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An Ergonomic Evaluation of Aircraft Pilot Seats

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by

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A Thesis Submitted to the College of Arts and Science

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Abstract

Seat comfort has become increasingly important in today's society as we spend more time at consoles, instrument panels, or just online. However, seat comfort is hard to define and difficult to measure. Several measures both objective and subjective were used to evaluate seat comfort in commercially available average pilot seats. Three pilot seats, which had the same material and similar adjustments but different physical attributes, and a universal classroom seat, with different material and no adjustments, were compared by20 volunteers using subjective and objective measures in a Latin square controlled repeated measures design. A Friedman's test was used to determine that both the comfort questionnaire and the body-map rating results were able to discriminate objective comfort levels between the seats. One-way repeated measures ANOVA tests were used to analyze both the objective tests, actigraph and pressure pad data. All results indicated that one seat was clearly the most comfortable and another, the classroom seat was clearly the most uncomfortable seat. Furthermore, the overall comments per seat were compiled and compared to Fazlollahtabar's (2010) predictive automobile seat comfort theory to determine which factors influence comfort perception. The use of both subjective and objective data can better distinguish comfort from one seat over the other. These results have implications for future tests of seats that will be used for long durations. Limitations and future recommendations are discussed later in the paper. An interesting finding may explain why pressure pad data are typically seemingly at odds with subjective measures of seat comfort.

Introduction

The amount of time spent sitting in uncomfortable and poorly designed seats coupled with inappropriate postures causes susceptibility to fatigue, lower back pain, and musculoskeletal disorders. The need for better seat designs that fit the target population and decreases biochemical problems and reduces fatigue is apparent. There has been a growing interest in the proper design of seat comfort to promote performance, safety, and user satisfaction in the workplace.

Problem Statement

The topic of comfort, specifically seat comfort, is extremely subjective and thus makes testing for discomfort difficult. The problem lies when trying to define comfort, the lack of an accepted definition and testing methods poses a problem when adequately determining what seat comfort entails. The literature associates comfort with positive feelings and discomfort with negative feelings coupled with a poor biochemical state.

However, which factors contribute to discomfort is unknown. For pilots, it has been suggested that inappropriate seat dimensions, improper sitting postures, poor physical conditions and stress levels (Mohler, 2001) are contributors to lower-back discomfort. Physical pain during flight can cause distractions and reduction in pilot performance, causing concerns in flight safety (Goossens, Snijders, & Fransen, 1999). Understanding how to prevent seat discomfort and thus biochemical issues is an investment in flight safety, as well as pilot comfort. This can be done by observing pilots' sitting behaviors and interactions with the systems in the cockpit, implementing comfort surveys, or running experiments to determine adequate seat measures and seat designs. It is important to come to an agreement of which comfort definition should be applied and which measures are the most appropriate to use. Which measures provide the most significant results is still under debate as well.

Purpose Statement

A manufacturer of aircraft pilot seats for light jets requested that the Embry-Riddle Aeronautical University's Human Factors Department determine which of three prototype seats is the most comfortable; subjectively and objectively defined. The present study is a non-flight version of a larger study which evaluated comfort in a 4-hour simulated flight. The current study will not be restricted to pilots and will sample a bigger population.

This study used pilot seats as a test bed for analyzing differences in comfort levels. The correspondence between subjective and objective measures of comfort also was assessed. Finally, first impressions were also compared against final seat comfort ratings.

Review of Literature

Ergonomics

During the 19^{th} century, Psychology began to emerge as a science, focusing on developing perceptual and psychometric theories in order to understand how the human brain interacted with the environment. During the 20^{th} century, a combination of industrialization and an increased reliance on office work led to the creation of a sub-discipline of Psychology, applying a theoretical science to an applied field called Ergonomics in Europe and Human Factors Psychology in the United States (Kroemer, Kroemer, & Kroemer-Elbert, 2001). The sub-discipline, focused on the human as the center of a design to enhance performance, increases safety, and increase user satisfaction (Wickens, Lee, Liu, and Becker, 2004). Some would argue that ergonomics is not the same as human factors and is instead a subfield of human factors. The difference, if such exists, argues that being that human factors has a psychology foundation, therefore places a greater emphasis on cognition; whereas ergonomics is derived from industrial engineering, placing a greater emphasis on the work place and the fit of the human (Wilson, 2000).

The term ergonomics was proposed to British researchers by K.F.H Murrell in 1950. The first half, *ergon*, is Greek for “work and effort”; while, *nomos* refers to “law or usage” (Kroemer et al., 2001). Originally, ergonomics required understating of anatomy/physiology and experimental psychology (Wilson, 2000). Additional fields such as sociology, anthropometrics, biomechanics, engineering science, and applied medicine now contribute to the use of ergonomics in the design of work systems, equipment design, human-computer interaction, industrial organization, and industrial engineering. The definitions for ergonomics are broad. Bridger (2003) describes ergonomics as a method for improving the interaction among humans and machines. Dempsey, Wogalter, and Hancock (2000) define ergonomics as "the design and engineering of systems for the purpose of enhancing human performance (p 6)." Wilson (2000) defines ergonomics as the study of human interactions with environmental systems and the design of those systems. Due to ergonomics' emphasis on physiology and the physical interaction between the human and the system, the term ergonomics will be used throughout this paper to refer to a sub-discipline of Human Factors Psychology.

Ergonomics encompasses a variety of knowledge and subsets of knowledge used to assess products with the purpose of properly fitting the product or system to maximize human productivity. Prior to the development of ergonomics, designed intended for humans were made then humans were chosen to fit the design, making it difficult for those who were at extreme levels of height, weight, and strength to use the tools or systems being designed. In addition, technology is constantly changing and rapidly growing; thus, operational procedures need to be identified, adapted, and allocated to the tool and the human, in order to design easy-to-use products (Blanchard and Fabrycky, 2006). In Europe, one of the first applications of ergonomics was in Europe during the First World War as technology grew to depend on how quickly and efficiently people could use the equipment. The increase in agricultural, industrial, military, and household tasks led to related fields of esearch in anthropometrics, anatomy, and biomechanics (Kroemer et al., 2001).

In the United States, one of the first applications of seat ergonomics was during World War II as the range of aircraft increased and the need for pilots to sit in the cockpit for longer durations increased. Initially, pilots gave feedback on seat comfort and discomfort by physically indicating parts on their body that hurt after long duration flights. Thus, the Air Force began to incorporate the use of objective measures along with pilot feedback in effort to redesign more comfortable pilot seats (Cohen, 1998).

Biomechanics and anthropometrics became separate sub fields of study used in ergonomic analyses to recommend design guidelines, which consider motion and force interactions and human physical dimensions, respectively. As subfields of ergonomics, they help describe the interaction between humans, machines, tools, or systems. Understanding how muscles and joints move, the limitations of physical dimensions of limbs are pertinent in the design of any element a human uses. Although the current study will not examine range of motion adjustments (this was done in the pilot seat part of the study), it is important to briefly describe these fields in the sections to follow to make their similarity and differences and contributions to successful ergonomic design clearer.

Biomechanics is the study of the mechanics of movement capable by the human body (Cerny, 1984). That is, it uses knowledge of the human neuromuscular system and human limitations to approximate mechanical load under varying conditions (Marras and Karwowski, 2006). For example, when designing a lever, biomechanics examines how a human pulls or pushes the lever, a biomechanics specialist would examine how much force is exerted on the lever, and how that force affects performance and body limitations.

Anthropometrics analyzes body dimensions to design products, systems, and tools to accommodate the diversity of human sizes (Wickens et al. 2004). Data are gathered by acquiring body measurements of the general population while considering the job at hand, user requirements, and what size of user is needed to achieve the job. Human variability in age, gender, ethnicity, race, height, weight, and occupation make anthropometric consideration important. Due to human variability, products are designed to fit up to the 5^{th} percentile of the population to the 95th percentile of the population on a bell shaped curve. For example, strength and reach requirements are designed up to the 5th percentile, while clearance requirements are designed for up to the 95th percentile. When designing a lever, for instance, the design must accommodate someone with less muscle strength, therefore designing for down to the 5th percentile. When designing a doorframe, the height must be taken into consideration for those in the 95th percentile, to accommodate those for all but the extreme heights. The current study considered each participant's height and width in a body mass index score to determine if larger individuals experience seat discomfort more.

Comfort

As previously mentioned, ergonomics is an applied field which seeks to improve the interaction of human performance with workspaces, work products (i.e. tools, seats, and desks) and systems in which they work. Much of the current approaches to ergonomics focuses on comfort (De Looze, Kuij-Evers, & Van Dieen, 2003). For example, one of the topics most commonly researched is seat comfort which may be due to the increasing amount of time humans sit to do work. There has been interest in designing for comfort to promote performance, safety, and user satisfaction in the workspace. However, the lack of a clear definition of comfort poses a problem when designing seats to maximize comfort. Most common theoretical definitions identify comfort with feelings of well-being or a neutral state, while discomfort is associated with feelings of fatigue and or pain (Zhang, Helander, and Drury, 1996). Furthermore, Zhang et al. (1996) and Kroemer et al. (2007) suggest that aesthetics can be an indicator for comfort perception, whereas biomechanics and physiological factors are typically indicators of discomfort. Some of these physiological factors may include but are not limited to stimulation of the sensory receptors in the skin, muscle and joints and internal organ systems (de Looze et al.2003). Biomechanical factors may include reach requirements and postural adjustments. Comfort then, can be considered to fall somewhere along a linear spectrum that spans from comfort to discomfort (Richards, 1980). Hansen and Cornog (1958) argue however that comfort and discomfort are not opposites, but rather the absence of one another. Comfort, in their view, is a reduction or an absence of discomfort. In addition to the variability of definitions of comfort, numerous models and frameworks have also been proposed to illustrate the factors, which comprise comfort.

Comfort Models.

de Looze et al. (2003) created a theoretical model (see Figure 1) to explain the different contributing factors which affect discomfort and promote comfort while sitting. The model deals with the effects of the environment, the product itself, and the human perception of sitting discomfort and comfort. The right side of the model denotes comfort; de Looze et al., like Zhang et al. earlier describe comfort as feelings of relaxation and well-being. The context level, in their models, concerns the environment, which includes the surrounding social, physical, and task-related factors. The product level involves the physical features of the seat. That is, the aesthetic design which according to Kolich (2008) includes stiffness, geometry, contour, breathability, and other styling factors as well as other physical features. The human level involves pre-conceived notions of comfort and the internal emotional state of the user (Kleeman, 1983). It can be assumed that while sitting, the combination of the psycho-social factors (job satisfaction), the workspace, and the task-at-hand coupled with individual emotions and expectations can lead to the perception of seat comfort.

The left side of this theoretical model is concerned with discomfort. de Looze et al. (2003) suggest discomfort as feelings of pain, soreness, numbness, and stiffness. The human, product and context levels are components of discomfort. At the context level of the model, only the physical environment is of concern in discomfort. The task and psycho-social factors in the model are not considered when determining discomfort. At the product level, the physicality of the seat itself is considered without the subjective aesthetic component. de Looze et al. (2003) argue that the physical factors attributed to discomfort, coupled with methods such as pressure distribution analysis and subjective ratings could prove valuable in the design of seats. At the human level the physical fitness of the human and biomechanics are evaluated without the inclusion of user psychological states.

While sitting, external exposure of the physical environment (the workspace) and the physicality of the seat (armrest length, stiffness) may promote a negative internal dose (overload of muscles) and a negative response (figdetiveness or peaked seated pressure) inducing the perception of discomfort. The negative external exposure, internal dose, and response may be correlated to the physical capacity of the user.

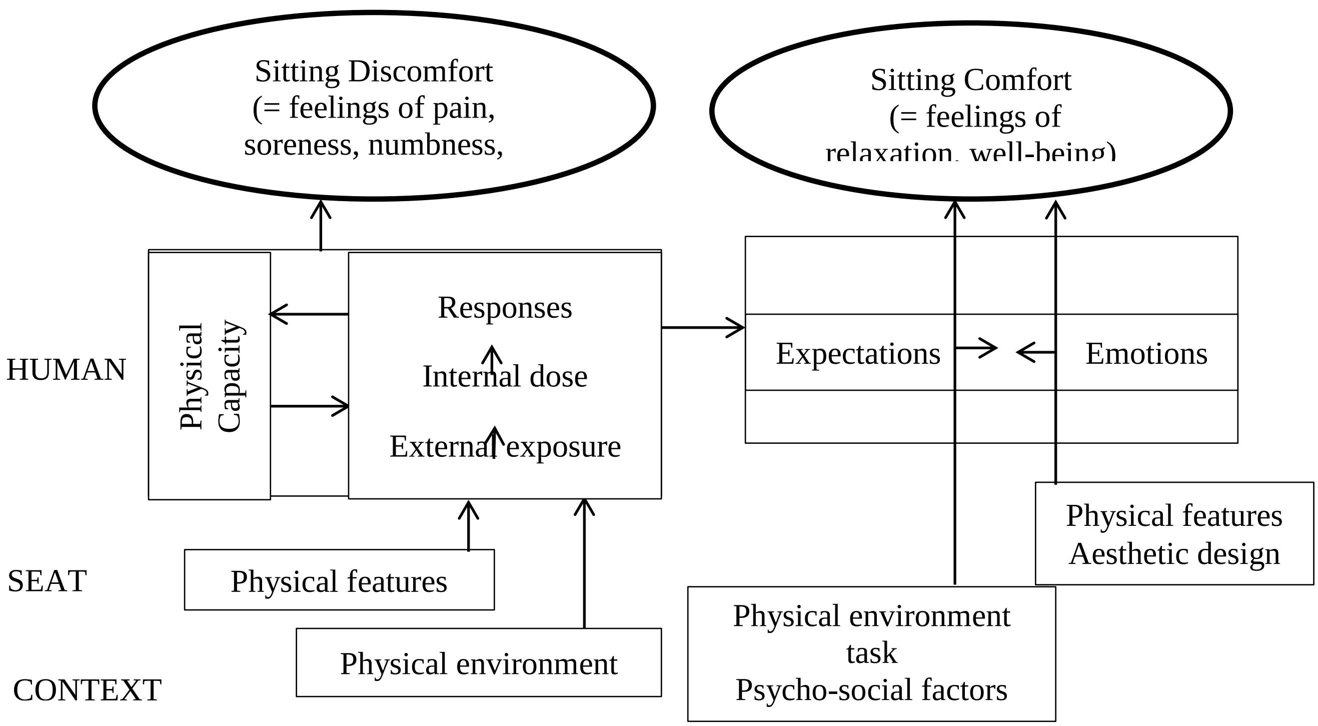

Figure 1. Adapted from de Looze et al.'s (2003) Theoretical Model of Comfort and Discomfort.

Fazlollahtabar (2010) proposed another model (see Figure 2) that dealt with factors influencing the subjective perception of seat comfort, particularly in the automotive industry. Although Fazlollahtabar (2010) does not provide an operational definition for comfort, he does recognize a need for an accepted operational definition of comfort that includes both static and dynamic components. He is also a proponent of the need for these components to be tested objectively. This model includes factors affecting seat comfort perception such as, vehicle/package factors, social factors, individual factors, and seat factors makeup what vehicle buyers, the human level, would perceive as comfortable in automobile seats.

The vehicle/package factors would also comprise the human level but more in terms of the physical fitness of the user of the seat, for example, head clearance or leg space. Social factors comprise preconceived notions regarding the type of automobile and economic status that is suggested, for example a seat in a BMW versus a seat in a Toyota. The individual factor comprises variability in users such as height, weight, posture, and age. Finally, the seat factor comprises aesthetics, which as previously mentioned encompasses the physical features of the seat, for example, the stiffness and styling of the seat. Unlike De Looze et al.'s theoretical model, Fazlollahtabar excludes the users' emotional state regarding the automobile seat. Furthermore, the model concerns solely the perception of comfort due to users own predilections of comfort factors (Fazlollahtabar, 2010).

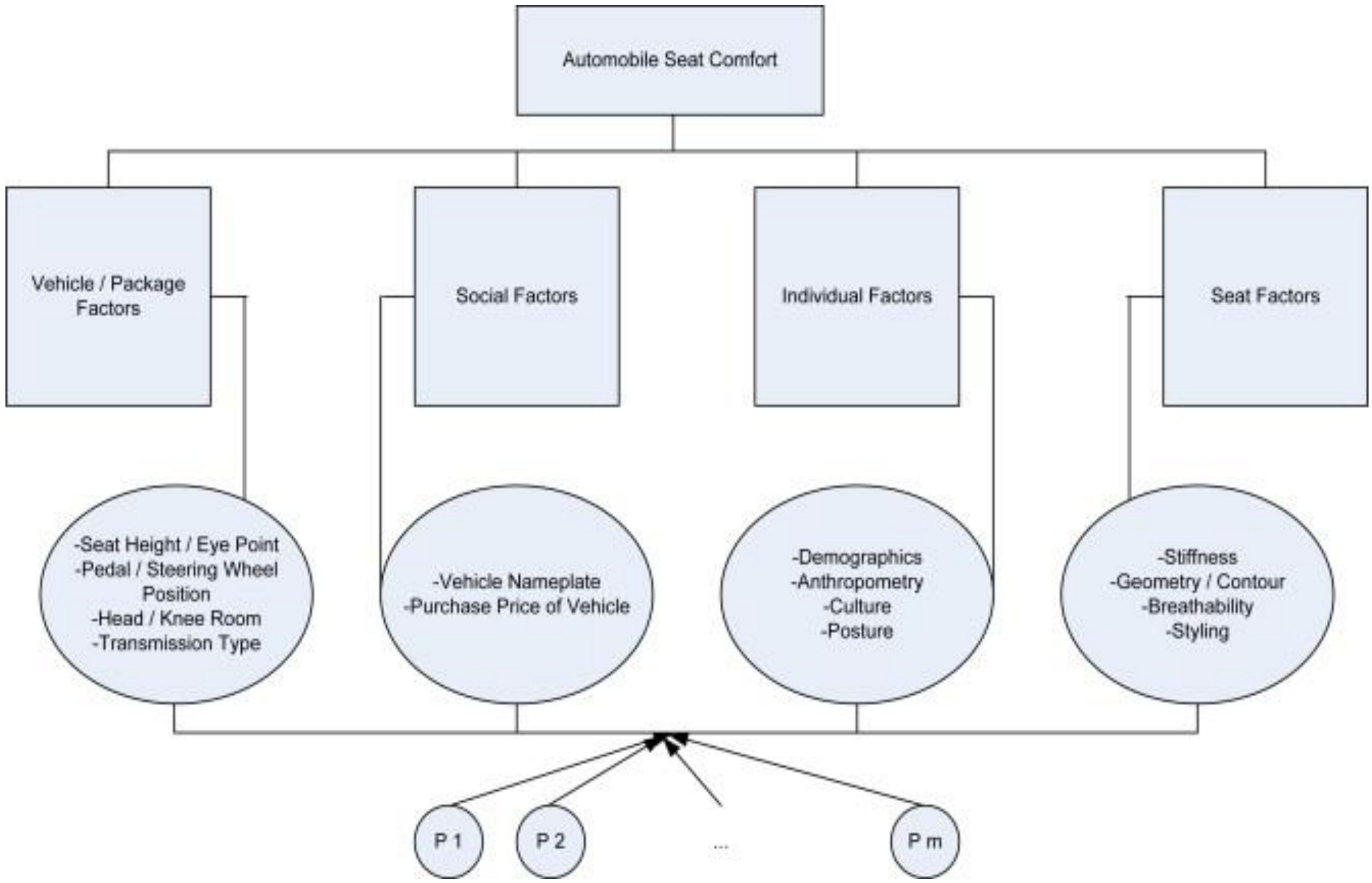

Figure 2. Adapted from Fazlollahtabar (2010). Factors affecting subjective perceptions of automobile comfort.

Fazlollahtabar further suggested what he calls the AET method to determine the relative weight of the subjective factor determinants proposed in his seat comfort model. The AET method is composed of a developed questionnaire coupled with the Analytical Hierarchy Procedure (AHP), a technique termed 'Entropy', and the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). The AHP is a decision-making tool which weighs each factor affecting seat comfort. Entropy measures the probability of uncertainty. That is, the amount of factor error there is likely to be in the information gathered. TOPSIS is a decision criteria tool used to evaluate the best alternative to the set goal. Hence, the AHP, Entropy and Technique for order make up the AET acronym.

Essentially, the AET method constructs a hierarchy of seat factors, starting with high level factors and further breaks these down into sub-factors. Next, user rankings are collected for each sub-factor and entered into paired comparisons to determine the relative weight of comfort for each factor, using AHP. Uncertainty is then calculated into this relative weight of each factor by using the entropy method. Finally, the ideal and least ideal solutions are calculated using TOPSIS. These steps allow for seat comfort to be described in terms of factors for finding the best seat features. Since the entire AET procedure is used for the design process of seats, only the factor ranking process was applicable for this study.

First Impressions

Ergonomics and aesthetics seem to mesh in the design of a product. However, there is a lack of research in the realm of comfort pertaining to aesthetics and first impressions. Those in marketing, manufacturing, and even advertisement have emphasized the importance of first impressions on aesthetics and attempted to understand their effects and how to apply that knowledge to the design and selling point of products. Nevertheless, some research was found that elucidated as to how the effects of first impressions affect comfort.For example, first impressions seem to persist even after the exposure to other stimuli (Myers, 2010).Groenesteijn, Vink, de Looze, and Krause (2009) conducted a study to determine the effects of different office seats when executing tasks. To test for first impressions, participants were asked to rate the external design as well as comfort expectancy. They found there was no significant difference between first impressions and seat preference.

On the other hand, Schmidt and Liu's (2006) study on aesthetic judgment in advertisement examined product size, font location, font size, color scheme and background in 300 magazine laptop advertisements. The 5 esthetic attributes mentioned contained three additional levels. Results indicated that individuals took approximately 1.5500ms to perceive and process the stimuli presented. Schmidt et al. (2006) demonstrated that after the stimulus pairs were rapidly processed as a whole, it then took participants approximately 300ms to form an aesthetic preference for one stimuli or the other. This processing strategy is typically called top-down processing. Top-down processing results when the stimulus is first viewed in its entirety and details are later processed to form a conclusion (Mueller and Hassenzahl, 2010). That is, when presented with more than one stimulus, participants chose the most aesthetically pleasing advertisement within seconds with no utilitarian perception of what attributes the product contains. Understanding which factors consumers look for when comparing products may lend pertinent information during the design phase of a product.

Yeung and Wyer (2004) conducted a study to determine if a consumer's decision to buy encompassed a hedonic or utilitarian criteria or an affect-based initial impression, and if the mood of the consumer affected the ultimate judgment decision to purchase the product. In their view, affect-based initial impression was an affective reaction stimulated by a product appraisal prior to knowing the products attributes. Researchers manipulated the mood of the participants as positive or negative; judgment criteria as hedonic or utilitarian. They manipulated the mood-picture order of presentation, for example, no picture vs. mood first, picture-second vs. picture-first, mood-second; picture type: hedonic vs. utilitarian vs. none; and the attribute information: favorable or unfavorable. Their results suggested a level of top-down processing occurred when analyzing the stimulus. That is, the visual stimuli presented to the subject allowed for the creation of a first impression. The mood felt at the time of the analysis affected this first impression. Additional information (e.g. the decision criteria) was then used to finalize the assessment of the product. Thus measurements of first impressions would appear useful in helping to interpret the user's perception of comfort.

Due to low amount of information pertaining to first impressions and seat comfort, there is a need for experimental tests that focus on first impressions and its effects on comfort perception. Furthermore, it is important to determine if once first impressions are made, how long they last.

Assessment Measurements

The variability in comfort definitions and components above indicates the diverse methods used to assess comfort, particularly seat comfort. There are two types of measurements used to evaluate any ergonomics device such as seat comfort: objective and subjective. Both measurements contain different types of methods to consider.

Objective Measures.

Objective measures are quantifiable and do not require human interpretation to assess discomfort. Some of the most common objective measures used are pressure distribution analyses, motion analyses, and postural angle analyses. For example, pressure pads are used to assess high-pressure body distribution levels on a seat. The positive aspect of objective measures is that human bias interferes very little with the measurement. Data taken from these direct measurements are concrete and unbiased user responses to the stimuli (Parsons, 2000).

Pressure Distribution Analysis.

A pressure distribution analysis is one of the most common methods for objectively identifying discomfort (Tan, Chen, Delbressine, and Rauterberg, 2008). It is a sensing and evaluation technique for measuring the distribution of pressure between the user and the seat (Kolich & Taboun, 2004) and is normally measured in PSI, or pounds per square inch. Seat pressure is an objective measure which presumably indicates that greater discomfort arises from the greater pressure; a hot spot.

Automobile, truck, train, bus and aircraft manufacturers often use body pressure distribution measurements to assess discomfort. In a study conducted for the Air Force, Hertzberg (circa 1950) used a pressure blanket to analyze pressure distribution. Although results indicated present pressure, it is believed that the pressure blanket was calibrated incorrectly (Cohen, 1998). Swearingen, Wheelright, and Garner (circa 1960), also conducted a study for the Air Force in which an absorbent paper and an ink cloth were used to assess discomfort in body pressure distribution. However, this too overestimated area pressure (Cohen, 1998). Early studies like these stressed the importance of ergonomic consideration, in particular, the use of seat pressure distribution as a method for determining discomfort in aircraft seat design.

An automobile seat manufacturer tested the feeling of seat cushion comfort in a short duration study. Participants were presented with different seat cushion compositions and discomfort was measured via pressure distribution analyses. Ebe and Griffin (2001) found that if even pressure distribution is not present, the seat would feel uncomfortable to the participants. Ebe et al. (2001) also noted that seat shape, participant's posture, and the aesthetics of the seat also determine comfort or lack thereof.

Deros, Daruis, and Nor (2009) tested 14 male participants in a pressure distribution seat study for Sedans. Pressure pad results indicated a correlation between static posture and seat discomfort. Furthermore, a correlation between subjective evaluations and discomfort were found in the seat pan and backrest.

Ng, Cassar, and Gross (1995) tested 20 subjects in a study relating to pressure distribution and seat comfort. A pressure pad was placed on both the seat pan and back of the baseline seat, while participants sat motionless for the required time (time was not specified). Air bladders, which inflated and deflated based on the pressure readings, were then placed on the baselines pan and back region. The air bladders did not interfere with the feel or style of the seat. Questionnaires related to comfort were distributed before and after air bladders were installed. Results indicated a consensus between subjective and objective data regarding areas of pressure load in the back. Pressure data indicated that the seat with the air bladders had better pressure distribution in both the seat pan and the back of the seat. Ng et al. (1995) argues that one common seat design is not applicable to every situation, task or human; therefore, air bladders with automatic pressure distribution adjustments should be used in all seats to accommodate a larger population.

Motion Analysis.

Actigraphy refers to accelerometers or motion-sensing devices that measure movement (Telfer, Spence, and Solomonidis, 2009). Most commonly, an actigraph is typically used during sleep studies to measure restlessness. Actigraph's have been used in measuring upper limb movement in seat studies depending on the accelerometers incorporated in the actigraph (Telfer, et al., 2009). Telfer et al. (2009) used actigraphy on 12 participants to measure discomfort in different chairs by measuring movement frequency. Researchers found that the actigraph accurately measured an increase in movement as discomfort increased. Foerster and Fahrenberg (2010) tested 31 participants using actigraphs in their assessment of movement and posture. Their results indicated that accelerometers accurately measured motion while sitting. These results suggest that actigraphy is a useful measure in assessing discomfort levels.

Postural angles analyses.

Preferred sitting positions differ from person to person (Telfer, Spence, and Solomonidis, 2009). However, these sitting positions may cause stress on the spine or be inappropriate for the task potentially leading to negative effects, such as musculoskeletal pain (Leuder, 1983). To examine the variety and intensity of sitting postures under various seating conditions, postural angle analyses are important (Dunk & Callaghan, 2005). One example is The Ovaco Working Posture Analysis System, which evaluates sitting postures that are preferred in a real-world setting. The system allows researchers to observe the frequency and duration in which each sitting posture occurs and later evaluate its appropriateness to the task (Kroemer et al. 2001). Branton et al. (1969) and Hansen (1985) suggest that discomfort can be measured by total time a participant can tolerate being exposed to a specific posture. Furthermore, discomfort could also be measured via performance. If discomfort is present, both cognitive and muscle fatigue may arise causing a decrease in performance (Hansen, 1985).

Branton and Grayson (1967) studied sitting behaviors of train passengers in two different seats. Findings indicated passengers seldom used headrests, armrest, and backrests, which were attached to the seats. However, the need for head support was shown by the passenger’s use of their hands to rest their heads. Furthermore, the use of a backrest was analyzed. Those of small stature were able to use the backrest, whereas taller passengers were unable to adequately rest their shoulders on the backrest. Differences among genders also indicated which aspects of the seat were utilized and what postures were most common among genders. For example, men used armrests more than women and men had worse back posture than women in the seats.

Subjective Measures.

Subjective measurements are important when assessing usability and user-product satisfaction (Klein-Teeselink, Siepe, and De Pijer, 1999). Comfort is ultimately a subjective experience; thus, most researchers use subjective methods to acquire information about a particular product via users input. Parsons (2000) defines subjective methods as information gathered from the user population, in which they report on their impressions of a stimulus, product, or event. Questionnaires, rating-scales, interviews, and body-map ratings are some of the most common types of subjective methods.

In questionnaires, words should be chosen cautiously, so as not to lead the subject, but rather ask the subject for his or her opinion. Fazlollahatabar (2010) suggests using well-developed questionnaires to determine dependent variables which could assist in the prediction of impressions from particular groups. Preferably, each questionnaire element would add a unique dependent variable and not simply be redundant with some other questionnaire element. That is, in a seat study, if questionnaires are reliable, the dependent factors could be analyzed separately and compared against each other to predict which seat will be the most comfortable.

Rating-scales gather the users perspective on what is being studied by asking subjects to rate the stimulus on a Likert-scale or visual analog scale. Kolich (2004) found that ratings are not only the opinions of what users like but are also indicators of comfort requirements and specifications.

Potential observer bias, misworded leading questionnaires, and complex rating-scales are criticism of the use of subjective methods (Shen and Parsons, 1997). Because subjective methods are difficult to quantify and objective methods do not gather the user's perspective on the product, tool, or systems, both methods should be performed to get at different perspectives on the product or event.

Integration.

A review of the literature indicates the success of using both subjective and objective methods in order to quantify comfort and discomfort. De Looze et al., 2003 suggests there is a benefit in integrating both objective and subjective measures to assess comfort. Objective measures quantify factors such as pressure distribution and postural angles, and physical dimensions; they do not take into consideration the user's input. Shen and Galer (1993) believe objective measures should be used to support the data derived from subjective measures, in regards to seat discomfort. They assert that both methods should be highly correlated; the physical measures should be predictive of the subjective measures and vice versa. The mixed results would determine which seat was optimal for comfort and would also indicate which was the most uncomfortable.

Although many researchers support the integration of objective and subjective data, not all research has indicated a significant correlation between objective and subjective results. De Looze et al. (2003) describe several studies (Thakurta, Koester, Bush, and Bachile, 1995; Yun, Donges, and Freivalds 1992; Lee, Ferraiuolo, and Temming, 1993) that used objective measures, such as pressure data and posture and movement analysis, in addition to subjective ratings on a five or 10-point scale to evaluate seat comfort. Yun et al. (1992) concluded that similar levels of pressure distribution on the back and buttocks area result in positive subjective levels of comfort. Thakurta et al. (1995) concluded though that pressure distribution is associated with perceived comfort across various body regions, though no information regarding statistical significance of the relationship with subjective measures was provided. Lee et al. (1993) results also indicated no meaningful correlations between pressure distribution and local comfort when measuring seat pan comfort in sixteen different car seats (De Looze et al., 2003).

Due to the inconsistencies reported regarding the relationship between objective and subjective results, there is a need for future research to consider both objective and subjective measures until their relationships to comfort are clearer.

Sitting

Both biomechanics and anthropometrics are fields of study used in the development and design of user-centered products that relate to sitting posture. Proper sitting posture is important to evaluate optimal seat designs. Like the definition of comfort, proper sitting posture is still continuous. One notion of ideal posture was an upright position, mimicking an erect standing human posture that distributes pressure evenly throughout the muscles in the body, relieving pressure around the mid-section of the body (Corlett, 2006). However, clinical studies (Keegan, 1953; Claus, Hides, Moseley, and Hodges, 2009) indicate that sitting upright can increase tension in the lower spine and may not be ideal for long periods of time.

The lower back sustains the most pressure when a human sits, stands, or lifts, making the lower back more prone to physical problems as a result (Mohler, 2001). Seat designs must consider suitable sitting positions, while keeping job requirements in mind, to reduce lower back pain. An understanding of how the spine looks in a seated position (both good and bad postures) is important. An abnormal curvature of the spine while seated can have significant long-term effects on the vertebrae and muscles, causing discomfort and even infirmity (Corlett, 2006). In a study evaluating the effects of assisted lordotic and kyphotic postures, William et al. (1991) found that a lordotic spinal posture is preferred over a kyphotic sitting posture because it reduces and centralizes pain in the back and legs.

Schoberth (as seen in Harrison et al. 1999) attempted to classify 3 possible sitting positions in relation to the center of gravity. The anterior, neutral, and posterior positions are shown in Figure 3. Parts A and B show anterior positions of the spine, where more than 25% of body weight is placed on the ground by the feet; part C shows a neutral position, which places about 25% of body weight on the ground; and part D shows a posterior position of the spine where less than 25% of weight is placed on the ground. Part A, specifically, shows a kyphotic spine with a slight pelvis rotation. Kyphosis is a backward lean that flattens the spine (Andersson, 1987). Part B shows a lordotic spine, a forward rotation of the pelvis (Andersson, 1987). Part C shows a neutral position relating to the center of gravity where the lumbar region is either straight or slightly kyphotic. A neutral posture is a minimal lordotic posture (Andersson, 1987). Finally, part D shows a posterior position caused by a kyphotic extension of the pelvis. Harrison et al. (1999) literature review concluded that although there is controversy regarding how much load lordosis or kyphosis places on the muscles and discs of the lower back; lordosis has shown to decrease the weight on the lower back when compared to kyphosis.

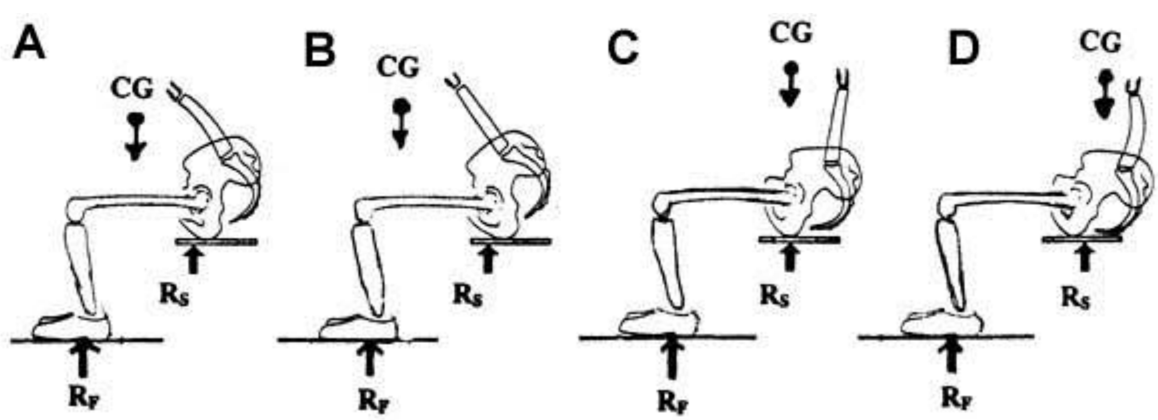

Figure 3. Adopted from Schoberth's three sitting categories as seen in Harrison et al., 1999.

The body performs many postures such as sitting, standing, lying, kneeling, squatting, reaching, bending, and twisting. A static position for extended periods of time can cause discomfort both physically and mentally and could even degrade performance (Kroemer et al. (2007). Humans tend to sit in their preferred positions and later seek comfort by adjusting their positions when physical discomfort is sensed (Telfer, Spence, and Solomonidis, 2009). For example, truckers perform frequent postural changes as a method to avoid discomfort (Tan, Chen, Debressine, and Rauterberg, 2008). Branton et al. (1967) described postural adjustments in his train study that consisted of crossing or uncrossing the legs, shifting positions, leaning to one side or the other, and slouching. Individual sitting postures vary considerably and frequently and underlay the dynamic sitting nature in humans (Dunk et al., 2005). Too much postural movement, however, is referred to as fidgeting; a frequent change in sitting positions associated to discomfort (Tan et al., 2008). Discomfort may be caused by physiological factors (such as local ischemia), physical factors (such as inadequate seat cushioning or contour), and poor anthropometric design (Branton, 1969).

Seat Design

Effects of Poor Seat Design.

According to the National Institute for Occupational Safety and Health (Niosh, 1997), 7% of the general adult population suffers from some form of musculoskeletal disorder. Musculoskeletal disorders (MSDs) are conditions that impact blood flow, peripheral nerves, tendons, joints, spinal discs and related muscles in the lower and upper extremities (Punnett and Wegman, 2004; Branton, 1969; Tan et al., 2008; and Bongers et al., 2007). Those affected by most MSDs are among truck drivers, clerical workers, and pilots (Punnett et al., 2004) in other words, people who sit for long periods of time.

More energy is required and circulatory strain is increased if discomfort is felt while sitting. Poor seat design also can affect mechanical load causing muscle fatigue and strain in the back, buttocks, and legs (Ng et al., 1995). Static pressure affects oxygen saturation in the buttocks which can lead to ailments such as deep vein thrombosis (reduced blood flow to a region due to a vein blood clot) (Parakat Pellettiere, Reynolds, Sasidharan, & El-Zoghbi, 2006). The extra amount of energy and muscle tension is needed to keep the trunk in the same position and this can lead to other problems like swelling of the feet and legs, and spinal column disorders (Kroemer et al., 2007). Seat design should not restrict a user's movement or circulation in the seat (Strickland, Pior, and Ntuen, 1996).

Sustained exposure to seat vibrations can also contribute to muscle fatigue and damage of the discs. Vibrations apply pressure to the spinal column, which in turn strain the intervertebral discs and end plates that can lead to blood flow problems and ultimately failure of nutrition to the discs (Bongers et al., 2007; Corlette, 2006). For instance, if metabolites accumulate it can increase disc degeneration (Enoka and Stuart, 1992; Pope, Goh, and Magnusson, 2002). In particular, truck drivers often experience muscle fatigue caused by repetitive exposure to vibrations during static long duration drives (Durkin, Harvey, Hughson, and Callaghan, 2006).

Although the need for an ergonomic seat design is recognized, inappropriate seat designs are still being used. For example, when civil pilot aircraft seats (Boeing 747-400/300, McDonnell Douglas DC10-30, Airbus A310 and Boeing 737-300) were evaluated for proper anthropometrics and biomechanical requirements, results showed inappropriate seat dimensions and adjustments options that would not fit all pilots (Mohler, 2001).

The ergonomic design of an aircraft cockpit is important when assessing a pilot's performance during flight (Strickland, et al., 1996). Although the literature for pilot seat comfort in commercial aviation is scarce, studies have been completed relating to helicopter vibration effects and helicopter pilot comfort. Sargent and Bachmann (2010) suggests that awkward postures while flying a helicopter can lead to fatigue, overload, and pain in pilots. Therefore, designing a pilot seat to reduce muscle fatigue and discomfort associated for both short and long duration flight should be important to pilot seat manufacturers. Both military flight crew members and helicopter pilots have also shown prevalence in back problems (Mohler, 2001). While controlling a helicopter, a pilot is required to constantly move his or her arms and legs. The “helicopter hunch”, a kyphotic position that requires a pilot to assume a forward bend and slight lean to the left, is assumed to compensate for discomfort felt due to the lack of seat support and seat vibrations (Bongers, et al., 1990). Some researchers however, do not find a relationship between the extent of vibration to which a pilot is actually exposed to (De Oliveira and Nadal, 2004).

Seat Design Criteria.

Pheasant and Haslegrave (1996) proposed that seat comfort is determined by the combination of the seat, the user, and the task’s interactions. Vink (2005) suggested that for an optimal seat design, seats should not only look comfortable but consumers should feel comfortable immediately after sitting in the seat and continue to feel comfort throughout their sitting duration.

Military standards are general design criteria commonly used in the design of systems, tools, and equipment. These standards provide anthropometric measurements such as height, depth, breadths, head dimensions, foot dimensions, hand dimensions, and weight for both male and females in the 5^{th} and 95^{th} percentile for, but not limited to, the design of displays, latches, controls, vehicles, workstations, the physical environment, and virtual environments.

Vehicle design criteria, specifically for vehicle seating is included in section 5.6.2 of the MIL-STD 1472G. Seats should be designed with a seat slope of 5-8 degrees, the ability for both vertical and horizontal adjustments, padding should not restrict blood flow in the legs nor apply extra pressure to the lower extremities for those in the 5-95 percentile, and durable upholstery made of a material with good airflow throughout, to reduce discomfort in extreme environments; and an integrated head restraint for head support (Department of Defense, 2012).

Workstation design criteria, specifically for the seated worker is included in section 5.10.3.4 of the MIL STD 1472G. Dimensions for armrests, back rest, and seat pan are provided along possible seat adjustments. Seat pan height, depth angle and pan-backrest angle shall be adjustable. The standards recommend adjustability in the space, height, and width of a backrest. However, an armrest should be fixed in length, width, and separation but should have adjustable height. Although these standards are generally accepted, it is important to consider task requirements, the population the seat is being designed for, and the environment in which the seat is being used in order to optimize work performance and decrease pain (Kroemer et al., 2001).

Although military standards are commonly used, the military creates these standards for functionality not necessarily with comfort considerations. Keegan et al. (1953) recommend 11 basic requirements needed to ensure safety and comfort in all seats (see Figure 4). These are based on physiological, anatomical, and pathological causes of pain and discomfort in the lower back. The first and most important requirement is the integration of a backrest. Support to the lower back is important in the reduction of a flat spinal curve (Keegan et al., 1953). A prolonged flat spine, the reduction in space between the thigh and trunk, can cause damage to the fourth and fifth disc, producing strain and discomfort to those who sit for long durations. Carcone and Keir

(2007) tested 30 participants to determine the effect of back rests on comfort. Results indicated that an additional backrest could decrease average and mean backrest pressure. As previously stated, a lordotic posture is preferred over a kyphotic posture. However, although participants retained lordotic postures, too much cushion was deemed uncomfortable.

Other requirements in Keegan's et al. model are the angle between trunk and thigh, shoulder support, armrests, seat pan height, seat pan curvature, seat tilt adjustability to avoid kyphosis (Corlette, 2006), and adequate foot space to allow for change in positions (Keegan et al., 1953).

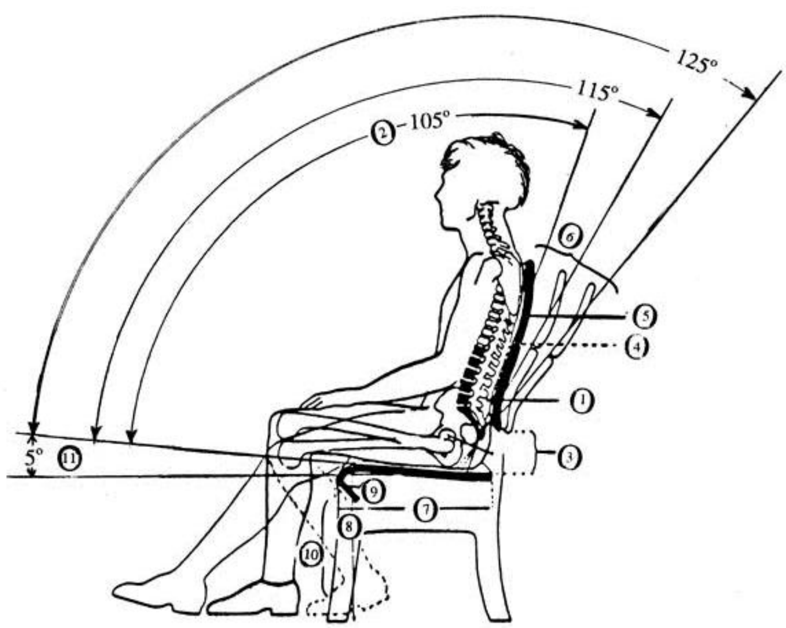

Figure 4. Adopted from Keegan's 1953 seat design requirements. Depicted are the need to consider back and buttocks support, backrest, seat height, and seat tilt adjustments, shoulder support, seat pan length and height criteria, and leg room.

Based off of Keegan's 11 seat design requirements, Harrison et al. (1999) suggest seat design criteria to entail lumbar support, ease of mobility, armrests, headrests, seat adjustments (i.e. seat height and inclination), and a curved seat pan to promote comfort and reduce sitting stress. Adjustments should be easy and provide plenty of options for the user. For example, in an aircraft cockpit, pilots should be able to sit for up to four hours without experiencing discomfort or degradation in work performance (Hansen et al., 1958).

Sanders and McCormick (1987) have recommendations for the contour of a seat. For example, contoured seats are used to distribute weight in the lower regions of the body due to the shape of the human spine a contour seat could be troublesome. Thus, an aggressive contour or a flat contoured seat should be deemed inappropriate for most seats. Moreover, Sanders et al. (1987) call attention to constraints in seat design criteria such as the necessary trade-offs in seat design due to the inability for one design to fit all aspects of siting.

Seat manufacturers realize that ergonomics are important during the initial developmental phases of a system, since retrofitting is difficult and more costly. Some manufacturers have taken advantage of the lack of ergonomic regulations and often fail to test or validate their system for comfort, safety, or performance. For example, the manufacturers of the "ergonomics kneeling chair" claim that the backless chair promotes ideal sitting and reduces overall body strain. However, studies have indicated the need for adequate back support in order to reduce tension on the back and fatigue (Eklund and Corlett, 1984; OSHA). No reputable research could be found to support the 'ergonomic' claims of the kneeling chair and this is the case for some products that simply lay claim that their product is 'ergonomic'. Operational Safety and Health Administration (OSHA) set standards, using MIL standards, to ensure a safe working environment. Specifically, ergonomic and anthropometric recommendations are provided in addition to considerations for potential hazards in design for workstations.

The previous sections all emphasize the need for seats to promote performance, comfort, and safety in the workplace. Ergonomics, anthropometrics, aesthetics, biomechanics and proper subjective and objective measurements are needed to optimize comfort in appropriate seat design. According to Andreoni, Santambrogio, Rabuffetti, and Pedotti (2002), a comfortable seat is important to reduce and prevent MSD's. The seats to be evaluated for comfort were supplied by a major manufacturer of commercial aircraft pilot seats in order to determine if any seat stood out as quantifiably more comfortable than the others. The questions to be addressed specifically by this study are enumerated in the hypotheses to be tested.

Hypothesis

There will be measureable differences in the seats, particularly between the classroom chair and the aircraft seats. Differences in the physical dimensions of people will lead to differences in the intensity with which they rate discomfort. These predictions are consistent with both De Looze et al.'s and Fazlollahtabar's seat comfort model discussed above. For example, larger people (girth) will have more contact than smaller people with the seats which will exceed their internal dose and cause greater response such as fidgeting (actigraphs) or increased pressure (pressure pad) and result in a more intense rating of discomfort.

Hypothesis I:

There will be quantifiable differences in comfort levels associated with one seat over the others.

Hypothesis II:

There will be close correspondence between subjective and objective measures of comfort.

Hypothesis III:

First visual impressions will be comparable with subsequent seat comfort ratings following the seating experience.

Hypothesis IV:

Males and females will experience seat comfort differently.

Hypothesis V:

Larger individuals (girth or height) will have greater contact with the seats and will indicate more discomfort than smaller sized individuals.

Methods

Participants

Twenty college students from Embry-Riddle Aeronautical University (ERAU) between the ages of 18 to 25 years of age were selected as participants in study. Branton et al. (1967) found that males and females differ in posture and utilization of seat parts while seated. Therefore, 10 males and 10 females were tested to control for gender differences.

Demographic data such as gender, age, stature, weight, hip breadth, and shoulder breadth were collected. The demographic questionnaire also inquired the participants' amount of regular physical daily activity, the amount of sedentary activity (sitting watching t.v., in class, at work, etc.), if he or she had any musculoskeletal disorders or chronic injuries (see Appendix B for demographic sheet). Table 1 shows the relevant characteristics of the participants. Participants were paid $30 for completing the 120-minute session. Each participant experienced each seat for approximately 20 minutes with the interim time being filled with evaluation questionnaires.

Table 1

Average demographics characteristic.

	Age	Height (in)	Weight	Hip Breadth	Shoulder Width	BMI
Average	22	67.05	156.05	41.71	25.23	24.56
Female Average	21.9	64.33	136.00	46.87	24.30	23.09
Male Average	22.1	69.50	176.10	36.55	26.15	26.05

Apparatus

Seats.

Participants sat on and assessed the comfort of three distinct prototype pilot seats shown in Figure 5. These pilot seats were provided to ERAU's Human Factors Department for evaluation and are all currently used in aircraft.

Figure 5. Pilot seats used throughout the study to assess short duration comfort. From Left to right: seat 1406, seat 1419, seat 1406.

Participants also assessed a generic plastic seat used in ERAU classrooms (see Figure 6). The seat was included to determine if the measures can distinguish a chair that is different in form and function from the others.

Figure 6. Control classroom chair used throughout the study to assess discomfort.

The differences of each seat are shown in Tables 2 and 3. The checkmarks in Table 1 indicate the seat adjustment capabilities for each seat. Most adjustments apply to all three pilot seats. Adjustments include the headrest height and position (forward or backward), armrest height, armrest direction (forward or backward), recliner position, seat height, seat belt length, lumbar support (out or in), and extra lumbar support (up or down).

Table 2

Seat adjustments.

	Seat 1423	Seat 1419	Seat 1406	Seat 0000
Neck height	✔	✔	✔	---
Neck position	---	---	✔	---
Armrest forward	✔ (Left armrest only)	---	---	---
Armrest height	✔	✔	✔	---
Recliner	✔	✔	✔	---
Seat height	✔	✔	✔	---
Lumbar Support (up/down)	---	---	✔	---
Lumbar Support (out/in)	✔	✔	✔	---
Seatbelt length	✔	✔	✔	---

Pilot seat descriptions were acquired via the seats' manufacturer. The seats differ in seat width, armrest design, headrest design, amount of lumbar support and contour design. Contour design refers to the shape or mold of the seat. The shapes of the seats are flat, aggressive, or a combination of both. A flat contour is a smooth and even seat shape, which contains no curves. An aggressive contour is a curved seat shape, which molds to the body of the average human body. The seat shape that is neither flat nor aggressive but a combination of both is the latest seat contour styling design.

Seat 1423 had wide armrests, an integrated headrest, and a contour that is neither flat nor molds to the body. Seat 1419 had a narrow seat pan, short armrests, a headrest that is separate from the body of the seat, and a flat contour. Seat 1406 had a wide seat pan, a headrest that is separated from the body of the seat, long armrests, and an aggressive contour. The classroom chair, seat 0000, had a wide seat and high armrest. Table 3 demonstrates the style differences.

Table 3

Seat style differences.

Seat 1423	**Seat 1419**	**Seat 1406**	**Seat 0000**
---	Relatively narrow seat	Relatively wide seat	Relatively wide seat
Left wide armrest/Right narrow armrest	Short armrests	Long/narrow armrests	Long/metallic armrests
Integrated headrest	Detachable headrest	Aggressive contour headrest	No headrest
Latest styling contours	Flat contours	Aggressive contours	---
---	---	Extra Detachable lumbar support	Lumbar support gap

Measures.

A pressure pad, an accelerometer, and four questionnaires were used to assess each participant's comfort. The pad (Sensor Products Inc., model number UT-5010-545, New Jersey) is a 20.12 x 20 inch thin pad. The pad is thin enough so as to minimally interfere with the feel or comfort of the seat. The sensor sheet is 43 cm x 29 cm, consisting of a matrix of 1024 pressure sensitive elements. Figure 7 illustrates the position of the pressure pad as positioned in this study. The pad was placed carefully on the seat pan such that half was on the seat pan and half was on the lower section of the backrest. Data available for the pressure pad consisted of pressure observations in pounds per in^2 (PSI). In addition, the data also displayed changes in pressure over time. The data was recorded continuously throughout the time each participant was in the seat. Peak pressure served as a discomfort indicator. Figure 8 is an example of the pressure pad data.

Figure 7. Example of pressure pad placements.

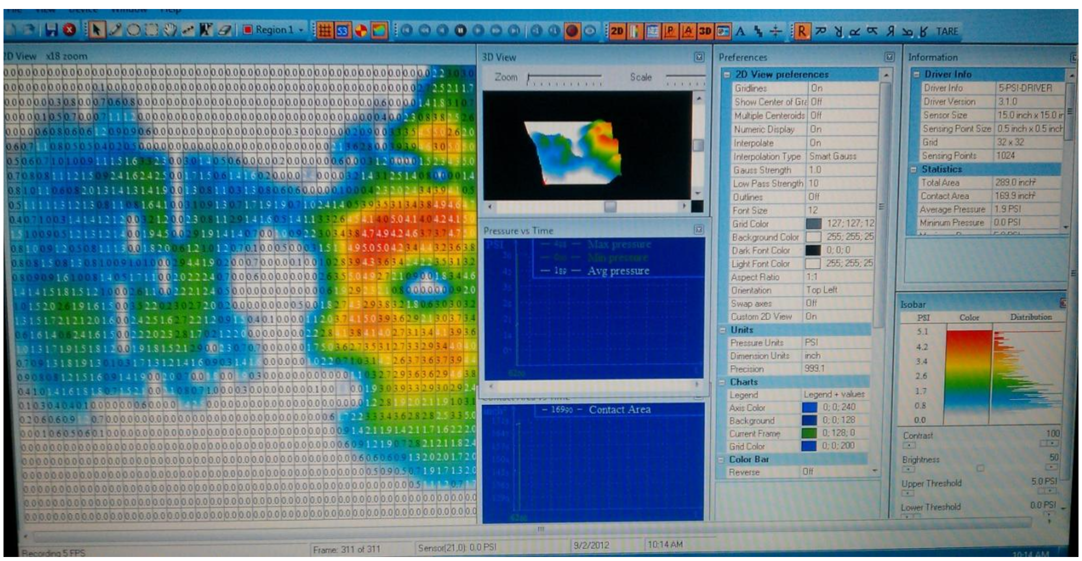

Figure 8. An example of the pressure pad data. The yellow and red areas denote a greater pound per square inch pressure on the seat.

An actigraph is an accelerometer that employs a quartz piezoelectric crystal to measure motion. The participants wore a belt with two actigraphs on each side of his or her hips. Two actigraphs were used as a precaution in case one of the actigraphs failed. The actigraph pictured in Figure 9, (Ambulatory Monitoring Incorporated), recorded movement frequency for each seat, which was considered an indication of the extent of restlessness associated with sitting in the seat. This data alongside the subjective measures and the pressure pad data were used to determine discomfort objectively.

Figure 9. Actigraph belt. Participants placed the belt around their waist during the time he or she sat on each seat.

A composite over the 20 minutes the participant was seated in each seat was used to find more ‘hot spots’ or increased pounds per inch (PSI) associated with each seat. This would indicate an increase in the number of hot spots or their size and suggest less comfort than a seat with smaller PSI for the sitting duration. To avoid the initial adjustments done in each seat and the possible movements associated with filling out the questionnaires, data from the pressure pad and actigraph were taken from 5 minutes after participants sat in the seat up until the body-map rating questionnaire was given. Thus, the average pressure, average movement, and standard deviation respectively for 5 minutes were calculated to give a more accurate measure of typical sitting.

The demographics questionnaire (see Appendix B) required the use of a measuring tape to obtain the hip breadth and shoulder width for each participant in inches. Participants also filled out questionnaires (see Appendix C through F) regarding their perceived level of comfort for each seat. The initial questionnaire (see Appendix C) pertained to the participants' initial perception of the most comfortable and most uncomfortable seat without any participant-seat interaction. The second questionnaire (see Appendix F) was a body map rating scale. The body map indicated different musculoskeletal parts for both the back and the front of the human. Using the rating scale, participants were asked to indicate which, if any, body parts felt uncomfortable after they sat in each seat. The third questionnaire (see Appendix D) was a comfort rating scale which contained questions regarding seat cushion length, width and firmness; backrest height, width, bolsters (sides), shape, and firmness; armrest position, shape, and firmness on a scale of 1 to 5 (1 being extreme discomfort and 5 being no discomfort). Furthermore, questions such as the overall rating of that seat and the adjustment capabilities of that seat (ease to get in and out and overall adjustment rating) and the opportunity for commentary feedback were included. The final questionnaire (see Appendix E) was administered at the end of the study. It prompted participants to choose the seat he or she felt the most comfortable and the most uncomfortable in. Furthermore, participants were asked to explain whether their initial perception of the most comfortable and uncomfortable seat was correct, if not why did their perception change.

Design

A 2 x 4 (gender x seat type) mixed design was used in the current study. The between subject factor (gender) and the within subject factor (seat) were evaluated across all subjective and objective measures including measured pressure, actigraph recorded movement, initial visual seat preference, seat preference after exposure, a questionnaire assessing specific areas of discomfort for each seat, and a body map rating. The significance level was set to $p = 0.05$.

Procedure

Table 4 describes how the study will be conducted step-by-step.

Table 4

Step-by-step design in minutes.

00	Arrive to test location (Lehman 373). Receive the study briefing, read and sign Informed Consent form, and fill out demographics (while standing).
10	Fill out initial visual perception questionnaire of all four seats (while standing).
15	Researcher will fit participant for actigraph belt and prepare seats with the pressure pad, according to Latin square. Researcher will indicate seat adjustments, prior to participant sitting in each seat.
20	Sit in first seat. Adjust seat. Fill out body-map rating and questionnaire.
50	Sit in second seat. Adjust seat. Fill out body-map rating and questionnaire.
80	Sit in third seat. Adjust seat. Fill out body-map rating and questionnaire.
110	Sit in fourth seat. Adjust seat. Fill out body-map rating and questionnaire.
115	Fill out final questionnaire while standing.
120	Debrief.

As indicated in the Table 4, each participant was briefed on the purpose of the research and the procedures that followed. An informed consent form describing the study in more detail was then given to each participant to sign. Each participant was asked to fill out the demographics sheet. To measure shoulder width, the researcher used a measuring tape from the deltoid crest of the right shoulder to the deltoid crest of the left shoulder. To measure hip breadth width, participants were asked to place the measuring tape evenly around their hips. To standardize weight and categorize it, Body mass index (BMI) was gathered from the demographics data and calculated as weight (kg) / height ^{2} (m ^{2}). Participants stood while completing these tasks in order to eliminate exposure to another chair that was not being evaluated. Exposure to another chair could complicate the subjective impression of the subsequent chairs.

While participants were standing, they were given an initial comfort-rating questionnaire prior to having any physical contact with the seats. The questionnaire compared the seats visual apparent comfort against each other. This was used to measure initial perception of comfort to later compare to exposed perception of comfort. To facilitate this visual process, the four seats were lined up next to one another. The seats were lined up from left to right: seat 0000, 1406, 1419, and 1423 during the entire study facing a blank wall in the lab. A concern pertaining to a within subjects design is the order in which stimuli are presented. To control for order effects, the order in in which each participant sat in each seat was set using a Latin square, which is shown in Table 5.

Table 5

Latin square for participant seat order.

	Seat 1423	**Seat 1419**	**Seat 1406**	**Seat 0000**
Participant 1	1st	2nd	3rd	4th
Participant 2	2nd	3rd	4th	1st
Participant 3	3rd	4th	1st	2nd
Participant 4	4th	1st	2nd	3rd

Note: Participants 5-20 will follow the same with-in group design.

Once completed, participants were given an accelerometer belt to be placed on their hips with the purpose of measuring how much movement is made within each seat. The belt contained two accelerometers, one on each side of the hip. Next, participants were shown the proper seat adjustments prior to sitting in each seat. The pressure pad was then placed on each seat. Participants were told to sit in the seat and then to adjust the seat accordingly. The researcher noted the adjustments in the order they were made. Pressure and actigraph data were collected throughout the 20 minutes each participant sat on each seat, the clock started as soon as the participant sat down.

Participants were tasked with solely focusing on the comfort of the seat. While in the seat, they were informed that the first questionnaire would pertain to discomfort in specific body parts. After 10 minutes participants was asked to fill out the body map rating scale to identify which body part (i.e. shoulders, head, buttocks, leg, etc.), if any, exhibited discomfort. The scale was a visual analogue scale, which prompted participants to indicate on a line how much comfort or discomfort was felt. Participants followed this procedure for each of the four seats. Afterwards, participants were informed that they would be given a questionnaire pertaining to the seat physicality. The questionnaire was administered after the 20 minute exposure. Participants were asked to rate each seat in terms of discomfort or comfort taking into consideration the seats dimensions (i.e. cushion length and width, backrest width and height, armrests shape and position, etc.) on a Likert scale of 1 to 5, with a score of 1 indicating a high level of discomfort and a score of 5 indicating a high level of comfort.

The final comfort questionnaire was distributed at the end of the study. It required participants to indicate their perception of the most comfortable and most uncomfortable seat. Further, it asked participants to explain if their initial visual perception of the most comfortable and uncomfortable seat changed, and if so, why. Finally, participants were then debriefed and asked to fill out the payment distribution sheet.

Results

Statistical analysis of the results focused on comparing comfort measures across seats to determine the most comfortable and the least comfortable seats. Due to technical difficulties, one person's actigraph data were not used and one person's pressure pad data were not used. In addition, because not every participant filled out the body-map rating questionnaire in its entirety, only 17 participant's data were analyzed. For the comfort questionnaire all 20 participant data were used. A one-way repeated measures analysis of variance (ANOVA) test with a Greenhouse-Geisser correction was used to analyze the effects of seat type on measured movement (actigraph data) and measured pressure (pressure pad, psi).

Actigraph.

The relative average movement as measured by the actigraph across seats is shown in Figure 10. The mean difference and standard errors are shown in Table 6. A significant difference between seats was found (F (2.26, 40.78) = 5.96, p = .004, η^2 = .25) for movement as measured by the actigraph.

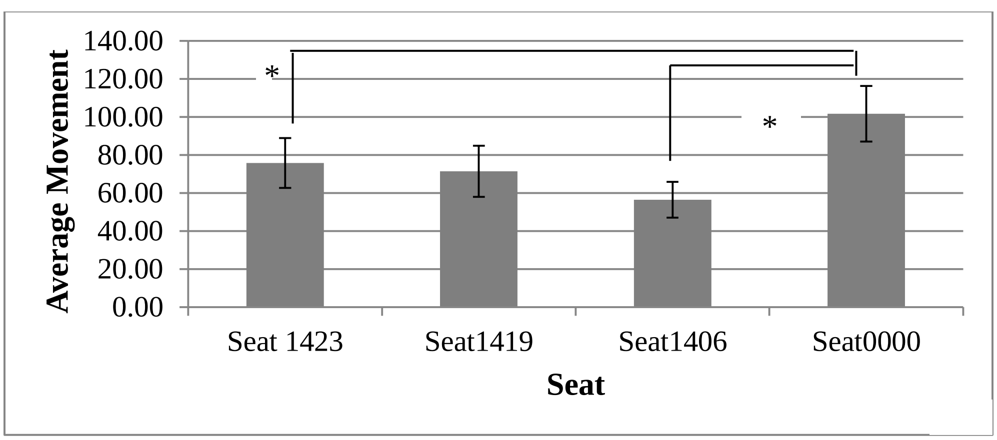

Figure 10. The average actigraph measured movement per seat +/- standard error of the mean. Significant comparisons are indicated with *.

As seen in Table 6, a pairwise comparison using a Bonferroni correction indicated there was a significant difference between seat 1406 and seat 0000, and between seat 1423 and seat 0000 in terms of activity while in the seat (movement). There was no significant difference between seat 1419 and the other 3 seats; furthermore, there was no significant difference between seat 1406 and seat 1423.

Table 6

Pairwise comparison for measured movement.

Seat	Seat	Mean Difference	Std. Error	Significance
1406	1423	-19.41	10.33	.46
	1419	-15.01	8.75	.62
	0000	-45.24	11.56	.01
1423	1419	4.40	12.40	1.00
	0000	-25.83	8.56	.04
1419	0000	-30.23	12.99	.19

Pressure Pad Data.

The pressure pad data showed PSI differences between seats. The average PSI and standard error of the mean are shown in Figure 11 for comparison. A significant difference between seats was found (F (2.73, 49.16) = 24.47, p = .000, η^2 = .576) for seat pressure as measured by the pressure pad.

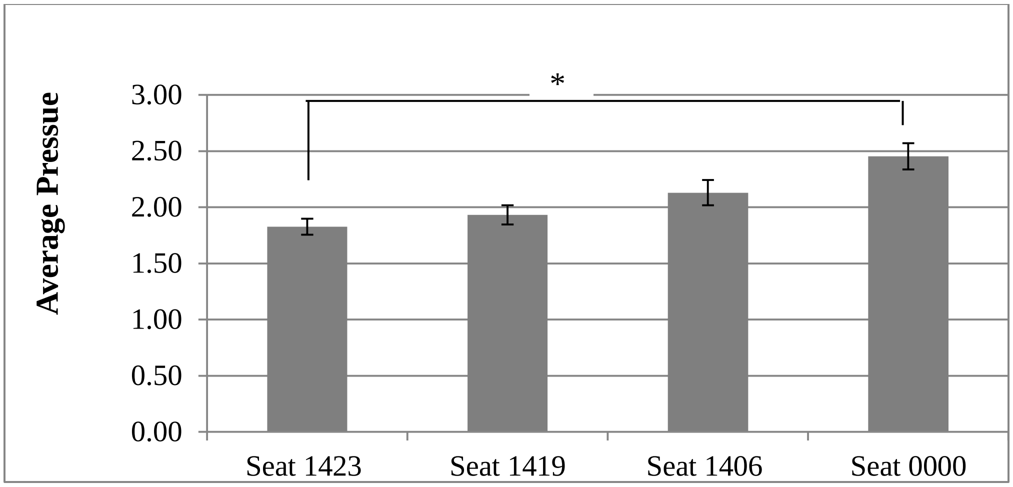

Figure 11. Average PSI per seat +/- standard error of the mean. Significant comparisons are indicates with *.

As seen in Table 7, a pairwise comparison using a Bonferroni correction indicated there was a significant difference in measured pressure between all seats and seat 0000, and between seat 1406 and seat 1423. There was no significant difference between seat 1419 and seats 1406 and 1423.

Table 7

Pairwise comparison for measured pressure.

Seat	Seat	Mean Difference	Std. Error	Significance
1406	1423	.31	.07	.00
	1419	.20	.07	.09
	0000	-.30	.08	.01
1423	1419	-.11	.08	.95
	0000	-.61	.08	.00
1419	0000	-.50	.09	.00

Seat Preference

Figure 12 shows the results of the final perception questionnaire. The final perception questionnaire results were compiled for which seat was rated as the most comfortable and the least comfortable. A Chi-Square test on this data indicated that independent of gender, seat 1406 was most frequently selected as the most comfortable seat (X^2 (3) = 16.2, p = .05). While seat 0000 was most frequently selected as the least comfortable seat (X^2 (3) = 16.2, p = .005). Seat 1423 and 1419 had equal ratings with no significant difference between them. Seat 1419 and seat 0000 were rated as uncomfortable. Seat 1406 and seat 0000 were rated as comfortable.

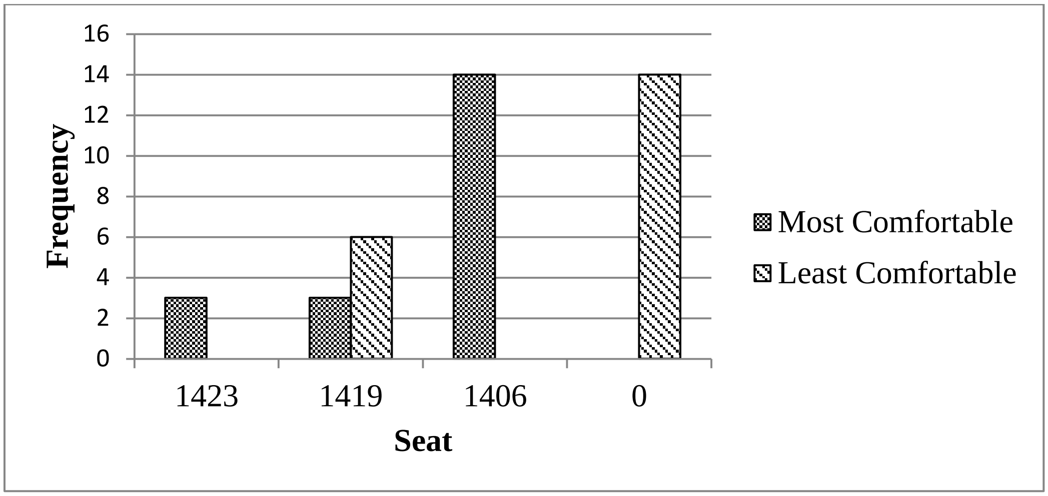

Figure 12. Final comfort perception frequency rating for each seat.

Comfort Questionnaire.

The comfort questionnaire contains a Likert-scale, and therefore required a non-parametric form of analysis. The data were gathered by summing responses from the17 questions from the comfort questionnaire. A Friedman's test was used to determine if there was significant difference between perceived comfort (comfort questionnaire) and each of the four seats. A significant difference was shown (X^2 (3) = 36.80, p = .00). Mean rank scores are shown in Table 8.

Table 8

Mean rank for comfort questionnaire.

	Mean Rank
Total 1423	2.00
Total 1419	2.80
Total 1406	1.45
Total 0000	3.75

A Wilcoxon Signed-Ranks test was used to compare the difference between the groups. A significance level was calculated as alpha level/ number of comparisons (0.05/6 = .008). Results indicated there was a significant difference between seat 1419 and seat 1423, seat 0000 and seat 1423, seat 1406 and seat 1419, seat 0000 and seat 1419, and seat 0000 and seat 1406.There was no significant difference between seat 1406 and seat 1423. Significance can be seen in Table 9.

Table 9

Wilcoxon's test statistics for comfort questionnaire.

	Seat 1419 – Seat 1423	Seat 1406 – Seat 1423	Seat 0000 - Seat 1423	Seat 1406 - Seat 1419	Seat 0000- Seat 1419	Seat 0000- Seat 1406
Z	-2.916[a]	-1.591[b]	-3.783[a]	-3.241[b]	-3.061[a]	-3.922[a]
Asymp. Sig. (2tailed)	.004	.112	.000	.001	.002	.000

Body Map Rating.

The body map rating scale is a visual analog scale and therefore required a non-parametric form of analysis. A Friedman's test was used to compare the average body-map rankings for each of the four seats. A significant difference between the four seats was shown, (X^2 (3) = 9.35, p = .025). Mean rank scores are shown in table 10.

Table 10

Mean rank for body-map rating questionnaire.

	Mean Rank
Seat 1423	2.35
Seat 1419	2.82
Seat 1406	1.76
Seat 0000	3.06

A Wilcoxon Signed-Ranks test was used to compare the difference between the seats. A significance level was calculated as significance level/ number of comparisons (0.05/6 = .008). Results indicated a significant difference between seat 0000 and seat 1406. There were no significant difference between seat 1423 and seats 1419, 1406 and 0000, seat 1406 and seat 1419, and seat 0000 and seat 1419. The test statistics are shown in Table 11.

Table 11

Wilcoxon's test statistics for body-map rating.

	Seat1419 – Seat 1423	Seat1406 – Seat 1423	Seat0000 – Seat 1423	Seat1406 - Seat1419	Seat0000 - Seat1419	Seat0000- Seat1406
Z	-2.286[a]	-.402[b]	-2.199[a]	-2.533[b]	-.457[a]	-2.896[a]
Asymp. Sig. (2-tailed)	.022	.687	.028	.011	.647	.004

Demographics Compared.

A Kurskal-Wallis test revealed there was no significant difference between gender and seats (H (1) = .02, p = .88. Figure 13 and 14 show the frequency each gender indicated for which seat they preferred the most and least, accordingly.

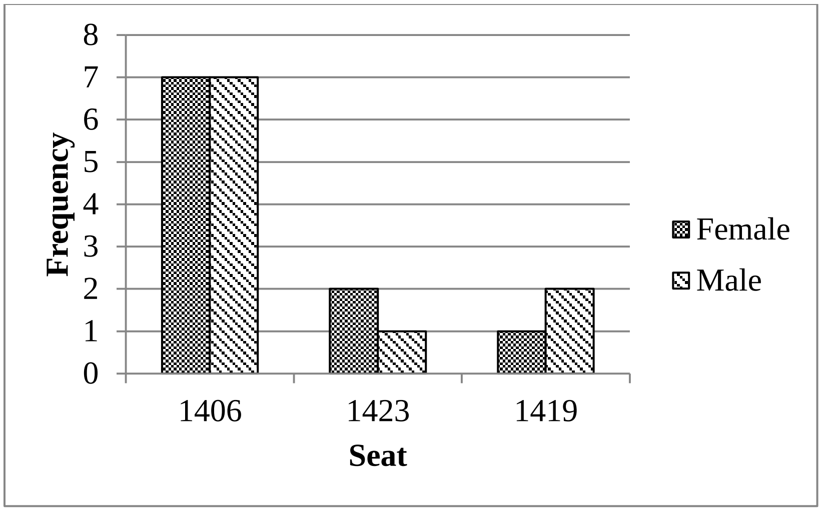

Figure 13. Gender by most comfortable seat preference

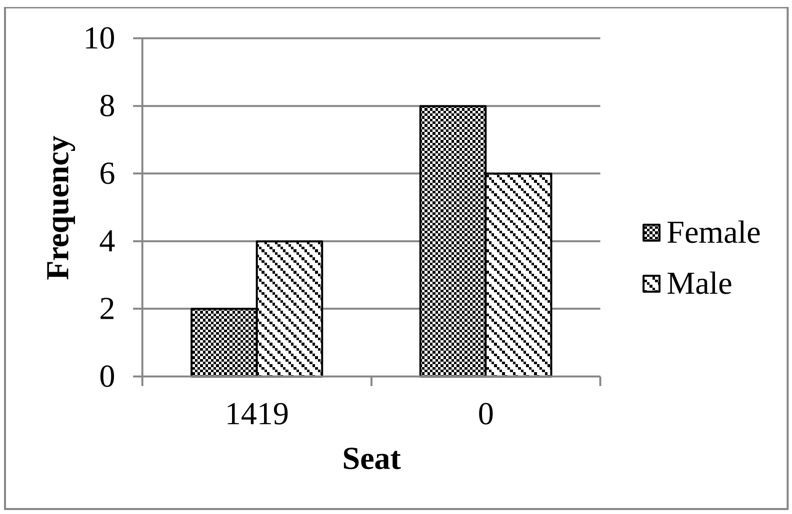

Figure 14. Gender by least comfortable seat preference

A Spearman's Rank Order correlation was run to determine the relationship between BMI and seat preference, BMI was calculated for each participant. There was no statistically significant correlation between BMI and seat preference, ($r_s(20) = -.392$, $p = .088$). Figure 15 and 16 show BMI preference for most comfortable and least comfortable.

A linear regression was run to determine if pressure could predict BMI. Pressure could statistically significantly predict BMI for seat 1406, (F (3, 16) = 8.02, p =.002). There was no statistical significance in prediction for seat 1423 and seat 1419 with BMI. Pressure accounted for 53% of the variance explained. The regression equation predicted BMI = 14.4 + 10.6 x (pressure seat 1406).

A linear regression was run to determine if movement could predict BMI. Movement could not statistically predict BMI for any of the four seats, (F (3, 15) = .82, p =.504).

Initial versus Final Comfort Perception.

Figure 15 depicts the subject's visual perception of initial seat comfort and discomfort perception, accordingly, before they sit in the seats. Figure 16 depicts the subject's experience perception of final seat comfort and discomfort, accordingly. The two graphs indicate that perception changed between initial visual perception and experienced final perception of comfort and discomfort. However, it is evident that Seat 1406 and Seat 0 remained the highest ranked most comfortable and most uncomfortable, accordingly, throughout the study. That is, participants ranked seat 1406 and seat 0 as most and least comfortable seats for both the initial and final perception questionnaire. Table 12 and 13 show where the change in perception lies.

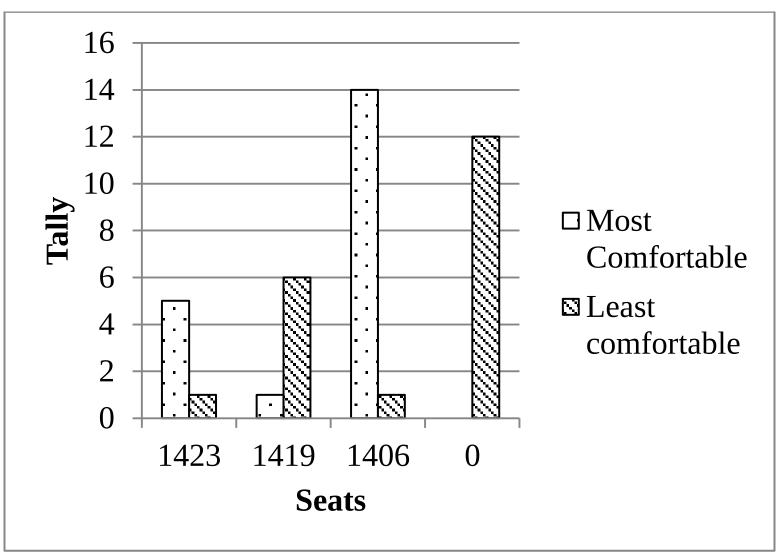

Figure 15. Visual perception of seat comfort

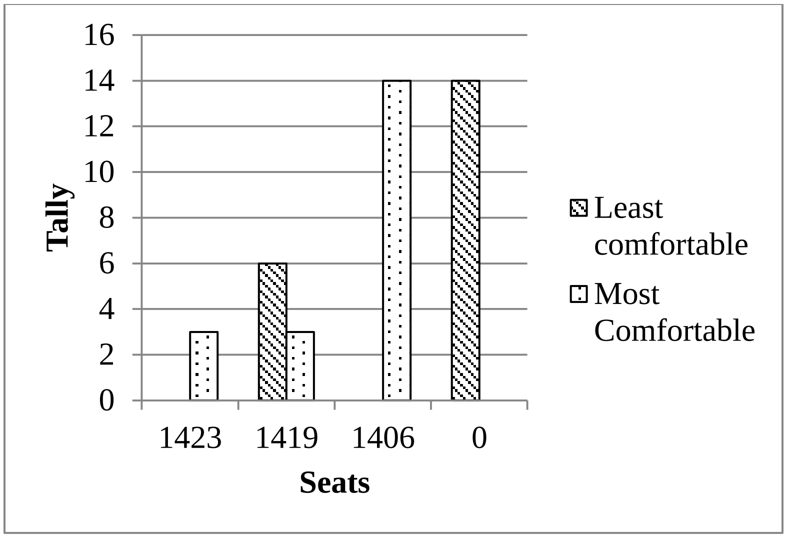

Figure 16. Experienced perception of seat comfort.

Table 12

Changes in most comfortable perception.

	Seat 1406-1419	Seat 1423-1406	Seat 1406-1423
Change	2	5	1

Table 13

Changes in least comfortable perception.

	Seat 1423-0000	Seat 1419-0000	Seat 1406-0000	Seat 0-1419
Change	1	2	1	2

Discussion

Seat 1406 was clearly rated more comfortable than the others in both subjective and objective measures. Similarly, seat 0000 was rated least comfortable. It may have been unnecessary to have included seat 0000 given the outcome; however, at the beginning of the study it was not clear how sensitive the measures would be. To determine how discriminable the measures were, seat 0000 was included. The study demonstrated that even among aircraft seats in current use, designed for comfort in commercial aircraft, the measures were able to discriminate between these seats as well as a standard classroom seat. It would be important for designers of future pilot seats to implement the design features of Seat 1406. Further, seat designers should consider what was inadequate about Seat 1423 and Seat 1419, which were slightly less comfortable than Seat 1406. Seat 1423 was received slightly less pressure than the other two pilot seats; however, it was rated more comfortable by subjective measures.

The three pilot seats differed in adjustments and aesthetics such as, extra lumbar support, armrest length and width, and headrest adjustments. The classroom chair and the pilot seats differed vastly in function, fabric construction, stiffness, and esthetics. The classroom chair was included to determine if both subjective and objective measures could distinguish it from the pilot seats.

It was expected that there would be a quantifiable difference in comfort levels associated with one seat over the others. This hypothesis was supported. The classroom chair performed poorly against the pilot seats on several comfort measures. Additionally, seat 1406 was rated the most comfortable seat on all measures.

It was also hypothesized that here would be a close correspondence between subjective and objective measures. The hypothesis was supported. As Shen and Galer (1993) suggested objective measures should be used alongside subjective measures to ensure support for the data. A close correspondence between subjective and objective measures was found. Both subjective and objective measures indicated that there was a significant difference in comfort perception between seats. Again, based on the results of the Friedman's test, seat 1406 was ranked as the most comfortable on the body-map rating and comfort questionnaire. Seat 0000 was ranked as the most uncomfortable on the body-map rating and comfort questionnaire. However, because the Friedman's test does not provide a post hoc to indicate where the differences lie, direct comparison between results cannot be made.

It was hypothesized that the first visual impressions would be comparable with subsequent seat comfort ratings following the seat experience. The hypothesis was not supported. Although, the visual impressions of seat comfort changed when the final comfort perception was reported, the most comfortable (seat 1406) and the least comfortable seats (seat 0000) were highest rated for both the first impressions and final impressions questionnaire. The slight change in perception of two or three individuals may be due to top-down processing as suggested by Schmidt and Liu (2006). That is, individuals may have observed the seats as a whole first and later processed the details such as adjustments, functions, or individual seat components after use. Aesthetics' play a role in comfort perception (De Looze et al., 2003; Fazlollahtabar, 2010; Kroemer et al., 2007; Ebe et al. 2001); this may explain why ratings for the most and least comfortable seat did not change. We think that first impressions, at least for seats, may be lasting. The participants in the short duration study chose Seat 1406 as the seat that looked the most comfortable even before they sat in it. They still had the preference after sitting in all the seats.

It was anticipated that males and females would experience seat comfort differently. The results failed to support the hypothesis. Branton et al. (1967) found that gender played a role in how people sat in a seat and what parts of the seat were most used. However, there were no statistically significant differences between genders on any seat comfort preference.

It was also anticipated that larger individuals (larger body mass index) would have greater contact with the seats and would indicate more discomfort than smaller sized individuals. There were no statistically significant differences based on participant size and seat preference. For the tallest and shortest, there were comments that mentioned the backrest, seat pan length, and headrest as inadequate for their height; however, it did not seem to influence the overall perception of the seats.

The combination of actigraphy with PSI data leads to an interesting hypothesis. It has been noted anecdotaly from many investigators that PSI data are frequently greater for the most preferred seat. It is generally believed that the higher the PSI levele, that is, the more 'hotspots', the more discomfort is felt but that does not seem to be the case. The actigraph data revealed that the least amount of activity can be associated with the most preferred seat. It seems reasonable to assume that the more movement that occurs the more uncomfortable the seat. This is consistent with the preference ratings, the seat with least preference is associated with more movement. The seat that wass preferred (1406) was associated with the least amount of movement, most amount of pressure, and the most most preference. It may be that the reason the PSI values are low for Seats 1423 is that the participants were squirming moving too much and not building up pressure points. This could explain the increase in movement from the actigraph and the decrease in pressure for the least preferred seat; they were squirming and not building up a PSI. Conversely, having a high PSI and a low actigraph score possibley means that they person is 'molded'into the seat with comfort. They move less and create more pressure. It may be that the more comfortable the seat is, the more participants relax and allow themselves to “fall” into the seat; this would also explain why movement decreased. This held true for Seat 0000 as well. Although movement and pressure did not have a vast difference for Seat 0000, there was a slight decline in pressure when compared to movement.The slight decline may be due to the difference in material as well as function Seat 000 had compared to the three pilot seats.

These could be characteristics of a good seat; a high pressure pad data and a low actigraph data. This is a testable hypothesis for future studies and may help to explain seemingly discordant results between subjective impressions and objective pressure pad data. This would make pressure pad data more useful.

As previously mentioned, two models, one by Fazlollahtabar (2010) and the other by De Looze et al. (2003) suggested seat comfort could be predicted theoretically. Both models relate seat comfort perception to the human, the seat, and the external environment. The present study adapted Fazlollahtabar’s proposed idea that seat and individual factors affect seat comfort. The seat factors incorporate stiffness, geometry/ contour, breathability, and styling as factors consumers consider. Furthermore, a set of individual factors included demographics and anthropometrics. Comments from gathered from the comfort questionnaire, body-map rating, and final questionnaire were coded as either positive or negative. Then they were tallied and placed under one of the 5 seat factors. Participants’ comments along with Fazlollahtabar’s comfort factors allow for a better understanding of participants’ preferences and indicate requirements and specifications that should be considered in seat design (Kolich, 2004). Coding results indicate that seat 0000 had no positive comments, which seems to agree with the previously mentioned objective and subjective results. Seat 1419 had more negative comments than good comments. Seat 1423 had one negative comment and Seat 1406 had no negative comments. Therefore if Fazlollahtabar would have used his proposed model to determine which seat would be preferred by consumers, he would have chosen seat 1406, similar to the subjective and objective results.

Conclusion

It must be remembered that this study concerned measuring seat comfort which is different from measuring seat ergonomics. All the pilot seats work in their intended environment and all are comfortable. We found that one seat was more comfortable than the others and that the measures could clearly distinguish an uncomfortable seat (0000). If the study was an ergonomic study, we would have evaluated video records of reach and adjustments needed to complete tasks, in addition to seat comfort. Seat comfort is important in the prevention of musculoskeletal disorders, lower back pain, and low productivity. However, it is difficult to determine what constitutes seat comfort when the word 'comfort' itself is subjectively defined. It is important to determine which definition of comfort is applicable to the study: The present study defined comfort as a linear measurement spanning from extreme comfort to extreme discomfort (Richards, 1980). Comfort was considered as a "positive" perception, while discomfort was considered something that could be measured objectively (Kroemer et al., 2007). Therefore, comfort was measured using subjective questionnaires pertaining to comfort perception, and discomfort was measured by observing movement and psi levels.

Both subjective and objective tests were determined to be important contributors to the accurate assessment of seat preference. All measures indicated seat 1406 as the most comfortable and seat 0000 as the least comfortable. The features of seat 1406 should be included in future pilot seat designs. Interestingly, unlike previous researchers have reported, the results indicated that an increase in pressure was not the equivalent of discomfort. As measured pressure "hot spots" increased, participants rated that seat as more comfortable. Additionally, as "hot spots" increased, recorded movement decreased. This may be based on the idea that as more discomfort is felt, fidgeting and movement increase (Telfer et al., 2009).

Although both subjective and objective tests showed similar results, it is important to gather the users' perception of comfort and discomfort as well as a physical measurement that quantifiably determines which seat is the best. The study allows for a better understanding for what measures should be used and how they should be assessed when testing for comfort.

Although the accelerometer indicated significant differences in participant movement among the seats, tests should be done using an actigraph in which the activity of "sitting" can be selected to properly detect sitting movement; the actigraph used in this study was meant for sleep studies. Furthermore, it is important to consider other confounds. For example, it's possible that movement may have been due to discomfort or to other factors such as boredom. During the experiment, some participants indicated restlessness by constantly moving, which could have masked movement as a result of seat discomfort based on actigraph results.

While the methods used to measure seat comfort in this study seem adequate to identify comfort in these seats and may be useful in future studies to evaluate seats along a comfort dimension, other measurement techniques should be considered as well.

There were some difficulties in data collection. The actigraph data for one participant could not be incorporated into the results due to technological error. However, the results indicated enough difference that not incorporating the results for one participant should not have affected the data. Pressure pad data for seat 0000 could not be used for one participant as well.

However, because seat 0000 indicated significant pressure, it is not believed that the data for the one participant would have changed the results.

Although this study did not indicate a significant difference between the genders, this factor may be interesting for future investigations. The relationship between BMI and seat preference should also be further investigated, although BMI was not shown as significant. Furthermore, it would be beneficial to analyze sitting postures in addition to movement and pressure, given that inadequate sitting postures could lead to discomfort (Mohler, 2001; Tan et al., 2008). Finally, when determining which pilot seat is the most comfortable, it may be appropriate to test the seats in an applied setting such as an aircraft cockpit during flight.

References

Andersson, G. B. J. (1987). Biomechanical aspects of sitting: An application to VDT terminals. *Behaviour & Information Technology*, *6*(3), 257-269.

Andreoni, G., Santambrogio, G. C., Rabuffetti, M., & Pedotti, A. (2002). Method for the analysis of posture and interface pressure of car drivers. *Applied Ergonomics*, *33*(6), 511-522.

Blanchard, B. S., & Fabrycky, W. J. (2006). *Systems engineering and analysis*. Prentice Hall.

Bongers, P. M., Hulshof, C. T. J., DlJKSTRA, L., Boshuizen, H. C., Groenhout, H. J. M., & Valken, E. (1990). Back pain and exposure to whole body vibration in helicopter pilots. *Ergonomics*, *33*(8), 1007-1026.

Branton, P. (1969). Behavior, Body Mechanics and Discomfort, Ergonomics, 12:2, 316-327.

Branton, P., & Grayson, G. (1967). An evaluation of train seats by observation of sitting behaviour. *Ergonomics*, *10*(1), 35-51.

Bridger, R.S. (2003). *Introduction to Ergonomics*. London: CRC

Broadbent, D., Vines, R., & Broadbent, M. (1978). Recency effects in memory, as a function of modality of intervening events. *Psychological Research*, *40*(1), 5-13.

Carcone, S. M., & Keir, P. J. (2007). Effects of backrest design on biomechanics and comfort during seated work. *Applied Ergonomics*, *38*(6), 755-764.

Cerny, K. (1984). Kinesiology versus biomechanics. *Journal of the American Physical Therapy Association*, *64*(121809).

Cohen, D. (1998). An objective measure of seat comfort. *Aviation Space and Environmental Medicine*, *69*, 410-414.

Claus, A. P., Hides, J. A., Moseley, G. L., & Hodges, P. W. (2009). Different ways to balance the spine: subtle changes in sagittal spinal curves affect regional muscle activity. *Spine*, *34*(6), E208-E214.

Corlett, E. N. (2006). Background to sitting at work: research-based requirements for the design of work seats. *Ergonomics*, *49*(14), 1538-1546.

Eklund, J. A., & Corlett, E. N. (1984). Shrinkage as a measure of the effect of load on the spine. *Spine*, *9*(2), 189.

De Looze, M.P., Kuij-Evers, L.F.M., Van Dieen, J. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics*, *46*(10), 985-997.

de Oliveira, C. G., & Nadal, J. (2004). Back muscle EMG of helicopter pilots in flight: effects of fatigue, vibration, and posture. *Aviation, space, and environmental medicine*, *75*(4), 317-322.

Dempsey, P. G., Wogalter, M. S., & Hancock, P. A. (2000). What's in a name? Using terms from definitions to examine the fundamental foundation of human factors and ergonomics science. *Theoretical Issues in Ergonomics Science*, *1*(1), 3-10.

Department of Defense (2012). *Human engineering design criteria for military systems, equipment*

and facilities.(MIL STD 1472G) Philadelphia, PA: Navy Publishing and Printing Office.

Deros, B. M., Daruis, D. D. I., & Nor, M. J. M. (2009). Evaluation of static car driver seat discomfort through objective and subjective methods. *APIEMS2009. Kitakyushu*.

Dunk, N. M., & Callaghan, J. P. (2005). Gender-based differences in postural responses to seated exposures. *Clinical biomechanics*, *20*(10), 1101-1110.

Durkin, J. L., Harvey, A., Hughson, R. L., & Callaghan, J. P. (2006). The effects of lumbar massage on muscle fatigue, muscle oxygenation, low back discomfort, and driver performance during prolonged driving. *Ergonomics*, *49*(1), 28-44.

Ebe, K., & Griffin, M. J. (2001). Factors affecting static seat cushion comfort. *Ergonomics*, *44*(10), 901-921.

Enoka, R. M., & Stuart, D. G. (1992). Neurobiology of muscle fatigue. *Journal of Applied Physiology*, *72*(5), 1631-1648.

Fazlollahtabar, H. (2010). A subjective framework for seat comfort based on a heuristic multi criteria decision making technique and anthropometry. *Applied ergonomics*, *42*(1), 16-28.

Foerster, F., & Fahrenberg, J. (2000). Motion pattern and posture: correctly assessed by calibrated accelerometers. *Behavior Research Methods*, *32*(3), 450-457.

Groenesteijn, L., Vink, P., de Looze, M., & Krause, F., (2009). Effects of differences in office chair controls, seat, and backrest angle design in relation to tasks. *Applied ergonomics*, *40* (3), 362-370.

Goossens, R. H. M., Snijders, C. J., & Fransen, T. (2000). Biomechanical analysis of the dimensions of pilot seats in civil aircraft. *Applied ergonomics*, *31*(1), 9-14.

Helander, M. G. (2003). Forget about ergonomics in chair design? Focus on aesthetics and comfort!. *Ergonomics*, *46*(13-14), 1306-1319.

Hansen, R., & Cornog, D. Y. (1958). *Annotated bibliography of applied physical anthropology in human engineering*. YOH (HL) CO Philadelphia, PA.

Harrison, D. D., Harrison, S. O., Croft, A. C., Harrison, D. E., & Troyanovich, S. J. (1999). Sitting biomechanics part I: review of the literature. *Journal of Manipulative and Physiological Therapeutics*, *22*(9), 594-609.

Keegan, J. J. (1953). Alterations of the lumbar curve related to posture and seating. *The Journal of Bone & Joint Surgery*, *35*(3), 589-603.

Kleeman, W., Jr. (1983). *The challenge of interior design.* New York: Van Nostrand Reinhold.

Klein-Teeselink, G., Siepe, H. & De Pijper, J.R. (1999). Log files for testing usability, in G. W. M. Rauterberg (ed.), IPO *Annual Progress Report 34* (Eindhoven: University of Technology), 63-71.

Kolich, M. (2008). A conceptual framework proposed to formalize the scientific investigation of automobile seat comfort. *Applied Ergonomics*, *39*(1), 15.

Kolich, M., Seal, N., & Taboun, S. (2004). Automobile seat comfort prediction: statistical model vs. artificial neural network. *Applied Ergonomics*, *35*(3), 275-284.

Kroemer, K., Kroemer, H., & Kroemer-Elbert, K. (2001). *Ergonomics how to design for ease and efficiency*. (2nd ed.). Upper Saddle River, New Jersey: Prentice Hall.

Lueder, R. K. (1983). Seat comfort: A review of the construct in the office environment. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *25*(6), 701-711.

Marras, W., & Karwowski, W. (2006). *Fundamentals and assessment tools for occupational ergonomics*. (2 ed.). Boca Raton, FL: CRC Press.

Mohler, S. R. (2001). Lower back pain a common complaint, but precautionary practices help pilots cope. *Human Factors Aviat Med Flight Safety* Foundation.

Mueller, G. F., & Hassenzahl, M. (2010). Sitting Comfort of Ergonomic Office Chairs—Developed Versus Intuitive Evaluation. *International Journal of Occupational Safety and Ergonomics*, *16*(3), 369-374.

Myers, D. G. (2010). *Social psychology*. (10th ed., Vol. 230). New York: McGraw-Hill Humanities/Social Sciences/Languages.

Ng, D., Cassar, T., & Gross, C. M. (1995). Evaluation of an intelligent seat system. *Applied Ergonomics*, *26*(2), 109-116.

Parakket, J., Pellettiere, J., Reynolds, D., Sasidharan, M., & El-Zoghbi, M. (2006). *Quantitative* *methods for determining US Air Force crew cushion comfort* (No. AFRL-HE-WP-TP-2006-0092). Air Force Research Lab Wright-Patterson AFB OH Human Effectiveness Directorate.

Parsons, K.C. (2000).Environmental ergonomics: a review of principles, methods, and models

Pheasant, S. T., & Haslegrave, C. M. Bodyspace: Anthropometry, Ergonomics and the Design of Work, 1996.

Pope, M. H., Goh, K. L., & Magnusson, M. L. (2002). Spine ergonomics. *Annual review of biomedical engineering*, *4*(1), 49-68.

Punnett, L., & Wegman, D. H. (2004). Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *Journal of Electromyography and Kinesiology*, *14*(1), 13-23.

Richards, L. G. (1980). On the psychology of passenger comfort. *Human Factors in Transport Research. Edited by DJ Oborne, Ja Levis, 2.*

Sanders, M., & McCormick, E. (1987). *Human factors in engineering and design*. (6 ed.). McGraw-Hill Publlishing Company.

Sargent, L. P., & Bachmann, L. A. (2010). Back pain in the Naval rotary wing community. *Naval Safety Center*.

Schmidt, K. E., & Liu, Y. (2006, October). The Effects of Aesthetic Attributes on Response Time and Aesthetic Judgement in a Multiattribute Binary Aesthetic Choice Task. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 50, No. 16, pp. 1701-1705). SAGE Publications.

Sharma, W. C. S., Raju, W. C. K., & Agarwal, W. C. A. (2007). Static anthropometry: Current practice to determine aircrew aircraft compatibility. *Ind J Aerospace Med*, *51*, 2.

Shen, W., & Galer, I. A. (1993, October). Development of a pressure related assessment model of seating discomfort. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 37, No. 10, pp. 831-835). SAGE Publications.

Shen, W., & Parsons, K. C. (1997). Validity and reliability of rating scales for seated pressure discomfort. *International Journal of Industrial Ergonomics*, *20*(6), 441-461.

Strickland, D., Pioro, B., & Ntuen, C. (1996). The impact of cockpit instruments on pilot exhaustion. *Computers & industrial engineering*, *31*(1), 483-486.

Tan, C., Chen, W., Delbressine, F., & Rauterberg, M. (2008). Objectifying discomfort seat measurement for next generation truck driver's seat. *International Federation of Automotive Engineering Societies. Student paper*, (F2008-SC), 028.

Thakurta, K., Koester, D., Bush, N., & Bachle, S. (1995). Evaluating short and long term seating comfort. *SAE Publications SP-1088. Human Factors in Vehicle Design. Lighting, Seating and*

Advances Electronics. (SAE Technical Paper 950144).

Telfer, S., Spence, W. D., & Solomonidis, S. E. (2009). The potential for actigraphy to be used as an indicator of sitting discomfort. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *51*(5), 694-704.

Vink, P. (Ed.), 2005. Comfort and Design: Principles and Good practice. CRC Press, Boca Raton.

Wickens, C. D., Lee, J., Liu, Y., & Becker, S. D. (2004). *Human Factors Engineering*. (2nd ed.). New Jersey: Pearson Education, Inc.

Williams, M. M., Hawley, J. A., McKenzie, R. A., & van Wijmen, P. M. (1991). A comparison of the effects of two sitting postures on back and referred pain. *Spine, 16*(10), 1185.

Wilson, J. R. (2000). Fundamentals of ergonomics in theory and practice. *Applied ergonomics*, *31*(6), 557-567.

Yeung, C. W., & Wyer Jr, R. S. (2004). Affect, appraisal, and consumer judgment. *Journal of Consumer research*, *31*(2), 412-424.

Yun, M. H., Donges, L., & Freivalds, A. (1992). Using force sensitive resistors to evaluate the driver seating comfort. *Advances in Industrial Ergonomics and Safety IV (London: Taylor and Francis)*, 403-410.

Zhang, L., Helander, M. G., & Drury, C. G. (1996). Identifying factors of comfort and discomfort in sitting. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *38*(3), 377-389.

Appendix A

Ergonomic Evaluation of Aircraft Pilot Seats

Conducted by Nicole Andrade
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Purpose of Research

The purpose of the study is to assess the comfort of four different seats.

Specific Procedures to Be Used

To participate in this research you must sign this informed consent form indicating that you have read and understood the conditions you will experience in the study. A demographics questionnaire will be completed and an identification number will be assigned to you to allow for confidentiality. The comfort of three different pilot seats and a control seat will be assessed in the Human Factors Lab. You will learn the adjustments for each seat and then sit in each seat for approximately 20 minutes with little to no distractions. Three questionnaires and a body map rating will be filled out by you before, after each seat, and after the four seats. To additionally assess comfort or lack thereof, a wrist watch sized motion detector will be worn around your waist and you will sit on a pressure pad to help us measure seat comfort.

Duration of Participation

Paperwork and questionnaires will take about 10 minutes for each seat. The study will take approximately 120 minutes.

Benefits to the Individual

You will be paid $30 for participating in the study.

Risk to the Individual

There are no foreseeable risks to you throughout the study.

Confidentiality

All your data is anonymous. An identification number will be assigned to allow you confidentiality. No individual data will be reported, only the aggregate (e.g. means and medians).

Voluntary Nature of Participation

You do not **have** to participate in the study and may opt to terminate your participation at any time throughout the study.

Statement of Consent

I acknowledge that my participation in this experiment is entirely voluntary and that I am free to withdraw at any time. I have been informed of the purpose of the study, the procedures to be followed, the expected duration of my participation, and that I will receive $30.00 upon completion of the study.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction.

Finally, I acknowledge that I have read and fully understood the consent form. I sign freely and voluntarily. A copy has been given to me.

Date: ______________________

Participant name (*please print*):________________________________

Participant signature: ____

Experimenter: ________________________________

_______ Yes, I would like to be contacted regarding the results of the study

Appendix B

<u>Demographics</u>

Participant Number: ____________________ Date : ____________________

Please answer the following questions:

1. Gender: ☐ Male ☐ Female
2. Age: __________
3. Height: __________
4. Weight: __________
5. Mid-pelvic width: _________
6. Shoulder width: __________

Activities:

1. What physical activities do you do regularly? _____________________________________
2. Approximately, how many hours a day are you sitting? (i.e. watching tv, in class, at work)

   ____

3. How felixible do you consider yourself? __________________________
4. Do you have any musculoskeletal injuries? (if yes, please specify)

   ____

5. Do you have any chronic illnessess? (if yes, please specifiy) _______________________

Appendix C

Initial Comfort Rating Form:

Participant Number: ___________________

Please answer the following questions (be as specific as possible):

1. Which seat looks the most comfortable? (Please check box number)

☐ 1423 ☐ 1419 ☐ 1400 ☐ 0000

2. Why does it look comfortable? (i.e. what physical features?)

3. Which seat looks the most uncomfortable? (Please check box number)

☐ 1423 ☐ 1419 ☐ 1400 ☐ 0000

4. Why does it look uncomfortable? (i.e. what physical features?

Appendix D

<u>Comfort Questionnaire</u>:

Participant Number: ___________________ DATE ____________________

Chair: ☐ 1423 ☐ 1419 ☐ 1400 ☐ 0000

To answer each question, please circle the correct rating.

1. In terms of how adjustable the seat is, I have… 1 2 3 4 5

   No Objections *Extreme Objections*

2. Ease to get in and out of the seat… 1 2 3 4 5

   No Objections *Extreme Objections*

3. Discomfort due to the width of the seat cushion 1 2 3 4 5

   No Discomfort *Extreme Discomfort*

4. Discomfort due to seat cushion length 1 2 3 4 5

   No Discomfort *Extreme Discomfort*

5. Discomfort due to seat cushion firmness 1 2 3 4 5

   No Discomfort *Extreme Discomfort*

6. Discomfort caused by the center of the seat cushion 1 2 3 4 5

   No Discomfort *Extreme Discomfort*

7. Discomfort caused by the curve of the seat cushion 1 2 3 4 5

   No Discomfort *Extreme Discomfort*

8. Discomfort produced by the height of the backrest 1 2 3 4 5

   No Discomfort *Extreme Discomfort*

9. Discomfort due to the width of the backrest 1 2 3 4 5

   No Discomfort *Extreme Discomfort*

10. Discomfort due to firmness of the backrest 1 2 3 4 5

No Discomfort *Extreme Discomfort*

11. Discomfort produced by the backrest sides(bolsters) 1 2 3 4 5

No Discomfort *Extreme Discomfort*

12. Discomfort due to the shape of the backrest 1 2 3 4 5

No Discomfort *Extreme Discomfort*

13. Discomfort created by lumbar stiffness 1 2 3 4 5

No Discomfort *Extreme Discomfort*

14. Discomfort produced by the position of the armrests 1 2 3 4 5

No Discomfort *Extreme Discomfort*

15. Discomfort due to the shape of the armrests 1 2 3 4 5

No Discomfort *Extreme Discomfort*

16. Discomfort created by the stiffness of the armrests 1 2 3 4 5

No Discomfort *Extreme Discomfort*

17. The seat has an overall discomfort level of… 1 2 3 4 5

No Discomfort *Extreme Discomfort*

Comment:

Appendix E

<u>Final Comfort Rating:</u>

Participant Number: ___________________

<u>Please answer the following questions</u>: (be as specific as possible).
Note: This sheet is double sided

1. Which seat did you find to be the most comfortable and why? (i.e. physical features of the seat)

☐ 1423 ☐ 1419 ☐ 1400 ☐ 0000

2. Which seat did you find to be the least comfortable and why? (i.e. phyiscal features of the seat)

☐ 1423 ☐ 1419 ☐ 1400 ☐ 0000

3. Was your intial visual perception of the most comfortable seat correct? If no, explain why it changed.

4. Was your intial visual perception of least comfortable seat correct? If no, explain why it changed.

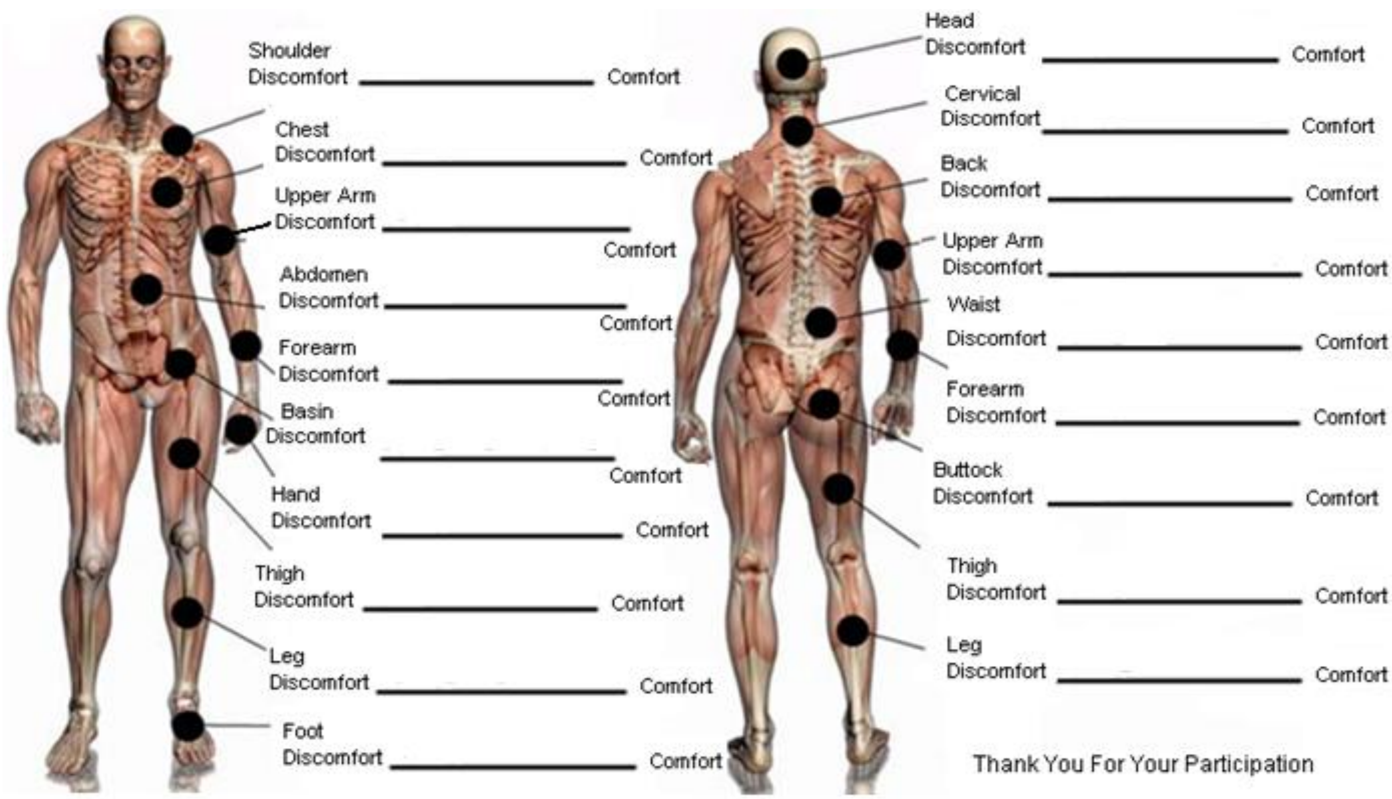
Appendix F

Body Map Rating:

Participant Number: ___________________ Date: ________________

Chair: ☐ 1423 ☐ 1419 ☐ 1400 ☐ 0000

Please place a slash (/) through the corresponding line to represent how uncomfortable this seat is. Note: only place a mark if the area is affected.



Comment: