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Quantitative Methods for Determining U.S. Air Force Crew Cushion Comfort

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14. ABSTRACT
Designing a single cushion to address the physiological problems of the entire aircrew population is a significant challenge. Often the cushion itself is the only item that can be replaced to improve comfort. In this study 22 subjects were tested on operational and prototype cushions, including one dynamic cushion. Tests were conducted over eight-hour durations, during which subjective survey data, cognitive performance data, seated pressures and contact areas, muscular fatigue levels, and lower extremity oxygen saturation were recorded. Peak seated pressures range from 1.22 - 3.22 psi. Oxygen saturation in the lower extremities decreased over the eight hours. Cognitive performance increased over time. Muscle fatigue increased throughout the eight hours regardless of cushion, with the exception of the dynamic cushion which promoted muscular recovery. Subjective comfort levels declined over the eight hours. Subjective measurements correlated with objective parameters for the static cushions. Trade-offs in performance and fatigue mitigation were apparent in the dynamic cushion which also highlighted differences between genders.

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QUANTITATIVE METHODS FOR DETERMINING U.S. AIR FORCE CREW CUSHION COMFORT

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Ejection seat cushions in current U.S. Air Force aircraft are not optimized for comfort during extended missions. Physiological problems such as buttock, leg and back pain, numbness and tingling, and overall fatigue have been documented in past laboratory and operational use. Designing a single cushion to address the physiological problems of the entire aircrew population is a significant challenge. Cushion material selection, cockpit space restrictions, and limited ability to reposition contribute to discomfort during extended missions. Ejection seat dimensions and contours are fixed, causing accommodation problems. Oftentimes the cushion, itself, is the only item that can be replaced to improve comfort.

A study was performed to investigate objective test methods for determining cushion comfort. Twenty-two subjects were tested on operational and prototype cushions, including one dynamic cushion. Tests were conducted over eight-hour durations, during which subjective survey data and cognitive performance data were gathered. As comparative objective data, seated pressures and contact areas, muscular fatigue levels, and lower extremity oxygen saturation were recorded.

Peak seated pressures ranged from 1.22 – 3.22 psi. Oxygen saturation in the lower extremities decreased over the eight hours. Cognitive performance increased over time regardless of cushion with the exception of the dynamic cushion, which induced a decrease in performance for females. Muscular fatigue increased throughout the eight hours regardless of cushion, with the exception of the dynamic cushion which promoted muscular recovery. Subjective comfort levels declined over the eight hours. Subjective measurements correlated with objective parameters for the static cushions. Trade-offs in performance and fatigue mitigation were apparent in the dynamic cushion which also highlighted differences between genders. These results will be used to develop cushion design guidelines both to prevent deep vein thrombosis and to promote comfort for long duration use.

Quantitative Methods for Determining U.S. Air Force Crew Cushion Comfort

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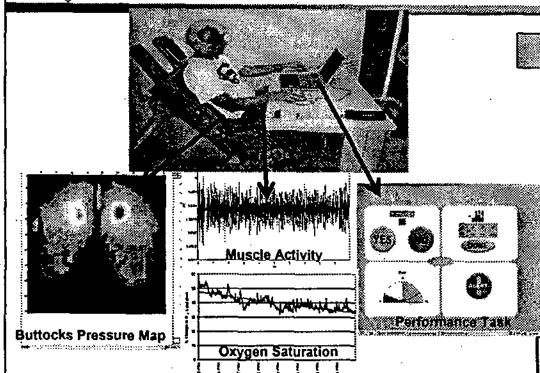
Overview



Benefits to the Warfighter

- Enabled long duration missions without lower back and buttocks soreness
- Reduced fatigue
- Improved comfort, alertness, & performance

"With combat missions during Operation ENDURING FREEDOM reaching 44 hours in length, it has become increasingly important that seat comfort be improved"
Memo from ASC/EN to AFRL/HE, July 2002

Description

- Defining seat and cushion parameters that will maximize comfort and performance without jeopardizing ejection safety
- Defining measurable parameters that will promote increased comfort for any weapons system

2

Biomechanical data in the form of an initial snap shot of the pressure distribution was collected. The physiologic response of the subject throughout the eight hours was collected. The subject's performance on a cognitive task was recorded.

This study is part of an overall effort to develop cushion design criteria.

This effort is necessary in order to enable long duration missions my minimizing lower back and buttock soreness, reducing muscle fatigue, and improving comfort, alertness, and performance.

Background

Other Research Efforts

AFRL/HEPA - 1999
- Pilot study leading to improvements 2003 study
- 4 hour sit duration
- Subject panel limited to 5 males
- Technical issues with Tekscan pressure mapping system

AFRL/HEPA – 2003
- Initial study leading to improvements in current study
- 8 hour sit duration
- Subject panel of 12 females & 8 males
- Objective measure - pressure mapping
  Performance measure - cognitive task battery
  Subjective measure - comfort ratings

Martin-Baker

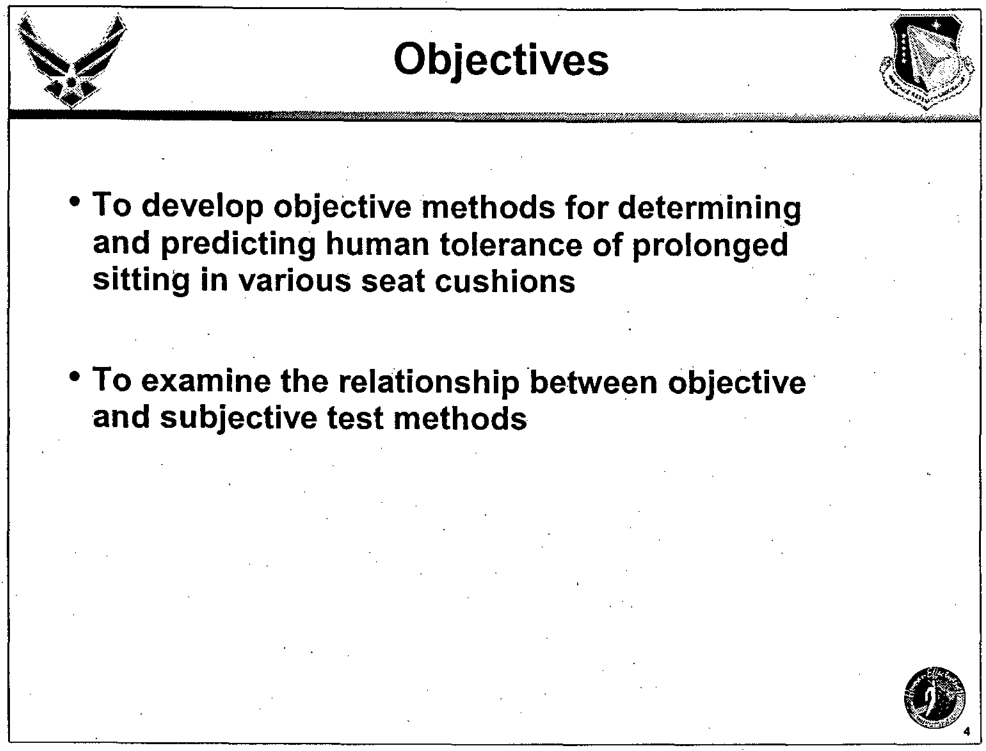
Martin-Baker – 2002
- Initial < 5 min sit duration
- No cognitive task measurement
- Follow-on 3-hour studies

3

The tools and measurement techniques employed were selected based on results of the pilot study completed in 2000 and the initial study completed in 2003.

Additional variables such as different seated surfaces, varying seat angles, active stimulation, and increased measurement frequencies were introduced in the current effort.

This study was expanded to a larger more diverse subject pool to allow for the collection of statistically significant data points.



The objectives of this effort were two fold:

1. To develop objective methods for determining and predicting human tolerance of prolonged sitting in various seat cushions
2. To examine the relationship between objective and subjective test methods

Facilities/Equipment

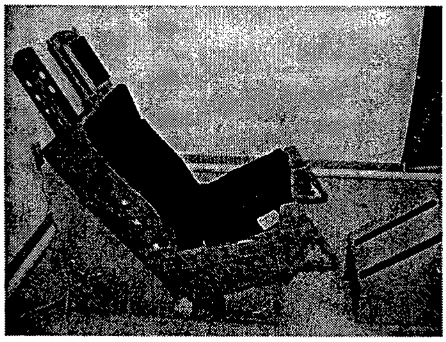
- WSU Laboratories
- Ejection Seat Fixture
- XSENSOR Pressure Mapping System
- SynWin Cognitive Task Battery
- Delsys Surface Electromyography
- Somanetics INVOS Oximeter
- 1 Operational and 3 Prototype Cushions
- Seated Comfort Questionnaire
- End-of-day Comfort Questionnaire

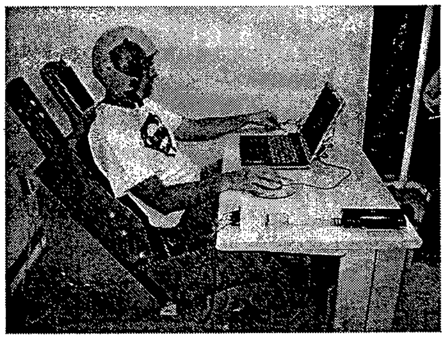
5

Testing was conducted at Wright State University.

Ejection seats, cushions, questionnaires, cognitive task battery, and equipment provided by AFRL/HEPA.

Ejection Seat Fixture



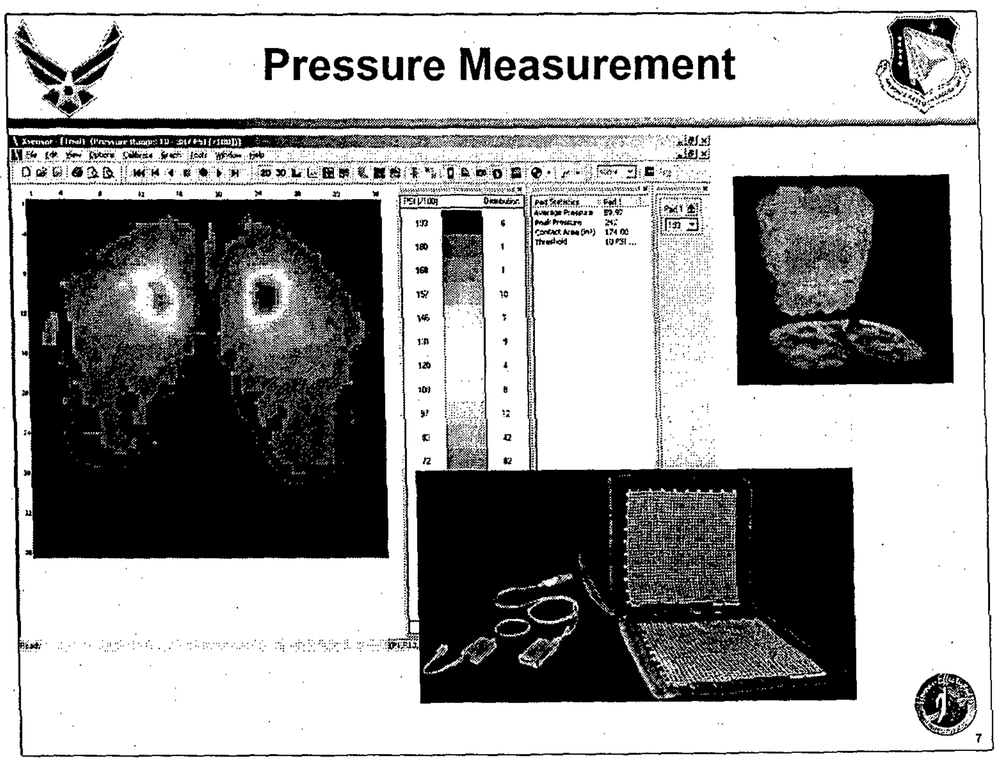


- ACES II ejection seats simulating F-16 configuration
- Rail Angle 34° aft of vertical
- Test Seat pan inclined 30° from horizontal

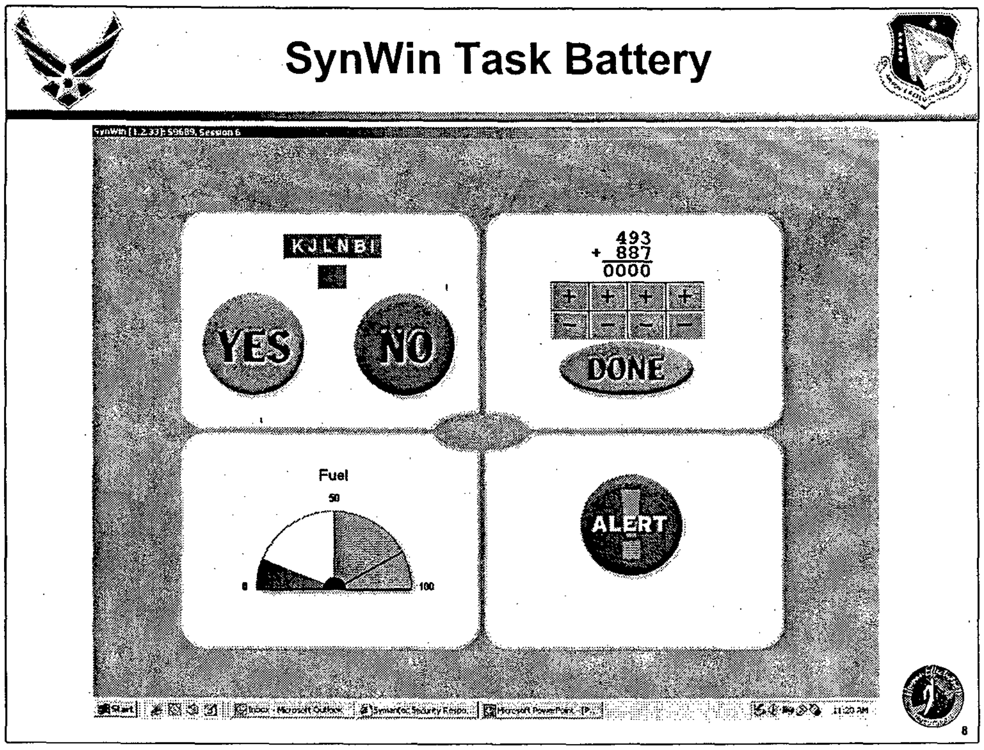
- Desks and laptops were provided.
- Horizontally adjustable foot pedestals were provided.

6

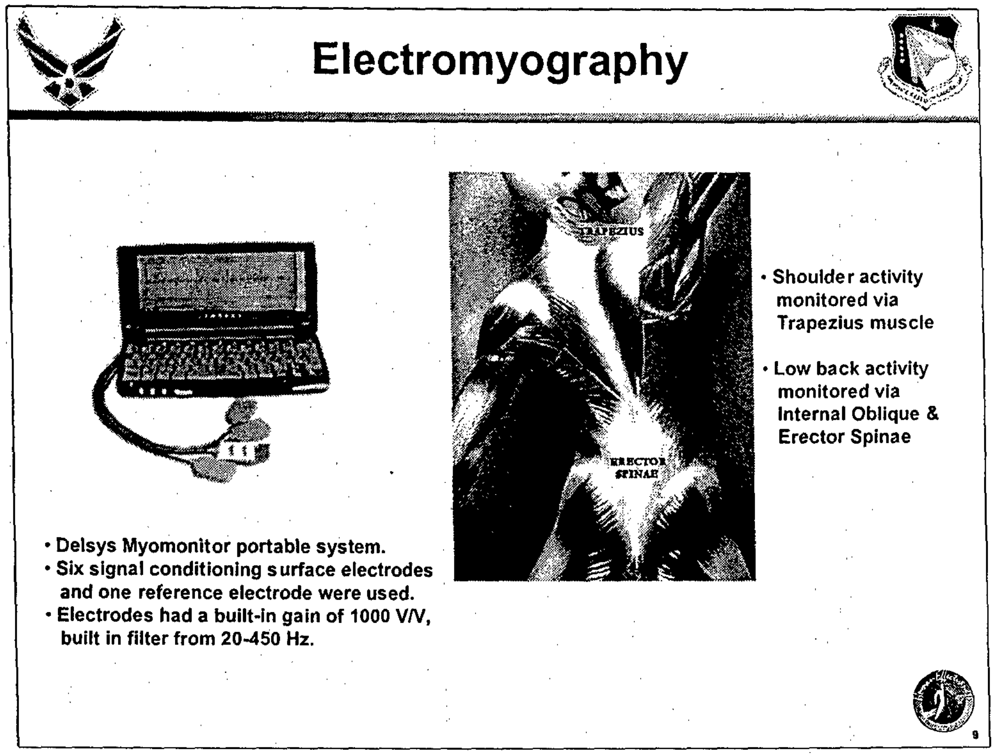
Two constructed workstations were provided by AFRL/HEPA and utilized in this study. The workstation configurations utilized ACES II ejection seats placed on 34-degree ejection seat mockups to simulate the ACES II seat in the F-16 configuration. The seat was mounted such that the rail angle was 34° aft of vertical and the seat pan was inclined 30° from the horizontal. Horizontally adjustable foot pedestals were used for all tests. The subjects were allowed to remove their feet from the foot pedestal during the session.



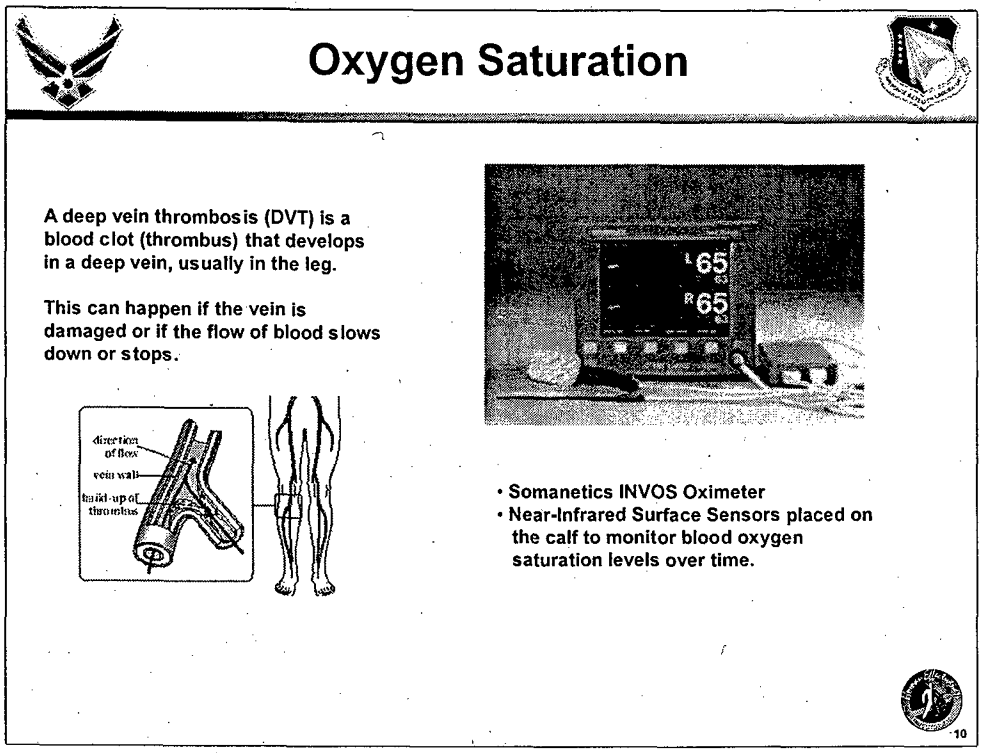
All pressure and contact area measurements were obtained using the XSENSOR® X2 Pressure Imaging System. The system consists of 2 thin mats containing an array of sensors in the same shape of the seat pan, a data interface cable, a software data acquisition and analysis system, and a personal computer. The sensor mats were placed on top of the seat and back cushions. The subjects sat directly on top of the sensor mats. Each mat is approximately 0.1 mm thick and takes the shape of any cushion that it is placed upon. Similar pressure measurement systems have been used extensively over the past decade for medical, automotive, and manufacturing pressure evaluations. The XSENSOR® software displays and stores a pressure map of the subject's seated contact area. Data can be sampled at a rate of up to 35000 sensors per second utilizing USB connectivity.



At the start of each session and every two hours thereafter, each subject completed a 5 minute SynWin cognitive task analysis as a performance measure over the eight-hour session. The SynWin analysis provided a benchmark set of tasks for use in a wide range of laboratory studies of operator performance and workload and is similar to the Multi-Attribute Task Battery (MATB). The software incorporates tasks analogous to activities that aircraft crewmembers perform in flight, while providing a high degree of experimenter control, performance data on each subtask, and freedom to use non-pilot test subjects. The SynWin primary display is composed of four separate task areas, or windows, comprising the memory, arithmetic, visual monitoring, and auditory monitoring tasks. Events presented to the subject are controlled by command-line switches, which can be easily edited by the researcher to manipulate task loading. The Warfighter Fatigue Countermeasures Branch (AFRL/HEPM) at Brooks City-Base, TX, has successfully used SynWin to evaluate human performance in numerous research programs.



Fatigue of the back muscles could be the primary parameter as far as comfort of ejection seats is concerned. Hence, the median frequency of the trapezius and lower lumbar muscles over time, were analyzed from the EMG signals collected using the DELSYS® hand held Myonitor® III data acquisition system. The data acquisition system consists of 8 channels and a reference channel. Six signal conditioning surface electrodes with a contact dimensions of 10 x 1.0mm with a built-in gain of 1000 V/V and a built-in filter from 20-450 Hz were used. The electrodes required little no skin preparation. The electrode interface is of medical grade adhesive. The EMG signals from the six electrodes were collected every 30 minutes for 10 seconds duration. A 3 minute file was also collected every two hours to relate EMG to other parameters studied every two hours during the study.

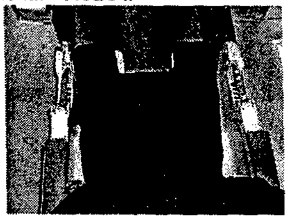


Measuring the oxygen saturation of the tissues below the buttocks region is an important parameter in objectively measuring the comfort and tolerance relationship of the subject. The oxygen saturation sensor was placed on the bulk of either the right or left calf muscle depending on the workstation that the subject was seated in. The contact point with the subject for the INVOS® Cerebral Oximeter was a flexible sticky of 1"x4" that contains no hazards to the subjects. The INVOS® Cerebral Oximeter collected a steady stream of blood oxygen saturation data over the entire eight-hour session.

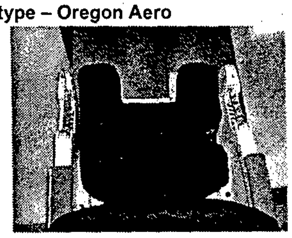
Cushions

Selected 4 test cushions with diverse range of materials and construction

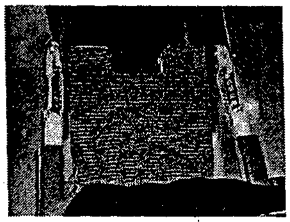
Operational – ACES II



Prototype – Oregon Aero



Prototype – SEA Systems



Specialty - ErgoAir

11

Three static cushions were tested and one dynamic cushion was tested.

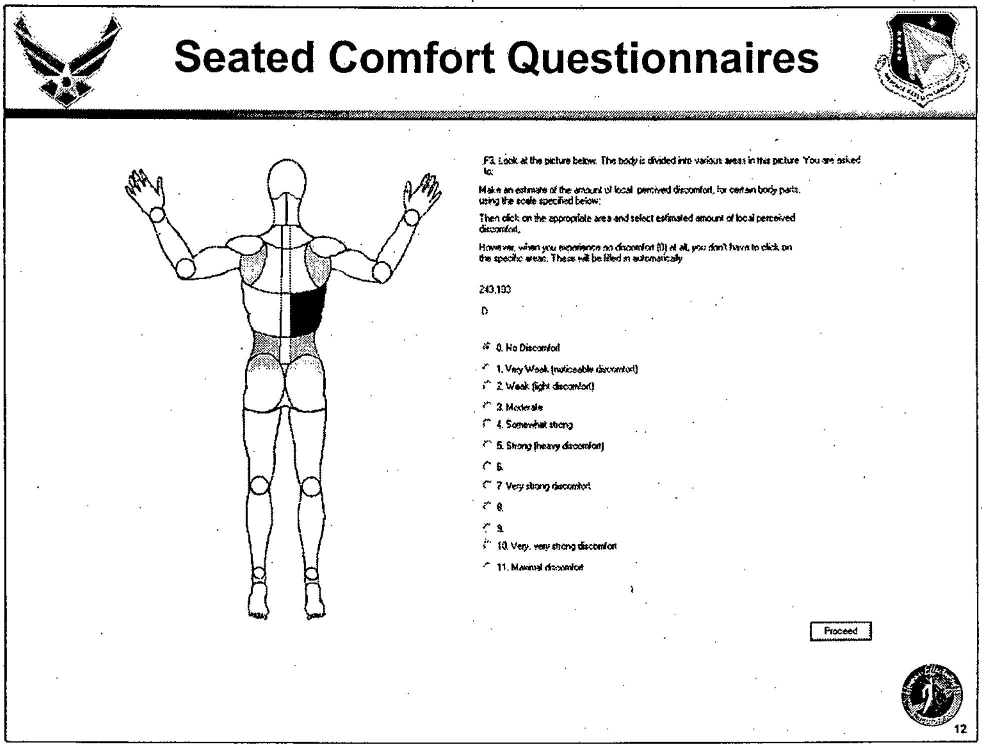
The four cushion specimens that were chosen for use in this study were selected based on their material properties and the anticipation that they would provide a diverse range of objective and subjective results. Each cushion specimen represented a separate test cell and each subject completed one eight-hour test on each cushion.

Current ACES II Cushion - ConforTM C-47 and Polyethylene with sheepskin cover

Oregon Aero Prototype – Contoured C-47 with sheepskin cover

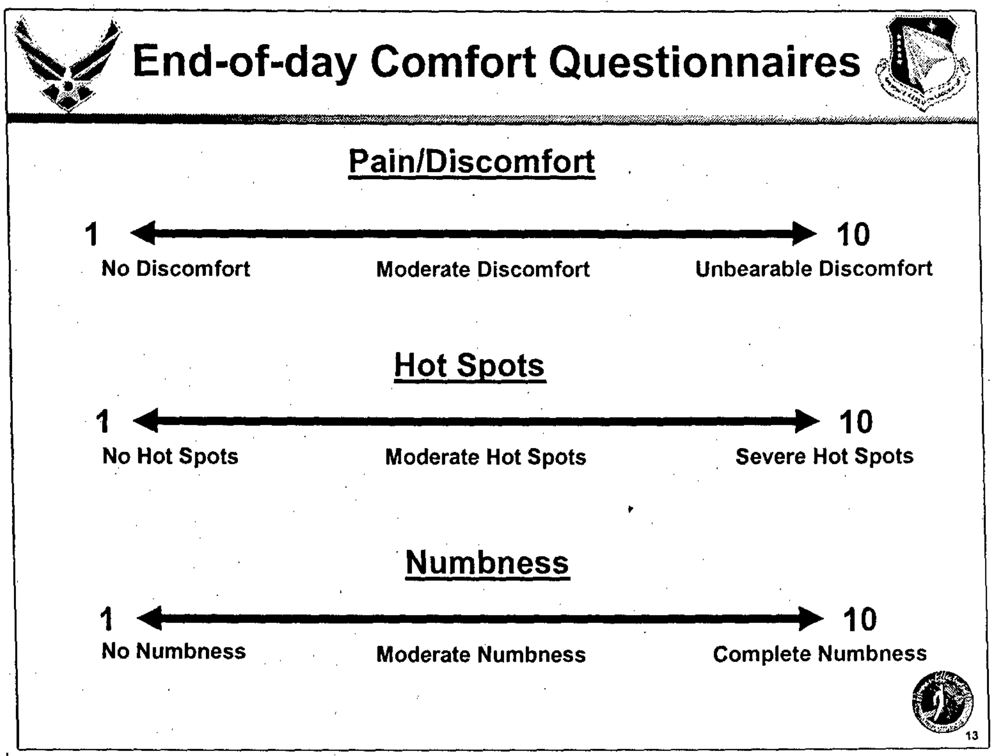
SEA Systems Prototype – Non-contoured ConforTM blend construction with fabric cover

Ergo Air ErgoDynamicTM Therapeutic Seating System 2000 with mechanical pumping action



Subjects completed comfort questionnaires asking them to rate any pain or discomfort in several parts of the body.

The rating was done every two hours throughout the 8-hour session.

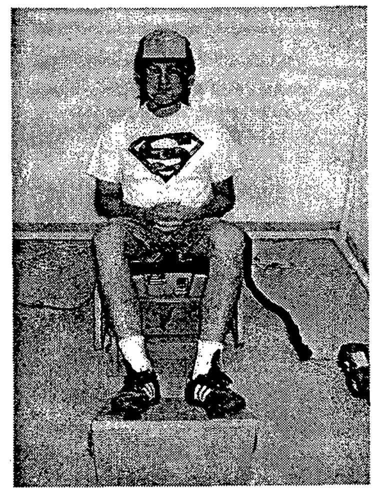


Subjects completed a comfort questionnaire after getting up from the seated position in the ejection seat.

This questionnaire asked the subjects to rank from 1 to 10 any pain or discomfort, hot spots, or numbness in 11 different body parts.

Subject Panel

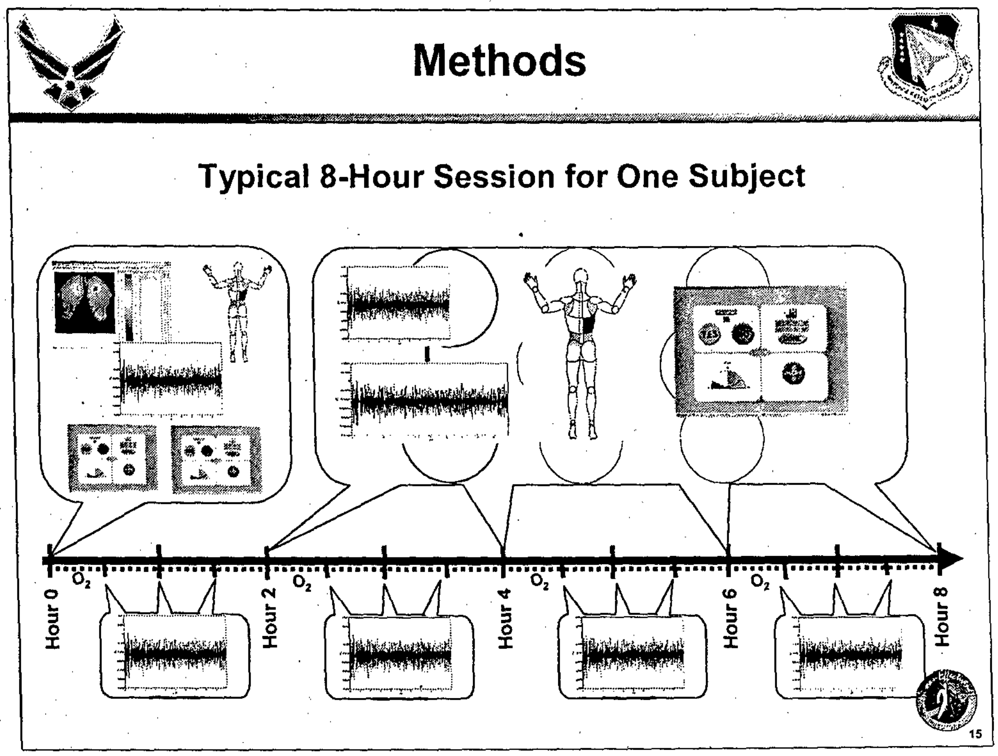
- 22 subjects participated (30 target)
- 9 Females & 13 Males
- Diverse range of stature and weight
- Panel comprised of civilian and college students
- All subjects exposed to 4 test cells
- Subjects informed of procedures and signed consent form prior to each session
- Subjects trained on SynWin prior to starting first 8-hour test
- IRB Approval by WPAFB & WSU



14

A total of 22 subjects participated. Of the total, 9 were female and 13 were male. The subject panel comprised of civilian and college students.

All subjects were exposed to all four test cushions. Prior to beginning each session, subjects were informed of the test procedures and signed the IRB approved informed consent form. Subjects had an initial session that consisted of training on the cognitive task prior to beginning the first eight-hour test session.



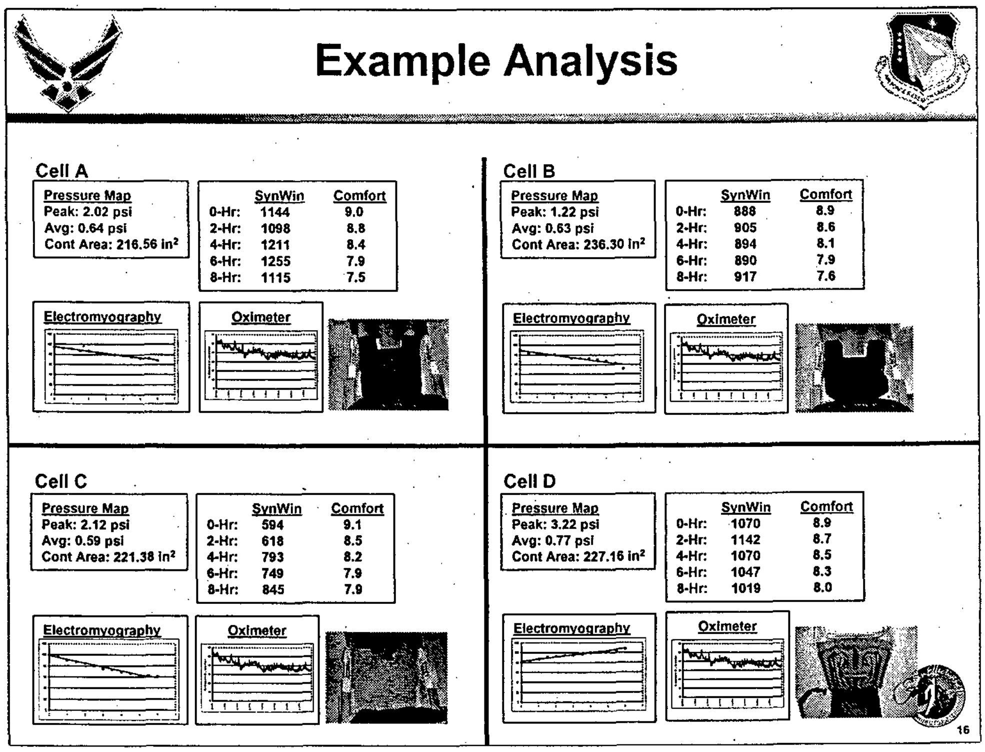
Two subjects were tested simultaneously.

Pressure map readings were taken at the beginning of the eight hours.

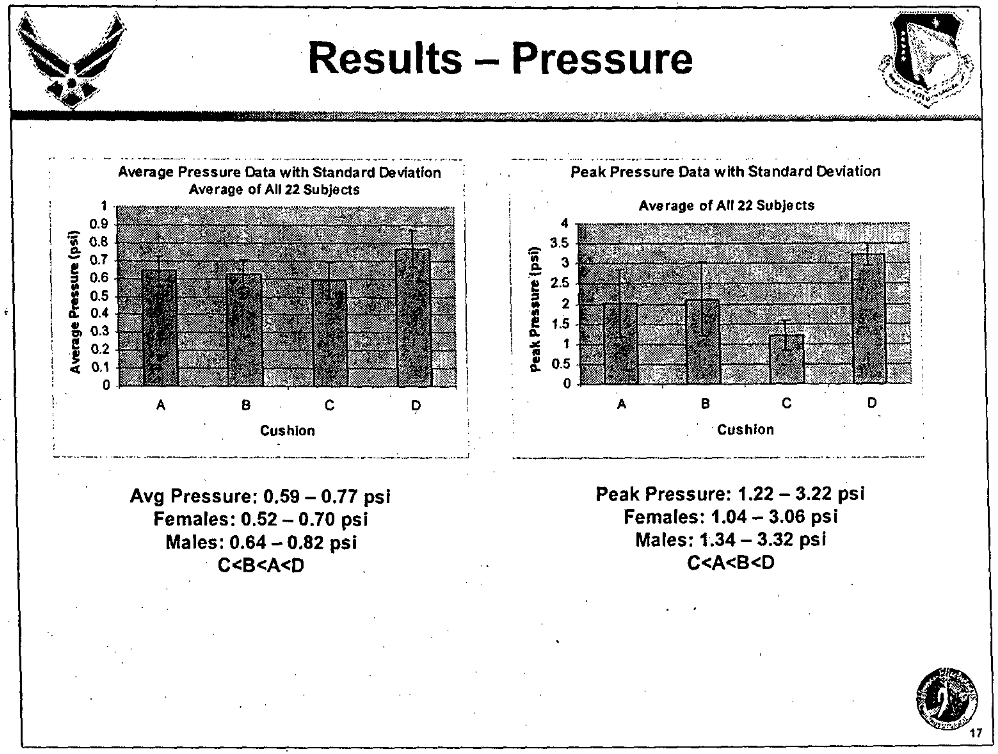
Comfort Survey and Cognitive task data were collected every two hours.

EMG data was collected every 30 minutes for 10 seconds.

Oximeter data was continuously collected throughout the eight hours.



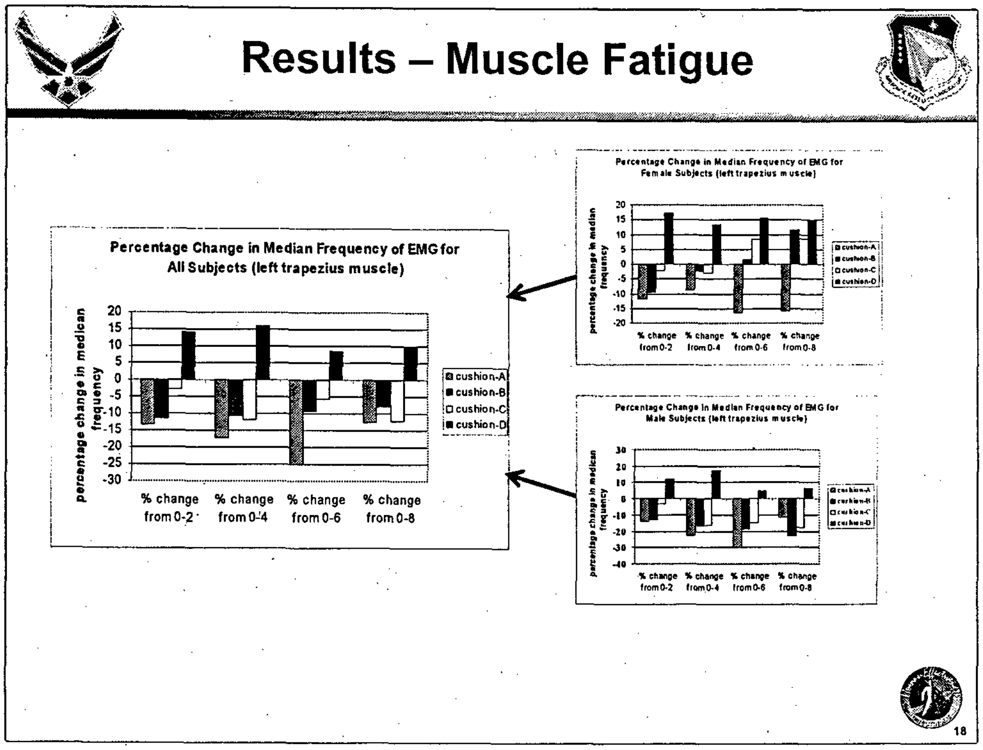
Analyses for each cushion involved evaluations of the pressure snapshot, SynWin and comfort scores at every two hours; median frequency of the EMG signal at every 0.5 hour and continuous oxygen saturation over the eight hours.



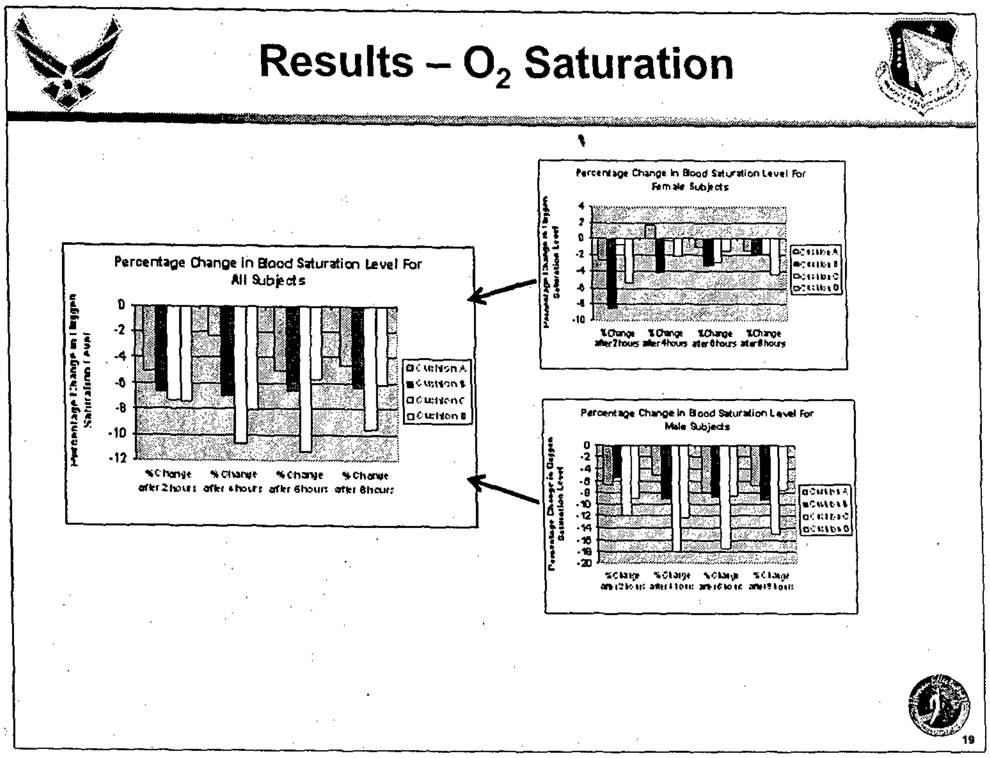
Pressure map results indicated that the dynamic ErgoAir cushion had the highest average and peak pressures in both males and females.

The average pressure ranged from 0.59 to 0.77 psi.

The peak pressure ranged from 1.22 – 3.22 psi.

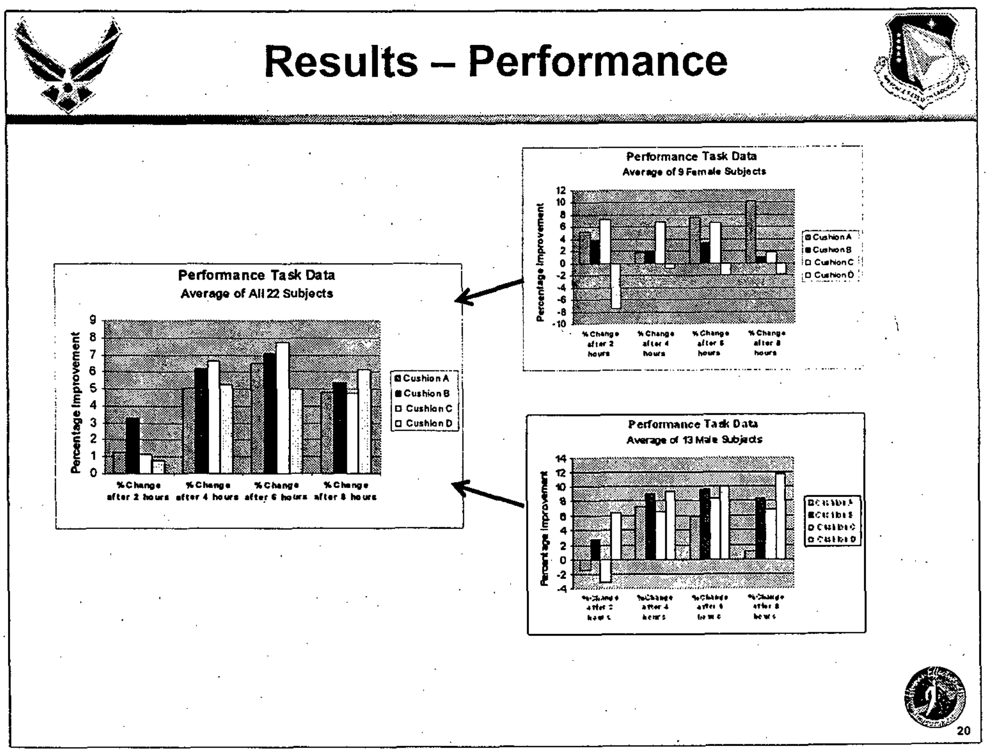


The median frequency of the EMG data was analyzed using EMGworks 3.0®. The median frequency of the trapezius muscles for every two hour interval is compared to the base value at time zero to calculate the average percentage change in median frequency. The average percentage change in MDF for twenty-two subjects along with gender data separation is shown. The median frequency of the lower lumbar regions did not yield any substantial result as there was barely any detected muscle activity in the erector spinae and internal oblique muscles. This was confirmed by the collected 3 minute EMG signal from every two hour interval. This analysis proved that a significant noise signal interfered with the EMG signal for these two muscles. This is demonstrated by the extremely large MDF values that were obtained. Therefore, the data from channels 3 through 6 were disregarded for this report (since they provided invalid data). The EMG signals were collected under rest conditions and there was no voluntary or submaximal contraction of the muscle.



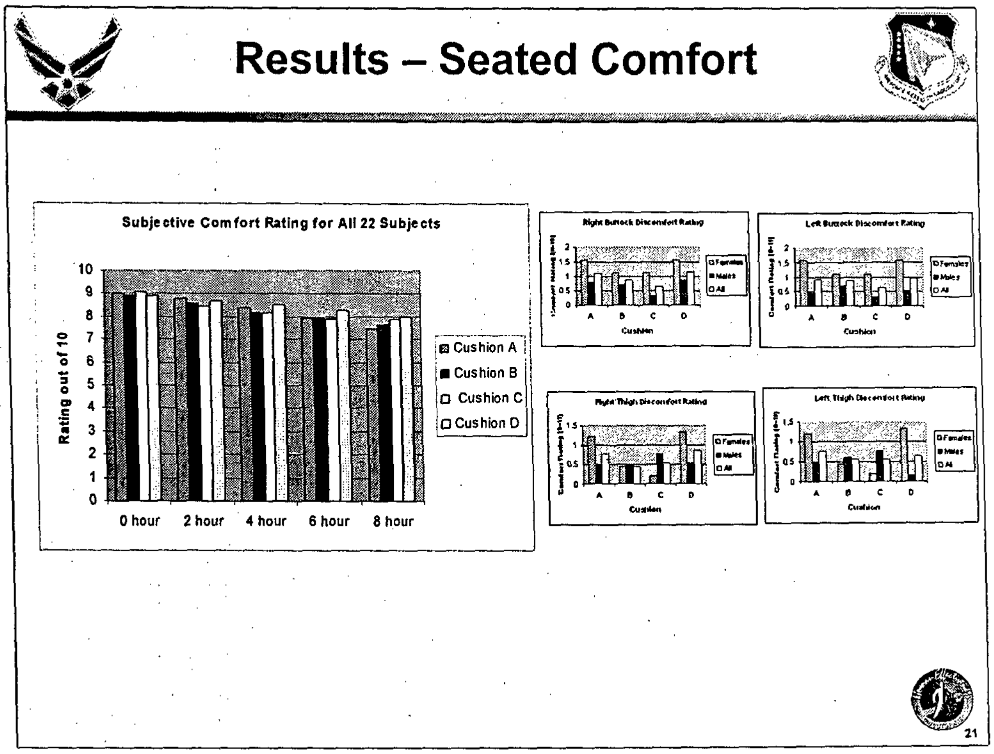
For the blood oxygen saturation in the lower extremities, an average of the blood saturation level for a 5 minute period was calculated at every two hour interval and compared to the baseline value to calculate a percent change. The percent changes in lower extremity blood saturation levels for all twenty-two subjects are shown. The general trend for all twenty-two subjects was a decrease in the blood oxygen saturation level at every stage of the eight-hour study. This trend remains consistent when the data is divided by gender, with the exception of one 1.66% increase from the baseline for female subjects on cushion A four hours into the study. The SEA Systems prototype cushion (cushion C) produced the greatest decrease in male oxygen saturation at every interval (as high as 18% decrease); however, it did not have the same effect on the female subjects.

Using one way ANOVA and Tukey Honestly Significant Differences analyses, it was concluded that there were no statistically significant differences between the female subject percent change in oxygen saturation levels for all four cushions and time intervals. Statistically significant differences were found between the percent change in oxygen saturation levels for the male subjects using cushion C and both cushions A and B. However, no statistically significant differences were found between the percent changes in blood oxygen saturation when analyzed against both time and cushion

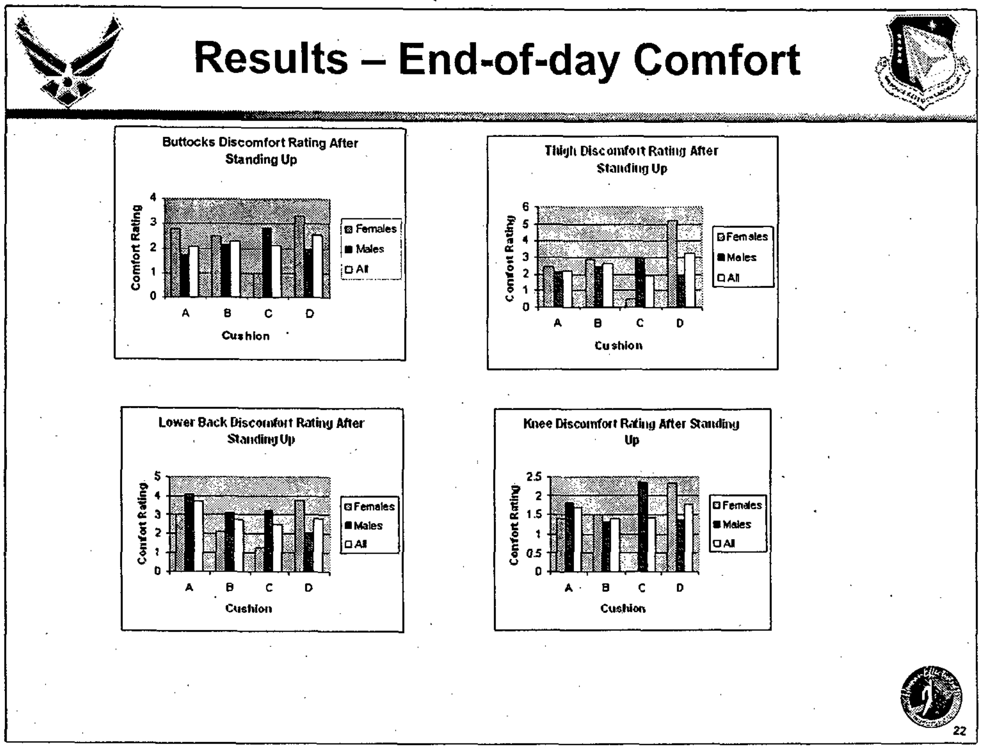


The performance data from the SynWin task were analyzed to determine the percent improvement or degradation between the initial assessment at the beginning of each eight-hour test and the scores of every two hour assessment. The general trend for all twenty-two subjects was a percent improvement between the initial assessment at the beginning of each eight-hour test and the scores of every two hour assessment. For all cushions except cushion D, subjects exhibited a steady increase in performance until the end where the percent improvement declined. Interestingly, the male performance while seated on cushion D steadily increased over the eight-hour session; however, for the female subjects, cushion D was the only cushion where there was a definite decline in performance throughout the entire eight-hour session.

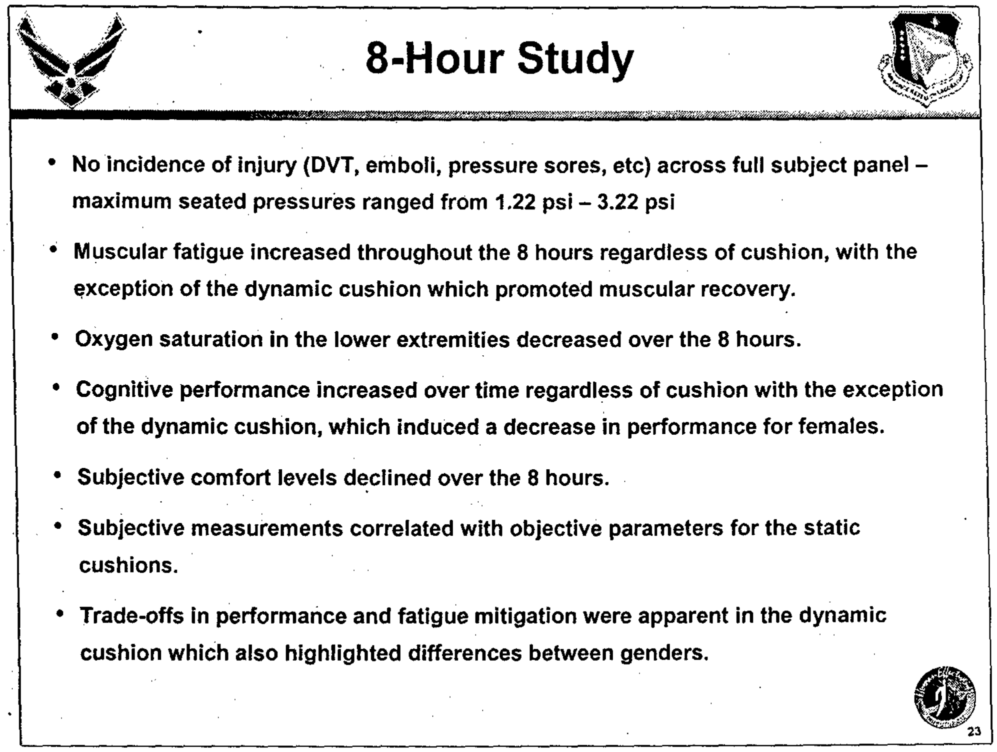
When the SynWin performance data were statistically analyzed, it was concluded that there were no statistically significant differences between subject performances while seated on the various cushions. Unfortunately, when the performance was analyzed by the session number, it was found that there was a learning curve between sessions that was not eliminated by the training sessions. For the male subjects, the SynWin scores steadily increased by session number and the differences were found to be statistically significant. For the female subjects, the SynWin scores steadily increased by session number, however, and statistically significant differences where found between sessions 1, 2, and 3. By session 4, their scores began to plateau indicating that the learning curve was overcome. This is consistent with the statistical analysis that found no statistically significant score increases between sessions 3 and 4.



The subject ratings of how they felt at every two hour interval during the study are shown. The rating scale ranged from 1 (feeling bad) to 10 (feeling great). A score of 7 indicated feeling okay. Generally, subjects felt very good at the beginning of the study; however, all subjects experienced a steady decline in comfort over the eight-hour study. The most notable decrease in comfort occurred on cushion A, where the rating fell from an average of 9 (feeling very good) to 7.5 (feeling okay). The next greatest rating declines were for cushions B, C then D. The male comfort rating follows the same trend as the overall twenty-two subject rating; however, the greatest female subject comfort rating decline was tied for cushions A and C. The next greatest decline in comfort was for cushion D followed by cushion B.



The subject discomfort ratings after standing up out of the seats are shown. The rating scale ranged from 0 "No Discomfort" to 10 "Unbearable Discomfort". Again, the survey responses for the buttocks and thigh discomfort were chosen for reporting because of the direct relationship of the buttocks and thighs to the seat pan cushion and the high frequency of subject complaints in that area. In addition, comfort ratings for the lower back and knees were chosen as a result of the high discomfort that was noticed by the subjects after they stood up. It is important to note that these two discomfort ratings were listed as no discomfort while the subjects were seated. The average survey results for the buttocks, thigh, and knee discomfort for all subjects showed that cushion D was the least comfortable. The average survey results for lower back discomfort for all subjects showed that cushion A was the least comfortable. Regarding the most comfortable cushion, the male and female subjects remained divided on the issue. The female subjects rated cushion C as the most comfortable regarding buttocks, thigh, and lower back discomfort, but the most uncomfortable regarding to knee discomfort. The male subjects rated cushion C the most uncomfortable in regards to the buttocks, thigh, and knee. The males rated cushion A as the least comfortable regarding the lower back.



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Further Work

- Collaboration with WSU to perform additional analyses on results from current study.
- Collaboration with WSU to further examine comfort issues related with dynamic cushion.
- Information from comfort studies to feed into overall project goal of defining seat and cushion parameters that will maximize comfort and performance without jeopardizing ejection safety.

24

Further collaborative work with Wright State University will involve additional analyses on the current study as well as further testing examining comfort issues related with the dynamic cushion.

The information from these comfort studies will feed into a future 6-3 program to define seat and cushion parameters that will maximize comfort and performance without jeopardizing ejection safety.