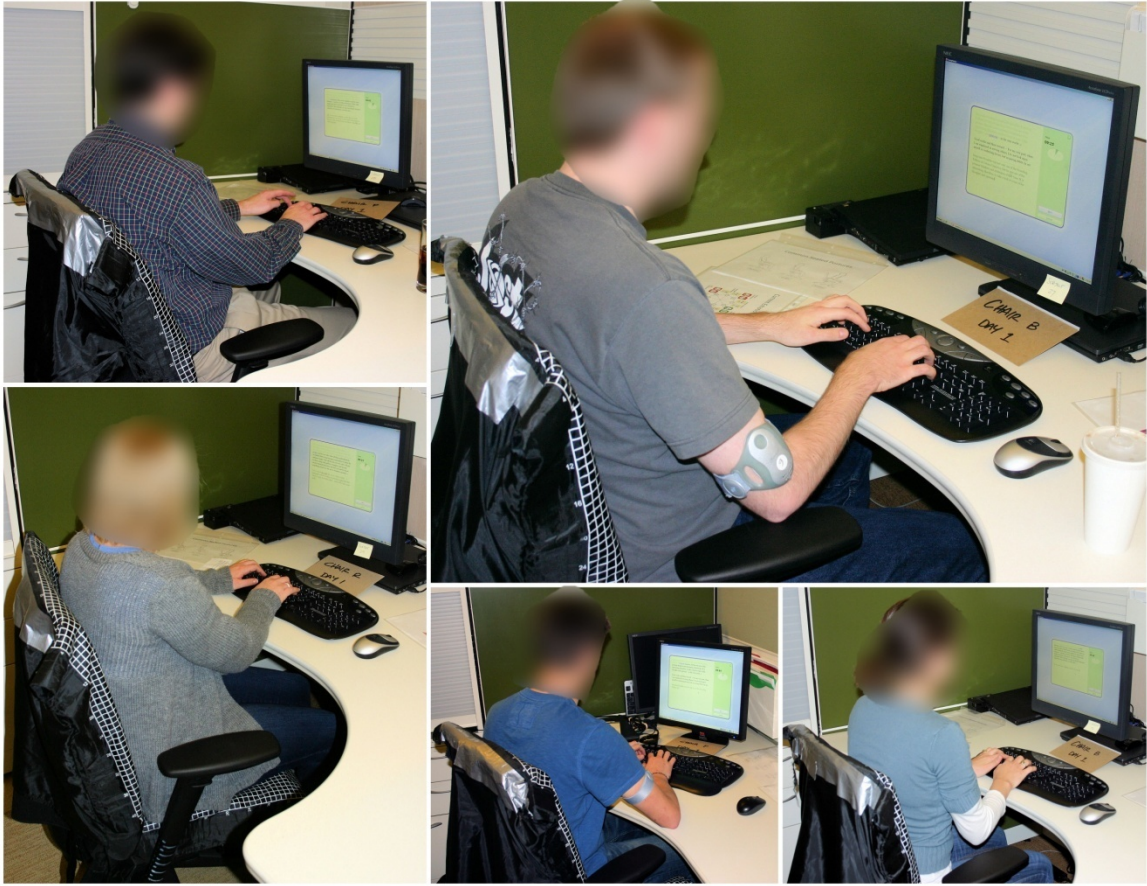


Figure L-3. Postures during the typing (keyboard) task

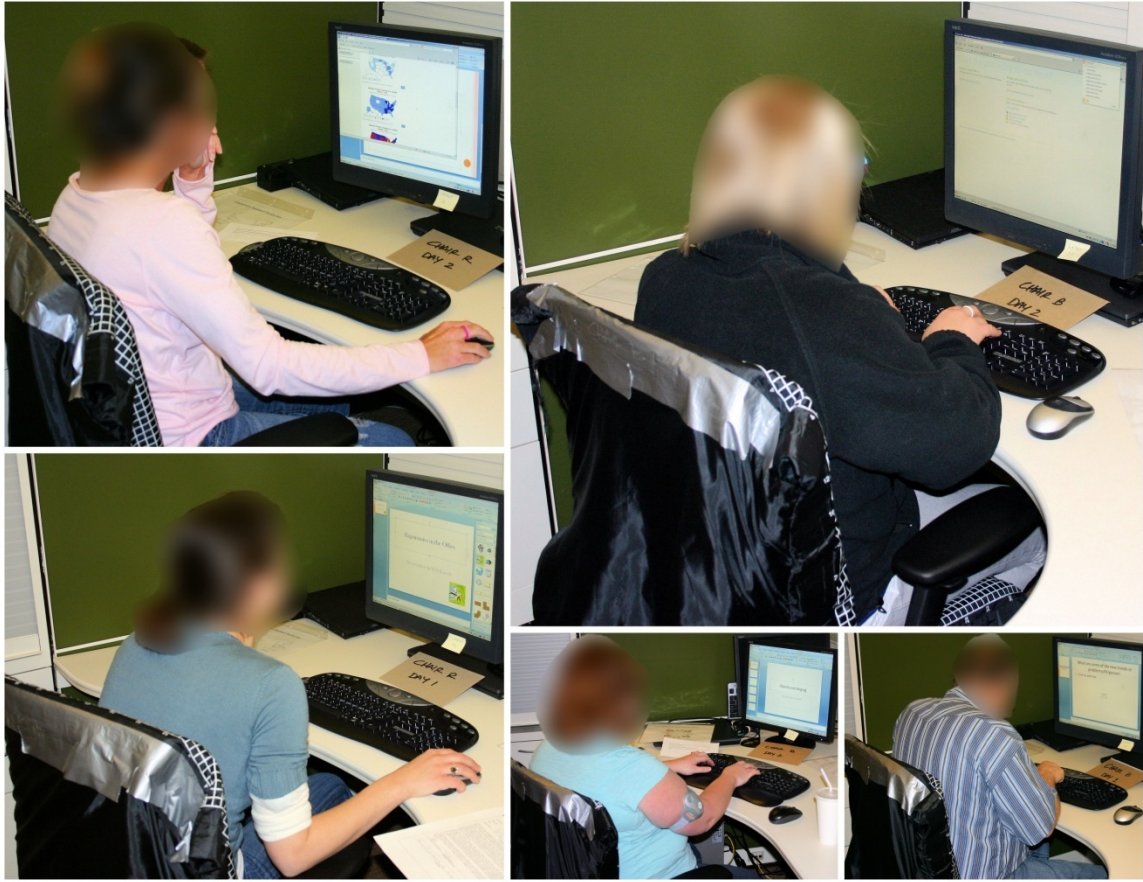


Figure L-4. Postures during the research (keyboard and mouse) task



Figure L-5. Postures during the paint (mousing) task



Figure L-6. Different foot postures during testing

APPENDIX M: SAMPLE PRESSURE MAPPING IMAGES

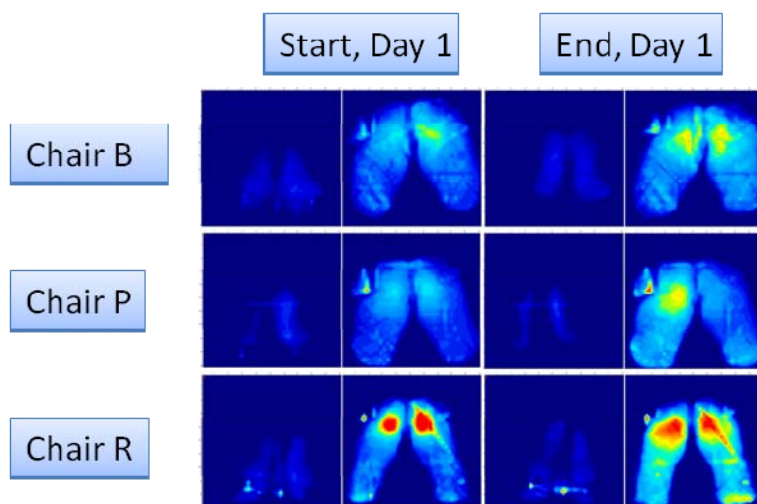


Figure M-1. Pressure maps of Subject 9, day 1.

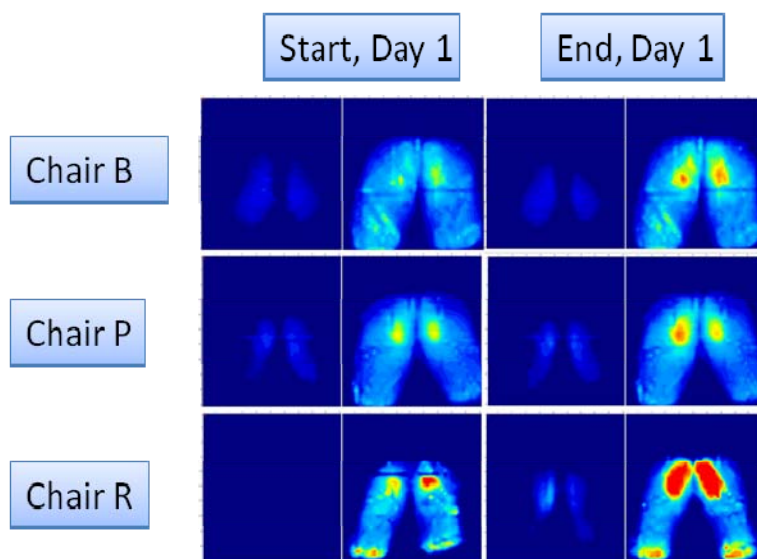


Figure M-2. Pressure maps of Subject 25, day 1

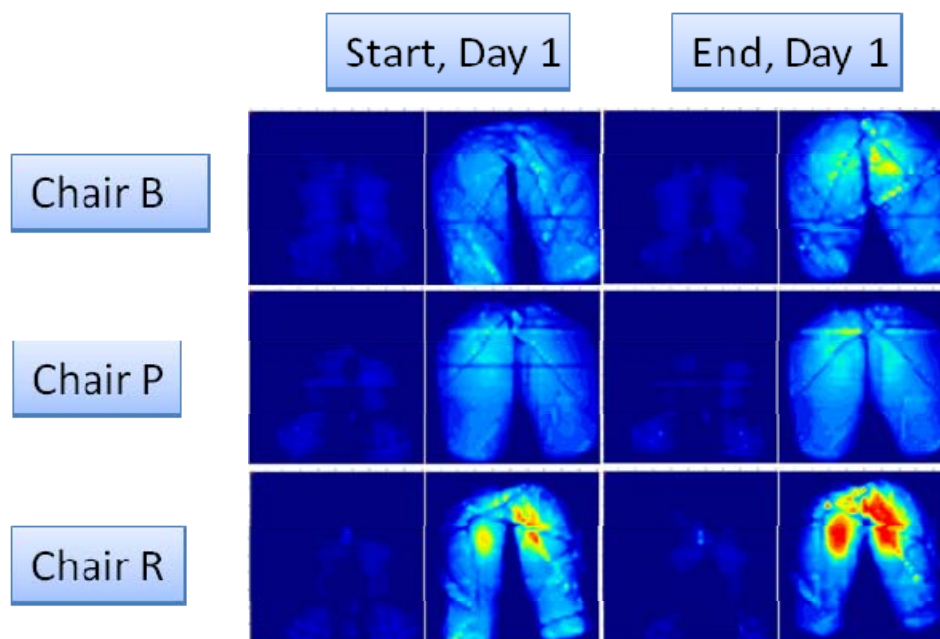


Figure M-3. Pressure maps of Subject 28, day 1

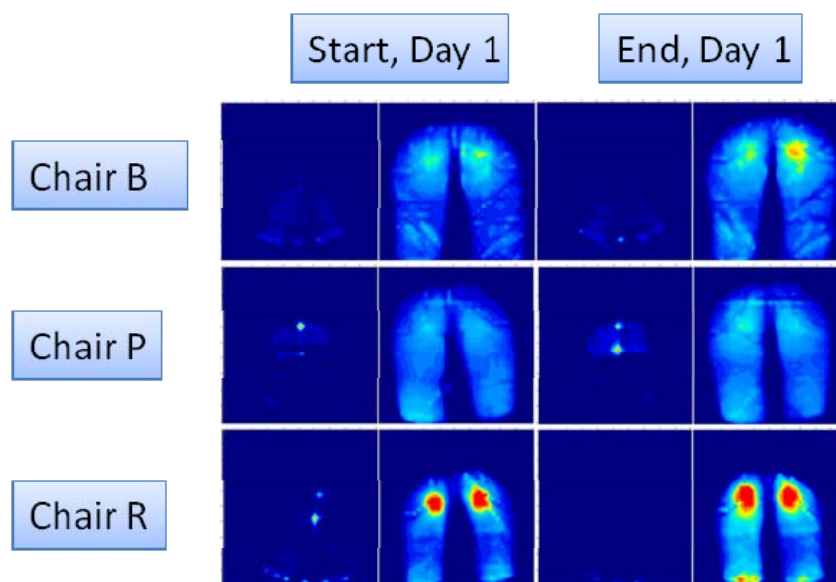


Figure M-4. Pressure maps of Subject 33, day 1

APPENDIX N: LINEAR MODEL

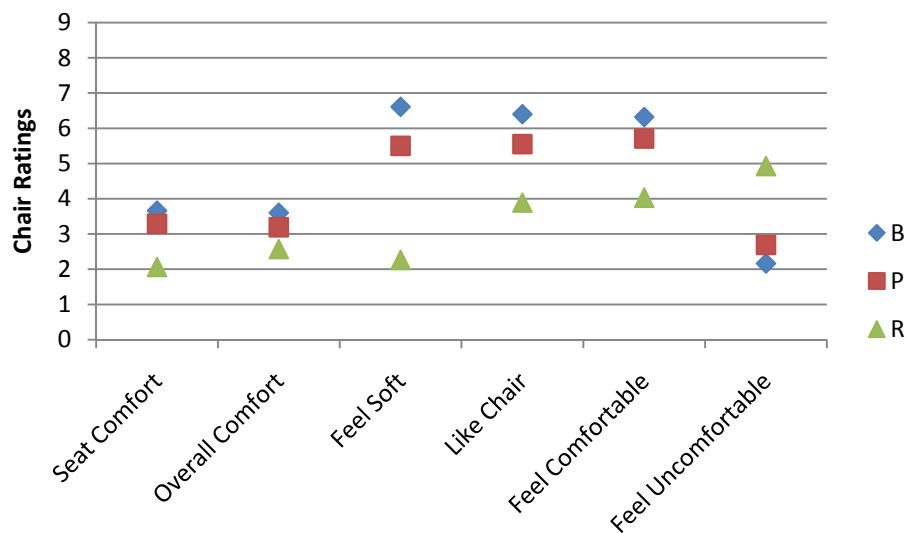
N.1 General Observations

Figure N-1. Difference between Chairs in survey responses

Table N-1. Mean values for subjective responses, by Chair

Chair	Seat Comfort	Overall Comfort	Feel Soft	Like Chair	Feel Comfortable	Feel Uncomfortable
B	3.66	3.60	6.61	6.40	6.32	2.16
P	3.29	3.19	5.50	5.55	5.71	2.69
R	2.06	2.57	2.26	3.89	4.03	4.93

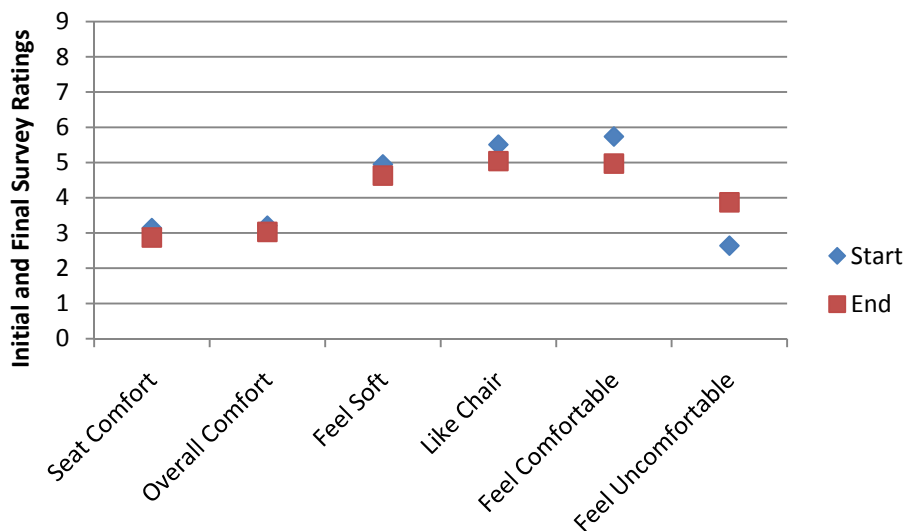


Figure N-2. Differences between Start and End in survey responses

Table N-2. Mean values for Initial and Final survey responses, all subjects

	Seat Comfort	Overall Comfort	Feel Soft	Like Chair	Feel Comfortable	Feel Uncomfortable
Initial						
Final						
Start	3.14	3.21	4.95	5.51	5.74	2.64
End	2.87	3.03	4.63	5.04	4.97	3.87

N.2 Stepwise Regression Statistics

Table N-3. Stepwise regression results for each Subjective Response

Subjective Response	SSE	DFE	RMSE	R ²	R ² Adj	Cp	p	AICc	BIC
NL Feel Soft	986.35	364.00	1.6461	0.6530	0.6435	59.58	11	1451.72	1497.98
Seat Comfort	314.07	369.00	0.9226	0.5899	0.5766	51.52	13	1038.41	1092.51
Overall Comfort	272.29	371.00	0.8567	0.5517	0.5396	38.40	11	979.58	1026.08
NL Feel Uncomfortable	1242.40	370.00	1.8324	0.5419	0.5295	38.74	11	1556.42	1602.89
NL Feel Comfortable	1123.52	365.00	1.7545	0.5311	0.5195	76.44	10	1498.42	1540.89
NL Like Chair	1182.39	371.00	1.7852	0.5217	0.5127	83.26	8	1525.25	1560.20
Back Comfort	360.91	370.00	0.9876	0.4338	0.4170	14.58	12	1089.37	1139.67
NL Feel Refreshed	1152.77	354.00	1.8046	0.4397	0.4064	37.65	22	1537.42	1624.67
Lin Feel Perfectly Comfortable	1128.68	364.00	1.7609	0.4221	0.3982	53.54	16	1527.77	1593.06
NL Feel Uneven Pressure	852.45	370.00	1.5179	0.4117	0.3942	19.57	12	1417.69	1467.99
Lin Feel Quite Comfortable	1167.59	364.00	1.7910	0.4042	0.3797	47.40	16	1540.64	1605.94
NL Feel Relaxed	1294.99	362.00	1.8914	0.4067	0.3788	30.34	18	1584.42	1657.17
BPD Pain Hips Buttocks	168.17	374.00	0.6706	0.3519	0.3398	42.28	8	789.14	824.16
Lin Feel Stiff	608.91	370.00	1.2829	0.3489	0.3365	15.03	8	1271.43	1306.35
NL Feel Pain	435.04	373.00	1.0800	0.3334	0.3191	37.17	9	1154.33	1193.19

N.2 Stepwise Regression
Statistics

Table N-3. Continued.

Lin Feel Uncomfortable	1307.97	370.00	1.8802	0.3275	0.3166	32.62	7	1555.25	1586.32
NL Feel Restful	1547.90	362.00	2.0678	0.3263	0.3058	88.47	12	1619.61	1669.61
NL Feel Stiff	449.64	372.00	1.0994	0.3211	0.3047	30.67	10	1169.06	1211.74
Lin Feel Completely Relaxed	1203.61	371.00	1.8012	0.3006	0.2855	67.12	9	1537.09	1575.90
BPD Pain Back	155.82	373.00	0.6463	0.2866	0.2694	57.11	10	765.18	807.89
Lin Feel Restless	1071.12	375.00	1.6901	0.2425	0.2365	46.21	4	1479.47	1499.00
BPD Pain Upper Legs	81.54	371.00	0.4688	0.2238	0.2029	25.19	11	518.97	565.47

NOTE: Items listed in order of Adjusted R^2 value. NL = Non-linear, Lin = Linear; p = number of parameters in the model, AIC = Akaike's Information Criterion, BIC = Bayesian information Criterion, Cp = Cp criterion, R^2 Adj = adjusts R^2 to compare to other models better, SSE = Sum of squares, DFE = degrees of freedom, RMSE = root mean square error

Table N-4. Values for factors in each stepwise model response

Response	Factor	Estimate	nDF	SS	"F Ratio"	"Prob>F"
SeatComfort	Chair {R-P&B}	-0.5157	2	46.60	27.38	0.0000
SeatComfort	Chair {P-B}	-0.2534	1	12.75	14.98	0.0001
SeatComfort	SetArmHeight	0.0493	1	5.18	6.08	0.0141
SeatComfort	SetSeatDepth	0.0000	1	3.64	4.31	0.0386
SeatComfort	FitLumbarSupport	0.1169	1	4.82	5.67	0.0178
SeatComfort	FitSeatContour	0.6176	1	73.74	86.63	0.0000
SeatComfort	FitSeatHeight	0.3313	1	8.24	9.68	0.0020
SeatComfort	FitSeatWidth	-0.4016	1	13.58	15.96	0.0001
SeatComfort	FitSeatDepth	0.0000	1	3.57	4.24	0.0403
SeatComfort	RITmax	-0.0070	1	15.88	18.66	0.0000
SeatComfort	LPCA	-0.0033	1	8.87	10.42	0.0014
SeatComfort	LoBCA	-0.0019	1	13.70	16.09	0.0001
SeatComfort	BL	0.0029	1	5.63	6.62	0.0105
SeatComfort	BSM	-0.0485	1	16.00	18.80	0.0000
OverallComfort	Chair {R-P&B}	-0.5495	2	42.89	29.22	0.0000
OverallComfort	Chair {P-B}	-0.2230	1	11.38	15.51	0.0001
OverallComfort	SetArmHeight	0.0000	1	3.60	4.96	0.0266
OverallComfort	SetSeatHeight	-0.2210	1	13.95	19.01	0.0000
OverallComfort	FitSeatContour	0.5921	1	64.85	88.35	0.0000
OverallComfort	FitSeatWidth	-0.2620	1	6.16	8.40	0.0040
OverallComfort	RLmax	-0.0048	1	6.38	8.69	0.0034
OverallComfort	LLCA	-0.0024	1	26.37	35.92	0.0000
OverallComfort	BSM	-0.0237	1	5.51	7.51	0.0064
OverallComfort	RPSM	0.0121	1	10.31	14.05	0.0002
OverallComfort	LITCper	0.0175	1	12.28	16.73	0.0001
NLFeelSoft	Chair {R-P&B}	-1.8002	2	448.76	82.80	0.0000
NLFeelSoft	Chair {P-B}	-0.4607	1	48.49	17.90	0.0000
NLFeelSoft	FitSeatContour	0.7898	1	117.40	43.32	0.0000
NLFeelSoft	FitSeatHeight	0.6593	1	31.92	11.78	0.0007
NLFeelSoft	FitSeatWidth	-0.6522	1	35.62	13.14	0.0003
NLFeelSoft	FitSeatDepth	0.0000	1	14.97	5.59	0.0185

Table N-4. Continued.

NLFeelSoft	LPCA	-0.0070	1	26.62	9.82	0.0019
NLFeelSoft	SCOPc	0.2284	1	22.16	8.18	0.0045
NLFeelSoft	RPSM	0.0296	1	28.38	10.47	0.0013
NLFeelSoft	RPCper	0.0192	1	21.21	7.83	0.0054
NLLikeChair	Chair {R-P&B}	-1.1713	2	335.26	52.60	0.0000
NLLikeChair	Chair {P-B}	-0.5010	1	52.63	16.51	0.0001
NLLikeChair	SetArmHeight	0.0000	1	14.52	4.60	0.0326
NLLikeChair	SetSeatHeight	-0.3049	1	29.18	9.16	0.0027
NLLikeChair	SetSeatDepth	-0.1925	1	36.63	11.49	0.0008
NLLikeChair	FitSeatContour	1.2527	1	322.94	101.33	0.0000
NLLikeChair	FitSeatWidth	-0.9685	1	83.90	26.33	0.0000
NLLikeChair	LITSM	0.0000	1	12.41	3.92	0.0483
NLLikeChair	UBSM	0.0000	1	12.91	4.09	0.0440
NLLikeChair	RPCper	0.0000	1	12.58	3.98	0.0468
NLLikeChair	RBCper	-0.0298	1	24.16	7.58	0.0062
NLFeelComfortable	Chair {R-P&B}	-1.4137	2	297.44	48.32	0.0000
NLFeelComfortable	Chair {P-B}	-0.3384	1	21.77	7.07	0.0082
NLFeelComfortable	StartEnd {End-Start}	-0.4115	1	53.69	17.44	0.0000
NLFeelComfortable	SetSeatHeight	-0.3496	1	37.46	12.17	0.0005
NLFeelComfortable	SetSeatDepth	-0.1798	1	32.49	10.55	0.0013
NLFeelComfortable	FitSeatContour	1.1709	1	270.77	87.97	0.0000
NLFeelComfortable	FitSeatWidth	-0.8244	1	58.65	19.05	0.0000
NLFeelComfortable	SPP	0.0097	1	20.97	6.81	0.0094
NLFeelComfortable	RLmax	0.0000	1	12.22	4.00	0.0462
NLFeelComfortable	LoBCA	-0.0020	1	18.55	6.03	0.0146
NLFeelComfortable	RPCper	0.0000	1	13.22	4.34	0.0380
NLFeelUncomfortable	Chair {B&P-R}	-1.0211	1	112.37	33.47	0.0000
NLFeelUncomfortable	StartEnd {Start-End}	-0.4685	1	57.51	17.13	0.0000
NLFeelUncomfortable	Temp	0.6145	1	24.47	7.29	0.0073
NLFeelUncomfortable	FitSeatContour	-1.3455	1	360.26	107.29	0.0000
NLFeelUncomfortable	FitSeatWidth	0.5926	1	33.30	9.92	0.0018
NLFeelUncomfortable	LLA	-0.0237	1	15.26	4.54	0.0337
NLFeelUncomfortable	UBmax	0.0081	1	31.34	9.33	0.0024

Table N-4. Continued.

NLFeelUncomfortable	UBCA	-0.0051	1	66.21	19.72	0.0000
NLFeelUncomfortable	UBmin	-0.1327	1	43.20	12.87	0.0004
NLFeelUncomfortable	RBCper	0.0707	1	79.34	23.63	0.0000

Table N-5. ANOVA for Seat Comfort and its predictors

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	12.00	470.94	39.24	46.64	< 0.0001*
Error	379.00	318.90	0.84		
C. Total	391.00	789.84			

Table N-6. Coefficients for linear relationship predicting Seat Comfort

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	3.58	0.57	6.29	< 0.0001*
BL	0.00	0.00	2.68	0.0077*
BSM	-0.05	0.01	-4.34	< 0.0001*
Chair[B]	0.58	0.08	6.95	< 0.0001*
Chair[P]	0.09	0.08	1.16	0.25
FitLumbarSupport	0.11	0.05	2.19	0.0292*
FitSeatContour	0.62	0.07	9.38	< 0.0001*
FitSeatHeight	0.33	0.10	3.17	0.0016*
FitSeatWidth	-0.37	0.10	-3.81	0.0002*
LoBCA	0.00	0.00	-3.89	0.0001*
LPCA	0.00	0.00	-3.13	0.0019*
RITmax	-0.01	0.00	-4.57	< 0.0001*
SetArmHeight	0.05	0.02	2.56	0.0108*

Table N-7. ANOVA for Overall Comfort and its predictors

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	10.000	367.759	36.776	50.126	< 0.0001
Error	395.000	289.800	0.734		
C. Total	405.000	657.559			

Table N-8. Coefficients for linear relationship predicting Overall Comfort

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	7.963	1.077	7.390	< 0.0001
BSM	-0.024	0.008	-2.850	0.00
Chair[B]	0.616	0.077	7.990	< 0.0001
Chair[P]	0.152	0.079	1.940	0.05
FitSeatContour	0.583	0.061	9.500	< 0.0001
FitSeatWidth	-0.282	0.086	-3.290	0.00
LITCper	0.017	0.004	4.200	< 0.0001
LLCA	-0.002	0.000	-6.030	< 0.0001
RLmax	-0.005	0.002	-2.920	0.00
RPSM	0.012	0.003	3.790	0.00
SetSeatHeight	-0.221	0.049	-4.530	< 0.0001

Table N-9. ANOVA for Feels Soft and its predictors

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	8.000	1948.730	243.591	85.081	< 0.0001
Error	390.000	1116.593	2.863		
C. Total	398.000	3065.323			

Table N-10. Coefficients for linear relationship predicting Feels Soft

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	6.918	2.464	2.810	0.005
Chair[B]	1.909	0.145	13.200	< 0.0001
Chair[P]	1.075	0.134	8.030	< 0.0001
FitSeatContour	0.760	0.118	6.430	< 0.0001
FitSeatWidth	-0.598	0.170	-3.520	0.001
LLCA	-0.003	0.001	-4.040	< 0.0001
RPSM	0.028	0.006	4.540	< 0.0001
SCOPc	0.201	0.079	2.550	0.011
SetSeatHeight	-0.293	0.091	-3.210	0.001

Table N-11. ANOVA for Like Chair and its predictors

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	8.000	1409.412	176.176	53.830	< 0.0001
Error	395.000	1292.777	3.273		
C. Total	403.000	2702.188			

Table N-12. Coefficients for linear relationship predicting Like Chair

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	11.833	2.217	5.340	< 0.0001
Chair[B]	1.306	0.153	8.530	< 0.0001
Chair[P]	0.343	0.135	2.550	0.011
FitSeatContour	1.176	0.123	9.530	< 0.0001
FitSeatWidth	-1.079	0.183	-5.900	< 0.0001
RBCper	-0.030	0.010	-2.910	0.004
SetArmHeight	0.109	0.036	3.020	0.003
SetSeatDepth	-0.244	0.057	-4.270	< 0.0001
SetSeatHeight	-0.270	0.100	-2.690	0.008

Table N-13. ANOVA for Feel Comfortable and its predictors

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	9.000	1348.263	149.807	46.460	< 0.0001
Error	389.000	1254.299	3.224		
C. Total	398.000	2602.561			

Table N-14. Coefficients for linear relationship predicting Feel Comfortable

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	13.796	2.139	6.450	< 0.0001
Chair[B]	1.315	0.156	8.410	< 0.0001
Chair[P]	0.644	0.173	3.730	0.000
FitSeatContour	1.074	0.124	8.630	< 0.0001
FitSeatWidth	-0.904	0.183	-4.950	< 0.0001
RBCper	-0.027	0.011	-2.580	0.010
SetSeatDepth	-0.191	0.056	-3.410	0.001
SetSeatHeight	-0.436	0.100	-4.350	< 0.0001
SPP	0.009	0.004	2.510	0.013
StartEnd[Start]	0.446	0.097	4.620	< 0.0001

Table N-15. ANOVA for Feel Uncomfortable and its predictors

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	9.000	1513.974	168.219	46.141	< 0.0001
Error	396.000	1443.731	3.646		
C. Total	405.000	2957.704			

Table N-16. Coefficients for linear relationship predicting Feel Uncomfortable

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	7.251	1.021	7.100	< 0.0001
Chair{B&P-R}	-1.035	0.177	-5.850	< 0.0001
FitSeatContour	-1.376	0.130	-10.630	< 0.0001
FitSeatWidth	0.593	0.188	3.150	0.002
LLA	-0.026	0.011	-2.270	0.024
RBCper	0.061	0.014	4.220	< 0.0001
StartEnd[Start]	-0.514	0.114	-4.510	< 0.0001
UBCA	-0.005	0.001	-4.000	< 0.0001
UBmax	0.007	0.003	2.740	0.006
UBmin	-0.137	0.037	-3.710	0.000

N.3 Neural Network Model Statistics

Table N-17. Training and validation statistics from five-node neural network

Training		Validation	
SeatComfort	Measures	SeatComfort	Measures
RSquare	0.643	RSquare	0.576
RMSE	0.846	RMSE	0.923
Mean Abs Dev	0.676	Mean Abs Dev	0.758
-LogLikelihood	366.609	-LogLikelihood	132.508
SSE	209.505	SSE	84.282
Sum Freq	293.000	Sum Freq	99.000
OverallComfort	Measures	OverallComfort	Measures
RSquare	0.623	RSquare	0.506
RMSE	0.787	RMSE	0.876
Mean Abs Dev	0.638	Mean Abs Dev	0.744
-LogLikelihood	345.510	-LogLikelihood	127.403
SSE	181.404	SSE	76.023
Sum Freq	293.000	Sum Freq	99.000
NLFeelSoft	Measures	NLFeelSoft	Measures
RSquare	0.672	RSquare	0.666
RMSE	1.556	RMSE	1.652
Mean Abs Dev	1.185	Mean Abs Dev	1.313
-LogLikelihood	537.908	-LogLikelihood	184.402
SSE	700.010	SSE	261.955
Sum Freq	289.000	Sum Freq	96.000
N.3 Neural Network Model Statistics			
Table N-17. Continued.			
NLLikeChair	Measures	NLLikeChair	Measures
RSquare	0.611	RSquare	0.546
RMSE	1.586	RMSE	1.762

Mean Abs Dev	1.280	Mean Abs Dev	1.480
-LogLikelihood	548.982	-LogLikelihood	192.561
SSE	734.379	SSE	301.019
Sum Freq	292.000	Sum Freq	97.000
NLFeelComfortable	Measures	NLFeelComfortable	Measures
RSquare	0.574	RSquare	0.578
RMSE	1.637	RMSE	1.716
Mean Abs Dev	1.320	Mean Abs Dev	1.431
-LogLikelihood	554.354	-LogLikelihood	186.113
SSE	776.764	SSE	279.824
Sum Freq	290.000	Sum Freq	95.000

Table N-18. Estimated values for neural network nodes and responses

Parameter	Estimate
H1_1:BL	-0.00105
H1_1:BSM	0.043315
H1_1:Chair:B	-1.26918
H1_1:Chair:P	-1.00398
H1_1:FitLumbarSupport	-1.10945
H1_1:FitSeatContour	0.303931
H1_1:FitSeatDepth	-0.35884
H1_1:FitSeatHeight	-1.71067
H1_1:FitSeatWidth	1.128467
H1_1:LITCper	0.013721
H1_1:LITSM	-0.01649
H1_1:LLA	-0.03147
H1_1:LLCA	0.003732
H1_1:LoBCA	-0.00174
H1_1:LPCA	0.004979
H1_1:RBCper	-0.01956
H1_1:RITmax	0.007976
H1_1:RLmax	0.012643
H1_1:RPCper	0.047344
H1_1:RPSM	-0.0178
H1_1:SCOPc	-0.30288
H1_1:SetArmHeight	-0.29824
H1_1:SetSeatDepth	0.078151
H1_1:SetSeatHeight	-0.18383
H1_1:SPP	0.008953
H1_1:StartEnd:Start	0.368946
H1_1:Temp	0.401117
H1_1:UBCA	0.000116
H1_1:UBmax	-0.00118
H1_1:UBmin	-0.09056
H1_1:UBSM	0.139866
H1_1:Intercept	-2.39254

Table N-18. Continued.

H1_2:BL	0.000414
H1_2:BSM	0.157414
H1_2:Chair:B	-1.69359
H1_2:Chair:P	-0.53742
H1_2:FitLumbarSupport	-0.0957
H1_2:FitSeatContour	-0.6287
H1_2:FitSeatDepth	-0.86234
H1_2:FitSeatHeight	-0.64754
H1_2:FitSeatWidth	-1.30666
H1_2:LITCper	-0.06833
H1_2:LITSM	0.003572
H1_2:LLA	0.029321
H1_2:LLCA	-0.0045
H1_2:LoBCA	0.006021
H1_2:LPCA	-0.0048
H1_2:RBCper	0.021605
H1_2:RITmax	-0.00531
H1_2:RLmax	0.014499
H1_2:RPCper	-0.02122
H1_2:RPSM	0.015702
H1_2:SCOPc	-0.18483
H1_2:SetArmHeight	-0.20966
H1_2:SetSeatDepth	-0.4263
H1_2:SetSeatHeight	-0.22299
H1_2:SPP	-0.01219
H1_2:StartEnd:Start	-0.60631
H1_2:Temp	1.500327
H1_2:UBCA	-0.00315
H1_2:UBmax	0.006342
H1_2:UBmin	0.04851
H1_2:UBSM	-0.02145
H1_2:Intercept	-9.22942
H1_3:BL	-0.00006
H1_3:BSM	0.064799

Table N-18. Continued.

H1_3:Chair:B	0.923174
H1_3:Chair:P	0.268204
H1_3:FitLumbarSupport	0.073508
H1_3:FitSeatContour	-3.25137
H1_3:FitSeatDepth	0.073302
H1_3:FitSeatHeight	1.37568
H1_3:FitSeatWidth	-0.08582
H1_3:LITCper	-0.0413
H1_3:LITSM	-0.03137
H1_3:LLA	-0.01365
H1_3:LLCA	-0.00105
H1_3:LoBCA	-0.00213
H1_3:LPCA	-0.01133
H1_3:RBCper	0.066203
H1_3:RITmax	0.004198
H1_3:RLmax	-0.00089
H1_3:RPCper	0.015029
H1_3:RPSM	0.0197
H1_3:SCOPc	0.430188
H1_3:SetArmHeight	0.218551
H1_3:SetSeatDepth	0.035624
H1_3:SetSeatHeight	0.241887
H1_3:SPP	0.001355
H1_3:StartEnd:Start	-0.40866
H1_3:Temp	0.158648
H1_3:UBCA	-0.00256
H1_3:UBmax	-0.00071
H1_3:UBmin	-0.05222
H1_3:UBSM	-0.07035
H1_3:Intercept	-12.0281
H1_4:BL	-0.00097
H1_4:BSM	0.055147
H1_4:Chair:B	0.676012
H1_4:Chair:P	1.049865

Table N-18. Continued.

H1_4:FitLumbarSupport	-0.25195
H1_4:FitSeatContour	0.810553
H1_4:FitSeatDepth	0.737314
H1_4:FitSeatHeight	0.650777
H1_4:FitSeatWidth	-0.23259
H1_4:LITCper	0.028713
H1_4:LITSM	-0.00473
H1_4:LLA	-0.00387
H1_4:LLCA	0.000142
H1_4:LoBCA	-0.00186
H1_4:LPCA	-0.00132
H1_4:RBCper	0.119075
H1_4:RITmax	-0.00975
H1_4:RLmax	-0.01512
H1_4:RPCper	0.012295
H1_4:RPSM	0.050038
H1_4:SCOPc	-0.05667
H1_4:SetArmHeight	-0.07556
H1_4:SetSeatDepth	0.068945
H1_4:SetSeatHeight	0.157817
H1_4:SPP	0.007826
H1_4:StartEnd:Start	0.075076
H1_4:Temp	0.051471
H1_4:UBCA	0.000282
H1_4:UBmax	-0.01753
H1_4:UBmin	0.091918
H1_4:UBSM	0.006895
H1_4:Intercept	-12.7628
H1_5:BL	-0.00047
H1_5:BSM	0.122221
H1_5:Chair:B	0.752434
H1_5:Chair:P	0.846471
H1_5:FitLumbarSupport	-0.74813
H1_5:FitSeatContour	-1.02492

Table N-18. Continued.

H1_5:FitSeatDepth	-0.26689
H1_5:FitSeatHeight	-0.04344
H1_5:FitSeatWidth	-0.82025
H1_5:LITCper	-0.04146
H1_5:LITSM	-0.00358
H1_5:LLA	-0.00743
H1_5:LLCA	-0.00594
H1_5:LoBCA	-0.00072
H1_5:LPCA	-0.00903
H1_5:RBCper	-0.04431
H1_5:RITmax	0.004622
H1_5:RLmax	0.01268
H1_5:RPCper	0.026939
H1_5:RPSM	0.015078
H1_5:SCOPc	0.319039
H1_5:SetArmHeight	-0.27314
H1_5:SetSeatDepth	-0.33167
H1_5:SetSeatHeight	-0.86692
H1_5:SPP	0.013733
H1_5:StartEnd:Start	0.337292
H1_5:Temp	0.533111
H1_5:UBCA	0.001169
H1_5:UBmax	0.005901
H1_5:UBmin	-0.11781
H1_5:UBSM	-0.09579
H1_5:Intercept	12.24652
SeatComfort_1:H1_1	-0.90032
SeatComfort_2:H1_2	-0.75284
SeatComfort_3:H1_3	-0.84731
SeatComfort_4:H1_4	0.369313
SeatComfort_5:H1_5	0.658517
SeatComfort_6:Intercept	2.421046
OverallComfort_6:H1_1	-0.79631
OverallComfort_7:H1_2	-0.57433

Table N-18. Continued.

OverallComfort_8:H1_3	-0.91397
OverallComfort_9:H1_4	0.259302
OverallComfort_10:H1_5	0.756078
OverallComfort_11:Intercept	2.45797
NLFeelSoft_11:H1_1	-1.2512
NLFeelSoft_12:H1_2	-1.29465
NLFeelSoft_13:H1_3	-1.10959
NLFeelSoft_14:H1_4	1.679596
NLFeelSoft_15:H1_5	1.638263
NLFeelSoft_16:Intercept	3.928493
NLLikeChair_16:H1_1	-1.23935
NLLikeChair_17:H1_2	-1.11598
NLLikeChair_18:H1_3	-1.9635
NLLikeChair_19:H1_4	1.068619
NLLikeChair_20:H1_5	1.920293
NLLikeChair_21:Intercept	3.991371
NLFeelComfortable_21:H1_1	-0.89036
NLFeelComfortable_22:H1_2	-1.04823
NLFeelComfortable_23:H1_3	-1.83422
NLFeelComfortable_24:H1_4	1.296808
NLFeelComfortable_25:H1_5	1.805544
NLFeelComfortable_26:Intercept	4.152448
NLFeelUncomfortable_26:H1_1	0.81537
NLFeelUncomfortable_27:H1_2	0.848619
NLFeelUncomfortable_28:H1_3	2.107859
NLFeelUncomfortable_29:H1_4	-1.14293
NLFeelUncomfortable_30:H1_5	-1.12778
NLFeelUncomfortable_31:Intercept	4.455525

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