ASSESSMENT OF THE IMPACT OF LARGE CRTS AND FLAT PANEL MONITORS ON PRODUCTIVITY AND QUALITY IN AN INSURANCE COMPANY

A Thesis

by

MICHAEL FEDERICO JOHNSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2004

Major Subject: Safety Engineering

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Approved as to style and content by:

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December 2004

Major Subject: Safety Engineering

ABSTRACT

Assessment of the Impact of Large CRTs and Flat Panel Monitors on Productivity and Quality in an Insurance Company. (December 2004)

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Co-Chairs of Advisory Committee: Dr. J. Steven Moore
Dr. Jerome J. Congleton

This field study evaluates the impact of replacing existing 17-inch Cathode Ray Tube (CRT) monitors with 19 and 21-inch CRT monitors and 18.1-inch Flat Panel Displays (FPDs) on matrices of productivity, visual comfort, and physical discomfort among 30 employees within a large insurance company (Policy Service and Claims). Metrics were analyzed over a five (5) month period.

During Phase One (initial eight weeks) of the study, metrics were gathered weekly on 17-inch CRT monitors to establish a baseline of data on productivity, visual comfort and physical discomfort. During Phase Two (12 weeks), each subject used the 19-inch CRT, 21-inch CRT and 18.1-inch FPD for two weeks, respectively interspersed with other subjects in the study utilizing 17-inch monitors for the same time period. Initially, it appears that the 19-inch monitor enables users to enter more keystrokes per hour ($\bar{X}_{19}$ =1894) than its 17-inch counterpart ($\bar{X}_{17}$=1721) which would be a productivity

enhancement. However, this value is not statistically significant ($p>0.34$). Analysis of additional performance metrics yielded similar results ($p>0.2$).

The users' level of visual comfort increased with all test display units over their existing 17-inch counterpart ($p<0.023$), but the data was not meaningful due to the minute difference between their mean values ($\Delta<0.75$). Physical discomfort metrics were analyzed among all of the monitor treatments. Most employees were relatively comfortable through the duration of the study. Mean values across all physical discomfort metrics measured were less than one on a Borg scale of zero to ten, but none of the values among treatments were significant ($p>0.31$). Anecdotally, the users preferred the larger monitors.

ACKNOWLEDGEMENTS

I would like to acknowledge my graduate advisor/committee Co-chairs, Dr. J. Steven Moore and Dr. Jerome Congleton; and committee members, Dr. Will Gaines, Jr. and Dr. Alfred A. Amendola.

I would also like to thank the National Science Foundation Industry/University Cooperative Research Center in Ergonomics and Hitachi, Inc. for their financial and equipment donations, which made this study possible. I would also like to recognize USAA for their support in research to make business decisions based upon sound scientific practices. Lastly, I want to acknowledge NSF (National Science Foundation) industry partners, Dr. Gordon Vos, Erin Walline, and fellow TAMU safety engineering graduate students for their guidance and support during the duration of this study.

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INTRODUCTION

In today's competitive business environment, evaluations must be conducted to determine how the introduction of new VDUs (Video Display Units) will affect productivity and the visual and physical comfort of the user. These newer and sometimes larger monitors enter the workplace with the expectations of increased productivity, fewer visual and musculoskeletal issues, and improved worker satisfaction (IBM, 2000, Wang, 2000). The type of display unit (CRTs or FPDs) and the size of monitor are meaningful variables that should be considered when evaluating the purchase of VDUs. The goal of this field study is to evaluate those effects.

Impact on Productivity

One area of investigation in the sustained use of VDUs is their impact on productivity. This study quantitatively evaluates productivity by assessing the number of keystrokes, number of mouse clicks, and feet of mouse movement metrics for test and control subjects on an hourly basis. These three units of measurement can serve as indicators of productivity in unison, or independently. The first area of investigation on productivity for this study is evaluating how a larger display screen impacts the number of keystrokes per hour. If the user is able to see more applications (Word, Excel, Outlook, etc.) on a video display unit,

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This thesis follows the style and format of Applied Ergonomics.

then the number of keystrokes that they perform may go up as they may not need to toggle between multiple software applications that are resident in the foreground. If the keystrokes increase for the same given time period, then a policy can be issued, or claim handled in a more expeditious manner. Additional intangibles include increased member satisfaction as they do not have to be on the phone as long during a transaction.

The second area of interest on productivity metrics is how the mouse or input device utilized is affected by the size of the monitor. If a user is able to review more information on a larger screen, then they will not have to toggle as much between each software application. This will result in less mouse usage and significant time savings as mouse clicks are non-value added activities in the transaction process when they are utilized strictly to navigate between applications. A reduction in mouse usage directly correlates to a decreased amount of time required to perform a transaction (i.e. issuing a policy, or settling on a claim) and can be quantified by standard motion time analysis (MTM 1978).

Lastly, the feet of mouse movement may correlate directly to the number of mouse clicks. If the number of mouse clicks goes down per hour, then the feet of mouse movement may also go down. A reduction in the feet of mouse movement could also indicate that the screens displayed more information and required the user to move the mouse less often while toggling between applications. The reduction in time to navigate with the mouse while processing a claim, or issuing a policy may serve as a means to justify larger display units, or units of differing technology. One variable that is not intuitive is that a larger

VDU may introduce more feet of mouse movement if the employee has to cover a greater area on a given screen. This may or may not be directly related to the number of mouse clicks.

Visual Comfort

Numerous studies have implicated visual fatigue with VDT use (Jaschinski-Kruza, 1991; Bergqvist and Knave, 1994, Bergqvist *et al.,* 1995, Sotoyama *et al.,* 1996; Jaschinski *et al.,* 1998). Visual fatigue has been defined as any subjective vision-related symptom or distress resulting from use of the eyes (Tyrrell and Leibowitz, 1990). A framework for analyzing visual discomfort was developed by Bervquist (Bervquist *et al.,* 1995) with several determinants postulated to be the source of discomfort and fatigue. These include the after-effects of poor resolution and fuzzy characters on the user's visual system for example. Visual metrics of comfort (or lack thereof) have also been utilized by others to evaluate the impact of VDUs on operators (Jaschinski-Kruza, 1991).

The technology in place (FPDs versus CRTs) may also affect visual discomfort. FPD technology has been touted to reduce eye fatigue (ISO-WG Final Text 13406-2, 1999, IBM, 2000). This reduction in visual fatigue is accomplished by removing flicker from the screen and by minimizing specular reflection—both byproducts of the newer visual technology. For example, perceived flicker on conventional CRT monitors has been linked to visual eye fatigue (Rogowitz, 1984). Flicker on screens resulting from the monitor refreshing the image both horizontally and vertically is non-existent on new FPD technology.

In addition, FPDs produce less specular reflection compared to conventional CRT technology by their inherent design (Video Electronics Society of America Flat Panel Standard, 1998). Visual fatigue may also be reduced by the larger font size on video display units if more real estate space is available.

Musculoskeletal Discomfort

Musculoskeletal disorders (MSDs) associated with repetitive motion (the vast majority of which are upper extremity disorders) are the fastest growing source of disability in the US workplace. This is evident from the 14-fold increase in incidence from 1972 to 1994, despite the slight reduction over the last several years (Bernard, 1997). Surveys of keyboard workers have demonstrated a 20 to 40% prevalence rate of upper extremity disorders of office workers (Bernard *et al.,* 1994; Polanyi *et al.*, 1997).

Musculoskeletal discomfort complaints are relatively common among VDU users (Ostberg, 1975; Hunting *et al.,* 1980; Bergqvist, 1984; Pickett and Lees 1991; Carter and Banister, 1994; Ong *et al.,* 1995). VDUs have also been implicated as a risk factor in musculoskeletal discomfort (Arndt, 1983; Knave *et al.,* 1985; Rossignol *et al.,* 1987; Gobba, *et al.,* 1988; NIOSH, 1990; Pickett and Lees, 1991; De Wall *et al.,* 1992; Carter and Banister, 1994).

Initially, field studies concerning the contribution of ergonomic factors in the workplace asserted positive associations between aberrant postures and musculoskeletal symptoms in office workers (Duncan and Ferguson, 1974; Hunting *et al.*, 1981, Maeda *et al.*, 1982). Later studies raised concern over the initial positive associations or doubt that all of the factors enumerated in conventional research contribute to the onset of work-related MSDs (Arndt, 1983, Starr *et al.*, 1985, Ryan and Bampton, 1988, Walsh *et al.*, 1991, Hagberg, 1996, Gerr *et al.*, 2002). Some authors contend that VDU users most commonly experience back, neck, and shoulder musculoskeletal discomfort (Smith *et al.*, 1981; Bendix *et al.*, 1985; Evans, 1987; Hagberg and Wegman, 1987; Rossignol *et al.*, 1987).

Numerous studies have indicated that musculoskeletal disorders in the distal upper extremities may be affected by risk factors including repetition, intensity, forceful exertions, awkward posture, and duration of exposure (Armstrong, 1986; Armstrong *et al.*, 1986; Cannon *et al.*, 1981, Moore and Garg, 1994).

Work-Related Musculoskeletal Disorders (WRMDs) account for one-third of all occupational injuries and illnesses reported to the Bureau of Labor Statistics (BLS) by employees every year (BLS, 2001). MSDs are detrimental in the modern workplace, resulting in health and financial losses for the worker and the organization (Federal Register, 1999, BLS, 2001).

Numerous ergonomic intervention programs have had limited success in that these programs often do not address the combination and interaction of the various risk factors on an individual basis, or the synergy of the related components that constitute an office work environment. One component of this synergy is the investigation of how larger VDUs may impact the overall physical comfort of affected users. A larger display may enhance physical comfort if the display unit possesses enhanced visual properties (i.e., larger font size, less flicker). A computer operator may not have to lean forward excessively to view information on the computer screen, which could reduce lower back fatigue. An employee may also feel less physically stressed if they can view a great deal of information on the screen and not be hampered by minimizing and maximizing assorted software applications when they are performing a transaction on behalf of a customer.

METHODS

This field intervention study utilized employees of USAA (United Services Automobile Association, 9800 Fredericksburg Road, San Antonio, Texas 78288). The subjects/employees were CCRs (Customer Contact Representatives) from the USAA Property and Casualty Division. These subjects are randomly chosen from different areas of the company, and are on the phone for more than 5 hours per day. Tasks are similar within subgroups, with some individuals handling phone calls for policy service activities, while some subjects will be handling insurance claims. All subjects type the majority of the day in conjunction with the use of a telephone.

Employees chosen from the study population had a 17-inch monitor issued to them prior to the study, and spent the majority of the day on the computer. These requirements were conveyed to upper management prior to the request for employees' names.

Managers of the respective employees were advised that employees participating in this study would fill out a *Questionnaire* (Appendix A-C) that summarized their productivity on a weekly basis in addition to their visual and physical comfort. They were also advised that this information would be summarized as an aggregate number, and that the information on each employee would be kept confidential by the Principal Investigator.

The Principal Investigator met with each employee prior to the beginning of the study to review the logistics of the study and to discuss how to complete the data fields on the questionnaire appropriately. All employees utilized a 17-inch Monitor as their standard video display unit prior to this study. No workstations were evaluated from an ergonomics perspective, or adjusted as a result of the employee's participation in this study for the duration of the data-gathering phase of this study. There was no investigation into whether employees were experiencing visual fatigue or physical discomfort prior to the study. Medical personnel did not evaluate employees, and no information on demographics other than age and gender was gathered.

Subjects served as their own controls, however, the concurrent Control group allowed for consideration of ecologic factors that might affect the independent variables. Prior to the study, all subjects were issued an Informed Consent Form (Appendix E) describing requirements in order to participate in the study. After the subject read the form, he or she was given the opportunity to discuss the form and ask questions about the experiment with the Principal Investigator.

Each participant then signed the Informed Consent Form as a condition of participating in the study. This form was approved by the Institutional Review Board (IRB) and Texas A & M University.

Thirty (30) employees were chosen from a pool of 3,000 employees with similar job responsibilities. Twenty two (22) of the study participants were females, and these demographics are approximately the same as the percentage of females in the entire workforce (66% female). The age range was from 25-54 years old.

It was requested by the Principal Investigator of area managers that all prospective subjects selected for this study not be involved in activities that would forego their opportunity to participate in the study for a period of twenty (20) consecutive weeks (i.e., extensive training, pending promotions, transferring to another division). Despite this negotiated arrangement, two employees dropped out of the study due to promotions. Twenty-eight (n=28) employees completed the study.

Employee participation was completely voluntary. All experimental data and questionnaire forms were maintained in a locked filing cabinet at USAA (Michael F. Johnson's filing cabinet). Only the Principal Investigator had access to this information.

Equipment Utilized

Existing 17-inch IBM™ P70 monitors served as controls in this study, and were approximately 3 years old. All three (3) treatment VDUs were manufactured by Hitachi™. They were 19-inch CRT technology (Model 772) Monitors, 21-inch CRT technology (Model 802) Monitors, and 18.1-inch Hitachi (Model CML 170S) FPDs respectively. The employee's respective manager set the resolution of all CRTs and FPDs to 1024 x 768 pixels due to electronic monitoring of work performance that takes place. The screen refresh rate of each monitor was set between 70 and 75 Hertz depending upon the initial settings on the IBM P70s. Every effort was made not to change the settings on each treatment display unit.

Productivity/performance metrics were captured by Office Athlete™ software. Office Athlete™ software dynamically captures the number of keystroke depressions, mouse clicks, and feet of mouse movement performed by a given operator on a daily, weekly and monthly basis. This numeric data was unique to each individual and was reported by the employee to the Principal Investigator on a weekly basis. Office Athlete also maintains a Stretch and Exercise Guide section, but this feature was not investigated in this study.

A sample screen is shown in Figure 1.

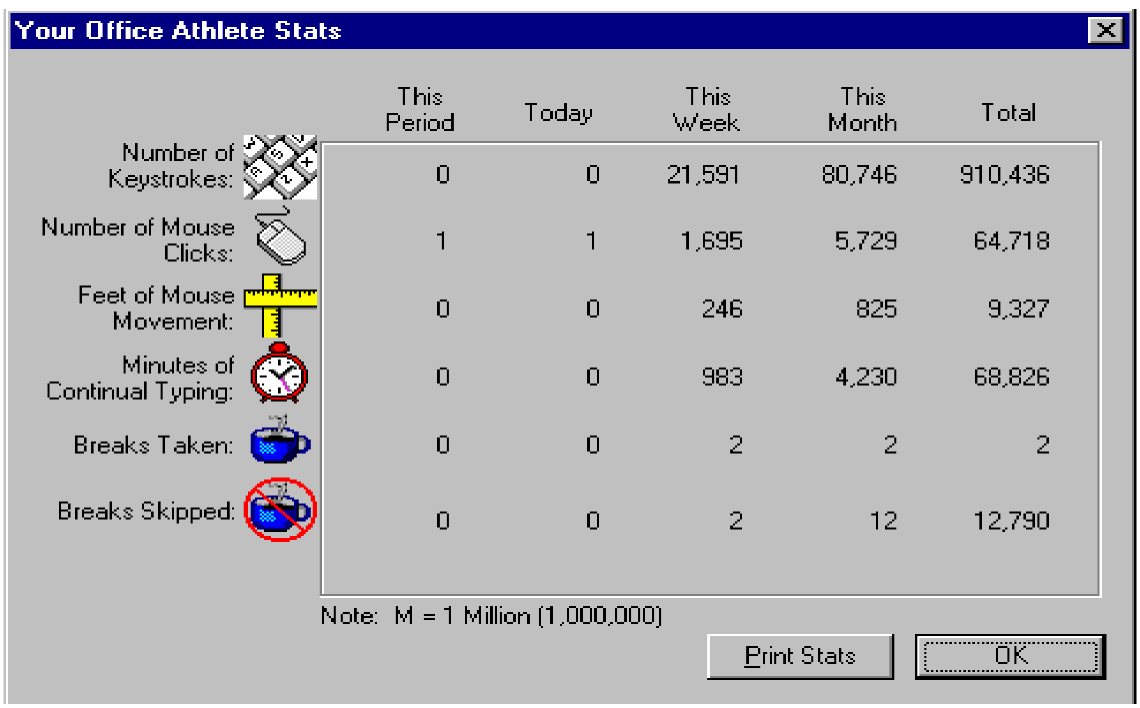


FIGURE 1: Office Athlete Software Sample Screen.

Participants in the study generally had at least three (3) software applications on the screen at any given time--but might have been utilizing as many as six (6) applications depending on the complexity of the transaction. Most of the applications had GUI (Graphical User Interface) on the front-end, while the older legacy/mainframe system operated in the background. A sample legacy screen is shown below in Figure 2 that highlights the congestion on the screen with 3 resident applications.

FIGURE 2: Mainframe Application Sample Screen.

As can be seen in Figure 2, real estate available to view information on the screen was a premium. The software applications were data intensive. Users struggle with minimizing, toggling, and maximizing screens in order to view all of the information necessary to perform transaction processing throughout the workday.

Productivity Metrics

Background data on work habits (i.e., hours worked per week and hours away from the workstation) were gathered on each participant over a period of twenty (20) weeks as outlined in the *Productivity Metrics Survey Questionnaire* (Appendix A). This allowed the Principal Investigator to determine the hourly rate of all productivity metrics that were tabulated. The total number of hours worked for the week was impacted by the amount of time an employee was away from their desk at meetings, lunch, training, or special events. The submission of productivity metrics did not affect the employee's performance in any manner. Information on productivity values was transposed from the Office Athlete screen on the employee's computer to page one of a four (4)-page *Questionnaire* on a weekly basis (Appendix A).

Visual Comfort Metrics

The second page of the *Questionnaire* (Appendix B) consisted of a series of seven (7) self-reported qualitative assessments of visual fatigue (Jaschinski, et al., 1998) that were reported on a weekly basis. Subjects were asked to rate the VDU font characteristics on a continuous scale from 1 to 7. Visual comfort ratings were based upon the Bervquist VAS (Visual Analog Scale), with a range of 1 to 7-cm (Bergqvist and Knave, 1994). The initial questions consisted of rating the size of the characters on the screen with 1=characters too small, 4=just right, and 7=too large. The remaining six (6) questions consisted of users self-reporting several visual fatigue metrics measured under a continuous scale from 1 to 7 (1=Not at all, 7=Yes, very much).

Physical Comfort Metrics

The last two pages of the *Questionnaire* consisted of an anatomical outline of the upper extremities, and space to enumerate the discomfort value (or lack thereof). This information was placed in a tabular format adjacent to the body part affected. Redundant sections (i.e., visual descriptors of the anatomy, with an accompanying visual analog scale and tabular entry forms) were provided to assist employees with several input options on entering their physical comfort locations and associated values. If employees did not experience any physical discomfort, then they could indicate "No Discomfort" in a field provided on the *Questionnaire* (Appendix C) and a value of zero was placed in the database on all physical discomfort metrics.

The investigation of physical discomfort was limited to the upper extremities. Subjects rated discomfort on a continuous Borg Scale (Borg, 1990) of 0 to 10, with 0=no discomfort and 10=agonizing pain (Huskisson, 1974). The continuous scale data for this section followed the protocol outlined by the National Institute for Occupational Safety and Health (NIOSH) in the Federal Register (OSHA 1910.900, 1999). This information was submitted on a weekly basis to the Principal Investigator.

Phase One (Baseline Testing)

The first eight (8) weeks of the study served as a baseline where no "treatment interventions" were introduced. All subjects during the first eight (8) weeks utilized a 17-inch CRT monitor that was located at their desk prior to the study. This is outlined in Table 1.

TABLE 1: Eight (8) Week Schedule Distribution of Control Monitors

Subject / Dates	Subjects 1-5	Subjects 6-10	Subjects 11-15	Subjects 16-20	Subjects 21-25	Subjects 26-30
Week 1	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor
Week 2	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor
Week 3	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor
Week 4	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor
Week 5	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor
Week 6	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor
Week 7	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor
Week 8	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor	17-inch Monitor

Phase Two (Rotation of VDUs)

Phase Two served as the intervention session. In this part of the experiment, some of the 17-inch CRT monitors were replaced with 19 or 21-inch CRT monitors or 18.1-inch FPDs for a period of two weeks based upon the schedule listed in Table 2.

TABLE 2: Twelve (12) Week Distribution of Control and Test Display Units

Subject / Dates	Subjects 1-5	Subjects 6-10	Subjects 11-15	Subjects 16-20	Subjects 21-25	Subjects 26-30
Week 9	17-inch Monitor	Flat Panel Display	17-inch Monitor	19-inch Monitor	17-inch Monitor	21-inch Monitor
Week 10	17-inch Monitor	Flat Panel Display	17-inch Monitor	19-inch Monitor	17-inch Monitor	21-inch Monitor
Week 11	Flat Panel Display	17-inch Monitor	19-inch Monitor	17-inch Monitor	21-inch Monitor	17-inch Monitor
Week 12	Flat Panel Display	17-inch Monitor	19-inch Monitor	17-inch Monitor	21-inch Monitor	17-inch Monitor
Week 13	17-inch Monitor	19-inch Monitor	17-inch Monitor	21-inch Monitor	17-inch Monitor	Flat Panel Display
Week 14	17-inch Monitor	19-inch Monitor	17-inch Monitor	21-inch Monitor	17-inch Monitor	Flat Panel Display
Week 15	19-inch Monitor	17-inch Monitor	21-inch Monitor	17-inch Monitor	Flat Panel Display	17-inch Monitor
Week 16	19-inch Monitor	17-inch Monitor	21-inch Monitor	17-inch Monitor	Flat Panel Display	17-inch Monitor
Week 17	17-inch Monitor	21-inch Monitor	17-inch Monitor	Flat Panel Display	17-inch Monitor	19-inch Monitor
Week 18	17-inch Monitor	21-inch Monitor	17-inch Monitor	Flat Panel Display	17-inch Monitor	19-inch Monitor
Week 19	21-inch Monitor	17-inch Monitor	Flat Panel Display	17-inch Monitor	19-inch Monitor	17-inch Monitor
Week 20	21-inch Monitor	17-inch Monitor	Flat Panel Display	17-inch Monitor	19-inch Monitor	17-inch Monitor

The 17-inch (Control) monitors are interspersed with the other treatment monitors to highlight the envelope of time they were placed on each employee's desk. The monitors were rotated every two weeks so that all subjects had different VDUs for a two-week duration, as highlighted in Table 2.

The same fifteen treatment Display Units (five 19-inch monitors, five 21-inch monitors, and five 18.1-inch Flat Panel Displays) were rotated during the study to fifteen different operators. Fifteen (15) employees utilized 17-inch monitors concurrently. The distribution of the monitors was randomized to allow employees within specific regions a mixture of Control and Treatment monitors during the same time period.

DATA ANALYSIS

The four (4) independent variables for this study were the Control monitor (17-inch CRT) and the three (3) Treatment variables (19 and 21-inch CRT monitors and 18.1-inch FPDs). Thirty-two (32) dependent variables were evaluated. This would encompass three (3) productivity metrics (keystrokes, mouse clicks, and feet of mouse movement), seven (7) visual metrics, and twenty-two (22) variables that defined upper extremity physical discomfort values in the ventral and dorsal planes.

The null hypothesis of this study is that the independent variables and the various interactions between the independent variables will have no effect on the dependent variables being studied. The criterion for rejection of the null hypotheses was alpha <0.05. The statistical analysis of data was executed by SAS® software (SAS, 1989). Ideally, workloads did not change except for internal fluctuations beyond the control of any field study. This study incorporates post-intervention with concurrent untreated control group. Except for monitor preference, all dependent variables were continuous and scaled. The type of monitor in place was defined as categorical data.

Productivity Metrics

Descriptive statistics were investigated on all productivity metrics of interest (keystrokes, mouse clicks, and feet of mouse movement). The Mean, Standard Deviation and Range of all values were evaluated. Histograms were created to evaluate the data visually. The Shapiro-Wilk's W Test evaluated the frequency distributions for Normality (Shapiro and Wilk, 1965). This method is appropriate given the sample size of the study (Royston, 1992). The productivity metrics were then subjected to a more robust method of analysis by reviewing the ANOVA (Analysis of Variance) through the statistical software, SAS® that calculate the "interaction" of the monitors with their dependent variables (if any) on a quantitative basis.

Visual Comfort Metrics

All dependent variables for visual comfort were continuous and scaled. This is based on the assumption that even though the VAS (Visual Analog Scale) is measured on an ordinal scale, it is representative of a continuous variable because raters do not have to choose from a finite set of points.

ANOVA was used to evaluate the hypothesis that the differences between the means for eye symptom scores were significant. An ANOVA F-test revealed significant differences among the treatment means, but it did not indicate which means differ. Therefore, additional comparisons were needed. Subgroups were examined by evaluating the Structured Contrasts of Means. The Structured Contrasts of Means determines the direction of association if one exists, if the ANOVA indicates a significant difference between the means.

The next step in the data evaluation process involved grouping of the data from the visual comfort surveys to test for internal consistency by Chronbach's Alpha (Chronbach, 1951). Others have used this technique in other selfadministered questionnaires to determine the acceptable reliability of questions (Bernard, 1994). Chronbach's Alpha determines if questions on the visual comfort survey are positively correlated with each other because they are measuring essentially the same concept (i.e., was the visual comfort of the users enhanced by the introduction of new technology or larger monitors?). This non-parametric approach to data evaluation provided an actual scale so that it was possible to determine just how much each test was related to one another on a scale of 0 to 1 for grouping questions together for further analysis. The closer the rating was to one (1), the higher the probability that repeating this test would yield the same result.

Physical Comfort Metrics

All dependent variables for physical discomfort were continuous and scaled. Discomfort ratings were based upon a 10-cm VAS. This method is utilized by the Occupational Safety & Health Administration (OSHA) and others to evaluate physical discomfort (Maeda, 1982, Lander, et. al., 1986, Gerr, et. al., 2002), and is referenced in OSHA's 29 CFR 1910.900-Ergonomics Program. An ANOVA was performed on the data created by the Physical Discomfort metrics.

RESULTS

Productivity Metrics

Descriptive Statistics

The Mean value for the number of keystrokes (KS) performed per hour on a 19-inch monitor is greater than any other monitor (KS_{17}=1721, KS_{19}=1894, KS_{21}=1635, KS_{FPD}=1664). This may lead to an initial assessment that the 19-inch monitor is superior to its counterparts. Therefore, further analysis was necessary to describe the parameters of interest across all cases. Low fidelity models provided the following descriptive results in the form of a histogram. The number of keystrokes per hour and their associated distributions were plotted and compared graphically to the normal curve using frequencies (Figure 3).

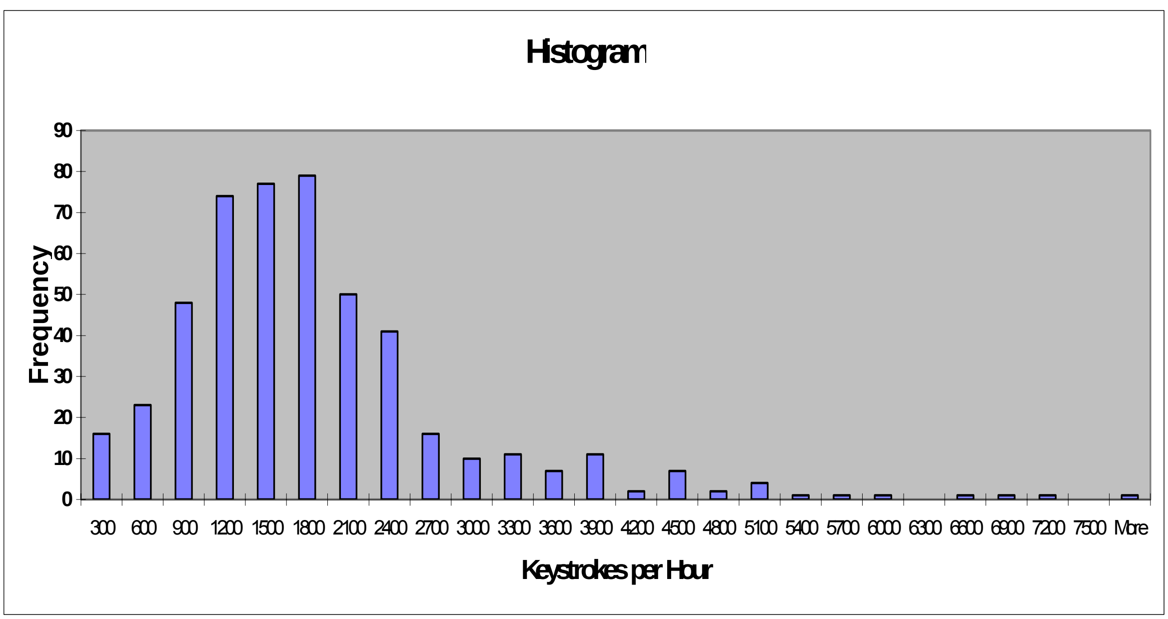


FIGURE 3: Histogram of Keystroke Depressions per Hour Distribution.

Descriptively, the data appears to be normal with skewing to the right as the distribution of the keystrokes per hour data is reviewed. Additional Histograms (Figures 5 and 6) for the other two productivity metrics of interest (mouse clicks and feet of mouse movement) are located in Appendix D. The histogram for the aggregate number of mouse clicks per hour demonstrates skewing to the right, but the collective distribution of the control and treatment effects appears to be normal. The histogram for the feet of mouse movement Figure 6 (Appendix D) reflects the same behavior observed in Figures 3 and 5, with heavy skewing to the right.

The next step in the evaluation process was to review the Mean, Standard Deviation, and Range of the productivity data. The data in Table 3 indicates a large Standard Deviation across all Control and Treatment monitors for keystrokes per hour.

TABLE 3: Exploratory Analysis of Keystrokes per Hour

Keystrokes per hour	17-inch Monitor	19-inch Monitor	21-inch Monitor	18.1-inch Flat Panel Display
Mean	1721	1894	1635	1664
Standard Deviation	763	836	770	809
Range	726 – 3928	793 – 4904	358 - 3807	458 – 4384

Table 12 (Appendix D) summarizes the Mean, Standard Deviation, and Range of the remaining productivity metrics (mouse clicks, and feet of mouse

movement) per hour. Both metrics exhibits a large Standard Deviation and Range. It is interesting to note that the values for mouse clicks, and feet of mouse movement is lower for the 17-inch CRT monitor, as well as the values for the number of keystrokes which is the most desirable outcome, or desired state.

Transformation of Data

Data that displays skewness may be more easily analyzed if we transform it (Bland J. and Altman, D, 1995). Each productivity metric that was under analysis was skewed to the right. Data that is skewed to the right may be transformed by square root (x), ln (x), or $\log_{10}$ (x). The histogram of the aggregate values for the transformed data on keystrokes performed per hour is outlined in Figure 4.

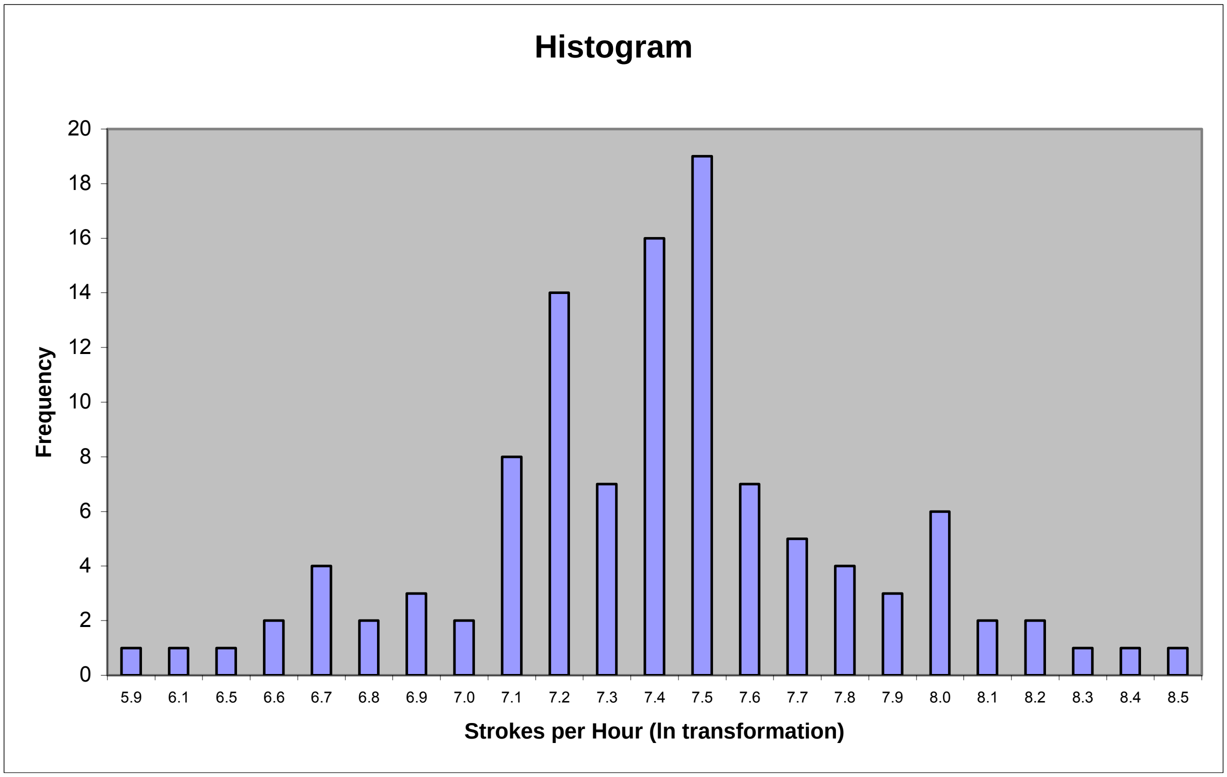


FIGURE 4: Histogram of ln (x) Keystroke Depressions per Hour.

The ln (x) transformation of the keystroke data in Figure 4 removed some of the skewness evident in the original data. Equivalent results were found on the data when the values were transformed by square root (x), and $\log_{10}$ (x) across all productivity metrics that were analyzed.

Similarly, the data was normalized for the number of mouse clicks and feet of mouse movement per hour for participants in this study. This yielded the histograms displayed in Figures 7 and 8 (Appendix D). Descriptively, the transformed histogram for the number of mouse clicks executed per hour appears bimodal despite the transformation. Likewise, it is not visually clear if the distribution of data for the feet of mouse movement histogram behaves normally. The skewness, however, is not as evident as before the data was normalized.

The next step in the evaluation process was to review the Mean, Standard Deviation, and Range of the transformed data for all of the productivity metrics (Table 4).

TABLE 4: Mean and Standard Deviation Values of Transformed Data

Variable	Mean	Standard Deviation	Minimum	Maximum
Keystrokes per Hour ln (x)	7.40	0.40	5.90	8.50
Mouse Clicks per Hour ln (x)	4.86	2.26	3.01	5.90
Feet of Mouse Movement per Hour ln (x)	3.22	0.94	1.66	4.37

All of the metrics will now be subject to a more robust method of analysis for normality of data distributions.

Shapiro-Wilk Test for Normality

Graphically, the productivity data does not appear to have a normal distribution across all lines of investigation. A more rigorous evaluation would be a quantitative measure to determine the normality of the data. This can be performed with the Shapiro-Wilk Test for Normality. The only data that is not normally distributed is the data on keystrokes performed per hour for the 21-inch monitor data. The rest of the data that was evaluated across all metrics has a normal distribution as indicated in Table 5.

TABLE 5: Shapiro-Wilk Test of Normality Table

Metric	Treatment	W statistic
Strokes In (x)	17-inch monitor	0.390
Strokes In (x)	19-inch monitor	0.785
Strokes In (x)	21-inch monitor	0.010
Strokes In (x)	18.1-inch FPD	0.370
Mouse Clicks In (x)	17-inch monitor	0.767
Mouse Clicks In (x)	19-inch monitor	0.412
Mouse Clicks In (x)	21-inch monitor	0.224
Mouse Clicks In (x)	18.1-inch FPD	0.083
Feet of Mouse In (x)	17-inch monitor	0.688
Feet of Mouse In (x)	19-inch monitor	0.149
Feet of Mouse In (x)	21-inch monitor	0.102
Feet of Mouse In (x)	18.1-inch FPD	0.410

Based upon the results listed above, we have no evidence that the distribution of the underlying population should not be considered normal except the data for the keystrokes on the 21-inch monitor. This distribution violates the assumption of normality.

Analysis Of Variance

Phase One (first eight weeks) of the study served as a baseline for the 17-inch monitor data, and allowed the users to become more comfortable with the process of submitting data to the Principal Investigator on a weekly basis. For the purpose of analysis, all of the 17-inch data during Phase One was compared to the 17-inch monitor data during Phase Two (last twelve weeks). An ANOVA was performed on both data sets to determine if there was any significant difference within the means in Phase One or Phase Two of the 17-inch monitors. This yielded the following results in Table 6:

TABLE 6: Productivity Metric p-Values of 17-inch Monitor Data

Variable	Pr > F	Pr > F Ln (x)	Pr > F Log (x)	Pr > F SQRT (x)
Keystrokes per Hour	0.66	0.59	0.59	0.63
Clicks per Hour	0.53	0.45	0.45	0.49
Feet of Mouse Movement per Hour	0.54	0.47	0.47	0.50

No significant difference was evident, therefore, all of the 17-inch monitor data was aggregated together. The second stage of analysis was then performed to determine if there is a significant difference between the means with our stated alpha (α) value of 0.05 for the normalized data. The respective p values are enumerated along with the values prior to the transformation in Table 7.

TABLE 7: Productivity Metric p-Values of Transformed Data

Variable	Pr > F	Pr > F Ln (x)	Pr > F Log (x)	Pr > F SQRT (x)
Keystrokes per Hour	0.41	0.33	0.33	0.35
Clicks per Hour	0.36	0.28	0.28	0.30
Feet of Mouse Movement per Hour	0.33	0.29	0.29	0.28

The significance of the F-statistic did not reveal a difference across all of the means that were analyzed, therefore, no further analysis was performed on the productivity metrics. The null hypothesis was not rejected, and a significant difference between the means could not be established. The analysis was then directed from Productivity to Visual and Comfort Metrics.

Visual Comfort Metrics

Chronbach's Alpha

The data from the Visual Comfort Surveys was grouped together to test for internal consistency. This is accomplished by determining the Chronbach's alpha value on the data sets. This technique is beneficial for evaluating self-reported assessments of physical discomfort (Bernard, et al., 1994). The minimal value across all lines of evaluation was not less than 0.94 (see Table 8).

TABLE 8: Values for Chronbach's Alpha on Visual Comfort Metrics

Visual Comfort Ratings	Chronbach's Alpha Value
Difficult to Read	0.95
Heavy Eyelids	0.94
Eye Strain	0.94
Burning Sensation in Eyes	0.94
Eyes Feel Weird	0.95
Eye Itching	0.95

Values greater than 0.9 for human predictability indicate that the variables are highly related (Chronbach, 1951). All of the rating questions used in this study possess a highly related and appropriate inferences can be made concerning the data if it is all grouped together into a category which was defined as Eye Symptoms Score.

Descriptive Statistics and ANOVA

The data was now analyzed by descriptive features in SAS®. SAS® reports several parameters that describe the variables of interest across all cases. This includes the Mean, Minimum, Maximum and p-values for eye symptom variables. Visual discomfort was based upon a continuous scale of 1 to 7. The data was analyzed as a continuous variable because raters do not have to choose from a finite set of points. A one-way ANOVA was used to evaluate the hypothesis that the differences between the Means for eye symptom scores were significant. This data is listed in Table 9.

TABLE 9: Descriptive Statistics and ANOVA of Visual Comfort

Dependent Variable	Mean Value	Minimum Value	Maximum Value	Pr > F
Character size (1=too small, 4=just right, 7=too large)	3.5	1.0	7.0	0.0034
Difficult to read (1=Not at all, 7=Yes, very much)	2.8	1.0	6.0	0.1338
Heavy Eyelids (1=Not at all, 7=Yes, very much)	2.4	1.0	5.0	0.2000
Eye Strain (1=Not at all, 7=Yes, very much)	2.7	1.0	5.5	0.0822
Eye Burning (1=Not at all, 7=Yes, very much)	2.2	1.0	5.0	0.1513
Eyes feel weird (1=Not at all, 7=Yes, very much)	2.0	1.0	5.0	0.6099
Eyes itch (1=Not at all, 7=Yes, very much)	2.1	1.0	5.0	0.7493
Reflections on Eyes (1=Not at all, 7=Yes, very much)	2.5	1.0	7.0	0.2839
Eye Symptoms Score	12.0	0.0	30.0	0.0140

There was a significant difference in the Means for the variables on Character Size, and Eye Symptom Score between the 17-inch monitor and its counterparts.

Contrast of Means

The ANOVA does not indicate which ones are different, so a Contrast of Means was performed on the data. One of the items investigated was whether the eye discomfort values were different between the 17-inch monitor and the other VDUs. Mathematically, that is expressed as:

$\mu_1 \neq \mu_2$, or $\mu_1 \neq \mu_3$, or $\mu_1 \neq \mu_4$

where: μ_1 = 17-inch monitor,
μ_2 = 19-inch monitor,
μ_3 = 21-inch monitor, and
μ_4 = 18.1-inch Flat Panel Display

For example, to test the 17-inch monitor versus the 19-inch monitor, the following equation would apply:

$\mu 1 = \mu 2$

which simplifies to: $\mu 1 - \mu 2 = 0$

with contrast coefficients of 1, -1, 0, and 0 respectively These coefficients were utilized to determine which treatments differed from the Control and 19-inch monitor, for example. This is summarized in Table 10, which outlines the variables that were analyzed and their associated values.

TABLE 10: p-Values from Contrast of Means on Visual Comfort Metrics

Variable	Contrast Equations	Contrast Coefficients	Pr > F for Character Size	Pr > F for Eye Symptom Summary
17-inch Monitor Versus 19-inch Monitor	$\mu 1 = \mu 2$	1, –1, 0, 0	0.0175	.0745
17-inch Monitor Versus 21-inch Monitor	$\mu 1 = \mu 3$	1, 0, –1, 0	0.0004	.0048
17-inch Monitor Versus 18.1-inch FPD	$\mu 1 = \mu 4$	1, 0, 0, -1	0.0235	.0048

The Contrast of Means values on Character Size revealed that there was a significant difference between the 17-inch monitor and its counterparts. The Eye Symptom Summary had a significant difference in Means between the 17-inch monitors and its counterpart, except for the 19-inch monitors. Unfortunately, the differences are not very great as the delta between the Mean values of the Video Display Units was only 0.756 on a self-reported scale of 1-7. The other metrics were not evaluated on other measures of visual fatigue (Difficult to Read, Heavy Eyelids, Eyestrain, etc.) as their ANOVAs did not indicate a significant difference between their Means.

Physical Comfort Metrics

Descriptive Statistics

The distribution of responses for all body parts were heavily skewed to the zero (0) or one (1) category, therefore most people were very comfortable throughout the study. These values are enumerated in Table 13 (Appendix D).

Analysis of Variance

Comparisons among treatments were constructed with an ANOVA model to allow for more precise estimates and powerful tests. The data in Table 11 did not reveal any differences between the means for all areas under investigation, therefore, no further evaluation of the data was merited.

TABLE 11: p-Values of Physical Discomfort Metrics

Upper Extremity Body Part	Left Value for Pr > F	Right Value for Pr > F
Front Neck	0.8732	0.9167
Back Neck	0.9467	0.4836
Upper Back	0.7577	0.4103
Lower Back	0.8634	0.3103
Chest	0.8106	0.7701
Front Hand	0.9867	0.5328
Back Hand	0.9654	0.3065
Front Shoulder	0.9495	0.6031
Back Shoulder	0.9156	0.4943
Front Elbow/Forearm	0.9760	0.3766
Back Elbow	0.9965	0.5517

CONCLUSION

Productivity Synopsis

The goal of this investigation was to quantify the effects of monitor type and size on productivity in keyboarding and mousing tasks. Unfortunately, no statistically significant inference could be made concerning the differences in means on our productivity metrics with the stated alpha value (α=0.05) when the ANOVA was performed. This is the case despite normalization of the data that was skewed to the right for evaluation purposes. The normality of the data was also verified through the Shapiro-Wilk test, and the data behaved normally except for the productivity data (W=0.010) on the 21-inch monitor. Therefore, this data does not indicate any reliability or reproducibility. No further statistical evaluation was performed on the mouse clicks or feet of mouse movement data, as it did not indicate a significant difference between the Mean values when the ANOVA was executed.

Anecdotally, it was observed that there are some “super performers” mixed in with the “normal” people. The employees generating more keystrokes per hour are generally processing Policy Service information (i.e. issuing insurance coverage for property or individuals) in lieu of Claims Administration, which is more paper-intensive. Individuals that had higher keystrokes and mouse clicks per hour performed consistently the same across all treatments.

Additional investigation revealed that certain employees are “power mouse users” and are interspersed with employees that do not rely solely on the mouse as a means of navigating through their applications. The power mouse users navigate through their applications primarily with the mouse, in lieu of utilizing the keyboard for some system commands, and will produce more mouse clicks and more mouse movement as a result of their work habits.

Visual Synopsis

The self-reported visual summary rating on the 10-cm visual analog scale yielded statistically significant differences ($p<0.0140$) between the VDUs with the ANOVA test on the metric Character Size. Further evaluation with the Contrast of Means test indicated significant differences on Character Size between the 17-inch monitor and all of the test monitors in place ($p < 0.0235$). Unfortunately, the Mean difference was only 0.756 on a self-reported scale of 1-7. The difference is not very meaningful in terms of recommending one VDU instead of another.

Subjects rated the 19 and 21-inch CRT monitors and 18.1-inch FPD as generating less visual fatigue than the existing 17-inch CRT monitor. This statistically significant value is interesting in light of the fact that the pixel ratings remained constant between the interventions. This may suggest that the larger monitors were easier to see because they were newer, or because the text is slightly larger.

Physical Discomfort Synopsis

An ANOVA was performed on the physical comfort data to investigate if a larger monitor, or a VDU of differing technology reduced discomfort. The data did not reveal any impact on physical discomfort as a result of these changes. The differences between the means for all areas under investigation were not significant when compared with the stated alpha value (α=0.05). Therefore, no further evaluation of the data was performed. Most employees were comfortable during the duration of the study. Those employees that were uncomfortable did not exhibit a change in symptoms as a result of replacing or substituting differing VDUs.

Despite the 14-fold increase in UEMD's (Upper Extremity Musculoskeletal Disorders) incidence rate from 1972 to 1994, and slight reduction of UEMD's over the last several years (Bernard, 1997), our numbers are quite low on self-reported assessments of physical discomfort. This may demonstrate a highly effective ergonomics program.

Limitations of Study

Strengths of this field study include having extracted data over 5 months, and on-site gathering of data on a weekly basis from participants. The participants worked on computers for at least 8 hours per day. Also, the subjects were encouraged to participate in the study by their supervisors and had a material interest in providing good data to the Principal Investigator. Additional strengths of this study include the electronic capture of the data (Office

Athlete) on the computer—which provided data-rich values for performing statistical analyses. All employees all maintained essentially the same furniture.

Limitations of this study include the impact of the data on the wide fluctuation of hours and work schedules which may have impacted the accuracy of the productivity metrics measured. This was partially controlled by having the users tabulate the number of hours worked at their desks on a weekly basis for the duration of the study. The Principal Investigator had to keep track of where employees were located and rely on employees accurately recording the data that they submitted. The Principal Investigator also had to rely on the users to submit paperwork in a timely manner, and this proved difficult due to the variant workload of the subjects. Further limitations include the lack of consideration of individual visual acuity, the short duration of the study for treatment interventions (two weeks), and the inability to discern whether the treatments had positive effects due to the larger monitors being new, or being superior to existing 17-inch VDUs that were at least 3 years old.

In addition, this field study did not control distance from the eye to the monitor, pixel size, refresh ratings, ambient lighting, intensity of the screen in light output, contrast settings on the monitor, or the physical placement of the monitor on the desk or CPU. A concerted effort was made by the principal investigator to place the test VDU in the same location as the control unit.

REFERENCES

Armstrong, T.J., Radwin, R.G., Hansen, D.J., Kennedy, K.W. 1986. Repetitive Trauma Disorders: Job Evaluation and Design. Human Factors 28 No. 3, 325-336.

Armstrong, T.J., 1986. Upper-Extremity Posture: Definition, Measurement and Control. In: N Corlett, J Wilson, I Manenica (Eds.), The Ergonomics of Working Postures: Models, Methods, and Cases. Taylor & Francis, London, pp. 59-73.

Arndt, R., 1983. Working Posture and Musculoskeletal Problems of Video Display Terminal Operators—Review and Reappraisal. American Industrial Hygiene Association Journal 44, 437-446.

Bendix, T., Krohn, L., Jessen, F., Aaras, A., 1985. Trunk Posture and Trapezius Muscle Load Whilst Working In Standing, Supported-Standing, and Sitting Positions. Spine 10, 433-439.

Bergqvist, U., Knave, B. 1984. Video Display Terminals and Health. Scandinavian Journal of Work. Environment, and Health 10, No. 2., 68-77.

Bergqvist, U., Knave, B. 1994. Eye Discomfort and Work with Visual Display Terminals. Scandinavian Journal of Work, Environment, and Health 20, 27-33.

Bergqvist, U., Wolgast, E., Nilsson, B., Voss, M. 1995. Musculoskeletal Disorders Among Visual Display Terminal Workers: Individual, Ergonomic and Work Organizational Factors. Ergonomics 38, 763-776.

Bernard, B., 1997. Musculoskeletal Disorders and Workplace Factors. National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 97-141, 1-2.

Bernard, B., Sauter, S., Fine, L., Peterson, M., Hales, T. 1994. Job Task and Psychological Risk Factors for Work-Related Musculoskeletal Disorders Among Newspaper Employees. Scandinavian Journal of Work Environmental Health 20, pp. 417-426.

Bland, J., Altman, D.G., 1995. The Normal Distribution, British Medical Journal 310, 298-300.

Borg, G., 1990. Psychophysiological Scaling with Applications in Physical Work and the Perception of Exertion. Scandinavian Journal of Work Environment and Health 16, 55-58.

Bureau of Labor Statistics, 2001. U.S. Department of Labor, Survey of Occupational Injuries and Illnesses. (Report No. USDL 01-71). Available Internet: http://www.bls.gov/case/osch0021.pdf.

Bureau of Labor Statistics, 2001. U.S. Department of Labor, Selected (sprains, strains, tears; carpal tunnel; tendinitis) Natures by Worker and Case Characteristics. Table 9, Occupational Safety and Health Data. Available Internet: www.bls.gov/oshsum1.htm.

Cannon, L., Bernacki, E., Walter, S.D., 1981. Personal and Occupational Factors Associated with Carpal Tunnel Syndrome. Journal of Occupational Medicine 23, No.4, April 1981, 255-258.

Carter, J.B., Banister, E.W., 1994. Musculoskeletal Problems in VDT Work: A Review. Ergonomics 37, No. 10, 1623-1648.

Chronbach, L.J., 1951. Coefficient Alpha and the Internal Structure of Tests. Psychometrica 16, No. 3, 297-334.

De Wall, M., Van Riel, M.P.J.M., Aghina, J.C.F.M, Burdorf, A., Sniders, C.J., 1992. Improving the Sitting Posture of CAD/CAM Workers by Increasing VDU Monitor Working Height. Ergonomics 35, No. 4, 427-436.

Duncan, J., Ferguson, D., 1974. Keyboard Operating Posture and Symptoms in Operating. Ergonomics 17, No. 5, 651-662.

Evans, J., 1987. Women, Men, VDU Work and Health: A Questionnaire Survey of British VDU Operators. Work and Stress 1, No. 3, 271-283.

Federal Register, 1999. Ergonomics Program, Proposed Rule, 29 Code of Federal Regulations, 1910.900.

Gerr, F., Marcus, M., Ensor, C., Kleinbaum, D., Cohen, S., Edwards, A., Gentry, E., Ortiz, D.J., Montielh, C., 2002. A Prospective Study of Computer Users: I. Study Design and Incidence of Musculoskeletal Symptoms and Disorders. American Journal of Industrial Medicine 41, 221-235.

Gerr, F., Marcus., M., Ortiz, D.J., 1996. Methodological Limitations in the Study of Video Display Terminal Use and Upper Extremity Musculoskeletal Disorders. American Journal of Industrial Medicine 29, 649-656.

Gobba, F., Broglia, A., Sarti, R., Luberto, F., Cavalleri, A. 1988. Visual Fatigue in Video Display Terminal Operators: Objective Measure and Relation to Environmental Conditions. International Archives of Occupational and Environmental Health 60, 81-87.

Hagberg, M., 1996. Exposure Considerations When Evaluating Musculoskeletal Diagnoses. Advances in Occupational Ergonomics and Safety I. 2, 411-415.

Hagberg, M., Wegman, D.H., 1987. Prevalence Rates and Odds Ratios of Shoulder-Neck Diseases in Different Occupational Groups. British Journal of Industrial Medicine 44, 602-610.

Hunting, W., Grandjean, E., Maeda, K., 1980. Constrained Postures in Accounting Machine Operators. Applied Ergonomics 11,145-149.

Hunting, W., Laubli, T., Grandjean, E., 1981. Postural and Visual Loads at VDT Workplaces I. Constrained Postures. Ergonomics 24, 917-931.

Huskisson, E. C., 1974. Measurement of Pain. The Lancet 2, 1127-1131.

IBM (International Business Machines), 2000. Think Research, Read the Fine Print, Available Internet: www.research.ibm.com/thinkresearch/pages/2000/200011_roentgen.shtml

International Standards Organization/ Technical Committee, 1999. ISO/TC 159/SC4/WG2 N435: WG2 final text for ISO/FDIS 13406-2: (E)., Ergonomic Requirements for Work With Visual Display Bases on Flat Panels—Part 2: Ergonomic Requirements for Flat Panel Displays. ISO Template Version 3.3 1998-01-12, ISO, Revision Date 1999-06-24 1-163.

International Standards Organization ISO 9241-PART 3, 1992. Ergonomics Requirements for Office Work With Visual Display Terminals: Visual Display Requirements, ISO, 1-27.

Jaschinski, W., Heuer, H. Kylian, H, 1998. Preferred Position of Visual Displays Relative to the Eyes: A Field Study of Visual Strain and Individual Differences. Ergonomics 41, No. 7, 1034-1049.

Jaschinski-Kruza, W. 1991. Eyestrain in VDU Users: Viewing Distance and the Resting Position of Ocular Muscles. Human Factors 33, No. 1, 69-83.

Knave, B.G., Wibom, R.I., Voss, M., Hedstrom, L.D., Bergqvist, U., 1985. Work With Video Display Terminals Among Office Employees: I. Subjective Symptoms and Discomfort. Scandinavian Journal of Work, Environment and Health 11, 457-466.

Lander, C., Korbon, G.A., DeGood, D.E., Rowlingson, J.C., 1986. The Balans Chair and Its Semi-Kneeling Position: An Ergonomic Comparison with the Conventional Sitting Position. Spine 12, No. 3, 269-272.

Maeda, K., Hunting, W., Grandjean, E., 1982. Factor Analysis of Localized Fatigue Complaints of Accounting Machine Operators. Journal of Human Ergology 11, 37-43.

Marcus, M., Gerr, F., Montielh, C., Ortiz, D.J., Gentry, E., Cohen, S., Edwards, A., Ensor, C., Kleinbaum, D., 2002. A Prospective Study of Computer Users: II. Study Design and Incidence of Musculoskeletal Symptoms and Disorders. American Journal of Industrial Medicine 41, 221-235.

Methods Time Measurement-1A, 1978. Standards and Research Application Course. Training and Applications Course, MTM Standards Committee, 124-128.

Moore, J.S., Garg, A., 1994. Upper Extremity Disorders in a Pork Processing Plant: Relationships Between Job Risk Factors and Morbidity. American Industrial Hygiene Association Journal 55, No. 8,703-715.

NIOSH, 1990. Health Hazard Evaluation Report HETA 89-250-2046, New York Newsday, 1-58.

NIOSH, 1993. Health Hazard Evaluation Report HETA 90-013-2277 Los Angeles Times, 1-46.

National Research Council, 1983. Video Displays, Work and Vision. Washington, D.C. National Academy Press, 15-19.

National Research Council & Institute of Medicine, 2001. Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. Panel on Musculoskeletal Disorders and the Workplace. Commission on Behavioral and Social Sciences and Education. Washington DC: National Academy Press, 164-179.

Ong, C.N., Chia, S.E., Jeyaratnam, J., Tan, K.C., 1995. Musculoskeletal Disorders Among Operators of Visual Display Terminals. Scandinavian Journal of Work, Environment, and Health 21, 60-64.

OSHA (Occupational Safety & Health Administration) 3123, 1993. Ergonomics Program Management Guidelines for Meatpacking Plants. U.S. Department of Labor, 1-40.

OSHA (Occupational Safety & Health Administration) 29 CFR 1910.900, 1999. Ergonomics Program. U.S. Department of Labor, 72-75.

Ostberg, O., 1975. CRTs Pose Health Problems for Operators. International Journal of Occupational Health and Safety 44, 24-26, 46, 50-52.

Pickett, C.W.L., Lees, R.E.M., 1991. A Cross-Sectional Study of Health Complaints Among 79 Data Entry Operators Using Video Display Terminals. Occupational Medicine 41, No. 3, 113-116.

Polanyi, M.F.D., Cole, D.C., Beaton, D.E., Chung, J., Wells, R., Abdoiell, M., Beech, L., Ferrier, S.E., Mondloch, M.V., Shields, S.A., Smith, J.M., Shannon, H.S. 1997. Upper Limb Work-Related Musculoskeletal Disorders Among Newspaper Employees: Cross-Sectional Survey Results. American Journal of Industrial Medicine 32, 620-628.

Rogowitz, B.E., 1984. Measuring Perceived Flicker on Visual Displays. In: E. Grandjean, (Ed.), Ergonomics and Health in Modern Offices, Taylor and Francis , London, pp. 285-293.

Rossignol, A.M., Morse, E.P., Summers, V.M., Pagnotto, L.D., 1987. Video Display Terminal Use and Reported Health Symptoms Among Massachusetts Clerical Workers. Journal of Occupational Medicine 29, No. 2, 112-118.

Royston, P., 1992. Approximating the Shapiro-Wilk W-Test for Non-Normality. Statistics and Computing 2, 117–119.

Ryan, A.G., Bampton, M., 1988. Comparison of Data Process Operators With and Without Upper Limb Symptoms. Community Health Studies, 12, No. 1, 63-68.

SAS Institute, 1989. User's Guide, Version 6, Fourth Edition, 1 and 2, Cary, NC: SAS Institute.

Shapiro, S.S., Wilk, M.B., 1965. An Analysis of Variance Test for Normality (Complete Samples). Biometrika 52, No. 3 and 4, 591-611.

Smith, M.J., Cohen, B.G.F., Stammerjohn, L.W., Happ, A., 1981. An Investigation of Health Complaints and Job Stress in Video Display Operations. Human Factors 23, No. 4, 387-400.

Sotoyama, M., Jonai, H., Saito, S., Villanueva, M.B.G., 1996. Analysis of Ocular Surface Area for Comfortable VDT Workstation Layout. Ergonomics 39, No. 6, 877-884.

Starr, S.J., Shute, S.J., Thompson, C.R., 1985. Relating Posture to Discomfort in VDT Use. Journal of Occupational Medicine 27, No. 4, 269-271.

Tyrell, R.A., Leibowitz, H.W., 1990. The Relation of Vergence Effort to Reports of Visual Fatigue Following Prolonged Near Work. Human Factors 32, No. 3, 341-357.

Video Electronics Standards Asociation, 1998. Flat Panel Display Measurements Standard, VESA, Version 1.0.

Walsh, M.L., Harvey, S.M., Facey, R.A., Mallette, R.R. 1991. Hazard Assessment of Video Display Units. American Industrial Hygiene Association Journal 52, No. 8, 324-331.

Wang, A. H., 2000. Effects of Polarity and Luminance Contrast on Visual Performance and VDT Display Quality. International Journal of Industrial Ergonomics 25, No. 4, 415-421.

APPENDIX A

PRODUCTIVITY METRICS QUESTIONNAIRE

Name:____

Date: ____

1. How much time do you spend working on your computer each day?:

1-2 hours ____________________
3-4 hours ____________________
more than 5 hours ___________________

2. I work the following number of days every workweek:

4-day work week ______________
3-day work week ______________
5-day work week ______________

3. I spend the majority of the week at my workstation:

Yes __________ No _________ (If no, number of hours) _____________

4. I was in training this week:

Yes __________ No _________ (If yes, number of hours) _____________

5. I worked overtime this week:

Yes __________ No _________ (If yes, number of hours) _____________

OFFICE ATHLETE STATISTICS SUMMARY

	This Week	This Month	TOTAL
Number of Keystrokes			
Number of Mouse Clicks			
Feet of Mouse Movements			

(GO TO NEXT PAGE)
Interoffice Questionnaires to: Safety, Michael Johnson

APPENDIX B

VISUAL COMFORT METRICS QUESTIONNAIRE

Monitor characteristics (circle response)

1. The characters on the screen were:

	(*Too small*)					(*Too large for me*)	
	1	2	3	4 ↑ *Just Right*	5	6	7

Eyestrain

	(*Not at all*)					(*Yes, very much*)	
1. I have difficulties seeing:	1	2	3	4	5	6	7
	(*Not at all*)					(*Yes, very much*)	
2. My eye lids are heavy:	1	2	3	4	5	6	7
	(*Not at all*)					(*Yes, very much*)	
3. I feel eye strain:	1	2	3	4	5	6	7
	(*Not at all*)					(*Yes, very much*)	
4. I have burning eyes:	1	2	3	4	5	6	7
	(*Not at all*)					(*Yes, very much*)	
5. I have a strange feeling around my eyes:	1	2	3	4	5	6	7
	(*Not at all*)					(*Yes, very much*)	
6. I have itching eyes:	1	2	3	4	5	6	7
	(*Not at all*)					(*Yes, very much*)	
7. I was disturbed by the reflections on the screen:	1	2	3	4	5	6	7

(GO TO NEXT PAGE)

APPENDIX C

PHYSICAL COMFORT METRICS QUESTIONNAIRE

Think about how you feel **RIGHT NOW:**

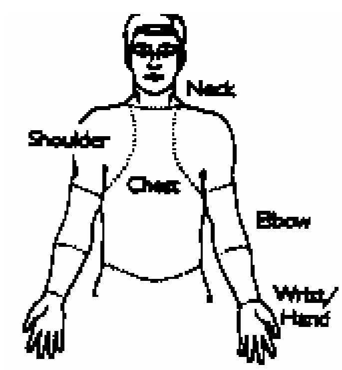
__________ I am experiencing no discomfort now. (Please complete reverse side also if this is true)

__________ I am experiencing discomfort now.

(1) Shade in areas of discomfort on the figure.
(2) Rate the discomfort for the left and right side of the body in the box below.
(3) Using the scale below, write the score in the box, then
(4) Comment on the discomfort in the comment section (if necessary).

No Discomfort Worst Imaginable Discomfort
0-------1-------2-------3-------4-------5-------6-------7-------8-------9-------10

Discomfort Area	Rating Score	
	Left	Right
Neck		
Shoulder		
Chest		
Elbow/ Forearm		
Hand/Wrist		



F R O N T

Comments:

Please Complete reverse side
Interoffice Questionnaires to: Safety, Michael Johnson

PHYSICAL COMFORT METRICS QUESTIONNAIRE

Think about how you feel **RIGHT NOW**

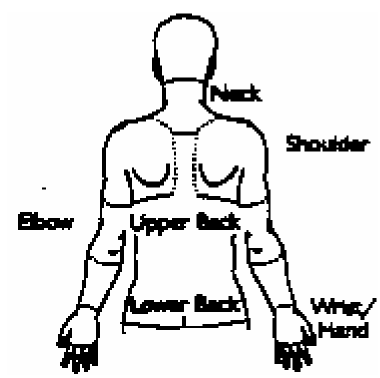
_________ I am experiencing no discomfort now. (Please complete reverse side also if this is true)

_________ I am experiencing discomfort now.

(1) Shade in areas of discomfort on the figure.
(2) Rate the discomfort for the left and right side of the body in the box below.
(3) Using the scale below, write the score in the box, then
(4) Comment on the discomfort in the comment section (if necessary).

No Discomfort Worst Imaginable Discomfort
0-------1-------2-------3-------4-------5-------6-------7-------8-------9-------10

Discomfort Area	Rating Score	
	Left	Right
Neck		
Shoulder		
Upper Back		
Elbow/ Forearm		
Hand/Wrist		
Lower Back		



BACK

Comments:

Interoffice Questionnaires to: Safety, Michael Johnson

APPENDIX D

PRODUCTIVITY/COMFORT METRICS TABLES/FIGURES

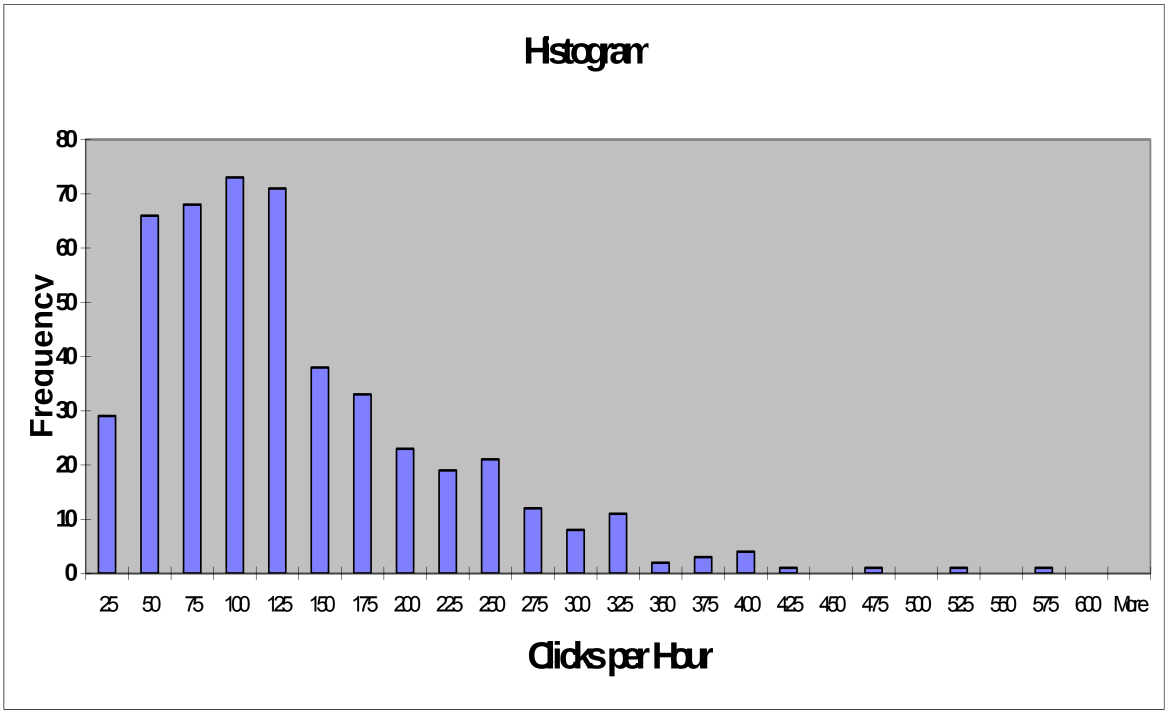


FIGURE 5: Histogram of Mouse Clicks per Hour.

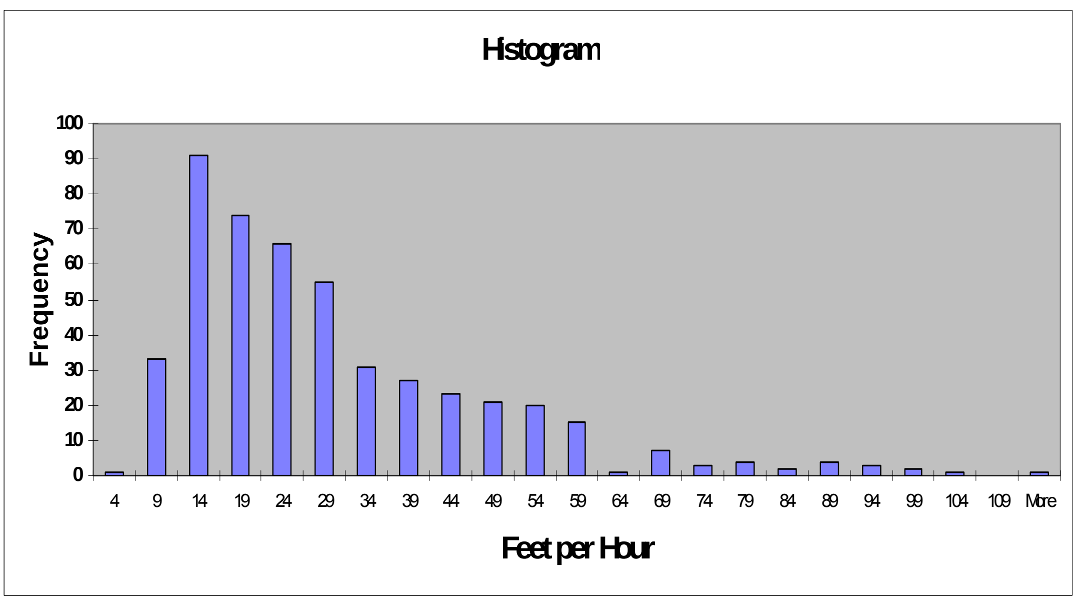


FIGURE 6: Histogram of Feet of Mouse Movement per Hour.

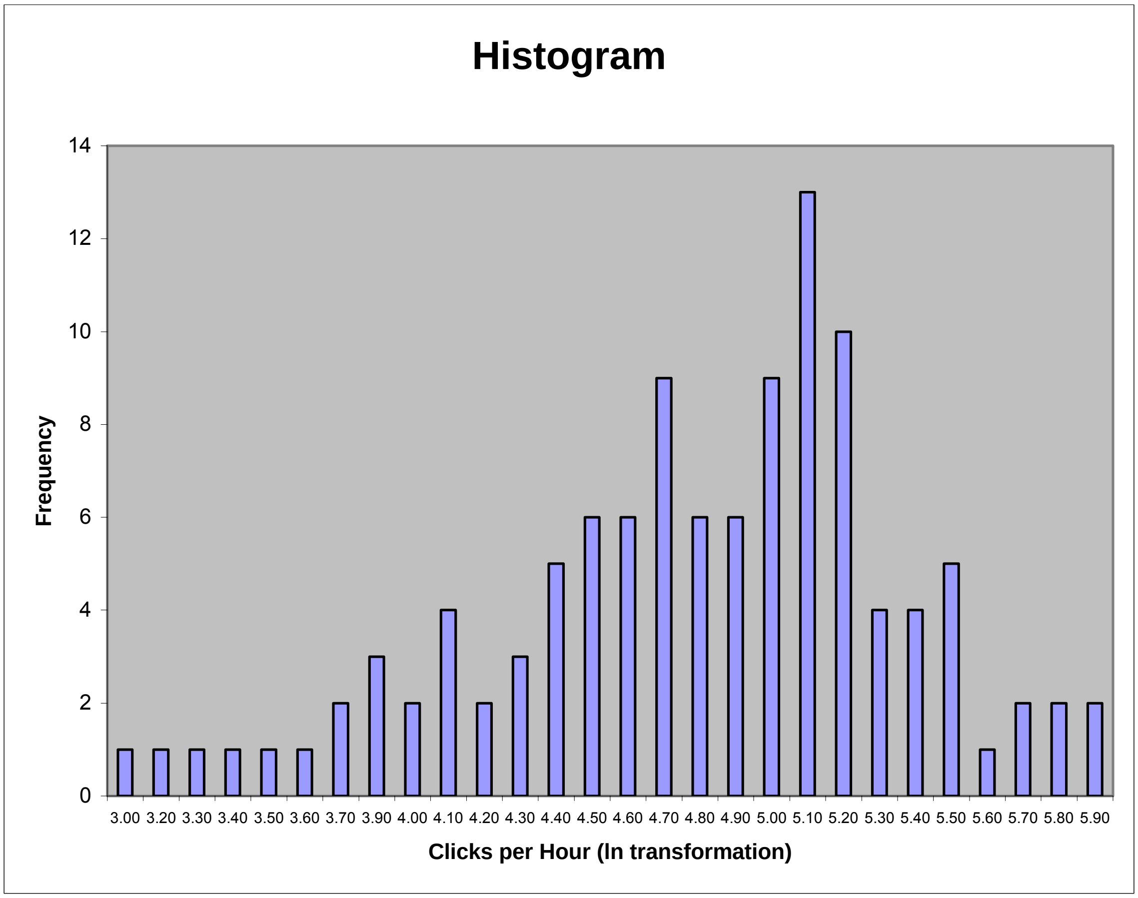


FIGURE 7: Histogram of ln (x) Mouse Clicks per Hour.

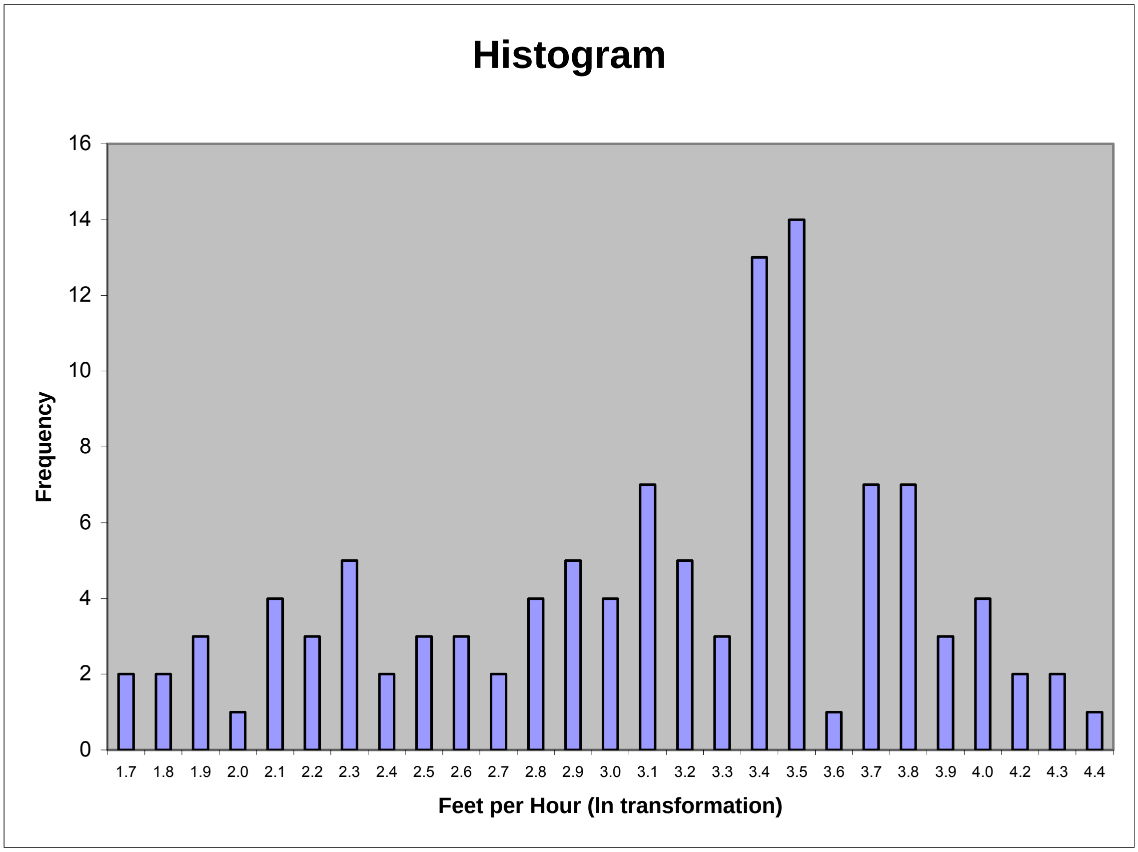


FIGURE 8: Histogram of ln (x) Feet of Mouse Movement per Hour.

TABLE 12: Descriptive Statistics on Productivity Metrics

Mouse Clicks per Hour	17-inch Monitor	19-inch Monitor	21-inch Monitor	18.1-inch Flat Panel Display
Mean	120	154	140	141
Standard Deviation	65	66	85	74
Range	25-310	39-323	20-369	28-364
Feet of Mouse Movement per Hour	17-inch Monitor	19-inch Monitor	21-inch Monitor	18.1-inch Flat Panel Display
Mean	23	31	28	27
Standard Deviation	19	19	15	15
Range	6-67	5-80	6-76	6-76

TABLE 13: Upper Extremity Physical Discomfort Metric Values

Dependent Variables	Mean Value for Left/Right	Median Value for Left/Right	Mode Value for Left/Right
Front Neck Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.650/0.491	0/0	0/0
Back Neck Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.995/0.667	0/0	0/0
Upper Back Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.713/0.482	0/0	0/0
Lower Back Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.620/0.514	0/0	0/0
Chest Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.223/0.271	0/0	0/0
Front Hand Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.538/0.825	0/0	0/0
Back Hand Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.555/0.460	0/0	0/0
Front Shoulder Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.716/0.511	0/0	0/0
Back Shoulder Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.874/0.668	0/0	0/0
Front Elbow/Forearm Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.447/0.456	0/0	0/0
Back Elbow Left/Right (0=No Discomfort, 10=Worst Imaginable Discomfort)	0.561/0.423	0/0	0/0

APPENDIX E

INFORMED CONSENT FORM

INFORMED CONSENT FORM

USAA periodically conducts usability tests on its equipment with the help of people like you. Your participation is an essential part of our product and technical equipment development process. Your participation in this study is vital to investigate the impact of new hardware and software for USAA employees before they are introduced throughout the company.

Your rights as a participant in this study are:

1. You may ask questions at any time. (However, some questions that might influence or bias the outcome of this evaluation will be noted and answered when the session is completed).
2. You may take a break at any time.
3. You may refuse to do any portion of the session.
4. You may stop participation in this study at any time during the session.

Audio-Video Images

None of the video study will be videotaped. You will however, be electronically monitored, and will be responsible for recording these numbers as a condition of participation in this study. This information is useful for:

- Data analysis by the USAA Safety/Environmental Affairs team.
- Providing management direction on equipment purchases

You will not be identified by name on any reports.

Questions?

The undersigned agrees that the procedure was fully explained and all questions were answered prior to signing this consent.

____________________________________ __________________

Signature Date

____

Usability Specialist Date

APPENDIX F

IRB APPROVAL

FORM II

TO THE INSTITUTIONAL REVIEW BOARD FOR THE USE OF HUMAN SUBJECTS

TEXAS A&M UNIVERSITY

PART A

Project Title: Assessment of the Impact of Large CRT and Flat Panel Displays (FPDs) on Productivity and Musculoskeletal Discomfort in an Insurance Company
Principal Investigators: Dr. J. Steven Moore and Michael F. Johnson
Department: Nuclear Engineering, Texas A&M University
College: Dwight Look College of Engineering
Phone: (409) 862-1345
Sponsor: NSF-I/UCRC in Ergonomics, Texas A&M University

PART B

We have read the Belmont report, "Ethical Principles and Guidelines for the Protection of Human Subjects of Research" and subscribe to the principles it contains. In light of this Declaration, we present for the Board's consideration the following information that will explain the proposed research:

1. SELECTION AND SOURCES OF SUBJECTS

Subjects used in this field study will be employees of USAA (United Services Automobile Association, 9800 Fredericksburg Road, San Antonio, Texas 78288). The subjects/employees will be CCRs (Customer Contact Representatives) from the USAA Property and Casualty Division. These subjects are randomly chosen from different areas of the company, and are on the phone for more than 5 hours per day. Tasks are similar within subgroups, with some individuals handling phone calls for policy service activities, and some subjects will be handling insurance claims. All participants type the majority of the day in conjunction with the use of a telephone.

Test subjects will **not** be chosen on the basis of prior physical discomfort or injury. The two stipulations for test subjects considered for this field study is that they currently utilize a 17-inch monitor, and spend the majority of the day on the computer. Choosing employees located throughout the company allowed the Principal Investigator to minimize some variation within the test subject's workloads in specific divisions that are not company-wide. Examples of this are catastrophes such as ice storms, which increase workloads for certain employees for short periods of time in specific areas.

Approximately 30 individuals will participate in this study (15 males and 15 females). The age range of the subjects will be between 18 to 60 years old, and will represent various ethnic populations within the company. Only five divisions within the company participated in this field study.

The field experiment will be 20 weeks in duration for each participant in the study. Volunteers will be provided with the "Informed Consent Form," and have been advised of the same. Agreement with the terms on the Informed Consent Form will be necessary for participation in this study. No subject will be penalized by the NSF-I/UCRC (National Science Foundation Industry/University Cooperative Research Center) in Ergonomics, or USAA if the information resulting from completing the "Informed Consent Form" is found unfavorable. Participation is completely voluntary. All experimental data and questionnaire forms will be kept confidential and maintained in a locked filing cabinet in USAA (Michael F. Johnson's filing cabinet). Only the Principal Investigator and his committee will have access to this information.

2. EXPERIMENTAL PROCEDURE

a. Physical/Behavioral Aspects

The purpose of this study is to answer the following question: What are the productivity and musculoskeletal impacts of replacing existing 17-inch computer monitors with a 19 or 21-inch monitor or large Flat Panel Display in an Insurance Company?

Each subject will first be given an "Informed Consent Form." After the subject reads the form, he or she will be given the opportunity to discuss the form and ask any questions about the experiment. Each subject that participates in the study will sign the "Informed Consent Form."

Subjects may refuse to answer any questions that make them feel uncomfortable, without any loss of benefit to the subject. Each subject will also be requested to fill out a Body Comfort Survey (questionnaire) before and after each treatment (replacement of existing 17-inch monitors with 19 or 21-inch monitors, or large Flat Panel Displays).

Subjects will be requested to fill out an Eye and Body Comfort Survey (see Attachment One) on a weekly basis for a period of 20 weeks.

The form will consist of questions on eye and physical body part discomforts. This form is based upon the Comfort Surveys that NIOSH (National Institute for Occupational Safety and Health) routinely administers to test subjects in studies that they perform. In addition, an eye section will address visual concerns that are brought up by the use of different input devices, and will address employees' perceptions of quality of fonts.

Subjects will rank body discomfort of the upper extremity on a 1 (one) to 10 (ten) scale, with "1" being “minimal to non-existent” and "10" defined as pain one would experience during pregnancy, or the most excruciating pain plausible. This scale distribution will be explained to each employee so that the scales are more homogenous between the subjects. These forms will be filled out for the duration of the study on a weekly basis. This will serve as the qualitative mechanism of gathering employees' perceptions of the effects of the treatments that are administered.

Quantitative data will also be recorded through the use of Office Athlete software. Office Athlete is a software package designed to electronically capture the number of keystrokes (daily, weekly monthly), feet of mouse movement (daily/weekly/ monthly), and mouse clicks (daily/weekly/monthly) performed on a computer for which the software is loaded. The test subjects will not be provided with any ergonomics guidance about their workstation setup, or assistance in optimizing screen performance (i.e., pixel size, monitor resolution, font size) for the duration of the study.

BASELINE SESSION :

The first part of this field experiment will serve as a baseline. Test subjects will also fill out Body Comfort Surveys for 6 weeks to establish a baseline prior to the first treatment (temporary replacement of existing 17-inch monitor with an FPD, or 19 or 21-inch monitor). Employees will be instructed to document the number of keystrokes, feet of mouse movement, and mouse clicks performed on a weekly basis. This information will be placed on the Comfort Survey questionnaire in a section dedicated to the same. The chief investigator will gather this data at the end of each week for the duration of the study (20 weeks).

All testing is invasive, and the participants will merely perform their routine functions that consume a typical workweek.

INTERVENTION SESSION:

In the second part of the experiment, the 17-inch monitor will be replaced with a 19 or 21-inch monitor or Flat Panel Display for a period of two weeks. The test subjects will then have their 19 or 21-inch monitor, or FPD replaced with a 17-inch monitor that they normally use at their job. In this manner, each test subject will serve as their own control, and compare each of three (3) Video Display Units independently. Ideally, workloads will not be changed except for internal fluctuations beyond the control of any field study.

b. Deception or Coercion
None will be used in this experiment.

3. RISKS AND BENEFITS TO SUBJECTS

a. Risks

There are no risks associated with participating in this experiment.

b. Benefits

Subjects will not be paid for their participation in this experiment.

4. SIGNATURES

Principal Investigators:

______________________________ Date: ________________
Michael F. Johnson

______________________________ Date: ________________
Dr. J. Steven Moore

Department Head:

______________________________ Date: ________________
Dr. Alan Waltar

VITA

Name: Michael Federico Johnson
Address: 21340 Cedar Gap, San Antonio, TX; 78266
Phone: 210-651-3108 (H)
210-913-5168 (W)

Education

University of Texas at El Paso (El Paso, TX)
December 1987
Bachelor of Science in Industrial Engineering (School of Mechanical and Industrial Engineering)

Texas A&M University (College Station, TX)
December 2004
Master of Science in Safety Engineering, (College of Nuclear Engineering)

Work Experience

<u>Highlands Insurance (Halliburton Company)</u>
<u>San Antonio, Texas</u>
Safety Representative
January 1988-March 1992

<u>USAA</u>
<u>San Antonio, Texas</u>
Safety Specialist
March 1992 to April 2002
Ergonomics Manager
April 2002-Present

<u>St. Mary's University College of Engineering</u>
<u>Adjunct Professor</u>

- Instructor of Methods Engineering class for Industrial Engineering Program Fall 1999.