Identification and Quantification of Video Display Workstation Set Up on Risk Factors Associated with the Development of Low Back and Neck Discomfort

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(ABSTRACT)

Work related musculoskeletal disorders (WMSD) remain the focus of research efforts as costs associated with these disorders range from 13 to 54 billion dollars annually. WMSDs associated with the back and neck compromise almost 27% of all reported WMSDs. Approximately 1/3 of visual display terminal (VDT) operators report back and neck pain annually (BLS, 1998). Physical risk factors of VDTs associated with low back and neck WMSDs include static work postures and workstation design. The objectives of this study were to assess the effects of monitor height, chair type and their interaction on task performance, back/neck electromyography (EMG), perceived discomfort, and number of posture shifts. Both monitor height and chair type were assessed using two levels (high and low). Participants, four male and four female college age students, performed two data entry tasks using a standard keyboard and monitor and a fully adjustable bi-level table. In addition to the experimenter defined workstation configurations, participants were allowed to adjust their workstation to their preferred settings. Analysis of variance was performed to assess differences in task performance, perceived level of discomfort, number of posture shifts, and EMG data associated with various combinations of monitor height and chair type. Correlation analysis was performed to assess the relationship between participant's perceived discomfort and measured muscle activity to help determine if these two measurements could be used interchangeably to assess workstation design.

No effect of workstation configuration (monitor height/chair type) was found for the majority of dependent variables. An exception was that configuration of low monitor, high chair, and their interaction generated significantly more muscle activity for the low back. User preferred settings were not found to differ significantly from those investigated with respect to muscle activity, perceived discomfort, posture shifts, and performance. Additionally, it was found the participants chose to position the workstation according to guidelines suggested in the literature for reducing WMSD discomfort.

Task effects were found for performance, posture shifts, and perceived level of discomfort. Higher levels of performance and posture shifts for the neck were associated with the typing task, as opposed to the math task. Higher levels of neck discomfort, posture shifts of the feet and posture shifts of the back were associated with the math task.

Correlation analysis provided evidence that perceived discomfort reported by participants and muscle activity for job tasks may not be related. Observed muscle activity for the tasks investigated in this study was low and in some instances, close to resting activity. Due to low levels of EMG, participants may not have been cognizant of their back and neck muscle activity, offering an explanation for why participants experience a cumulative effect of workstation design and seated postures, but linking particular causal factors to the development of LBP and NP is difficult.

The findings of this study suggest that there are no gross physical differences between the chair types or monitor heights as defined in this study. Other factors (such as user preferences, job task demands, specific chair parameters, etc.) may significantly effect chair selection. This study found that task was a significant effect for the majority of dependent variables, and therefore may need to be a major factor driving workstation design. Workstation configuration will help determine the type of static posture assumed at a workstation, but the “discomfort or number of posture shifts” associated with that workstation and posture might be more a result of the job task requirements.

DEDICATION

I dedicate this thesis to God and my family: Mom, Dad, Grandpa, Grandma, Uncle Jeff, Alvin, Carmen, Lloyd, Heather and Ben.

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The author would like to express her sincere gratitude to those whom which this would not have been possible. To my family, you have always provided me love and are undoubtedly the source of my strength and confidence. You are the rock to which I cling in troubled waters, and the rock on which I sprawl upon on bright sunny days. All of you in some way or another have role-modeled the importance of perseverance, faith, wisdom, and humor. With you all behind me, I know that any goal is obtainable and any outcome acceptable. Dr. Kari Babski-Reeves, my thesis advisor, many times along the way, I have stumbled. You not only picked me up, but carried me -- even when your own load was already heavy. You have shown enormous amounts of patience, understanding, and wisdom, and have dedicated countless hours to my student/professional betterment. I feel very lucky and honored to hold the title, “your first student.” To my thesis committee members; Dr. Brian Kleiner and Dr. Maury A. Nussbaum, thanks for your open-door policy, unlimited assistance, high expectations, and unwavering support. To my roommates (Steph, Jen, Cas, and Karen) and other graduate students (Hope, Jimmy, Ken, Ryan, Andrea, Miguel, and Nancy), thank-you for aiding me in my thesis endeavors, but thank-you more for listening, making me laugh, and providing unforgettable friendship. Finally to my close friends (you know who you are) thanks for never failing to show me the silver lining of every cloud, for reminding me on a continual basis of who I am and who I want to be, and for loving me unconditionally.

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Chapter 1

INTRODUCTION

1.1 Background

Due to growing concern over the rise of musculoskeletal disorders (e.g. carpal tunnel syndrome, tendonitis, tenosynovitis, epicondylitis, and low back pain), the years 2000-2010 were coined the "Decade of the Bone and Joint System" (Gatchel and Mayer, 1999) (NIOSH, 1997), (Sauter, Schleifer, and Knutson, 1991). The US Bureau of Labor Statistics (BLS) reported that over 253,000 work related musculoskeletal disorders (WMSDs) occurred in 1998 (BLS, 2000) with total costs (medical expenses, compensation, lost earnings, and lost productivity) approaching $100 billion a year (Pope, Devocht, McIntyre, and Marker, 1999).

A NIOSH report (1997) indicated that the most prevalent and costly WMSD among U.S. industries is back pain. American National Health Statistics show that the number of people disabled from back pain increased approximately 168% from the years of 1971-1986 (Bongers, De Winter, Kompier, and Hildebrandt, 1993). From the years of 1992-1998, the total number of reported cases associated with back and neck pain declined; yet, the percentage of reported back injuries of the total number of occupational injuries and illnesses remained constant (Figure 1.1).

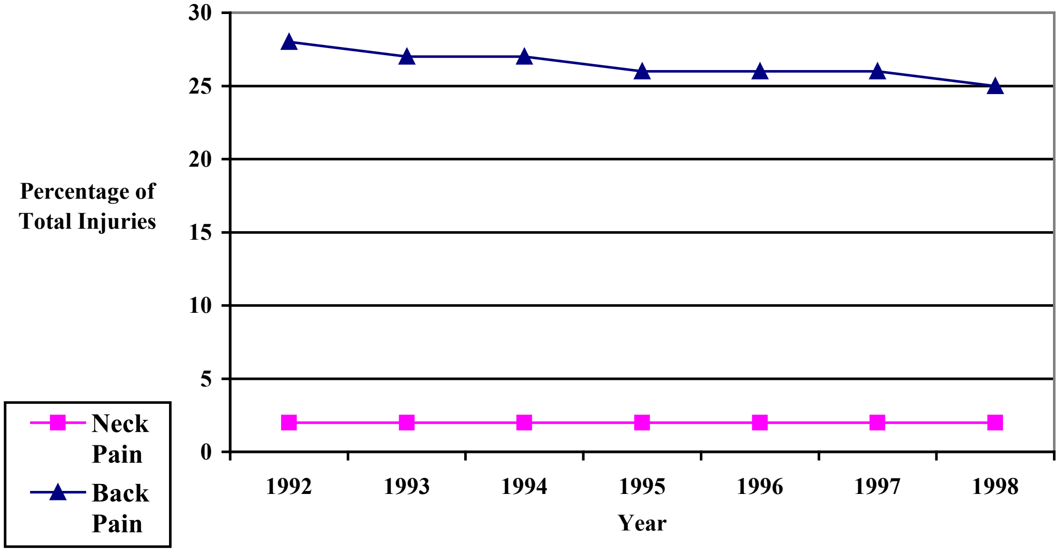


Figure 1.1 Percentage of Back and Neck Pain Injuries During Years of 1992-1998 (BLS, 2000)

Low back pain (LBP) is also one of the most frequent causes of disability among people of working age (18-75 years of age), and the most frequent cause of activity limitation in individuals under 45 (Andersson, 1981). Taylor (1976) estimated that one out of every 25 people either change work tasks or occupations due to LBP.

Economic consequences of BP, the second most common absence from work, can be illustrated from data on lost workdays (Pope et al., 1999). The BLS (2000) reports that 75% of BP cases associated with lost workdays resulted in 3 or more lost workdays, and 26% result in 31 or more lost workdays (Table 1.1).

Table 1.1 Lost Work Days Due to Back Injuries/Back Pain

	Lost Work Days						
Hurt Back/Back Pain	1	2	3-5	6-10	11-20	21-30	31+
Number	5,484	5,160	8,476	5,631	4,273	2,544	10,785
Percent	13	12	20	13	10	6	26

As a result of its frequency and economic consequences, LBP is one of the most frequently studied occupational illnesses, particularly related to sedentary job tasks (Grieco, 1986) (Kelsey, White, Pastides, and Bisbee, 1979) (Mackfarlane, Thomas, Papageorgiou, Croft, Jayson, and Silman, 1997). Pope et al. (1999) estimated that 75% of all workers in industrial countries are employed in sedentary jobs. Rowe (1969) found that 35% of participants classified as sedentary workers reported experiencing back pain.

Since sedentary job tasks span numerous types of activities, typically affecting the entire spine, investigations sometimes report neck pain (NP) as well as LBP (Table 1.2) (Nishiyama, Nakeseko, and Vehata, 1984) (Rowe, 1969) (Smith, Stammerjohn, Cohen, and Lalich, 1980). Although NP accounts for a much smaller percentage of WMSDs than LBP, it too has been frequently studied, especially for sedentary job tasks associated with significant amounts of computer usage.

Table 1. 2 Summary of Research Involving Sitting Postures and Back and Neck Pain (Greico, 1986)

Author	Job Type	# of Participants	Back Pain %	Neck Pain %
Rowe (1969)	Sedentary workers	1,000	35	Not reported
Smith et al (1980)	VDT operators	250	31	Not reported
Van der Heiden et al (1984)	Data entry	53	Not reported	24
	Traditional office workers	55	Not reported	8
Laubli, Grandjean Hunting (1980)	VDT use, data entry	53	Not reported	11
Nishiyama et al (1984)	VDT operators	437	Not reported	38

In 1998, a large number of lost workdays were the result of back and neck pain for persons employed with computerized job tasks (Table 1.3) (BLS 2000). Technical sales and administrative support jobs had over 250,000 lost workdays. Approximately 1/3 of visual display terminal (VDT) operators report back pain (Smith et al., 1980) and neck pain yearly (Nishiyama et al., 1984).

Table 1. 3 Number of Lost Workdays as a Function of Job Type and Body Parts Affected

Occupation	Total # of days	Neck	Back
Accountants and Auditors	1,345		447
Reporters	378		64
Technical sales and administrative support	251,056	5,087	69,194
Computer Operators	664		126
Receptionists	2,969	97	1,640
Secretaries	7,405	40	535

Three main categories of risk factors associated with the development of LBP and neck pain (NP) have been identified.

1. Physical, occupational or ergonomic factors defined as factors that involve interaction between the person's physical body and the environment include: vibration, temperature, heavy lifting, work/rest schedules, static postures, and office layout (Andersson, Ortengren, and Nachemson, 1977) (Helander and Quance, 1990) (Mackfarlane et al.).
2. Individual, personal, or non-occupational risk factors defined as factors associated with the worker's physiological responses and demographics include items such as: age, sex, anthropometrics, musculoskeletal abnormalities, muscle strength, and physical fitness (Yu, Roht, Wise, Killian, and Wier, 1984).
3. Psychosocial, environmental, or organizational risk factors defined as factors involving the interaction between the worker and the organizational or social environment include items such as: work pace, qualitative demands, job content, job control, social support, and job satisfaction (Hoogendoorn, Van Poppel, Bongers, Koes, and Bouter, 2000).

The effects of physical risk factors on LBP and NP during computer use have been the focus of many studies (Psihogios, Sommerich, Mirka, and Moon, 1998) (Rogers and Thomas, 1990) (Sauter et al., 1991) (Shute and Starr, 1984). Two risk factors commonly investigated are prolonged seated postures and VDT equipment positioning. Prolonged seated postures are often associated with job tasks utilizing VDTs, and have particularly been implicated as the cause of LBP and NP in several different studies (Eklundh, 1967) (Kelsey, 1975) (Kottke, 1961) (Magora, 1972). Support is found in the literature that musculoskeletal discomfort is associated with prolonged seated postures due in part to static muscular loading and biomechanical stress (Ankrum and Nemeth, 1995) (Carter and Banister, 1994) (Hagberg, 1984) (Stock, 1991). It is also hypothesized that static spinal loads ensuing from prolonged seated postures impair disc nutrition (Grandjean, 1982) (Hunting, Laubli, and Grandjean, 1981) (Melhorn, 1999).

In addition, numerous studies of VDT workstations have investigated the impact of chair design parameters (e.g. seat height, lumbar support, etc.) and VDT equipment positioning (monitor height, size, distance from operator, etc.) on LBP and NP respectively (NIOSH, 1998) (Psihogios et al., 1998) (Rogers and Thomas, 1990) (Sauter et al., 1991) (Shute and Starr, 1984) (Sommerich, Joines, and Psihogios, 1998). This type of research led to several design recommendations regarding the use of chairs, the importance of the layout, and the formation of standards. Chaffin, Andersson, and Martin (1999) stated "the era of simply providing a chair to solve posture problems is over. Attention to detail in design and layout can improve the safety of seated job tasks (Chaffin, Andersson, and Martin, 1999). ANSI/HFS-100 (1998) recommended several guidelines for minimal chair design features and monitor positioning based on past research.

1.2 Statement of the Problem

An abundance of literature exists on the effects of seated posture on LBP, and monitor height on neck pain. However, Melhorn (1999) argued that insufficient epidemiological evidence exists to suggest a relation between posture and musculoskeletal disorders involving the back. Discrepancies also exist between opinions offered by biomechanists and visual experts on what constitutes optimal parameters for monitor height. Evidence is needed to determine if an interaction exists between NP and ergonomic chair design and between LBP and monitor height. Additionally, research needs to be performed to objectively determine differences, if any, between costly (greater than $1,000) and relatively inexpensive (less than $200) "ergonomic" chair designs on reporting of LBP and NP.

1.3 Objectives of the Study

One objective of this research is to identify and quantify the effects of video display workstation set up (chair type and monitor height) on risk factors associated with developing musculoskeletal pain/discomfort of the back and neck. Associations between the biomechanical aspects of sitting, monitor height, and chair type on LBP and NP will provide indications of potential causal mechanisms, guide further investigation, and directly assist in specification of desirable equipment parameters. A second objective is to determine if physiological differences exist between ergonomic chairs at opposing ends of the price spectrum.

1.4 Justification and Utility

A void exists in the literature regarding the usefulness of, and interaction between, different types of workstation furniture. Quantifying muscle activity, discomfort, performance, and posture shifts for the low back and neck will yield results to improve the design of ergonomic office furniture. The results of this study may be used for future chair design, workstation recommendations, or development of tools for VDT workstation set-up. By identifying the physiological differences between ergonomic chairs with different costs, implications of this research may aid future decisions associated with chair purchases.

1.5 Scope and Limitations

The study was limited to the effects of chair type, monitor height, and their interaction in a VDT setting on LBP and NP. While there are other physical parameters that affect the workstation; such as desk height, lighting, and sound; they will not be manipulated in this study. In addition, evaluation of personal and psychosocial work factors as they interact with the physical aspect of the seated work environment will not be addressed.

Numerous jobs require seated postures, yet this study will only address tasks related to VDT's. Although considerable debate exists between the increased risk of musculoskeletal disorders associated with VDTs versus traditional office jobs, VDTs were selected for evaluation based on the number of lost workdays due to LBP, 1369, and NP, 48, and the growing number of VDT workstations. The number of lost workdays associated with VDT work were presented in Table 1.2. These numbers identify the need for research directed at reducing LBP and NP for VDT workstations.

Finally, this study is designed to objectively and subjectively measure musculoskeletal activity and discomfort. As referenced in Chapter 2, visual fatigue also plays an important role in determining monitor height and has an impact on NP. Visual fatigue will be addressed subjectively, but will not be objectively measured.

Chapter 2
LITERATURE REVIEW

2.1 Introduction

The National Institute for Occupational Safety and Health (NIOSH, 1997) performed a critical review of the epidemiological evidence for a causal relationship between static postures and LBP and NP. Based on this review, there is insufficient evidence to identify a causal relationship between back pain and static work postures (NIOSH, 1997). Conversely, strong epidemiological evidence does exist relating neck disorders and physical work factors, such as posture (Melhorn, 1999). Based on several studies, NIOSH suggested that an exposure-response effect existed, wherein increasing levels or durations of exposure to static posture resulted in an increased number of neck MSDs.

The particular static posture assumed, or the length of time the posture is maintained, can be directly related to workstation set up (i.e. parameters associated with the chair, desk, keyboard, and monitor). Recommendations vary regarding workstation parameters (specifically regarding chairs and monitors) during seated postures, with two primary modalities emerging: workstation set-up as a function of anthropometrics (usually guidelines) (Akerblom, 1954) (NIOSH, 1998) and workstation set up as a function of user preference (usually recommendations) (Grandjean, Hunting, and Piderman, 1983) (Hunting et al., 1981) (Shute and Starr, 1984). Shute and Starr (1984) found in their VDT analysis that an erect posture, with vertical trunk and upper arms and horizontal thighs and forearms (as suggested by NIOSH, 1997) was not typically adopted in the field. Coleman et al. (1998) argues that even with anthropometric information available, people do not necessarily prefer chairs that correspond to their anthropometric dimensions, and thus frequently fail to adjust the furniture according to this criterion.

2.2 Back Pain

With the exception that existing back pain would increase as the mechanical stresses upon the back increased (Andersson et al., 1977) (Yu et al., 1984), past studies evaluating the relationship between seated/static postures and monitor height, and back disorders were primarily epidemiological in nature and lacked the numbers, quality, consistency, and/or statistical power necessary to determine presence or absence of causal relationships (Melhorn, 1999) (Petersen III, White III, and Panjabi, 1999). Since unclear relationships exist between seated postures and back pain (Burton, 1984), it is difficult to say that a sedentary occupation alone is the cause of LBP or NP. Researchers have presented cases demonstrating no risk associated with sedentary occupations (Frymoyer, Pope, and Costanza, 1980) (Heliovaara, 1987) (Hildebrandt, 1995) (Kelsey, Golden, and Mundt, 1990), prolonged seated postures have been particularly implicated as the cause of LBP in several studies (Eklundh, 1967) (Kelsey, 1975) (Kottke, 1961) (Magora, 1972). Nachemson (1971) believed that LBP occurred with approximately the same frequency among persons with sedentary occupations as persons performing heavy labor. Kelsey et al. (1990) showed an increased risk of prolapsed lumbar disc for people employed in sedentary occupations for prolonged periods of time. Additionally, Magora (1972) found that prolonged exposure to seated postures over time is associated with high frequencies of reported LBP -- 35 % of sedentary workers had made visits to doctors for LBP within a 10-year period (Table 1.1) (Rowe, 1969) (Yu et al., 1984). Hettinger (1985) measured the effect of sitting posture on LBP through an epidemiological study where he evaluated the number of sick days taken by both administrative and traditional laborers. Since workers in the administrative sector reported more sick days associated with LBP than the industrial sector, he concluded that seated postures should be considered on same hazardous level as lifting of weights and vibrations.

2.2.1 Chair Studies Involving Physical Risk Factors

Because the chair affects the static posture assumed by the operator and is directly linked to the other components of a VDT workstation, it has been deemed the most important factor of the workstation (Carter and Banister, 1994) and studied extensively. However, due to disagreements regarding optimal seated postures and the use of participant preferences, typically confounded by body dimensions and work habits, recommendations regarding an optimal seat position or seat type are often difficult to make.

Discussions of ergonomic chairs commonly consider the impact of psychosocial and individual parameters on the set up and importance of the “ergonomic” chair. These non-physical parameters consist of anthropometric dimensions (Coleman, Hull, and Ellitt, 1998), physical fitness, gender, age, job satisfaction, task complexity, comfort, work-rest schedules, etc. (For more see Chapter One defining these parameters). Specifically, research by Helander and Zhange (1997) has shown that a person is less likely to experience LBP in a chair that they find "comfortable," and that this comfort level can be assessed almost instantaneously regardless of anthropometrics. Thus, Coleman et al. (1988) claims that what is considered comfortable to the user is the best practice. Greico (1986) further states that due to the physiological aspect of lumbar disc metabolism, the worker should be given more than an ergonomic chair. The work environment or tasks should encourage the worker to change posture frequently. Recommendations based on non-physical parameters address work task design; such as maximum times that various fixed seated postures can be held, and the frequency, minimum, and optimum length of pauses and postural alternatives assumed by the operator (Grieco, 1986).

In addition to the non-physical parameters, studies have been developed and evaluated to show the influence of numerous physical chair parameters on the development of LBP (Shute and Starr, 1984). The chair parameters evaluated include items such as seat type (Rogers and Thomas, 1990), seat pan (Lueder, 1986), seat height (Helander, Zhang, and Michel, 1995), backrest type (Helander et al., 1995), backrest angle (Burton, 1984) (Grandjean et al., 1983) (Lueder, 1986), lumbar support (Sauter, Chapman, and Knutson, 1984) (Van Popple, De Looze, Roes, Smid, and Bouter, 2000), and presence of armrests (Andersson and Ortengren, 1974) (Kroemer, Kroemer, and Kroemer-Elbert, 2000) (Tijerina, 1984). Specifically, Andersson et al. (1977) found that chair configuration has a substantial effect on both intra-discal pressure and lumbar muscle response. Unsupported seated postures are related to higher lumbar responses than supported seated postures utilizing chairs equipped with backrests, arm rests, and lumbar support. Burton (1984) found that trunk muscle activity varies depending on the seat, backrest type, and backrest angle, where specifically, disc pressure decreases (from approximately 700 N to 450 N) as the backrest angle increases (from 80 degrees to 110 degrees with lumbar support present) (Magnusson and Pope, 1998) (Magnusson and Pope, 1998). Despite the abundance of research focused on the various aspects of seated postures, chair type as defined monetarily, has not yet been researched.

Results from chair study research yielded important information for the establishment of chair recommendations and guidelines. The American National Standard for Human Factors Engineering of Visual Display Terminal Workstations used some of the past research collected from various researchers to create chair guidelines for tasks requiring moderate or extensive VDT interaction (Table 2.1).

Table 2.1 Guidelines for Chairs used for Applications Requiring Moderate to Extensive VDT use (Chaffin, 1999) Summary of Researchers taken from Chaffin Table 9.5

Features	ANS/HFS 100-1988 (cm)	Ranges from Various Researchers (cm)
Seat		
Height	35-45	35-54
Width	40	40-45
Length (depth)	33-37	33-38
Slope	0-10 degrees	0-6 degrees
Backrest	Required	
Top Height		32-50
Bottom Height		20
Center Height		17-26
Height		10-23
Width		25-40
Horizontal Radius		31-70
Vertical Radius		Convex
Seat-to-back angle	90-105 degrees	
Lumbar Support	Required	
Backrest –Seat Angle		35-105
Inter-armrest Width	41	46-51
Armrest		
Length		15-28
Width		4-9
Height		16-25

2.2.2 Monitor Studies Involving Physical Risk Factors

Although there is a direct relationship between recommendations for the monitor height and chair set-up, few studies have investigated the impact of monitors on static posture effects related to LBP. However, Sommerich (1998) did find (using EMG data) significant results associated with the back in her treatment condition utilizing small monitors (13.6 inches) and viewing angles of –35 degrees.

2.2.3 Measurement of LBP

Low back discomfort and pain are both abstract variables. As such, measurements of these constructs often combine objective and subjective techniques—whereby discomfort is considered an indicator of future pain (Table 2.2). Subjective measures of discomfort are typically used in workstation design in and of themselves to determine user preferences associated with VDT design parameters (Grandjean et al., 1983) (Helander et al., 1995) (Sauter et al., 1991) (Shute and Starr, 1984), and to make comparisons between different environmental settings (non VDT vs VDT, sit-stand workstations) (Starr, Thompson, and Shute, 1982) (Nerhood and Thompson, 1994). Subjective measures can also be used to augment objective measures by yielding the psychological nature of static postures (Bonney, Weisman, Haugh, and Finkelstein, 1990) (Hagberg and Sundelin, 1984) (Psihogios et al., 1998) (Rogers and Thomas, 1990) (Sommerich et al., 1998). Objective data collected for workstation design studies tend to focus on physiological and biomechanical aspects of the worker's static postures. Techniques used to measure the effects of static posture include: EMG (Sommerich et al., 1998), intra-abdominal pressure (Andersson et al., 1977), spinal length measurement (Helander and Quance, 1990), postural analysis (Psihogios et al., 1998) (Schuldt, Ekholm, Harms-Ringdahl, Nemeth, and Arborelius, 1986), radiological methods and counting the number of times position changed (Shackel, Chidsey, and Shipley, 1969) (Turville, Psihogios, Ulmer, and Mirka, 1998). Two of the most common assessment techniques include perceived discomfort and EMG techniques.

Table 2.2 Common Objective and Subjective Measures Utilized to Assess the Effect of Static Posture

Objective	Subjective
EMG	Perceived Level of Exertion
Intra-abdominal Pressure	Discomfort Maps
Postural Analysis	Questionnaires
Spinal length measurement	Visual Analogue Scale
Imaging Techniques (Future)	

2.2.3.1 Perceived Discomfort

Subjective measures such as Perceived Level of Discomfort (Borg, 1982) (Hagberg and Sundelin, 1984), questionnaires, body maps (Corlett and Bishop, 1976) (Schulze and Woods, 1994), and visual analogue scales (Bonney et al., 1990), have been used in VDT studies to yield chair recommendations. Shute and Starr (1984) conducted a field study using discomfort questionnaires to compare conventional adjustable chairs with more advanced ergonomic chairs (the distinction primarily being ease of adjustability). Researchers found that ergonomic chairs were easier to use, and thus, participants adjusted their chair more frequently and with reports of less discomfort. Sauter et al. (1991) used Corlett and Bishop's (1976) discomfort body map to determine the effects of workstation variables (such as keyboard height and seat pan composition) on discomfort. Through regression analysis, they found a significant result regarding the prediction of general trunk discomfort relative to seat back height. Specifically, decreasing the distance between the seat backrest height (above the seat pan) and the seventh cervical vertebra increased the discomfort in the operator's lower back. In addition, Sauter et al. (1991) found that shoulder, neck, and back discomfort coupled with each other in factor analysis, thus suggesting that discomfort experienced during VDT work tends to effect the cervicobrachial regions of the body.

2.2.3.2 EMG

Several disadvantages have been particularly noted with the various objective techniques (mentioned earlier) associated with studying workstation design and/or static posture.

Andersson et al. (1977) found that intra-abdominal pressure is invasive and not ideal for field studies because of lack of environmental control. Spinal length measurement is significantly influenced by time of day and is extremely sensitive to posture within the stadiometer (frame used to measure spinal length) (Helander and Quance, 1990). Further, due to these disadvantages and because Andersson et al. (1977) found no statistical significance between intra-abdominal pressure, spinal length measurement and procedures where simple myoelectric activities were used for data collection, EMG is usually selected for VDT studies where it is suspected that a specified muscle or group of muscles is adversely affected by the design of the workplace (Marras, 1990) (Sommerich et al., 1998) (Van Popple et al., 2000).

A fundamentally challenging aspect of an EMG study is maintaining reliability and establishing validity associated with the reproduction of specific postures (Andersson et al., 1977). Controlling the pick-up area, placing the electrodes in the same spot across treatment conditions, and maintaining a static posture help improve reliability (Marras, 1990). Validity is defined primarily by the initial placement of the electrodes for determining the particular muscle(s) under study (Figure 2.1). Sommerich et al. (2000) further stresses that EMG data must be normalized (due to issues identified by (Veiersted, 1991) identifying factors that effect the EMG signal: interelectrode resistance, muscle temperature, local muscle fatigue, electrode spacing, and electrode position relative to muscle), and further suggests that the relation of the muscle activity and load on the spine (instead of just the mean or median) be investigated further.

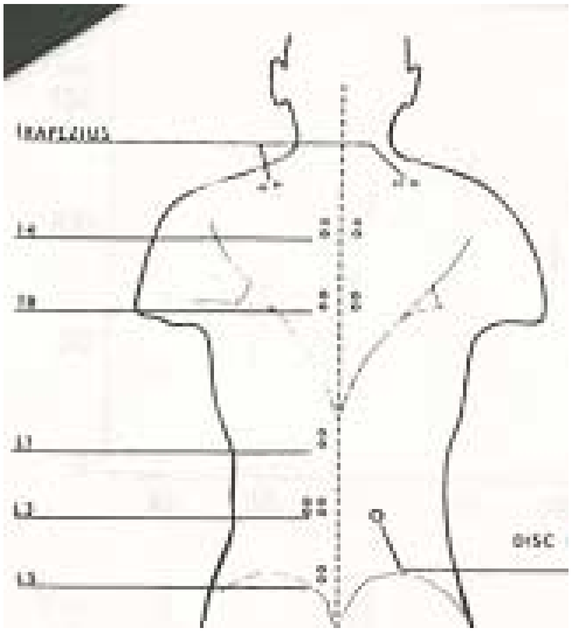


Figure 2.1 Electrode Placement in Andersson et al. (1977)

2.3 Neck Pain

Although strong epidemiological evidence exists relating posture and musculoskeletal neck disorders (NIOSH, 1997) (Petersen III et al., 1999), the majority of studies examining seated postures and neck pain have been characterized by job title rather than job characteristics (such as loads, detailed descriptions of posture, head movements, and materials handled), thereby making comparisons of epidemiological studies difficult (Magnusson and Pope, 1998). Several underlying hypotheses exist for explaining causality of NP while performing seated job tasks: job description, position of the trunk, document placement, and load on the neck (Petersen III et al., 1999) (Stock, 1991). Hagberg (1984) discussed several potential physiological explanations for work-related musculoskeletal discomfort in the neck and shoulder regions, including increased muscular loads as a result of postural fixity, task complexity, environmental stressors and/or characteristics of the individual.

Static postures (postural fixity) have been particularly theorized as the cause of neck pain during data processing on VDT's, where the head acts as a reference between the workstation and the body and must remain still for transference of visual information

(Grieco, 1986). Cervical positioning is influenced by lumbar positioning (Petersen III et al., 1999) since the trunk is connected to the head; thus, during VDT work both the head and trunk will remain immobile while shoulder and neck muscles contract to sustain the load created by the weight of the head on the neck.

2.3.1 Chair Studies

Very few studies thus far have focused on the chair design's effect on the neck. The studies that have measured neck variables often do so as an extension of measuring some other primary region such as the low back or the shoulder.

2.3.2 Monitor Studies

Monitor placement is a key factor in VDT workstation design (Villanueva, Sotoyama, Jonai, Takeuchi, and Saito, 1996) and has been shown to affect both posture and vision. The question of optimal monitor placement has been debated for over two decades without reaching consensus: Sommerich (1998) states, however, that the best location would, seemingly, be one associated with the least discomfort and fatigue, both visual and musculoskeletal. There lies the conflict. Research regarding optimal monitor height parameters is divided between two main occupational categories, biomechanists (recommend higher monitor heights) and visual perceptionists (recommend lower monitor heights) (Psihogios et al., 1998) (Sommerich et al., 1998). Thus, differences regarding monitor height recommendations divulge from two different occupational hazards, the risk of elevated discomfort and fatigue for the eyes and the risk of elevated discomfort and fatigue for the spinal column. Further discussion results from the following: the type of measurement utilized (relative or absolute), inconsistent reference points as discussed in ANSI/HFS (1988), and lack of interactive studies, such as studies that illustrate the relation between monitor height and distance from the operator (Sommerich et al., 1998).

Conventional standards set forth by the National Occupational Health and Safety Commission, NOHSC, (1989), indicated that monitors should be located even with or just below horizontal eye level; however, multidisciplinary researchers disagree on what constitutes the optimal height. Jampel and Shi (1992) show that the ear-eye line in normal erect posture is typically fifteen degrees above the horizontal eye height. Thus, in order for seated workers to fixate on a visual target placed at horizontal eye height, the workers must either compromise preferred gaze angles or rotate heads posteriorly.

Other researchers indicated that monitors should be set lower than desk height, specifically, 15-30 degrees below horizontal eye height (Kroemer et al., 2000) (Mon-Williams, Plooy, Burgess-Limerick, and Wann, 1998), and behind the keyboard to aid in maintaining a neutral posture of the neck and upper extremities to reduce musculoskeletal stress (Magnusson and Pope, 1998). A study by Ankrum (2000) showed that when operators experience musculoskeletal fatigue of the neck, they have few alternative neck postures from which to choose where one option is to tilt the head backward (extension). Neck extension slightly reduces the cost to the visual system; however it greatly increases the cost to the postural system (Ankrum, 2000). In addition, Kumar (1994) found that EMG activity in neck and back muscles increased as neck extension increased. Hattori et al. (1981) found that maximum neck flexions forces were approximately 590 N, but that maximum neck extension forces far exceeded this number with forces approximately 910 N.

A study by Mon-Williams et al. (1998) found that for objects 0.5 m from the operator, the range of preferred gaze angle ranged from 19-36 degrees below the ear-eye line -- at or 15 degrees below the horizontal eye level (Figure 2.2). Sommerich et al. (1998) conducted a study to determine the interaction if any between monitor size, height, keyboard familiarity, and individual differences in visual capabilities. They determined that for VDT work, locating the center of the monitor within a viewing angle of 0 to negative 17.5 degrees, resulted in lower muscle activity, and higher levels of acceptance from operators, than placing the monitor at a negative 35 degree viewing angle. Because of work by Chaffin (1973), illustrating the decrease from five to two hours of time to fatigue musculoskeletally, for visual displays ranging from 30-60 degrees below horizontal, respectively, general viewing angle guidelines do not recommend exceeding this lower envelope (Table 2.3).

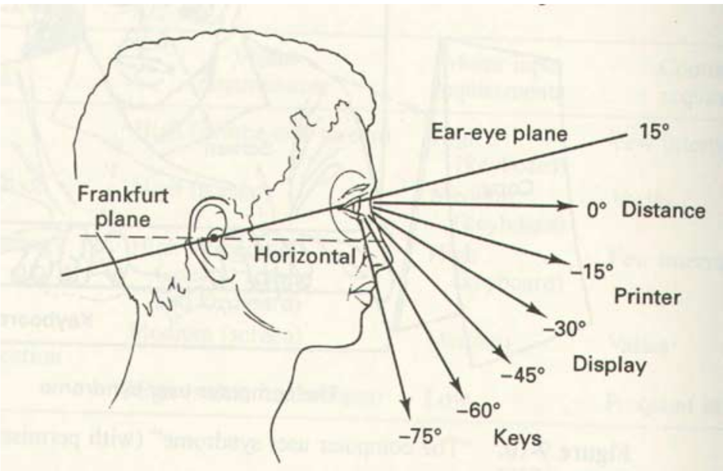


Figure 2.2 Ear-Eye Plane and Horizontal Distance (Chaffin, 1999)

Table 2.3 Summary of Monitor Height Recommendations

Researcher	Monitor Location Range	General Findings
Jampel and Shi (1992)	Approximately 15 degrees above horizontal (0 degrees)	Preferred gaze angle
Mon-Williams et al. (1999)	–15 degrees to horizontal (0 degrees)	Preferred gaze angle
Sommerich et al. (1998)	-17.5 degrees to horizontal (0 degrees)	Participants preferred this to the –17.5 degree to –30 degree range
Kroemer et al. (2000)	-15 degrees to –30 degrees	Based on past studies
Chaffin (1973)	-30 degrees should be the cut-off	Time to fatigue went from 5 hrs (-30 degrees) to 2 hrs (-60 degrees)

Burgess-Limerick et al. (2000) determined that the posture adopted to view any target represents a compromise between visual and musculoskeletal demands. Thus, there still appears to be no definitive answer to the question of the optimal posture (or range of postures) for the head and neck (Burgess-Limerick, Mon-Williams, and Coppard, 2000).

2.3.3 Measurement of Neck Pain

Like LBP, researchers studying the effects of VDT workstation set-up utilize both subjective and objective tools to study discomfort and pain. The subjective tools used to study NP are similar to the ones used by researchers studying LBP (Body maps, PLD, questionnaires, etc.) and are usually combined with objective techniques. Unlike LBP, these objective techniques primarily consist of postural analysis and EMG.

2.3.3.1 Discomfort Studies

The question of optimal monitor height and its effects on discomfort have been debated for years (Sommerich et al., 1998) where some researchers used discomfort as their primary dependent measure and others used it as augmentation to other behaviorally based dependent measures. Many of the guidelines regarding VDT workstations and monitor viewing envelopes were based solely on preferences; thus, Psihogios et al. (1998) suggested that more specific guidelines considering an individual's anthropometrics and visual and musculoskeletal discomfort may be more useful. They used discomfort ratings along with posture analysis at C7 and preference analysis and found that discomfort ratings conflicted with some preferences and recommended monitor height recommendations should be made in conjunction with the preferred slight leaning posture found in other VDT studies (Psihogios et al., 1998).

2.3.3.2 EMG

The neck is particularly affected by crosstalk, normalization methods, and low muscle activity. Since the neck muscles are small and densely packed, innervations zones exist resulting in higher levels of crosstalk concern (e.g. between the neck muscles and the trapezius), thus creating measurement difficulties regarding the collection of specific muscle activity via surface electrodes - especially for the splenius capitis (top most layer of the cervical erector spinae muscle) and semispinalis (Sommerich, Joines, Hermans, and Moon, 2000). For particular neck muscles, crosstalk associated with ECG (heartbeat) poses a problem; however, it is only slightly evident in recording activity of splenius capitis and the data can be filtered for artifacts (Queisser, Bluthner, Brauer, and Seidel, 1994). Schuldt et al. (1986) questions whether it is possible to record from a single anatomically defined muscle in the neck and shoulder using surface electrodes.

Even with careful placement of the EMG electrode over the C7 joint to avoid trapezius activity, the amount of muscle activity generated by the surrounding rhomboids and erector spinae muscles are unknown (Schuldt et al., 1986). Thus, some neck research is defined as location specific (C7) rather than muscle specific.

After careful selection of electrode placement (Figure 2.3), normalization procedures usually commence. For neck EMG studies, normalization procedures including maximal exertion are questioned due to impending validity associated with participants' motivation level and familiarity with the task (Mathiassen, Winkel, and Hagg, 1995). Threat of injury during maximal contractions is also an issue since the neck is not typically engaged in this type of muscle activity (Veiersted, 1991). Sommerich et al. (2000) suggested that since light work tasks (VDT operation) are characterized by submaximal exertions (no fast or forceful neck actions), using a dynamic reference condition does seem warranted; thus, a static reproducible posture should be adopted for reference testing. However, it is important to note that using sub-maximal reference conditions reduces, if not eliminates, comparability to other studies and the ability to state how much of the muscles maximum is being used for a particular task (Sommerich et al, 2000).

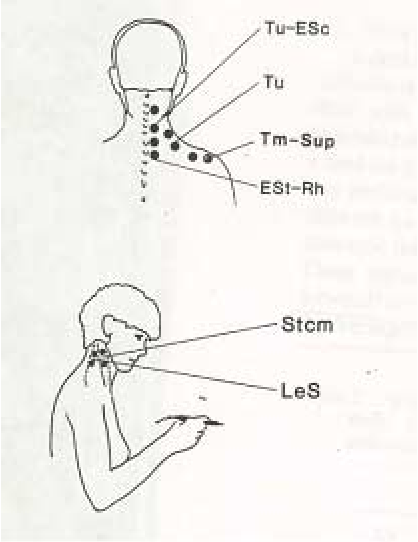


Figure 2.3 EMG Sample Electrode Placement Taken from Sommerich (1998)

Posture specific normalization has also been recommended due in part to the changing of the muscle length “seen” by the electrode and the changing of the muscle length in terms of moment arm and force generation during different postures (Harms-Ringdahl, Ekholm, Schuldt, Nemeth, and Arborelius, 1986) (Harms-Ringdahl et al., 1986). Schuldt and Harms-Ringdahl (1988) found that particular sections of the neck (cervical ES/trapezius, levator scapulae, or splenius) were not impacted by extension exertions during the upper cervical spine position; however, during the lower cervical spine position there was an effect on participants sitting upright. Thus, the practice of using any maximum value from any maximum exertion may not be valid and consideration should be given to the primary direction of action for the specific muscle(s) under study (Mayoux-Benhamou, Revel, and Vallee, 1995).

Except for the trapezius, few EMG studies have been performed on the muscles of the cervical spine (Schuldt et al., 1986). Harms-Ringdahl et al. (1986) stated that low muscle activity in both extreme flexed and extended neck postures indicates that the load moment of the neck is mainly counterbalanced by passive connective tissues, such as joint capsules and ligaments (Takebe, Vitti, and Basmajian, 1974). Takebe et al. (1974) found that the splenius capitis was not active during upright sitting. In fact, very little muscle activity is demanded to keep the head in a normal upright position and bending forward requires only a low activity of cervical erector spinae musculature, carried primarily in the C7-T1 joint (Harms-Ringdahl et al., 1986). Thus, utilizing EMG to measure neck muscle activity may be difficult for small degrees of neck flexion or extension (less than 30 degrees), whereas a neck flexion of 30 degrees or greater can result in a 50% higher rating of muscle activity as compared to the neutral posture of 0 degrees of neck flexion (Harms-Ringdahl et al., 1986).

Villanueva et al (1997) found that normalized static and median neck extensor activity could be attributed to a combination of monitor size, type of screen, and location of the center of the screen. Lie and Watten (1987) evaluated neck muscles as a function of VDT and viewing angles, monitor distance and vergence. Although they found increased postural stress as a result of increased visual fatigue, they can not really explain what caused the increased muscle activity: was the increase due to an increased need for stabilization, forward positioning of head, or a connection between the extraoccular and smooth eye muscles and the postural muscles? Schuldt et al. (1986) used EMG to find that flexed posture associated with sitting tasks yielded significantly higher neck activity than tasks associated with a straight and vertical spine; however, postures with a slight backward-inclination yielded lower neck activity than the straight and vertical spine.

Sommerich et al. (2000) provided a summary of neck studies utilizing EMG to measure muscle activity along and around the cervical spine; studies involving workstation parameters relevant to monitor placement or chair type (Table 2.4). This table illustrated various approaches to using EMG during VDT type work.

Table 2.4 Summary of EMG and Neck Activities (Sommerich, 2000)

Study and Task	Factor of Interest	Muscle and electrode placement	Data collection	Data processing	Muscle activity estimates
Bauer and Wittig; VDT work: reading and mousing	VDT viewing angle, copy holder location	SPL, one at C2 (C3) and other 3 cm caudally	SR=500 Hz	HPF = 40 Hz FWR, AVG	Data presented relative to one of the rest conditions
Hamilton; Reading and typing from copy holder	Source document position	STRN at midpoint, extensors at C2	BW =8 Hz – 100 Hz	FWR, MAW: 20 sec, NMAX	MVC -Typing Extensor: -14.8-5.2% STRN .8-2.4%-
Hautekiet et al.; VDT work: quiet computer game	VDT height and backrest inclination	SPL capitis STRN		NREST	Average SPL: 99.9-128.3 Average STRN 97.8-102.9
Saito et al; Typing	Display type and location	CES covered by TRAP		Integrated for 10 min, AVG, min, max	Data in arbitrary units
Villanueva et al; VDT work: mousing	VDT screen height	Neck extensors at C2 or C3, TRAPD at midpoint between acromion and C7	SR=1000Hz	NMAX, APDF	EMG varied by condition, Neck extensor -Static: 4.9-6.7% MVC -Median: 7.5-9.1% MVC

Key:

- Abbreviations for common muscles: TRAPC--trapezius in cervical region, TRAPD—trapezius pars descendens, LEV—levator scapulae, STRN—sternocleidomastoid, CES—cervical erector spinae, TES—thoracic erector spinae, SPL—splenius
- Abbreviations for common collection procedures: BW—bandwidth, SR—collection sampling rate, RAW—collected raw signal, INT—collected a processed signal
- Abbreviations for common procedures: FWR—full wave rectification, MAW—moving average window, LPF—low pass filter, HPF—high pass filter, NMAX—normalization to a maximum exertion, RVC—normalization to a reference contraction (likely a submax), NREST—normalized to rest, S—maximum in standard posture, W--maximum in working posture, VLT—data presented as voltage, APDF—amplitude probability distribution frequency, AVG—mean values, MED –median values, TAMP—time averaged myoelectic potential

2.4 Summary

There is insufficient evidence relating LBP to static postures assumed while sitting. Since static postures associated with sitting are directly affected by parameters associated with the workstation, some studies have investigated the relationship between chairs and varying levels of LBP and discomfort. Various forms of objective and subjective measure are commonly used to assess LBP, two of which are EMG and perceived level of discomfort surveys, respectively.

Conversely, sufficient evidence does exist relating NP to static postures. Studies evaluating the effect of workstation design on static posture have identified the monitor height as a key element. However, monitor height recommendations have been highly debated throughout the research where a where a majority of the evaluations have been conducted utilizing participant body part discomfort and/or EMG.

In addition to the insufficient evidence existent for relating chair parameters and sitting posture to the development of low back pain and the identification of monitor height as a key factor, yet not being able to pinpoint one optimal range; few studies have identified the effects of the chair on the neck and/or the effects of the monitor height on the low back. In addition, no studies found in this literature review examined the neck and/or back effects associated with evaluating similar chair types on different ends of the price spectrum.

Chapter 3

METHODOLOGY

3.1 Research Design Summary

A 2x2x2x3 within subjects experimental design was used to test for main effects and appropriate interactions of the independent variables -- monitor height (High, Low), chair type (High, Low), task (Math, Typing) and sample (1, 2, 3). A within subjects experimental design was chosen due to its inherent control for variance amongst users during more than one trial.

In addition to the workstation manipulations described above, the participant was also permitted to adjust their monitor height to any height they felt was comfortable and select the chair they would most like to use. Thus, a preference condition was created. A 5x2x3x2 mixed factor design was used to test for main effects and appropriate interactions of the independent variables -- configuration (monitor height and chair type (e.g. MHCL) plus preference section), task (Math, Typing), sample (1,2,3), and the order of which the preference section was given (First, Last). Order of preference was the only between subjects variable; for participants 1-4 it was given last and for participants 5-8 it was given first.

3.2 Independent Variables

Monitor height and chair type variables consisted of two levels, low and high (Table 3.1). Monitor height was defined by the viewing angle created between the user's sitting eye height and the top half of the monitor screen (Figure 3.1). "Low" was approximately 15 to 20 degrees below the horizontal eye line, and "High" was approximately 10-15 degrees above the horizontal eye line (approximate ear-eye line) (Figure 2.1, pg 17). Selection and definition of "High" and "Low" chair type was dependent on cost and basic characteristics. High chair type consisted of a chair pricing over $2000 (market value), while low chair type priced at or under $200 (market value). To ensure chairs were not radically different, comparisons of chairs were conducted to identify chairs with similar adjustable/stable features (Table 3.2), with measurements made according to Appendix B. It is important to note, that the two specific chairs utilized to represent “Low” and “High” chair type were representative of a larger sample of chairs within the given price ranges and these chairs were compared for gross physical differences only.

Table 3.1 Design Representations

	High	Low
Monitor Height	10 –15 degrees above horizontal eye line	Negative 15-20 degrees below horizontal eye line
Chair Type	Approximately $1,500	Approximately $200

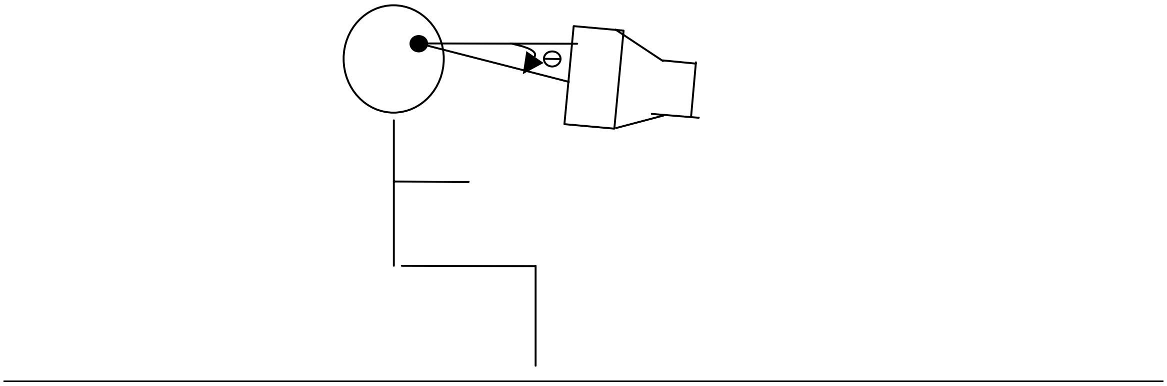


Figure 3.1 Sample of Viewing Angle

Table 3.2 Chair Characteristics

Feature	Pneumatic Executive Task Chair Model OM-105 (cm and degrees)	Steelcase Model 453533IDW (cm and degrees)
Arm Rests		
Inner Distance	52	48
Height (lowest)	22	30
Height (highest)	25	42
Seat Pan		
Width	53	48
Depth	42	46
Height (lowest point)	35	46
Height (highest point)	48	53
Back Rest	Padded, contour, concave, curves in at lower back, not a 90 degree angle with chair, easy to adjust, approximately 10-15 degrees of adjustability	Padded, contour, concave, curves in at lower back, not a 90 degree angle with chair, easy to adjust, approximately 10-15 degrees of adjustability
Height	56	47
Width	48	48

Other factors associated with the independent variable, "chair type" included backrest angle, seat pan depth, seat pan height and armrest height. Since backrest angle and seat pan depth are not adjustable for the Pneumatic Executive Task Chair, the backrest angle for both chairs was fixed at 90 degrees with approximately 10 degrees of adjustability. The edge of the seat pan depth for the Steelcase chair was adjusted so that it matched the 42 cm available on the Pneumatic Executive Task Chair. Participants were instructed to adjust their seat pan according to ergonomic recommendations--sit in an upright position, and adjust the height of the seat pan such that feet are touching the floor with their upper and lower legs forming a 90-degree angle (NIOSH, 1998). Arm rests were adjusted such that the participants arms formed as close to a 90-degree angle with the work surface as possible to minimize wrist flexion or extension (NIOSH, 1998). Seat pan height and armrest configurations remained consistent across multiple testing days for each participant.

In addition to the two chairs, a seventeen-inch Dell monitor and a Generation IV fully adjustable bi-level table were used to manipulate monitor height. Sitting eye height, along with co-tangent calculations, yielded the specific height of the monitor for each testing condition. The monitor screen remained at a 0-5 degree tilt throughout the experiment. The table was adjusted such that the top of the screen was at a height congruent to the high and low conditions specified earlier (Table 3.1). Keyboard height remained constant at 63 cm (29 inches) above the floor for leg clearance (within ANSI/HFS standards).

As a product of the experimental design, task and sample were also considered independent variables. Task consisted of either typing or completing computerized math problems. Samples referred to the three times the participant performed each of these tasks during the testing session (repetitions). Task will be discussed further in section 3.5 Task Design, Procedures and sample are further discussed in section 3.5.3 Test Session.

3.3 Dependent Variables

The dependent variables included muscle activity, number of posture shifts, body part discomfort, and task performance. A detailed description of these is presented in the following sections.

3.3.1 EMG Equipment and Set- Up

Surface-EMG recordings were obtained from selected trunk and neck muscles using bipolar disposable electrodes (one cm diameter, Ag/AgCl pre-gelled). Before attaching the electrodes, the skin was lightly shaved, abraded and cleansed with alcohol to ensure minimal impedance. Electrodes were placed three centimeters to the left of the midline at C7, L1, and L5 vertebrae, in an attempt to capture the activity of the splenius capitis (C7-neck muscle) and multifidi-erector spinae complex (L1 and L5-back muscle). The signals were then transmitted through short (less than 30cm) leads to preamplifiers (100 gain), which were wrapped against the body to maintain adhesion and reduce noise. EMG signals were then hardware amplified, band-pass filtered (30-1000 Hz), RMS converted (55ms time constant), and AD converted. Amplifier and filter settings were not adjusted during the experiment. If electrodes were removed during the experiment, the trial was re-run (Marras, 1990). The time constant was set such that the signal did not exceed 2-3 volts.

After initial electrode placement and a five-minute time elapse, input impedance was measured and the experiment progressed with signal verification, resting muscle activity assessment and a reference contraction. Acceptable levels of input impedance ranged from zero to approximately 10 volts (as measured by standard volt meter). Participants then moved their back and neck to verify that the signal was being received. The participants were then asked to lay on a padded area of the floor with arms resting at their side and legs straight for approximately twenty minutes. EMG readings were sampled at 5Hz for 60 seconds every other minute for a total of four minutes. A reference contraction was used to capture sub-maximal muscle activity of spinal loads on the neck and back while sitting in a neutral posture. Neck reference contractions were obtained by attaching a 2lb weight to the front of a helmet. Back reference contractions were obtained by holding two five pound weights straight out in front of the torso, with arms parallel to the floor.

EMG data was analyzed using a program created in Lab View. This program captured, converted, stored, and analyzed the data according to specified parameters, such as muscle group, frequency (5 Hz), sampling frequency (every other minute), duration of experiment (90 minutes), resting (60 sec) and testing times (60 sec). EMG activity was then averaged across the 60 sec time periods every other minute resulting in 45 different data points used for analysis of each muscle group.

EMG data was normalized using equation 3.1, where EMG_{rest} indicates the muscle activity captured for the resting session and EMG_{ref} indicates the muscle activity captured during the reference contraction session.

Equation 3.1

$$\text{Normalized EMG (NEMG)} = \frac{(EMG - EMG_{rest})}{(EMG_{ref} - EMG_{rest})}$$

3.3.2 Number of Posture Shifts

Posture data was captured redundantly by both the experimenter and a video recorder camera (Panasonic PV-L558) stationed perpendicular to the participant. Neutral posture was defined as the back being upright (i.e. head, shoulders, and tailbone in a straight line). Posture shifts consisted of visual deviations from neutral, and were classified according to the direction and type of movement (Table 3.3). Posture shifts were recorded and tallied for 15 minute intervals throughout the testing session.

Table 3.3 Classification of Posture Shifts (Sample Data)

Body Part Affected	Move Forward	Move Back	Move to Side	Move Up	Other
Neck	5	4	3	3	0
Back	4	3	1	0	0
Other (feet, shoulders, etc.)	4	2	8	5	0

3.3.3 Body Part Discomfort Survey

Body part discomfort was assessed using a modified Borg's Perceived Level of Exertion Scale where zero equaled no perceived discomfort and ten equaled very, very high discomfort (Appendix A) (Borg, 1973). Participants were asked to verbally rate their perceived level of discomfort for the back, neck and eyes every fifteen minutes. The scale was mounted to the monitor to provide visual cues associated with scale anchors. The participants were asked to relate 0-1 on the scale to the feeling of lying on the floor expending little energy, and to relate 5+ to how they felt performing the reference contraction.

3.3.4 Task Performance

Performance was assessed utilizing two separate tasks: simple math tasks (addition and multiplication) and a typing task. For the math tasks, participants responded either true or false. The typing task will be discussed further in section 3.5.1 Task Description. Assessment of task performance consisted of quantifying the number of correctly answered math problems or typed words minus errors. Participants were instructed every 15 minutes to finish the line or problem they were currently working on and switch tasks. Performance on each task were compared across time and treatment conditions.

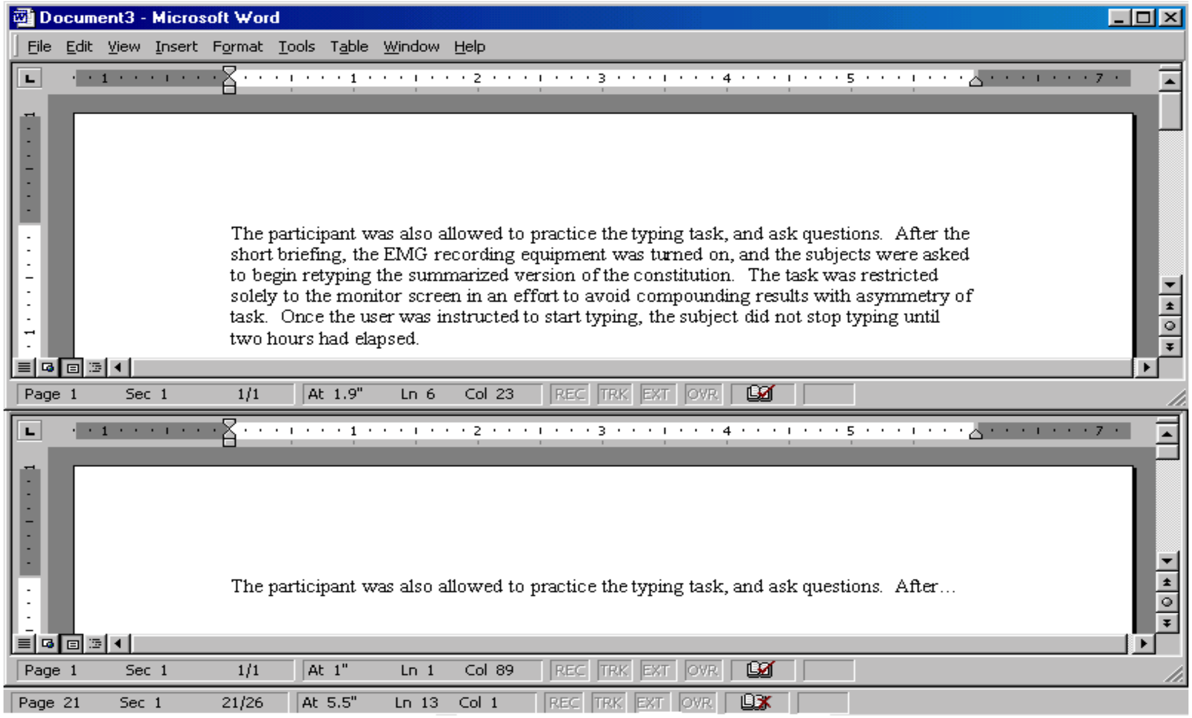
3.4 Confounding/categorical variables

Potential confounding variables included background noise, lighting, and monitor distance (approximately 50-60 cm--within ANSI/HFS 1988 standards). Noise was minimized in the laboratory (shutting the door and posting “quiet” signs), but all participants were permitted to listen to music at a very low level across all treatment conditions. The participants did have the choice of whether or not to listen to music; however, if they chose to listen to music, they listened to the same CD during every treatment condition. The current lighting was sufficient for the typing tasks and remained constant over the treatment conditions (750 lx-sufficient for reading and clerical work). Attempts to fix monitor distance across all treatment conditions were insufficient because the chairs rolled, and participants inadvertently pushed themselves out of the designated range on numerous occasions. Thus, monitor distance varied between 50-60 cm. Gender, age, height, weight and physical fitness were defined as categorical variables and assessed utilizing a short demographic questionnaire at the beginning of the study (Appendix A).

3.5 Job Task Design/Procedure

3.5.1 Task Description

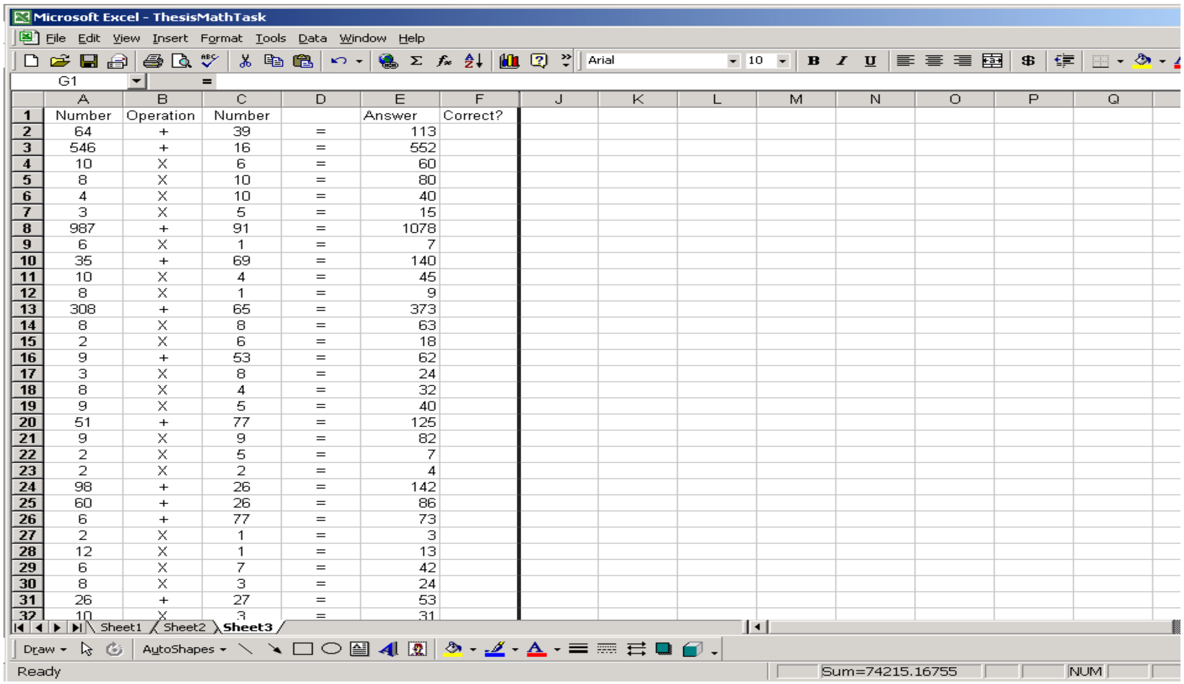
The tasks consisted of alternating between a typing and math task utilizing a standard computer keyboard at a VDT workstation. For the typing task, participants were asked to read the top window on the display and recreate the information via typing in the bottom window (Figure 3.2). Every time the users returned to the typing task, they began where they had last finished. The math task consisted of observing a math problem and answer presented on an Excel spreadsheet and typing either “T” for True or “F” for False (Figure 3.3). Every time the user returned to the math task, they started a new worksheet. Each worksheet consisted of the same problems in randomly different orders, with some having different answers (e.g. 2*5=10 might be on one worksheet, while on another 2*5=7). Both tasks were restricted solely to the monitor screen in an effort to avoid confounding results with asymmetry of task. Twelve-point font was used to comply with ANSI/HFS 1988 standards.



The participant was also allowed to practice the typing task, and ask questions. After the short briefing, the EMG recording equipment was turned on, and the subjects were asked to begin retyping the summarized version of the constitution. The task was restricted solely to the monitor screen in an effort to avoid compounding results with asymmetry of task. Once the user was instructed to start typing, the subject did not stop typing until two hours had elapsed.

The participant was also allowed to practice the typing task, and ask questions. After…

Figure 3.2 Typing Task Representation



	A	B	C	D	E	F
1	Number	Operation	Number		Answer	Correct?
2	64	+	39	=	113	
3	546	+	16	=	552	
4	10	X	6	=	60	
5	8	X	10	=	80	
6	4	X	10	=	40	
7	3	X	5	=	15	
8	987	+	91	=	1078	
9	6	X	1	=	7	
10	35	+	69	=	140	
11	10	X	4	=	45	
12	8	X	1	=	9	
13	308	+	65	=	373	
14	8	X	8	=	63	
15	2	X	6	=	18	
16	9	+	53	=	62	
17	3	X	8	=	24	
18	8	X	4	=	32	
19	9	X	5	=	40	
20	51	+	77	=	125	
21	9	X	9	=	82	
22	2	X	5	=	7	
23	2	X	2	=	4	
24	98	+	26	=	142	
25	60	+	26	=	86	
26	6	+	77	=	73	
27	2	X	1	=	3	
28	12	X	1	=	13	
29	6	X	7	=	42	
30	8	X	3	=	24	
31	26	+	27	=	53	
32	10	X	3	=	31	

Figure 3.3 Math Task Representation

3.5.2 Screening Session

Participants initially completed written informed consent (Appendix E) and were verbally instructed about the experiment. Inclusion in this study was based on the participants' visual capabilities (glasses, except for bifocals, and contacts were accepted), lack of injury or chronic neck or back pain, keyboard familiarity, and personal characteristics (Sommerich, 1998). Lack of injury or chronic pain was evaluated via interview. Participants were asked if in the past year they had experienced any noticeable back/neck pain. Participants were also asked if they had ever had a back/neck operation or any serious musculoskeletal injury. If potential participants had experienced noticeable back/neck pain, a back/neck operation, or a musculoskeletal injury, the participant was excluded from the experiment. Potential participants were given a 50-word paragraph to assess typing proficiency. Participants only needed to demonstrate their ability to type approximately 50 words per minute with less than five errors, else they were excluded from the study. Finally, because EMG electrodes were applied directly to the skin for measurement of muscle activity, the participant could not have excessive hair. If the participant did have excessive hair, he/she was asked if they could be shaved for electrode placement. If the participant did not wish to be shaved, they were not included for this study.

3.5.3 Participants

Eight participants were selected from a university student population. The age range was restricted to a minimum of eighteen years of age, the earliest age for "working age" given in the literature (Mackfarlane et al., 1997). No range maximum existed for this study. Five of the eight participants were engineering students; two were industrial engineering. Personnel demographic information (age, gender, height, weight, and physical fitness) were recorded using a subjective questionnaire (see Appendix A). With the exception of male weight (range was below 50%), participants of this study approximated the 50% percentile for male or female height and weight (Katch, 1996). A summary of the biographical data collected from the participants is presented in Table 3.4.

Table 3.4 Participant Demographics

Participant	Gender	Age	Weight (pds)	Height (in)	Sitting eye (in)
1	F	20	145	66	50
2	M	22	150	70	54
3	F	22	130	66	54
4	F	22	133	66	53
5	M	26	140	66	51
6	M	18	145	69	53
7	M	18	160	70	54
8	F	33	125	64	53
50th %M (Range)			162(140-160)	68 (66-70)	
50th % F (Range)			134 (125-145)	64 (64-66)	
Average (SD):	-	22.6 (4.9)	140.1 (11.8)	67.1 (2.23)	118 (2.14)

3.5.4 Test Session

Participants participated in five test sessions (Table 3.5). The order of the testing sessions were initially randomized and then balanced. Each session lasted approximately two hours including set up time, testing and clean up. Set-up time associated with the participant included issuing the subjective questionnaire, modifying and measuring the chair and monitor height at the workstation, applying the EMG electrodes, and obtaining resting and reference EMG readings. After set-up, the cameras were set to record, the instructions read aloud, and the practice task completed. The EMG recording system was then turned on and the testing session initiated. The participant laid on the floor for approximately twenty minutes while resting EMG was captured. The participant then performed a reference contraction and began the typing task. The typing task lasted 90 minutes. Every 15 minutes the participant alternated between the typing task and the math tasks. At the end of the fifth day of testing, the subjects were asked to rank order their preferred days of testing and to answer Likert scale type questions regarding the different monitor and chair type levels (Appendix A). The participants were compensated at the end of all five trials or in the case of attrition, proportionally, for time spent in the laboratory.

Table 3.5 Treatment Assignments

			Days		
Participant	1	2	3	4	5
1	MLCH	MHCH	MLCL	MHCL	P
2	MHCH	MLCL	MHCL	MLCH	P
3	MLCL	MHCL	MLCH	MHCH	P
4	MHCL	MLCH	MHCH	MLCL	P
5	P	MHCL	MLCL	MHCH	MLCH
6	P	MLCH	MHCL	MLCL	MHCH
7	P	MHCJ	MLCH	MHCL	MLCL
8	P	MLCL	MHCH	MLCH	MHCL

M=Monitor, C= Chair, L=Low, H=High, P=Preference

3.6 Pilot Study

A pilot study was conducted utilizing three females of the population previously described. The pilot study yielded sample data that aided in determining particular task parameters such as the sampling frequency, number of experimental sessions, and discrete data collection categories. Raw data was compared across treatment conditions to determine the differences between using 5, 10 and 15-minute data collection categories. ANOVA revealed no significant difference between data collected using shorter time periods. Therefore, 15-minutes intervals were selected for data collection.

Participants were asked for feedback regarding the task complexity, length, and number of sessions. Overall, they felt frustrated with typing the same material for 2 hours each of the four testing days. Thus, two tasks were created to improve generalizability. The typing task was modified to ensure participants did not type the same material, thus reducing learning effects. Also, music was included at low levels in the background, pending the subject desired background noise.

The pilot study also yielded information for procedural changes such as where/how to apply the electrodes and particular statistical analyses necessary to evaluate data. Specifically, software program (Labview), hardware (channels being utilized) and experimenter errors associated with EMG data collection were identified. Additionally, the Borg scale was not anchored to the monitor during the pilot, so subjects had no frame of reference when responding to perceived levels of discomfort. Posture analysis using goniometers was deemed too difficult/cumbersome because the subjects barely moved during the testing condition. Due to these identified errors, data collected during the pilot was not analyzed and will not be presented.

3.7 Testable Hypotheses

The objective of this study was to determine the effects of chair type and monitor height on worker discomfort and the possible occurrence of low back pain and neck pain. The specific hypotheses tested were:

1. The chair type influences back/neck muscle activity, number of posture shifts, task performance and body part discomfort.
2. Monitor height influences back/neck muscle activity, number of posture shifts, task performance and body part discomfort
3. The interaction of chair type and monitor height influences back muscle activity, number of posture shifts, task performance and body part discomfort.
4. User preference will not differ from anthropometric workstation set-up as measured by muscle activity, number of posture shifts, task performance and body part discomfort.

3.8 Data Analysis

Analysis of the data was both quantitative (descriptive statistics, ANOVA, trend analysis) and qualitative (observing possible trends). Descriptive statistics (means, frequencies, standard deviations, etc.) were calculated for each variable in this study. Associations between the dependent measures and temporal and categorical data for each testing session were analyzed utilizing trend analysis. The exit questionnaire consisting of likert scale type questions and a ranking exercise was summarized and general participant impressions identified. Correlations were drawn between particular EMG data and perceived level of discomfort rating. Analysis of variance, ANOVA, was performed to assess differences in task performance, perceived level of discomfort, number of posture shifts, and EMG data. Post hoc analysis consisted of a Turkey HSD test on all significant results, alpha = .05.

Two main types of ANOVA's (preference and non-preference) were utilized to analyze the data. The same data gathered from the dependent variables were used for both; however, the "non-preference ANOVA" did not use the data gathered from the preference treatment condition and thus monitor height and chair type were considered separate factors of analysis (within participant design). The "preference ANOVA" on the other hand was comprised of the data gathered during the preference treatment condition and thus monitor height, chair type, and user preference combined to create one variable know as configuration. The order of when the preference section was administered (either on the first day or the last) became a between participant's variable; thus this ANOVA was based on a mixed factor design (5 levels of configuration, 2 tasks, 3 samples, 2 preferences).

Chapter 4

RESULTS

4.0 Introduction

This section is divided into two separate analysis phases, primary and subjective. The primary analyses were comprised of descriptive statistics, two separate ANOVA's (preference and non-preference), trend analysis, and correlation analysis. Subjective analysis consisted of collecting and analyzing information gleaned from the participant responses on the exit questionnaire regarding workstation configuration. Results were considered significant at alpha = 0.05.

Throughout the various ANOVAs performed (in the primary analysis), significant results were found for the factors of order, task, and sample. Since these factors are found significant repeatedly, they are defined and briefly explained here. Further discussion is provided in later sections as warranted.

Order effects, defined as the day each treatment condition was received, were found for every major dependent variable (performance, normalized EMG (NEMG), perceived level of discomfort (PLD), and posture shifts (PS)) in at least one of the ANOVA summaries. However, order was not found significant for every subset of the dependent variables. For example, the preference ANOVA for performance found a significant order effect where performance increased as the number of days of testing increased. However, this effect was not found significant for the non-preference ANOVA summary. As another example, it was found that order significantly affected normalized EMG (NEMG). For some participants, NEMG activity level for a specific muscle increased as the number of days increased (Figure 4.1) and in others it decreased (Figure 4.2). Tukey HSD analysis was performed to determine the significance between the different orders of the treatment conditions (which were initially randomized and then balanced). A summary of the results is presented in Table 4.1 and 4.2. Order effect appears to be random, thus, no clear trend could be identified for the dependent variables. Order was accounted for by the balanced design so the effect of order on the other results should be minimal.

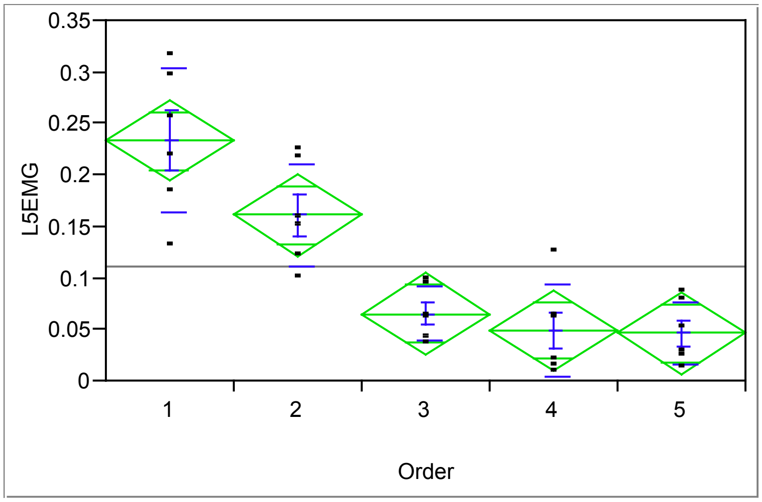


Figure 4.1 Participant 7 Oneway Analysis of L5 EMG by Order

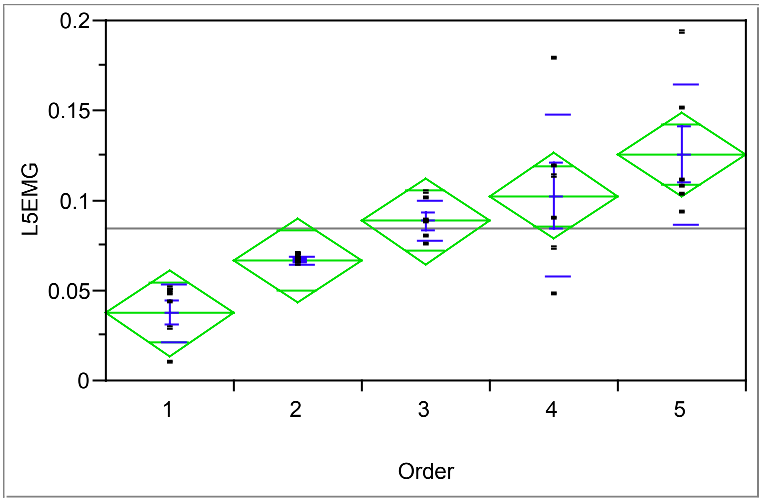


Figure 4.2 Participant 8 Oneway Analysis of L5 EMG by Order

Table 4.1 Order Effects for ANOVApref

DV	Subset	Factor	Significant
Performance	Perf	Order	Order 5 higher than 4 Order 4 higher than 1,2, and 3
NEMG	L5 NEMG	Order	Order 1,2, & 3 higher than 4
	L1 NEMG	Order	Order 5 higher than 1,3, & 4
	C7 NEMG	Order	Order 2 higher than 1 and 4
Perceived Level of Discomfort	PLDN	Order	Order 4 higher than 2
Number Of Posture Shifts	PSB	Order	Order 3 higher than 5

Table 4.2 Order Effects for ANOVAnon-pref

DV	Subset	Factor	Significant
NEMG	L5 NEMG	Order	Order 1,2, & 3 higher than 4
	L1 NEMG	Order	Order 5 higher than 1,3, & 4
Perceived Level of Discomfort	PLDN	Order	Order 4 higher than 2

Task was also found significant for each dependent variable in both ANOVA summaries. It is important to note that task was not counterbalanced in the experimental design, thus conclusions drawn about this factor could be confounded with other factors. In general, as expected for performance, the mean values associated with typing were significantly higher than those associated with completing math problems, since this was simply a frequency count minus the errors. Some of the other task effects yield more interesting results and will be discussed further in appropriate sections.

Recall that within each testing session, participants completed three 15-minute segments of each of the two tasks. A sample effect was found for perceived level of discomfort and number of posture shifts. As the number of samples increased from 1-3, so did the mean value of the dependent variable.

In addition to the ANOVA performed to determine the effect of the preference selection on the dependent variables, subjective characteristics of the preference selection were also collected and are discussed further in the subjective analysis. Overall, three of the eight participants preferred the low-end chair and all eight participants placed the monitor at approximately eye level.

4.1 Phase I: Primary Analysis

The first phase of data analysis consisted of quantifying effects on normalized EMG (NEMG), performance, perceived level of discomfort (PLD), and posture shifts (PS). The goal of this phase was to utilize two ANOVA summaries (preference and non-preference) to identify significant independent variables and their second-order interactions. Based on these analyses, a total of eighteen ANOVA tables were generated. A sample ANOVA summary is given for a single dependent variable, and a synopsis of significant factors is given for every dependent variable. Linear regression analysis and correlations were performed to assess the relationship between PLD ratings and NEMG data. In addition, an ANOVA was performed utilizing gender as an additional factor.

4.1.1 Descriptive Statistics

Descriptive statistics, mean and standard deviation, were pooled across participants for each dependent variable and grouped according to the independent variable “configuration.” Performance had a high standard deviation because it included both the typing and math task. For the most part, NEMG had standard deviations equal to or less than the means. Higher mean values and standard deviations were found for PLD of the back, PLDB, than for PLD of the neck or eyes, PLDN and PLDE. Posture shift means tended to vary across body regions, but remain fairly constant across configuration (Table 4.3). Muscle activity for C7 appeared lower for MHCH than any other configuration, L1 muscle activity appeared higher for MLCH and MLCL than any other configurations, and PSB had highest mean values for MLCL, MHCL, and the preference section. No single configuration had consistently lower or higher mean values than another (it appeared that no trends existed).

Table 4.3 Mean and Standard Deviation for Dependent Variables

DV	MLCH	MHCH	MLCL	MHCL	PREF
Perf	370 (177)	367 (172)	369 (181)	371 (170)	366 (163)
L5	0.12 (0.05)	0.19 (0.2)	0.18 (0.18)	0.18 (0.18)	0.15 (0.16)
L1	0.20 (0.19)	0.10 (0.07)	0.07 (0.05)	0.10 (0.05)	0.09 (0.06)
C7	0.15 (0.17)	0.08 (0.07)	0.14 (0.11)	0.16 (0.15)	0.13 (0.08)
PLDN	0.9 (0.9)	0.7 (0.07)	1 (1)	0.8 (0.9)	0.6 (1)
PLDB	1.5 (2.1)	1.2 (1.7)	1.4 (1.4)	1.5 (1.6)	1.4 (1.7)
PLDE	1 (1.4)	0.7 (0.9)	0.8 (0.9)	1.1 (0.9)	0.9 (1.4)
PSN	7 (4.5)	7 (4)	6.8 (4.3)	7.3 (4)	7.6 (4.3)
PSB	1.8 (1.5)	1.7 (1.6)	2.5 (2)	2.9 (2.8)	2.3 (1.9)
PSF	4.6 (4.7)	4.5 (4.5)	3.4 (3)	4.3 (4.5)	4.4 (4.2)

Numbers are presented as sample mean (sample standard deviation)
Perf = performance data measured by word/number count; L5, L1, and C7 = NEMG data at that specific location; PLDN, PLDB, PLDE = Perceived level of discomfort for neck, back and eyes (respectively) measured using the Borg scale; PSN, PSB, PSF = posture shifts of neck, back and feet (respectively) measured using frequency counts of these body segments.

4.1.2 Normalized EMG

Data gathered from NEMG was averaged across samples, relative to task. Figure 4.3 illustrates NEMG data gathered during one treatment condition. Outliers were not included in data analysis. In general, muscle activity was highest in the beginning of a sample and for typing samples in general. L1 was most affected by sample. Appears that apart from the first sample, muscle activity, according to body region, and across samples was fairly constant. The person settled into their chair and found a rhythm after the first couple of minutes.

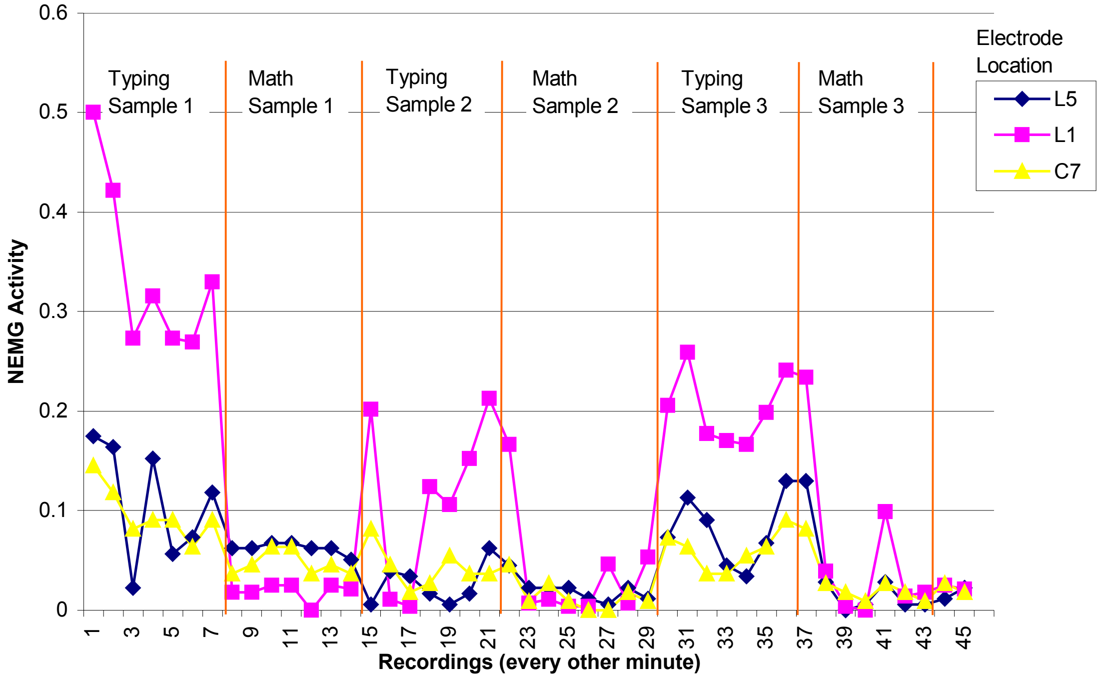


Figure 4.3 NEMG for Participant 7 using Monitor High and Chair High (MHCH)

4.1.2.1 NEMG ANOVA$_{nonpref}$

Table 4.4 shows an ANOVA table utilized to evaluate L1NEMG activity. It is representative of the analysis performed on L5 and C7 NEMG. A summary of the significant factors affecting NEMG activity for the ANOVA$_{nonpref}$ is given in Table 4.5. As depicted in the Table 4.5, workstation factors such as Monitor Height, Chair Type and the interaction of Monitor Height * Chair Type were significant for L1and C7 NEMG activity; where for L1NEMG, low monitor height generated significantly more activity (0.13v) than the high monitor height (0.08v), and the high chair generated more activity (0.15v) than the low chair (0.07v).

Table 4.4 Non-Preference ANOVA for L1 NEMG

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	0.433	0.062	7.224	.000*
Within Participant					
Monitor Height	1	0.035	0.035	4.045	0.046*
Monitor Height*Chair Type	1	0.085	0.085	9.88	0.002*
Monitor Height*Task	1	0.004	0.004	0.454	0.501
Monitor Height*Sample	2	0.003	0.002	0.186	0.831
Chair Type	1	0.103	0.103	12.021	0.001*
Chair Type*Task	1	0.019	0.019	2.296	0.132
Chair Type*Sample	2	0.015	0.007	0.844	0.432
Task	1	0.048	0.048	5.57	0.019*
Task*Sample	2	0.005	0.002	0.266	0.767
Sample	2	0.024	0.012	1.424	0.244
Order	3	0.158	0.053	6.147	0.001*

* Significant at alpha = 0.05

Table 4.5 Summary of Significant Factors ANOVAnonpref

DV	Sub-section of DV	Factor	Significant (alpha = 0.05)
NEMG	L5 NEMG	Order	0.000
	L1 NEMG	Monitor Height	0.046
		Chair Type	0.001
		Monitor Height*Chair Type	0.002
		Order	0.001
		Task	0.020
	C7 NEMG	Monitor Height*Chair Type	0.000

Additionally, post-hoc analysis (Tukey HSD) showed that low monitor height in combination with the high chair yielded significantly higher mean muscle activity for the L1 region as compared to all other combinations (see Table 4.6 and Figure 4.4). However, this configuration of low monitor height in combination with the high chair was only significantly higher than the high monitor height in combination with the high chair for C7 NEMG activity (See Table 4.7 and Figure 4.4). (Error bars indicate range of standard error in the plus and minus direction.) Task was also found significant for L1NEMG, indicating that higher mean values were associated with typing, 0.14v, than with completing the math problems, 0.08v.

Table 4.6 Response L1 EMG Mon Ht * Chair Type

Level	Least Sq Mean	Code	Std Error
MLCH	0.19522104	A	0.02526869
MHCH	0.10176822	B	0.02437448
MHCL	0.06344762	B	0.02433046
MLCL	0.06686609	B	0.02521773

“A” is significantly different than all levels represented by “B”

Table 4.7 Response C7 EMG Mon Ht *Chair Type

Level	Least Sq Mean	Code	Std Error
MLCH	0.16459633	A	0.03135924
MHCL	0.11077964	AB	0.03028378
MLCL	0.08347047	AB	0.03413619
MHCH	0.06342844	B	0.03011796

“A” is significantly different than the level represented by “B,” where “A” and “B” are not significantly different than “AB.” Same letters are not significantly different than each other.

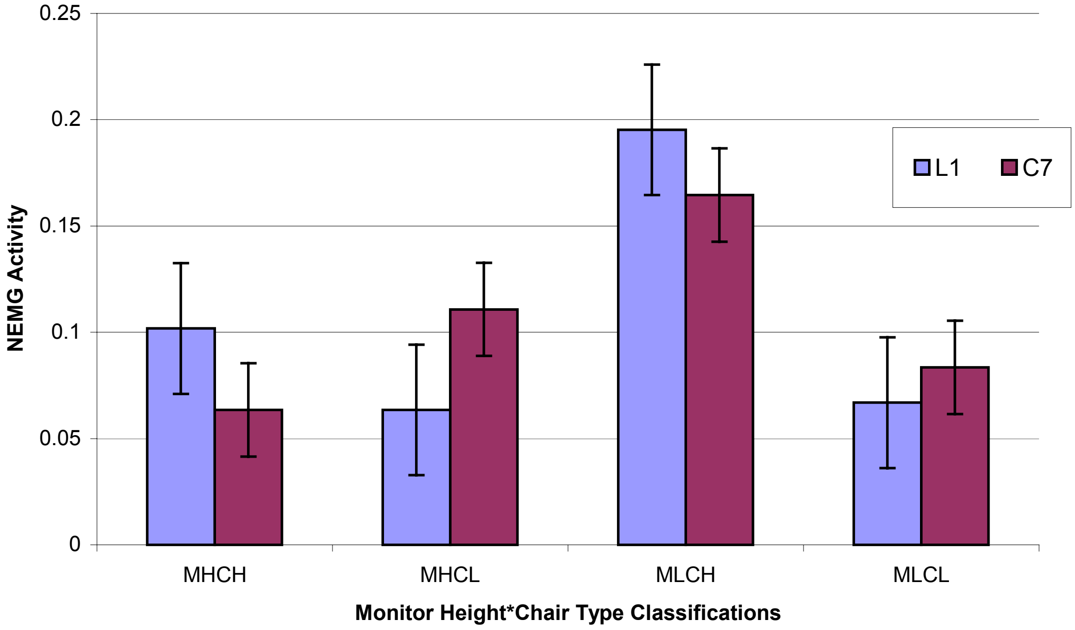


Figure 4.4 Tukey HSD-NEMG Mean Activity for Monitor Height * Chair Type

4.1.2.2 NEMG ANOVA$_{pref}$

Table 4.8 is an example ANOVA table for the preference analysis utilizing L1NEMG data. Configuration (MLCH, MLCL, MHCH, MHCL and preference) and task were found significant in the ANOVA$_{pref}$ for L1 and C7 NEMG (Table 4.9). Post-hoc analysis (Tukey HSD) showed that the MLCH configuration had significantly higher muscle activity than all other configurations for L1 (Table 4.10 and Figure 4.5). This configuration also yielded a significantly higher muscle activity than the MHCH and MLCL configurations for C7 NEMG (Table 4.11 and Figure 4.5). The configuration factor yielded similar results to the "Monitor height*Chair type" interaction found in ANOVA$_{nonpref}$. Also, higher values were once again associated with typing, 0.14v, versus math task, 0.09v, for L1 NEMG.

Table 4.8 Preference ANOVA for L1 NEMG

Source	DF	SS	MS	F	P
Between Participant					
Participant (Preference)	6	0.433	0.072	9.528	0.000*
Preference	1	0.0758	0.0758	1.069	0.341
Within Participant					
Configuration	4	0.239	0.059	7.89	0.000*
Configuration*Task	4	0.031	0.008	1.018	0.399
Configuration*Sample	8	0.029	0.003	0.488	0.864
Task	1	0.045	0.045	5.987	0.015*
Task*Sample	2	0.004	0.002	0.242	0.786
Sample	2	0.023	0.011	1.485	0.229
Order	4	0.126	0.031	4.151	0.003*

* indicates significance at alpha = 0.05

Table 4.9 Summary of Significant Factors for NEMG ANOVA$_{pref}$

DV	Level of DV	Factor	Significant
NEMG	L5 NEMG	Order	0.001
	L1 NEMG	Configuration	0.0001
		Order	0.003
		Task	0.0153
	C7 NEMG	Configuration	0.0059
		Order	0.0122

Table 4.10 Response L1 EMG - Tukey HSD Test

Level	Code	Std Error	Mean
MLCH	A	0.02715672	0.201776
MHCH	B	0.02601884	0.103915
MHCL	B	0.02597809	0.099046
MLCL	B	0.02711044	0.079262
PREF	B	0.02349774	0.095385

“A” is significantly different than “B.” Same letters are not significantly different.

Table 4.11 Response C7 EMG-Tukey HSD Test

Level	Code	Std Error	Mean
MLCH	A	0.03463148	0.154650
MHCL	AB	0.03328347	0.156137
PREF	AB	0.02955830	0.126008
MLCL	B	0.03869957	0.133547
MHCH	B	0.03334089	0.084206

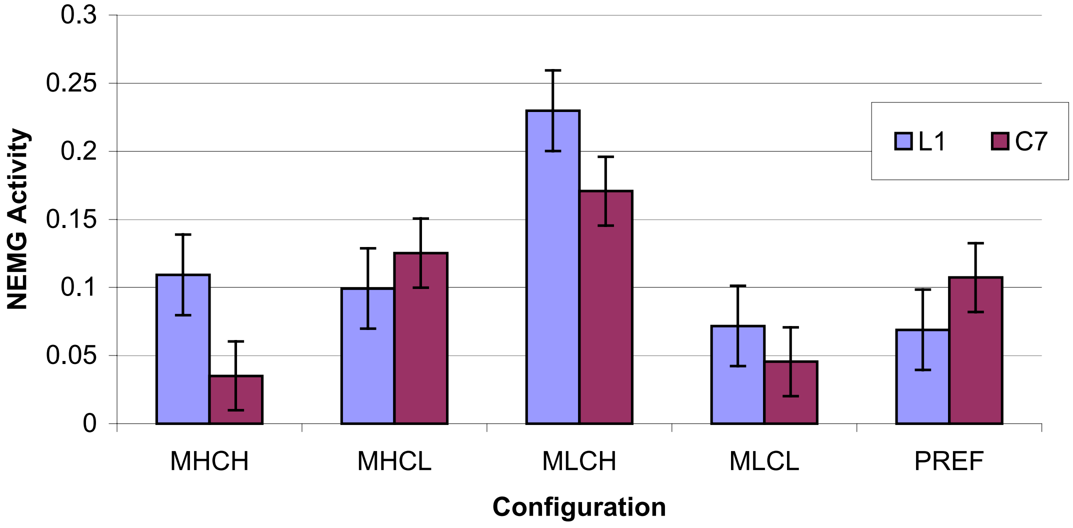


Figure 4.5 Tukey HSD - Post Hoc Analysis for NEMG

4.1.3 Perceived Level of Discomfort

4.1.3.1 PLD ANOVA$_{nonpref}$

Sample, task, order and the interaction between Monitor Height*Chair Type was found to be significant for ratings of PLD for the back, neck, and eyes (Table 4.12). However, post hoc analysis, Tukey HSD, of the monitor height*chair type interaction did not find any specific configuration associated with significantly higher PLD ratings. Task is also important to note; it appears that higher levels of neck discomfort are associated with the math task, 0.5, as opposed to the typing task, 0.17. No task effect was found for the perceived level of discomfort for the back and eyes.

Table 4.12 Non-Pref ANOVA Summary for PLD

DV	Body Part	Factor	Significant
Perceived Level of Discomfort	Back	Sample	0.0001
	Neck	Order	0.0002
		Task	0.0216
	Eyes	MonHtxChair Type	0.0033
		Sample	0.0001

4.1.3.2 PLD ANOVA$_{pref}$

Similar to ANOVA$_{nonpref}$, sample, order and task were found to be significant (Table 4.13). No workstation manipulation effect was found for this analysis. Post hoc analysis revealed that mean PLD ratings significantly increased as the number of samples increased for all body parts, indicating that time may have played a role in perceived level of discomfort. Once again, mean neck PLD ratings were higher for the math task, 0.64, than for the typing task, 0.38.

Table 4.13 Preference ANOVA Summary for PLD

DV	Body Part	Factor	Significant
Perceived Level of Discomfort	Back	Sample	0.0001
	Neck	Order	0.008
		Task	0.04
		Sample	0.001
	Eyes	Sample	0.0001

4.1.3.3 Relationship between PLD and NEMG-Based on preference data

Linear regression analysis was used to investigate the relationship between PLD ratings and NEMG ratings for the neck and back. Lines were initially fit between neck PLD ratings and C7 NEMG and for back PLD ratings and L5 and L1 NEMG. No significant trend existed between C7NEMG and neck PLD for any of the participants. For four out of the eight participants, no significant linear relationship existed between L5 and L1 NEMG and PLD ratings for the back. However, four participants did show significant linear trends between at least one of the back regions studied and the rating of PLD of the back (Figure 4.6). Two of the four participants demonstrated a positive relationship, whereas two participants had negative relationships (Table 4.14). Only one participant showed a significant linear trend between both L5 and L1 NEMG and PLD of the back.

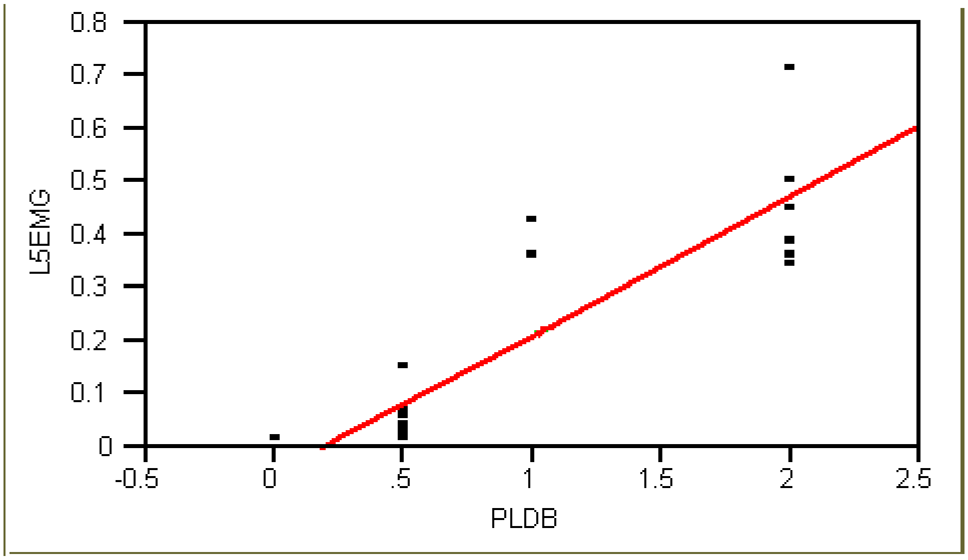


Figure 4.6 Participant (2) Significant Positive Relationship Between PLD of the Back and L5 NEMG (Note: the linear fit line was based on thirty data points --six data points for each of the five days. In some cases NEMG data was not entered for a day; thus, some of the points not visible are along the x axis)

Table 4.14 Trend Data for NEMG and PLD

Participant	Region (P value)	Relationship
2	L5 and PLD (0.0001)	Positive
	L1 and PLD (0.001)	Positive
6	L5 and PLD (0.045)	Positive
7	L1 and PLD (0.001)	Negative
8	L1 and PLD (0.02)	Negative

After examining the data for existence of linear trends, the non-significant data was analyzed for second order polynomial fit. Only the relationship between PLD of the back and L5 NEMG showed a significant positive second order polynomial trend and this existed solely for participant one, (P=0.047, parabolic relationship).

Additionally, the Spearman's Rho statistic was used to evaluate the correlation between PLD of the back and L5 and L1 NEMG for participants showing significant linear trends. Spearman's Rho correlation coefficients are summarized for each participant in Table 4.15. A significant relationship existed between the reporting of PLD for the back and L5/L1 NEMG; however this relationship is unclear since the coefficient was both positive and negative for different participants. In some cases the participant reported higher levels of discomfort for higher levels of NEMG; whereas, in other instances, the participant reported lower levels of discomfort for higher levels of NEMG.

Table 4.15 Summary of Spearman Rho Statistic

Participant	**Relationship (Spearman's Rho)**	**Strength of Correlation (Fisher, R.A., 1972)**
2	L5 and PLD (0.87)	Strong (positive)
	L1 and PLD (0.65)	Moderate (positive)
6	L5 and PLD (0.29) (not significant)	Weak (positive)
7	L1 and PLD (0.57)	Moderate (negative)
8	L1 and PLD (0.46) (not significant)	Moderate (negative)

4.1.4 Posture Shifts

4.1.4.1 PS ANOVAnonpref

Only two factors, sample and task, were found significant for number of posture shifts (Table 4.16). A larger number of posture shifts of the neck were associated with the typing task, 7.4, than the math task, 5.7; whereas, the inverse is true for postures shifts of the feet (typing task = 1.5 and math task = 4.5). Also, posture shifts increased as number of samples increased. Tukey HSD test revealed that for posture shifts associated with the back there is a significant difference between sample one, 1.2, and sample two, 2, and between sample one, 1.2, and sample three, 2.2. Significant results were also found for posture shifts of the feet, where sample one, 3, possessed lower results than sample three, 4.4.

Table 4.16 Summary of Significant Factors for PS (ANOVA$_{nonpref}$)

DV	Body Part	Factor	Significant
Number Of Posture Shifts	Neck	Task	0.0329
	Back	Sample	0.005
	Feet	Sample	0.0123
		Task	0.0001

4.1.4.2 PS ANOVA$_{pref}$

Like the ANOVA$_{nonpref}$ results, task and sample were once again found significant (Table 4.17). Increasing numbers of posture shifts were found for the neck during the typing task and for the feet during the math task. Also, a higher number of posture shifts of the back were associated with the math task. Once again, significantly higher posture shifts of the back were associated with Sample two, 2.2, as compared with sample one, 1.3, and with sample three, 2.3, as compared to sample one, 1.3. Higher posture shifts of the feet followed this same pattern, where sample one, 4.2, was significantly lower than sample two, 5.4, and sample three, 5.7.

Table 4.17 Summary of Significant Factors for PS (ANOVA$_{pref}$)

DV	Body Part	Factor	Significant
Number Of Posture Shifts	Neck	Task	0.03
	Back	Sample	0.001
		Task	0.0147
		Order	0.0128
	Feet	Sample	0.002
		Task	0.0001

4.1.5 Performance

As discussed previously, the only effects found significant for both ANOVA's (preference and non-preference) regarding performance were task and order (not discussed in this section). As expected the mean number of words typed were higher than the mean number of math problems completed. Also, the number of words or math problems completed increased as the participant progressed from sample one through sample three (Figure 4.7). This trend was not expected for the typing task, but the performance variable takes into account both the typing and math task. Although the math problems were not presented in the same combination or order on the spreadsheet across samples, problems were similar (e.g. 5 + 2 = 7 or 5 * 2 = 7). It is hypothesized that as participants were exposed to more of the math problems, they became familiar with the task and identified similarities as well as strategies for faster math completion.

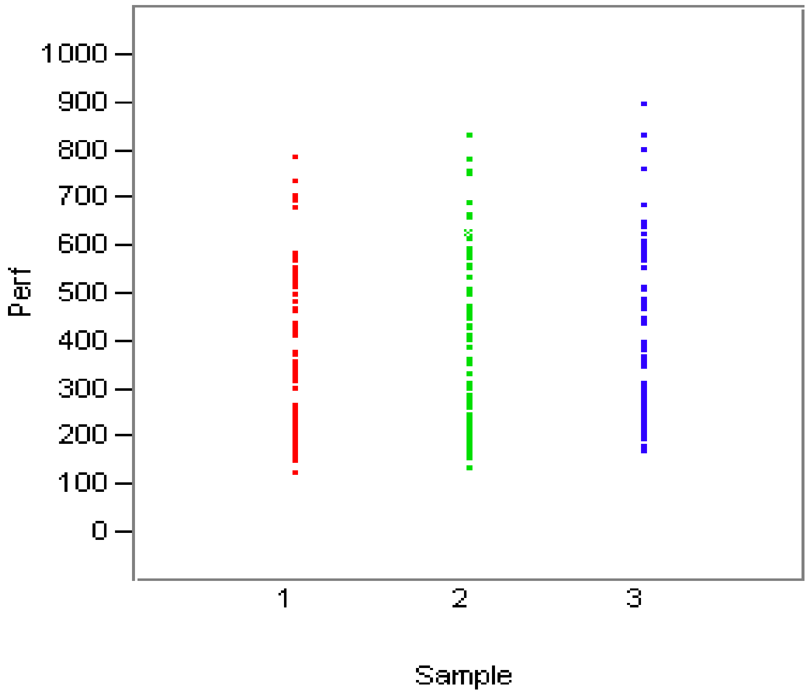


Figure 4.7 Performance Effects Across Sample (raw data)

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4.1.6 Gender Effects

Gender was analyzed by adding this between participants variable to the preference and non-preference ANOVA's performed earlier. Only main effects of gender were evaluated for significance. For the preference ANOVA, females had significantly more posture shifts, 8.5, associated with the neck than males, 4.1. No significant effects were found for the non-preference ANOVA.

4.2 Phase II - Subjective Analysis

The purpose of soliciting exit interview information was to provide further information about the participants' perceptions of the various workstation configurations (likes, dislikes, etc.). At the end of the experiment the participant was asked to complete an exit survey and rank order their preference of conditions (Table 4.18). The analysis was qualitative and minimal, consisting of gathering and summarizing the information presented. Recall that participants rated the degree of comfort for both the chair and monitor at both levels of high and low utilizing a seven point Likert Type scale (1 indicated low and 7 indicated high). In the exit survey, the mean participant rated value for the high chair was a "5," above average, whereas the low chair was rated as average, "4" with some above and below average markings. Overall, five participants selected the high chair and three selected the low chair. In this part of the analysis, no attempts were made to distinguish between the different monitor heights, low and high, since the number of participants' who selected ratings of "2", "4" and "6" were equal for both the low and high levels. All the participants chose to place the monitor at eye level (plus or minus 4 cm) during the preference section, which might explain the varied responses for monitor height.

For the second half of the exit survey, participants were asked to rank order the configurations presented during the study. Participants preferred the configuration, MLCH, followed by MHCL. The participant's preference section was not included in this rank ordering. However, since some participants received the preference section at the beginning of the survey, comparisons were made between their initial selection and their final ranking. Two of the four people who received the preference order on the first day changed their preference as evidenced by their ranking of the configurations at the end of the experiment (Table 4.19). The participants' decisions were not based on cost; as they were not given cost information. Pooled means (Table 4.3) were rank ordered (highest to lowest) for each of the dependant variables and compared to the subjective rankings for configuration (Table 4.20). For the configurations ranked one and two (MLCH and MHCL respectively), the pooled mean rankings were primarily one and two for the dependent measures. Thus, the number of times a configuration did or did not have the highest mean value associated with the dependent variable, would not be a good indicator of participant preference.

Table 4.18 Rank Ordering of Configuration

Subject	MHCH	MHCL	MLCH	MLCL	Comments
1	2	4	1	3	Felt like CL was stiff and unaccommodating, the CH caused less discomfort in the back and the low monitor caused less discomfort in the neck.
2	2	4	1	3	Didn't really notice too much difference between chairs, but the CH was similar to one he had at home and he felt like he could lean back better in it.
3	2	1	4	3	Felt like CL had more support higher up, and with the low monitor I had to look down too much—it hurt my eyes (especially on the math part), high monitor good-felt like eyes were looking parallel with floor
4	3	2	1	4	Didn't really like the contours in the back of the CL
5	3	1	4	2	Low monitor with the CH put a strain on my neck, I liked the CL because of the design of the lower back region
6	4	1	2	3	Liked the monitor high for math tasks, but with CH I felt like I was sitting more upright, the original preference is demonstrated in his number one choice
7	1	2	3	4	CL with the monitor low had the most neck pain, glare w/ low monitor, chose CH with high monitor because that is how it is at home
8	3	4	1	2	Both chairs were comfortable at first, but over time, CH was more comfortable

Table 4.19 Preference Condition Comparison with Configuration

Subject	Pref Order	Preference Condition	Differences between Preference and Rank?	# 1 Rank Order
1	Last	CH Monitor height=eye level	NO	CH Monitor Height=low
2	Last	CH Monitor height=eye level	NO	CH Monitor Height=low
3	Last	CL Monitor height=slightly above eye level	NO	CL Monitor Height=high
4	Last	CH Monitor height=eye level	NO	CH Monitor Height=low
5	First	CH Monitor height=slightly below eye level	YES	CL Monitor Height=high
6	First	CL Monitor height=eye level	NO	CL Monitor Height=high
7	First	CH Monitor height=eye level	NO	CH Monitor Height=high
8	First	CL Monitor height=slightly below eye level	YES	CH Monitor Height=low

Table 4.20 Comparison of Ranking to Pooled Means Presented in Table 4.3

DV	MLCH (1)	MHCL (2)	MHCH (3)	MLCL (4)
Perf	2	1	4	3
L5	3	2	1	2
L1	1	3	3	2
C7	2	1	4	3
PLDN	2	3	4	1
PLDB	1	2	4	3
PLDE	2	1	4	3
PSN	2	1	2	3
PSB	3	1	4	2
PSF	1	3	2	4

4.3 Summary

Primary data analysis consisted of descriptive statistics, ANOVAs, and trend analysis. Both the non-preference and preference ANOVA summaries yielded similar results for the independent variables (configuration, task, sample, order, and preference order). Post hoc analyses showed that significant effects of configuration variables were only found for NEMG, specifically, L1 and C7 NEMG. In both ANOVAs, the MLCH configuration yielded higher muscle activity than other configurations.

Task effects consisted of higher mean values for performance, L1 NEMG, and PS of the neck for the typing task. Higher mean values were found while completing the math task for PLD of the neck, and PS of the back and feet. Sample effects were found for almost every independent variable and showed a general increase in mean values as the number of samples increased chronologically. Order effects were present throughout the analysis, but no clear relationship was identified; it appeared as though order's effect on the different variables were random. In addition, the presentation of the preference section (i.e. first or last) did not significantly affect any measure of the dependant variables. The only gender effect present was the higher number of posture shifts for the neck in females versus males (note: only main effects were tested for significance).

Trend analysis found that most participants do not show a significant linear relationship between the reporting of PLD and levels of NEMG, especially for the C7 region. Some participants did show significant trends between the activity in one or both of the back regions and NEMG; however, this relationship was sometimes negative and sometimes positive, indicating an inability of persons to effectively rate discomfort using the Borg scale.

Supplemental analyses consisted of an evaluation of the preferred settings for the workstation, an exit survey questionnaire and a rank ordering exercise. Regardless of order of preference section, all eight participants chose to place their monitor height at eye level. Five out of the eight participants chose the high chair and rated the high chair as being more comfortable. The rating of level of comfort for the high and low monitor height varied considerably. Also, rank ordering revealed that MLCH was the most preferred configuration.

Chapter 5

DISCUSSION and CONCLUSIONS

5.1 Objective

Because of the risks (described in Chapter Two) associated with seated/static postures and the growing number of video display terminals, one of the main objectives of this research was to determine the effect of monitor height and chair type manipulations on the neck and back. This was accomplished through measurement of muscle activity, perceived level of discomfort, and posture shifts. Performance was also measured and other body regions such as the eyes and feet were observed. Another objective was to determine whether a difference existed between the experimenter controlled configurations and the participant selected (preference) configuration. Also, the research provided preliminary results as to how well subjective reports of discomfort correlated with EMG readings. The experimental hypotheses present in Chapter 3 represented these objectives and the findings are discussed in terms of the null hypotheses.

5.2 Primary Results

5.2.1 Effects of Monitor Height and Chair Type

Several results obtained from ANOVA analysis were of particular interest. The first and foremost factors of interest were those associated with manipulation of the workstation: monitor height, chair type, configuration and the monitor height*chair type interaction. Although, these factors were only significant for two dependent measures (NEMG and PLD), it is interesting to note which sub-sections (areas of the body, eg L1 or back) of the measures are/are not affected by the manipulation of the workstation.

Post-hoc analysis revealed that for L1 NEMG all of the factors associated with manipulating the workstation were significant; however, none of these factors were significant for L5NEMG. This finding suggested the postures assumed, and thus the loads acquired for L5, for the high and low monitor heights and the different chair types were not different across the treatment conditions. This result could have been due to the similarities in chair type that would specifically affect the L5 region—such as lumbar support. Also, the participants very rarely leaned their torso forward for the different configurations, but they often leaned their neck forward and down (captured in the posture analysis). It was possible that the muscle groups responsible for this type of action relied more on those found in the L1 region rather than those found in the L5 region, thus aiding in an explanation as to why differences in NEMG were found between the two. It is also important to note that L1 and L5 are both considered the low back; however, if this study would have only evaluated one or the other, the results for the "low back," would not have held true at a different location in this same region (e.g. If the study only evaluated results from L5, which did not yield significant results, the conclusion may have been that configuration did not affect the "low back.") Additional research on various portions of the same region of the back need to be studied.

Most of the research conducted on monitor heights (See Chapter Two-section 2.3.2) involved the investigation of extremes, consisting of placing the monitor 30-60 degrees below the horizontal or 15-20 degrees above the horizontal. Debates between biomechanists and visual perceptionists revolved around concerns of neck flexion versus extension and the compromise between the visual and musculoskeletal systems for different postures. The current research yields danger zones (not higher than + or – 30 degrees) and recommended monitor heights, but it does not necessarily attempt to combine the two sets of recommendations from the biomechanists and the visual scientists. Burgess and Limmerick (2000) reported that there appears to be no definitive answer to the question of optimal ranges that takes into account the trade off between the demands placed on the visual and musculoskeletal system. Some researchers, such as Kroemer et al (2000), recommended placing the monitor at 15-30 degrees below the horizontal to minimize discomfort. Sommerich (1998) compared 17.5 degrees below the horizontal to 30 degrees below the horizontal and found that 17.5 degrees had less muscle activity. The current study attempted to find the largest envelope of monitor heights a person could create and not experience any difference. The monitor low condition in this experiment was approximately 15 to 20 degrees below the horizontal and it created significantly higher muscle activity in the L1 region than placing the monitor at horizontal or 10-15 degrees above horizontal. However, the statistics for the ANOVA were not highly significant at alpha=0.05, and no other dependent measure yielded significant results. Thus, it is possible that placing the monitor at –17.5 degrees as suggested by Sommerich (1998), at horizontal eye level as suggested by NOHSC (1989), or at 10-15 degrees above the horizontal as suggested by Jampel and Shi (1992) are all acceptable.

Chair type was also found significant, for L1 NEMG, where the high chair had more muscle activity than the low chair. Recall that Burton (1984) found that backrest height and angle of inclination significantly affected trunk muscle activity. Although attempts were made (Table 3.2) to ensure similarity between the two chair types, the chairs were not the same. Thus, the difference in muscle activity for the chairs could be accounted for by backrest height, since the high chair had a slightly smaller backrest height than the low chair. The high chair also offered less support in the upper back region, which may have perpetuated into higher NEMG activity for the L1 muscle region. Additionally, Corlett and Bishop (1976) found that a decrease in distance between backrest height and the seventh cervical vertebrae increased discomfort in operators' lower back. Another explanation for the increase in L1 muscle activity could be associated with the slightly different type of armrests. Andersson et al (1977) found that the use of armrests had significant effects on back EMG. Thus, one explanation for higher muscle activity associated with the high chair could have been a result of armrest size and use. The high chair had smaller armrests and it appeared as though participants utilized them less often than with the low chair, thus creating higher physical demands on the musculoskeletal systems responsible for maintaining the loads created by the arms typing.

For the muscles represented by L1NEMG and C7NEMG, both configuration and the interaction between monitor height and chair type were significant. For both ANOVAs the configuration or interaction denoted, “MLCH: monitor low, chair high” resulted in significantly higher L1 NEMG than all other configurations. This was most likely due to the significant factors of monitor height and chair type discussed above. Yet, for C7 NEMG, MLCH was only significantly higher than MHCH and MLCL. Since the neck was slightly flexed for the MLCH, the significantly higher muscle activity for MLCH versus MHCH are similar to the results found in Schuldt et al (1986). Because the factors comprising this interaction were not significant for C7 NEMG, this result is hard to interpret except to possibly note that the particular chair type selected for one monitor height may not be a viable option for differing monitor heights.

Because only one configuration, MLCH, was significantly different than all the others for only one dependent variable, for the most part, the null hypothesis: there will not be a difference between the two levels of monitor height and two levels of chair type on performance, muscle activity of the back/neck, PLD of the back/neck, and PS of the back/neck, was correct. Gross physical differences were not found between the two chair types; however, the high chair was selected more frequently during the preference section. This could have been due to the general contour of the chair or even possibly the color or feel of the chair.

5.2.2 Experimenter vs. Participant Selected Configuration

No differences were found between the experimenter selected and participant selected configurations, indicating that how the participant chose to set up the workstation was acceptable. Further insight was gleaned by observing the preference section and comparing the exit questionnaire/ranking results to the configuration results. Shute and Star (1984) and Coleman et al (1998) both found that even with anthropometric information available, people would not adjust their workstation accordingly. However, given the opportunity to set up the workstation, the participants inevitably chose to place the monitor at their eye level, and also set the chair such that their upper and lower legs formed a 90-degree angle regardless of whether they received the preference section first or last (thus they were not biased by the experimenter set configurations). Similar to the results found by Helander and Zhange (1997) this result indicated that what is comfortable to the participants might be the best practice. Unlike Helander and Zhange (1997) though, the current study did not find that this “comfort” was assessed instantaneously, in fact two of the participants that were given the preference section first, changed their mind at the end of the experiment.

When the participants were asked to rank the order of the experimenter set configurations, the preferred configuration was MLCH—monitor low chair high. Recall that this configuration yielded the highest muscle activity for L1. It is possible that although there was a significant difference in muscle activity for this configuration, that the participants did not actually perceive this difference, did not care, or other functions overweighed their reporting of muscle activity. In addition, the second most preferred configuration was the MHCL—monitor high chair low, the opposite of the first. This could be explained in part by evaluating the questionnaires. The scores yielded for degree of comfort for the two chair types were comparable meaning that the high and low chairs were rated approximately the same. However, about half the people ranked the low monitor very comfortable and the high monitor very not comfortable and the other half vice versa. This mixed response along the two dimensions of the independent variables could have surfaced in the rankings of the configurations. Simply meaning that when subjects rank ordered the configurations, they typically chose one variable over the other, e.g. the monitor height over the chair, and selected the configuration with their preferred monitor height designation as rank orderings one and two, regardless of the chair type.

5.2.3 Trend Analysis of PLD and NEMG

Subjective analysis is often used independently to compare various workstation configurations, (Nerhood and Thompson, 1994), and as an augmentation to objective measures to determine the psychological nature of static postures (Psihogios et al., 1998). Determining the relationship between the psychological and physiological responses is important. Trend analysis results between PLD and NEMG showed that participants did not typically report higher/lower perceived level of discomfort for higher/lower NEMG acquired during the typing and math task. This could be due to several reasons such as low EMG levels, time effects, response bias, and differentiation between body regions. The EMG levels reported in this study were relatively low, in some cases resting EMG and task EMG were virtually the same. It is possible that for these low levels of EMG, participants did not feel discomfort and thus did not report it, explaining why a significant linear trend was not discovered for most participants. The negative relationship that was discovered between PLD of the back and L1 and L5 NEMG could be most easily explained by time and response bias. Although, the back or neck was not experiencing higher level of EMG activity, the longer the participant sat in the chair, the more bored they became, thus possibly increasing their perceived level of discomfort. The varying trends found could also be due to response bias, where the participant may have guessed that they were supposed to increase the rating as time increased and thus felt compelled to do so. In addition, since the PLD assessment of the back was not specific, participants may have experienced problems differentiating between PLD of the back and the low back and between the low back and the two different NEMG locations, L1 and L5. This could have resulted in mixed responses. Overall, the fact that the participants may not be cognizant of their back and neck muscle activity on a small scale, (90 minute interval over 5 days) may offer an explanation for why participants experience a cumulative effect of workstation design and seated postures, but linking particular causal factors to the development of LBP and NP is difficult.

5.2.4 Task and Gender

Although, determining differences in tasks was not originally part of the objectives, the significance of task is important when viewed with other results. For example, the typing task had higher mean L1NEMG activity. This result was expected after observing that the participants extended and elevated their arms more for typing, whereas for the math task, they rested their hands on the table and punched one of two keys. What was not expected was that the number of posture shifts for the back was significantly lower for the typing task. According to the higher levels of L1NEMG, one may propose that it could have been due to the participant moving around, but the inverse is true. Although a significant difference existed for L1NEMG activity and posture shifts, no task effect was present for perceived levels of discomfort for the back.

No task effect existed for C7 NEMG; however, participants did report significantly higher levels of discomfort associated with the neck during math tasks. This could be in part due to the nature of the task. Because the math problems required greater visual attention (as evidenced by observation), the participant had less freedom to move their neck, thus the number of posture shifts (strictly for the neck) for the math task was significantly lower than those associated with typing. Due to the inherent nature of the math task, a static posture was assumed for the neck, and participants may have perceived the math task as being more uncomfortable. This finding was consistent with those found by NIOSH (1997)—fewer posture shifts relate to higher reporting of discomfort.

Only one gender effect was found throughout the various analyses. In the $\text{ANOVA}_{\text{pref}}$, females had significantly higher posture shifts associated with the neck than males. For the most part (since this study only looked at main effects of gender), this study could have been conducted with a varying number of average males or females.

5.3 Sources of Error/Limitations

Several sources of potential errors and limitations existed for this study: PLD measurement, electrode placement, participant movement, chair configuration, and experimenter error. One major source of error existed in the scale utilized. Since PLD for the back included occurrences at both L5 and L1, participants may have experienced difficulty determining which muscle(s) to use in their reporting. It is possible that the scale was better used to represent the L5 region, where there was no difference in NEMG activity. It is also possible that the participant used the scale to represent discomfort in their entire back and not just the regions represented by electrode placement. (The same holds true for the neck). The scale utilized for PLD was a 10 point Borg Scale; however, for this task there was never a reference for what would constitute a 10 point response—

the submaximal reference contraction, needed to validate or calibrate the scale with the NEMG responses to truly correlate them. The anchors were poorly defined except for the 0-0.5 section of the scale, where the participant was asked to relate this to how they felt during resting EMG measurements.

Another source of potential error could have been the use of electrodes. Electrodes were placed according to physical landmarks (i.e., bone that protrudes from neck is where C7 electrode was located, under rib cage for L1, and close to top of pelvis bone for L5). For some subjects the L1 electrode measured heartbeat and it was possible that crosstalk existed for all other measurements of muscle activity. Also, no deep muscle activity was recorded; thus, differences induced by workstation manipulation may have affected deeper muscle activity that was not captured during data collection. Although the leads to the electrode were taped to the preamplifier, spikes in EMG data were still recorded due to the inevitable movement (other than that required of the tasks) of participants during the 90-minute session.

Sources of error during data collection, entry, reduction, manipulation, or analysis may have arisen due to human error. Results could have been missed or misinterpreted. The mere presence of the experimenter (sitting in the room watching the subject), consistent asking of participant PLD every 15 minutes, the tasks chosen (only two, they did not type the same thing everyday, etc.), the length of the testing session, or the presence of music could have also changed the nature of the study.

Equipment features also became confounds of the study. For instance, some people used the armrests and some did not. Since armrests were slightly different for both chairs, this may have had an effect. Also, the lumbar support in the low chair protruded from the back of the chair, making it less similar to the high chair than originally intended.

5.4 Implications for Industry

For the most part, these results indicated that workstation set-up can be flexible and that there is no set monitor height or type of chair that accommodates all people. A person of average height and weight could set-up their monitor height within the range of 15-20 degrees below the horizontal to 10-15 degrees above the horizontal, and use a chair similar to the low chair (purchased at a local department store) and not experience any higher levels of perceived level of discomfort, degraded performance, increased posture shifts, and/or higher levels of EMG activity associated with the low back or neck region. Either chair could be used for monitor heights of eye-level to 15 degrees above eye level with the same performance characteristics as listed above. These results could be useful for small businesses incapable of spending large amounts of money on office furniture. It is important to note that given the choice, 60% of the subjects did prefer the high chair based on subjective differences given in the exit survey. These subjective differences may perpetuate into other factors (not under study in this research) associated with the job. Manufacturers of high chair types (as defined by this research) should focus on marketing specific attributes of their chair that are beneficial to consumers above and beyond the basic adjustability features; whereas, manufacturers of low chair types should continue to provide adjustability similar to those companies producing high chair types. Conclusions are limited to tasks similar to those presented in the study.

5.5 Future Research

Further studies could be conducted to increase the levels of the workstation variables, evaluate the preference settings in a real world environment, increase the power of the experiment by reducing variability, and try to more objectively determine the relationship between PLD and EMG for this type of task. Since the levels of monitor height and chair type were dichotomous, it is difficult to understand where the relationship between the high chair and the low monitor starts to significantly differ from the other configurations utilized in the study. Specifically, depending on what independent measure is of interest (independent variables effected the dependent variables differently), future studies could increase the number of levels of the independent variables. Future studies could evaluate chair types that were priced similarly to the ones previously used with an inclusion of some middle values (such as $750). Plus, the definitions or categories could be further scrutinized to determine what would really constitute a low or high chair. In industry these values could be completely different than what was used, e.g. 40 dollars and 5000 dollars (respectively). Since all of the participants chose to place the monitor at horizontal eye level for the preference condition, in essence, they created a third monitor level. However, this third level could not be evaluated independently of the configuration for which it was a part; thus, further research could evaluate the difference between the low monitor condition, the horizontal eye level condition and some mid value condition.

It is important to note there were no significant differences among the other configurations utilizing the monitor low or chair high, thus the effect of the monitor low in combination with the high chair could have been due to small differences in backrest height/size. This chair attribute could be further manipulated or controlled to determine if differences would still persist. It is also important to note, that the enhanced value of the high chair may be a synergistic effect, and since only basic features (arm rest height, lumbar support, height of chair, etc.) of the chairs were evaluated/manipulated for this study, it is possible that not enough factors were utilized to see evidence of this effect. Future studies could train the participant to use all of the chair's features and then again assess the dependent measures.

Since 60% of the participants preferred the high chair due to subjective differences given in the exit survey, it is possible that these subjective differences could have perpetuated into other factors (not under study in this research) associated with the job. Thus, future research should evaluate the impacts of workstation design on psychosocial factors such as job satisfaction and stress.

In the laboratory, participants naturally configured the workstation such that their lower and upper legs formed approximately 100-90 degrees and such that the monitor height was at eye level. This was regardless of the order of the preference section. These results could be confirmed in a real world setting to determine if that is truly how participants choose to set-up their workstation, especially if they have not been trained to do so. It may also be possible that a generation/age and education effect exists, where most of the participants utilized in the study were in their 20's, five out of the eight were engineering majors, and all had heard of "Ergonomics." They appeared well versed in how their workstation should be configured. Participants from older generations and non-engineering majors may not have even heard of Ergonomics; thus, studies should be conducted utilizing these different populations to determine if the prevalent monitor trend in the preference configuration would still exist.

No difference in chair type was found for posture shifts, thus one chair did not support or facilitate a more "dynamic" posture. In fact, it appeared that task type may have had the most impact on dynamic versus static posture and should be further studied. To determine the nature of this relationship, further studies should increase the amount of time spent on each task and in each chair, conduct the study in a real world situation, use a larger number of participants, and use participants from different populations, e.g. the elderly.

For this type of setting (VDT), the relationship between EMG and PLD needs to be further evaluated and discussed. Since the level of EMG increased linearly with some participants and decreased linearly with others, it is no surprise that some of the linear trends were significantly positive and negative. It appeared that the longer the participant was at the experiment, the more PLD they reported. Thus, future studies could attempt to manipulate the level of EMG in a randomized pattern, and then measure the reporting of PLD to see if the response pattern remains linear. Future studies should provide clear anchors for the beginning, middle, and end of the scale specifically for a video display type workstation. This information could further be utilized to create a different scale of PLD for this type of work.

Also, these results do not address the question of what features about the workstation contribute most to back and neck muscle activity (i.e., was it chair height, arm rest use, placement of backrest?). Does a Pareto rule exist, where 20% of the chairs' features are responsible for 80% of the activity experienced? Future research should focus on specific attributes of the combination of chair and monitor configuration on the affects of the dependent measures. Since the current research failed to reject the majority of null hypotheses proposed, it is hoped that future studies aimed at some of the key issues presented previously will help pinpoint more precisely the relationship between the independent variables, monitor height, chair type, and task and the dependent variables performance, NEMG, posture shifts and perceived level of discomfort.

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Appendix A

QUESTIONNAIRES

Pre-Experimental Questionnaire

Demographic

1. Age:
2. Gender: M F
3. Height:
4. Weight:

5. Using the following scale how would you rank your level of physical fitness?

1	4	7
Not physically fit	Average	Very Physically Fit

6. Using the following scale, how often a week do you engage in physical activites?

1	4	7
Never	Average (twice a week)	Often (daily)

7. Body Part Discomfort- Modified Borg's Exertion Scale

Perceived level of discomfort in the Neck Region

0	--Not Noticeable
0.5	--Very, Very Light (just noticeable)
1	--Very Light
2	--Light
3	--Moderate
4	--Somewhat High
5	--High
6	
7	--Very High
8	
9	
10	--Very, Very High

Perceived discomfort for the neck:_____________________

Perceived discomfort for the back:_____________________

Perceived discomfort for the eyes:_____________________

Exit Questionnaire Regarding Preferences

1. Using the following scale how would you rank the comfortableness of the "red chair?"

|__________|_________|________________|______|___________|____________| |

1 4 7

Low Average High

2. Using the following scale how would you rank the comfortableness of the "grey chair?"

|__________|_________|________________|______|___________|____________| |

1 4 7

Low Average High

3. Using the following scale how would you rank the comfortableness of the monitor "low?"

|__________|_________|________________|______|___________|____________| |

1 4 7

Low Average High

4. Using the following scale how would you rank the comfortableness of the monitor "high?"

|__________|_________|________________|______|___________|____________| |

1 4 7

Low Average High

5. Rank order your "day" preferences from most to least preferred. (Sommerich, 1998)

What condition did you prefer the most? Why? (glare, how it is at home, read that was the acceptable height?

Appendix B

ANTHROPOMETRIC TABLES AND FIGURES

Table Selected Body Dimensions and Weights of U.S. Adult Civilians (Kroemer, 2000)

Body Dimension	Sex	5th Percentile (cm)	50th Percentile (cm)	95th Percentile (cm)
Stature	M	161.5	173.6	184.4
	F	149.5	160.5	171.3
Eye Height	M	151.1	162.4	172.7
	F	138.3	148.9	159.3
Height, Sitting	M	84.5	90.6	96.7
	F	78.6	85.0	90.7
Eye Height,	M	72.6	78.6	84.4
Sitting	F	67.5	73.3	78.5
Weight	M	56.2	74.0	97.1
	F	46.2	61.1	89.9

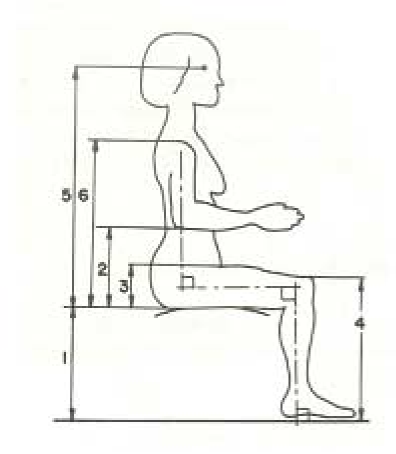


Figure B.1 Anthropometric Dimensions (Kroemer, 2000) : 1) Sitting Height, 2)Elbow height, 3) Thigh Height , 4) Knee Height, 5) Eye Height, 6) Shoulder Height

APPENDIX C
SUPPLEMENTAL DATA

1.1 Trend Analysis and Raw Data

Supplemental analysis consisted of qualitatively analyzing strings of data for trends and then comparing the trends to the rank orders presented in the subjective analysis section of the results. First the data table was segregated by subjects and then further by configuration. Averages were calculated for the dependent measures: Performance (Perf), L5 NEMG, L1 NEMG, C7 NEMG, PLDN, PLDB, and PLDE. Frequency counts were performed on the PSN, PSB, and PSF variables (Supplemental Table 1.1). From this table, Supplemental Table 1.1 was generated. The configuration with the highest value for each dependent variable was identified and then the number of times the configuration was identified as the "highest value" was counted. In addition, the rank orders provided by the participant in the exit interview were incorporated for comparison to and generalization across dependent measures.

The easiest way to explain the trends, and/or lack thereof, in the data is to present the results by participant. Participants one and two rank ordered the preferences by chair type, preferring the high chair. Their rankings coincided with a descending "count," meaning that their configuration of choice was least often the "highest value." The low chair, for these two participants, was associated with higher values of L1 NEMG, PLDB, PSN, and PSB. Participant three preferred the monitor height high conditions. In this case monitor low conditions resulted in higher values associated with L5, L1, and C7 NEMG, while the high monitor conditions were associated with higher PLDB and PS's of the neck and eyes. Participant four did not weight one independent variable more important than the other, plus he/she chose MLCH as their number one ranking despite the fact that this configuration had the "highest value," for 6 out of the 8 dependent measures. In contrast, participant five rank ordered according to the chair low conditions and MLCH was ranked as this participant's last choice. MLCH was again the "highest value," for half of the dependent variables. Participant six chose MLCH and MHCL, the "highest values" for all NEMG measures and PLDE, as their number one and two (respectively) preferred rankings. (Again, one independent variable was not weighted more important than the other.) The seventh and eighth participant rank ordered the configurations by weighting monitor height more important than chair type. Similarly, both sets of rank orders corresponded poorly with "count." However, participant seven preferred the monitor high conditions, associated with higher values of L1 NEMG and higher postures shifts of the neck and back, while participant eight preferred the low monitor conditions associated with higher values of L1 and C7 NEMG and higher values of PLD of the back and eyes. The number of times a configuration had or did not have the "highest value," associated with these dependent variables, would not be a good indicator of participant preference.

Supplemental Table 1.1 Configuration/Ranking comparison

	Average					**Frequency**						
Subject 1												
Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*	*Count*	*Rank*
MLCH	373.2	0	0.05	0.03	0.08	0.5	0	36	10	60	1	1
MHCH	386.5	0.48	0.09	0.17	0	0	0	40	8	55	2	2
MLCL	404.3	0.37	0.03	0.05	0.17	1.67	0.08	53	24	38	3	3
MHCL	438.3	0.05	0.12	0.11	0.83	1.25	0	32	45	37	3	4
PREF	449	0.11	0.02	0.08	0	0	0	39	9	25	1	
Highest Value	*PREF*	*MHCH*	*MHCL*	*MHCH*	*MHCL*	*MLCL*	*MLCL*	*MLCL*	*MHCL*	*MLCH*		
Subject 2												
Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*	*Count*	*Rank*
MLCH	280.3	0	0	0	0.75	0.92	1.1	16	10	1	1	1
MHCH	232.3	0.02	0.03	0.01	1.17	0.42	0.33	20	7	16	2	2
MLCL	267.3	0.34	0.1	0.29	0.58	1.5	0.17	21	10	8	3	3
MHCL	284	0.3	0.05	0.51	0.92	1.17	0.92	39	6	8	3	4
PREF	305.3	0.03	0.01	0.03	0.42	0.75	0.67	24	3	1	1	
Highest Value	*PREF*	*MLCL*	*MLCL*	*MHCL*	*MHCH*	*MHCL*	*MLCH*	*MHCL*	*MLCL*	*MHCH*		
Subject 3												
Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*	*Count*	*Rank*
MLCH	326.3	0.1	0.11	0.05	0.92	0.42	0.25	56	15	39	2	4
MHCH	359.8	0.06	0.11	0.04	0	0.92	0.25	57	19	41	2	2
MLCL	320.3	0.06	0.1	0.04	0.5	0.42	0.33	33	9	29	0	3
MHCL	338.7	0.06	0.09	0.01	0	1.1	0.42	52	14	51	2.5	1
PREF	374.8	0.04	0.13	0.06	0	0.92	0.08	45	16	51	3.5	
Highest Value	*PREF*	*MLCH*	*PREF*	*PREF*	*MLCH*	*MHCL*	*MHCL*	*MHCH*	*MHCH*	*PREF* *MHCL*		

Subject 4

Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*	*Count*	*Rank*
MLCH	297.2	0.15	0.23	0.23	0.58	1.33	1.58	35	14	13	6	1
MHCH	304.5	0.09	0.15	0.12	1.1	0.5	0.33	44	11	1	1	3
MLCL	320.5	0	0	0	0.67	0.67	0.25	29	4	4	0	4
MHCL	251	0.16	0.1	0.11	0.17	0.75	1	53	6	4	1	2
PREF	329.5	0.05	0.16	0.12	0.33	0.75	0.75	55	10	4	2	
Highest Value	*PREF*	*MHCL*	*MLCH*	*MLCH*	*MHCH*	*MLCH*	*MLCH*	*PREF*	*MLCH*	*MLCH*		

Subject 5

Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*	*Count*	*Rank*
MLCH	425.7	0.17	0.29	0.27	0.42	0	0.83	45	12	17	4	4
MHCH	419.8	0.1	0.1	0.04	0.58	0	1	41	6	16	0	3
MLCL	416.3	0.18	0.11	0.1	0.17	0	0.67	42	28	24	2	2
MHCL	417.8	0.17	0.16	0.11	0.58	0	1.1	43	18	18	1	1
PREF	378.3	0.14	0.16	0.15	0.08	0	0.75	55	26	28	2	
Highest Value	*MLCH*	*MLCL*	*MLCH*	*MLCH*	*MHCL*	*NONE*	*MLCH*	*PREF*	*MLCL*	*PREF*		

Subject 6

Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*	*Count*	*Rank*
MLCH	498.7	0.13	0.12	0.22	2.08	1.5	2.75	25	4	23	2.33	2
MHCH	535.2	0.55	0.07	0.13	1.67	2.5	2.75	18	6	25	1.88	4
MLCL	510.8	0.22	0.06	0.08	2.17	1.25	2.58	19	20	16	1	3
MHCL	471.5	0.56	0.08	0.1	1.25	1.17	2.75	22	18	19	1.33	1
PREF	437.3	0.53	0.08	0.1	2.67	2.5	4	29	16	37	3.5	
Highest Value	*MHCH*	*MHCL*	*MLCH*	*MLCH*	*PREF*	*MHCH* *PREF*	*MHCL* *MHCH* *MLCH*	*PREF*	*MLCL*	*PREF*		

Subject 7

Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*	*Count*	*Rank*
MLCH	386.8	0.07	0.1	0.05	1.83	6.17	0.67	50	17	12	1	3
MHCH	384.2	0.16	0.14	0.08	0.83	4.67	1	59	19	6	3	1
MLCL	407	0.05	0.11	0.04	2.83	4.33	1.67	51	13	15	4	4
MHCL	406	0.05	0.1	0.09	2.17	5.17	1.33	48	16	7	0	2
PREF	359.3	0.23	0.06	0.21	1.41	5	0.5	36	8	10	2	
Highest Value	*MLCL*	*PREF*	*MHCH*	*PREF*	*MLCL*	*MLCH*	*MLCL*	*MHCH*	*MHCH*	*MLCL*		

Subject 8

Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*	*Count*	*Rank*
MLCH	360.5	0.1	0.21	0.24	0.5	1.33	1.33	82	9	64	3	1
MHCH	339	0.09	0.17	0.08	0.42	0.83	0.42	57	12	61	0	3
MLCL	329.2	0.07	0.04	0.28	0.67	1.75	0.58	80	14	27	2	2
MHCL	332.3	0.13	0.09	0.22	0.75	1.42	1.17	63	15	66	4	4
PREF	294.7	0.04	0.14	0.25	0.33	1.58	0.58	83	20	56	1	

Highest Value	*MLCH*	*MHCL*	*MLCH*	*MLCL*	*MHCL*	*MLCL*	*MLCH*	*PREF*	*MHCL*	*MHCL*
Number of Times Configuration Had "Highest Value"										
Configuration	*Perf*	*L5*	*L1*	*C7*	*PLDN*	*PLDB*	*PLDE*	*PSN*	*PSB*	*PSF*
MLCH	2	1	4	3	1	2	4.33	0	1	2
MHCH	1	1	1	1	2	0.5	0.33	2	2	1
MLCL	1	2	1	1	1	2	2	1	3	1
MHCL	0	3	1	1	3	2	1.33	1	2	1.5
PREF	4	1	1	2	1	0.5	0	4	0	2.5

Supplemental Table 1.2 Frequency (PSN, PSB, PSF)/Average (all other dependent measures) Values for Configuration by Subject

Subj	Config	Perf	L5	L1	C7	PLDN	PLDB	PLDE	PSN	PSB	PSF
1	MLCH	541	.	0.0551	0.03144	0	1	0	3	1	3
1	MLCH	508	.	0.0374	0.027	0	0	0	6	3	12
1	MLCH	552	.	0.0577	0.03144	0	0	0	7	0	6
1	MLCH	156	.	0.0361	0.0237	0.5	0	0	10	2	19
1	MLCH	206	.	0.0688	0.0386	0	1	0	4	2	5
1	MLCH	276	.	0.0347	0.0221	0	1	0	6	2	15
		373.2	**0**	**0.0483**	**0.02905**	**0.0833**	**0.5**	**0**	**36**	**10**	**60**
1	MHCH	497	0.4581	0.0967	0.0911	0	0	0	3	0	1
1	MHCH	240	0.4989	0.0873	0.1824	0	0	0	6	3	15
1	MHCH	532	0.4513	0.0755	0.2044	0	0	0	6	0	5
1	MHCH	273	0.508	0.1098	0.0945	0	0	0	13	1	12
1	MHCH	487	0.4558	0.0855	0.2747	0	0	0	5	1	4
1	MHCH	292	0.517	0.1135	0.1978	0	0	0	7	3	18
		386.8	**0.48152**	**0.09472**	**0.17415**	**0**	**0**	**0**	**40**	**8**	**55**
1	MLCL	508	0.1085	0.0081	0.041	1	0	0	11	0	4
1	MLCL	246	0.1139	0.0225	0.04498	0	1	0	12	5	11
1	MLCL	556	0.4801	0.0137	0.0618	0	2	0	4	5	5
1	MLCL	302	0.7272	0.0169	0.0564	0	2	0	6	6	6
1	MLCL	506	0.6735	0.0973	0.0826	0	3	0	9	2	2
1	MLCL	308	0.1042	0.0299	0.0208	0	2	0.5	11	6	10
		404.3	**0.3679**	**0.0314**	**0.05126**	**0.1667**	**1.667**	**0.083**	**53**	**24**	**38**
1	MHCL	478	0.0324	0.2021	0.1353	0	2	0	5	5	1
1	MHCL	368	0.0636	0.1581	0.1278	2	1	0	6	9	8
1	MHCL	589	0.0384	0.0836	0.1248	1	2	0	4	6	4
1	MHCL	328	0.0564	0.1155	0.0677	1	2	0	5	11	7
1	MHCL	578	0.0192	0.0456	0.1248	1	0.5	0	8	3	5
1	MHCL	289	0.0816	0.1299	0.0556	0	0	0	4	11	12
		438.3	**0.0486**	**0.12247**	**0.106**	**0.8333**	**1.25**	**0**	**32**	**45**	**37**

1 PREF	518	0.0907	0.0145	0.1307	0	0	0	2	0	1
1 PREF	296	0.127	0.0363	0.0956	0	0	0	9	3	2
1 PREF	659	0.1224	0.0387	0.0506	0	0	0	11	.	7
1 PREF	267	0.1156	0.0242	0.0571	0	0	0	6	3	8
1 PREF	598	0.1043	0.0145	0.0669	0	0	0	6	1	4
1 PREF	356	0.0952	0.0145	0.0679	0	0	0	5	2	3
	449	**0.1092**	**0.02378**	**0.07813**	**0**	**0**	**0**	**39**	**9**	**25**
2 MHCH	324	0.0089	0.0286	0.0124	0.5	0	0	4	0	0
2 MHCH	152	0.0089	0.0325	0.0052	0.5	0.5	0	2	3	3
2 MHCH	280	0.0143	0.0299	0.0096	2	0.5	0	4	1	5
2 MHCH	167	0.0268	0.0338	0.019	1	0.5	0.5	1	1	3
2 MHCH	275	0.0214	0.0299	0.0168	2	0.5	0.5	8	1	3
2 MHCH	196	0.0375	0.0312	0.0109	1	0.5	1	1	1	2
	232.3	**0.01963**	**0.03098**	**0.01232**	**1.1667**	**0.417**	**0.333**	**20**	**7**	**16**
2 MLCL	318	0.022	0.0386	0.1176	0	0.5	0	1	0	0
2 MLCL	164	0.0654	0.1023	0.1558	0.5	0.5	0	3	0	0
2 MLCL	347	0.3582	0.0772	0.3659	1	2	0.5	3	4	4
2 MLCL	176	0.3851	0.1757	0.4053	1	2	0	7	3	1
2 MLCL	364	0.5021	0.1757	0.3562	1	2	0	6	3	3
2 MLCL	235	0.7122	0.0541	0.3323	0	2	0.5	1	0	0
	267.3	**0.34083**	**0.10393**	**0.28885**	**0.5833**	**1.5**	**0.167**	**21**	**10**	**8**
2 MHCL	329	0.0549	0.0663	0.5404	0	0.5	0	0	1	0
2 MHCL	177	0.1491	0.03	0.442	0.5	0.5	1	1	1	0
2 MHCL	409	0.3561	0.029	0.499	1	1	0.5	18	0	0
2 MHCL	207	0.3406	0.117	0.3986	1	2	1	2	2	5
2 MHCL	345	0.4255	0.0145	0.5414	2	1	1	15	0	1
2 MHCL	237	0.4451	0.06	0.6242	1	2	2	3	2	2
	284	**0.29522**	**0.0528**	**0.5076**	**0.9167**	**1.167**	**0.917**	**39**	**6**	**8**
2 MLCH	334	.	.	.	0	0.5	0	7	2	1
2 MLCH	168	.	.	.	0.5	1	1	2	1	0
2 MLCH	383	.	.	.	2	1	0.5	3	3	0
2 MLCH	199	.	.	.	1	1	4	0	2	0
2 MLCH	358	.	.	.	0.5	1	0.5	1	1	0
2 MLCH	240	.	.	.	0.5	1	0.5	3	1	0
	280.3	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**0.75**	**0.917**	**1.083**	**16**	**10**	**1**
2 PREF	353	0.0253	0.0171	0.03	0.5	0	0	3	1	0
2 PREF	242	0.0253	0.0149	0.0326	0	1	1	9	1	0
2 PREF	358	0.0265	0.0149	0.0235	0	1	0	2	1	0
2 PREF	256	0.0265	0.0149	0.0365	1	1	2	8	0	0
2 PREF	354	0.0265	0.0149	0.0424	0.5	1	0	0	0	0
2 PREF	269	0.0253	0.0128	0.0267	0.5	0.5	1	2	0	1
	305.3	**0.0259**	**0.01492**	**0.03195**	**0.4167**	**0.75**	**0.667**	**24**	**3**	**1**

3	MLCL	376	0.0883	0.1209	.	0.5	0	0	7	0	1
3	MLCL	174	0.0583	0.0693	.	0.5	0	0	4	3	10
3	MLCL	451	0.094	0.1463	.	0.5	0	0.5	8	1	2
3	MLCL	188	0.0376	0.0693	.	0.5	0.5	0.5	3	0	6
3	MLCL	480	0.0132	0.1516	0.0386	0.5	1	0.5	6	0	3
3	MLCL	253	0.0959	0.0275	0.0382	0.5	1	0.5	5	5	7
		320.3	**0.06455**	**0.09748**	**0.0384**	**0.5**	**0.417**	**0.333**	**33**	**9**	**29**
3	MHCL	411	0.0587	0.1351	0.0049	0	0	0	11	2	3
3	MHCL	211	0.0481	0.0726	0.0058	0	0.5	0	7	1	10
3	MHCL	495	0.0721	0.1405	0.0075	0	1	0	6	1	9
3	MHCL	211	0.0628	0.0524	0.0036	0	1	1	10	3	12
3	MHCL	444	0.0267	0.1292	0.0049	0	2	0.5	12	4	7
3	MHCL	260	0.0708	0.011	0.0023	0	2	1	6	3	10
		338.7	**0.05653**	**0.09013**	**0.00483**	**0**	**1.083**	**0.417**	**52**	**14**	**51**
3	MHCH	480	0.1046	0.1521	0.0266	0	0	0	5	1	7
3	MHCH	221	0.057	0.0921	0.0128	0	0	0	3	1	4
3	MHCH	427	0.0986	0.1531	0.022	0	0.5	0	15	3	4
3	MHCH	263	0.023	0.0669	0.0101	0	1	0.5	10	3	11
3	MHCH	466	0.034	0.0967	0.0092	0	2	0	17	5	4
3	MHCH	302	0.0383	0.081	0.1593	0	2	1	7	6	11
		359.8	**0.05925**	**0.10698**	**0.04**	**0**	**0.917**	**0.25**	**57**	**19**	**41**
3	MLCH	458	0.0539	0.1333	0.0335	0	0	0	7	3	3
3	MLCH	210	0.1065	0.0824	0.0434	0.5	0	0	8	1	10
3	MLCH	399	0.0593	0.1475	0.0479	1	0	0	16	0	6
3	MLCH	240	0.1294	0.0102	0.0552	1	0.5	0.5	8	2	8
3	MLCH	345	0.1482	0.2039	0.047	1	1	0	10	5	4
3	MLCH	306	0.1119	0.1044	0.0633	2	1	1	7	4	8
		326.3	**0.10153**	**0.11362**	**0.04838**	**0.9167**	**0.417**	**0.25**	**56**	**15**	**39**
3	PREF	425	0.0264	0.1145	0.0648	0	0	0	10	1	5
3	PREF	315	0.0305	0.1378	0.0482	0	0	0	9	3	9
3	PREF	428	0.0335	0.1185	0.0714	0	0.5	0	9	3	6
3	PREF	300	0.0755	0.1479	0.0606	0	1.5	0	6	5	10
3	PREF	433	0.0169	0.1266	0.0947	0	1.5	0	8	2	11
3	PREF	348	0.0545	0.155	0.0357	0	2	0.5	3	2	10
		374.8	**0.03955**	**0.13338**	**0.06257**	**0**	**0.917**	**0.083**	**45**	**16**	**51**
4	MHCL	333	0.2321	0.1233	0.1399	0	0.5	0.5	7	0	1
4	MHCL	168	0.1548	0.0838	0.1399	0	0.5	0.5	7	0	2
4	MHCL	309	0.1756	0.1046	0.1667	0	0.5	1	13	1	0
4	MHCL	183	0.0565	0.0577	0.0714	0	1	1	6	0	1
4	MHCL	277	0.2589	0.1267	0.0923	0.5	1	1.5	13	0	0
4	MHCL	236	0.0893	0.0765	0.0744	0.5	1	1.5	7	5	0
		251	**0.1612**	**0.09543**	**0.1141**	**0.1667**	**0.75**	**1**	**53**	**6**	**4**

4	MLCH	369	0.1957	0.6975	1.002	0	0	7	0	0	0
4	MLCH	212	0.07	0.1314	0.0676	0.5	0.5	0.5	5	3	0
4	MLCH	349	0.1371	0.2066	0.093	0.5	1	0.5	8	5	0
4	MLCH	210	0.1157	0.0719	0.0554	1	2	0.5	5	1	6
4	MLCH	396	0.2643	0.27	0.0963	0.5	2	0.5	11	3	2
4	MLCH	247	0.1157	0.021	0.0532	1	2.5	0.5	6	2	5
		297.2	**0.14975**	**0.23307**	**0.22792**	**0.5833**	**1.333**	**1.583**	**35**	**14**	**13**
4	MHCH	350	0.1584	0.2204	0.1762	0	0	0	11	4	0
4	MHCH	234	0.0518	0.1299	0.1134	1	0.5	0	4	2	0
4	MHCH	354	0.1636	0.1908	0.1817	1.5	0.5	0.5	11	1	0
4	MHCH	244	0.0274	0.0942	0.0551	1.5	0.5	0.5	9	0	0
4	MHCH	382	0.1155	0.1868	0.1623	1	1	0.5	7	3	1
4	MHCH	263	0.0178	0.0509	0.0357	1.5	0.5	0.5	2	1	0
		304.5	**0.08908**	**0.1455**	**0.12073**	**1.0833**	**0.5**	**0.333**	**44**	**11**	**1**
4	MLCL	347	.	.	.	0	0.5	0	5	0	0
4	MLCL	233	.	.	.	0.5	0.5	0	3	2	2
4	MLCL	385	.	.	.	0.5	0.5	0	5	0	1
4	MLCL	284	.	.	.	1	0.5	0.5	3	1	0
4	MLCL	381	.	.	.	1	1	0.5	9	0	1
4	MLCL	293	.	.	.	1	1	0.5	4	1	0
		320.5	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**0.6667**	**0.667**	**0.25**	**29**	**4**	**4**
4	PREF	343	0.0631	0.191	0.139	0	0	0	9	1	0
4	PREF	245	0.0384	0.1565	0.0833	0	0.5	0.5	10	0	0
4	PREF	426	0.0729	0.1825	0.1621	0.5	1	0.5	10	2	0
4	PREF	264	0.0424	0.123	0.0839	0.5	1	1	3	1	1
4	PREF	391	0.0719	0.1999	0.1915	0.5	1	0.5	17	3	0
4	PREF	308	0.0355	0.0871	0.0897	0.5	1	2	6	3	3
		329.5	**0.05403**	**0.15667**	**0.12492**	**0.3333**	**0.75**	**0.75**	**55**	**10**	**4**
5	PREF	567	0.1341	0.1639	0.1533	0	0	0	10	0	0
5	PREF	198	0.1341	0.1706	0.1185	0	0	0	6	4	2
5	PREF	459	0.1077	0.1402	0.1394	0	0	0.5	10	7	10
5	PREF	225	0.167	0.1614	0.1638	0	0	1	10	5	8
5	PREF	604	0.1352	0.1362	0.1324	0.5	0	1	14	8	2
5	PREF	217	0.1626	0.1786	0.1864	0	0	2	5	2	6
		378.3	**0.14012**	**0.15848**	**0.14897**	**0.0833**	**0**	**0.75**	**55**	**26**	**28**
5	MHCL	549	0.1099	0.1736	0.077	0	0	0	11	0	0
5	MHCL	264	0.1117	0.1736	0.1228	0.5	0	0.5	3	0	2
5	MHCL	613	0.2354	0.1349	0.1071	0.5	0	1	11	4	3
5	MHCL	232	0.1053	0.1802	0.1395	0.5	0	1	2	4	3
5	MHCL	553	0.3681	0.0908	0.1016	1	0	2	7	7	2
5	MHCL	296	0.10531	0.1802	0.1406	1	0	2	9	3	8
		417.8	**0.17262**	**0.15555**	**0.11477**	**0.5833**	**0**	**1.083**	**43**	**18**	**18**

5 MLCL	582	0.1707	0.1239	0.0587	0	0	0	9	4	2
5 MLCL	243	0.1618	0.1222	0.1301	0	0	0.5	1	5	6
5 MLCL	579	0.2845	0.0881	0.0841	0	0	0.5	17	7	1
5 MLCL	266	0.1606	0.1186	0.1184	0.5	0	1	4	5	0
5 MLCL	564	0.1214	0.1069	0.0978	0	0	1	7	2	6
5 MLCL	264	0.1568	0.1159	0.1272	0.5	0	1	4	5	9
	416.3	**0.17597**	**0.1126**	**0.10272**	**0.1667**	**0**	**0.667**	**42**	**28**	**24**
5 MHCH	496	0.1071	0.0889	0.0345	0.5	0	0	14	0	2
5 MHCH	263	0.1062	0.0678	0.0402	0.5	0	1	6	2	3
5 MHCH	586	0.0635	0.0455	0.033	0.5	0	1	11	1	5
5 MHCH	296	0.129	0.0984	0.0682	0.5	0	1	2	0	3
5 MHCH	584	0.0764	0.0359	0.0201	0.5	0	1	5	1	0
5 MHCH	294	0.0893	0.0888	0.0495	1	0	2	3	2	3
	419.8	**0.09525**	**0.07088**	**0.04092**	**0.5833**	**0**	**1**	**41**	**6**	**16**
5 MLCH	532	0.1979	0.6177	0.239	0	0	0	11	0	5
5 MLCH	255	0.1965	0.6345	0.3379	0.5	0	0.5	5	1	3
5 MLCH	626	0.1507	0.6008	0.2558	0.5	0	0.5	16	6	3
5 MLCH	261	0.1782	0.6135	0.2115	0.5	0	1	4	2	2
5 MLCH	575	0.1683	0.4958	0.2445	0.5	0	1	6	2	3
5 MLCH	305	0.1494	0.5714	0.3269	0.5	0	2	3	1	1
	425.7	**0.1735**	**0.58895**	**0.26927**	**0.4167**	**0**	**0.833**	**45**	**12**	**17**
6 PREF	679	0.387	0.0343	0.0658	2.5	2	1	6	0	7
6 PREF	161	0.5262	0.0803	0.0987	2.5	2	4	4	4	6
6 PREF	685	0.5461	0.0454	0.0628	2.5	2.5	4.5	6	3	6
6 PREF	200	0.5805	0.1222	0.1458	2.5	2.5	5	3	3	6
6 PREF	684	0.5552	0.0671	0.0868	3	3	5	4	3	4
6 PREF	215	0.5805	0.1201	0.1406	3	3	4.5	6	3	8
	437.3	**0.52925**	**0.07823**	**0.10008**	**2.6667**	**2.5**	**4**	**29**	**16**	**37**
6 MLCH	784	0.1255	0.1015	0.1819	0.5	0	1	3	0	5
6 MLCH	199	0.1117	0.1242	0.2009	2	1	2	5	0	6
6 MLCH	749	0.1319	0.1015	0.2121	2	2	3	5	2	3
6 MLCH	202	0.1172	0.0961	0.2478	2	2	3.5	3	1	4
6 MLCH	798	0.1291	0.0961	0.3627	3	2	3.5	4	0	3
6 MLCH	260	0.1538	0.1762	0.1317	3	2	3.5	5	1	2
	498.7	**0.1282**	**0.11593**	**0.22285**	**2.0833**	**1.5**	**2.75**	**25**	**4**	**23**
6 MHCL	693	0.5619	0.0757	0.1342	0.5	0.5	2	3	1	0
6 MHCL	188	0.5381	0.0707	0.0832	0.5	0.5	2	2	4	3
6 MHCL	752	0.5619	0.0712	0.1584	1	1	2.5	4	4	3
6 MHCL	201	0.5595	0.0834	0.0524	1.5	2	3	6	3	3
6 MHCL	756	0.5643	0.0747	0.1477	2	1	3.5	1	4	3
6 MHCL	239	0.5667	0.092	0.0462	2	2	3.5	6	2	7
	471.5	**0.55873**	**0.07795**	**0.10368**	**1.25**	**1.167**	**2.75**	**22**	**18**	**19**

6 MLCL	701	0.2026	0.0422	0.0657	1	0.5	2	4	4	1
6 MLCL	207	0.2529	0.0611	0.0704	2	1	2	3	3	4
6 MLCL	830	0.1698	0.0572	0.1056	2	1	2.5	6	3	2
6 MLCL	227	0.2459	0.0792	0.0708	2	1	2.5	3	2	3
6 MLCL	829	0.1803	0.0439	0.1073	3	2	3	0	3	2
6 MLCL	271	0.2623	0.077	0.0389	3	2	3.5	3	5	4
	510.8	**0.21897**	**0.0601**	**0.07645**	**2.1667**	**1.25**	**2.583**	**19**	**20**	**16**
6 MHCH	731	0.4349	0.079	0.152	1	2	2.5	3	0	1
6 MHCH	256	0.6095	0.059	0.0937	1	2	2.5	1	3	3
6 MHCH	780	0.6635	0.0547	0.1734	2	2	2.5	5	0	5
6 MHCH	270	0.5778	0.0752	0.0925	2	2.5	2.5	2	2	4
6 MHCH	895	0.3556	0.0758	0.1833	2	3	3	4	0	4
6 MHCH	279	0.6698	0.072	0.0623	2	3.5	3.5	3	1	8
	535.2	**0.55185**	**0.06928**	**0.1262**	**1.6667**	**2.5**	**2.75**	**18**	**6**	**25**
7 PREF	546	0.1311	0.1413	0.1498	0.5	3	0	5	1	0
7 PREF	148	0.2564	0.0309	0.1396	1	4	0	6	2	0
7 PREF	447	0.184	0.0803	0.224	1	5	0.5	9	1	3
7 PREF	199	0.2975	0.0385	0.2695	1	5	0.5	6	1	1
7 PREF	645	0.2192	0.0237	0.2987	2	6	1	6	2	3
7 PREF	171	0.3151	0.0498	0.1688	3	7	1	4	1	3
	359.3	**0.23388**	**0.06075**	**0.2084**	**1.4167**	**5**	**0.5**	**36**	**8**	**10**
7 MHCH	572	0.1498	0.3262	0.1087	0.5	2	0.5	8	2	0
7 MHCH	166	0.1585	0.106	0.0386	0.5	3	1	8	1	0
7 MHCH	589	0.0993	0.2052	0.131	1	5	1	13	6	1
7 MHCH	206	0.2247	0.034	0.0171	1	5	0.5	7	3	0
7 MHCH	551	0.122	0.1477	0.161	1	6	1	12	3	2
7 MHCH	221	0.216	0.032	0.0167	1	7	2	11	4	3
	384.2	**0.16172**	**0.14185**	**0.07885**	**0.8333**	**4.667**	**1**	**59**	**19**	**6**
7 MLCH	531	0.0625	0.2377	0.0857	0	3	0	6	4	0
7 MLCH	191	0.0614	0.1116	0.019	1	3	0.5	9	4	0
7 MLCH	571	0.0357	0.1417	0.0775	2	6	0.5	10	2	1
7 MLCH	174	0.0949	0.0509	0.0216	3	8	1	5	1	3
7 MLCH	637	0.0424	0.0706	0.08	2	8	1	7	5	5
7 MLCH	217	0.0982	0.0098	0.0025	3	9	1	13	1	3
	386.8	**0.06585**	**0.10372**	**0.04772**	**1.8333**	**6.167**	**0.667**	**50**	**17**	**12**
7 MHCL	533	0.0637	0.123	0.179	0.5	4	0.5	9	1	0
7 MHCL	201	0.0154	0.0301	0.0743	0.5	5	1	6	0	0
7 MHCL	657	0.0614	0.1748	0.0914	2	5	0.5	9	6	1
7 MHCL	212	0.0207	0.0448	0.061	3	6	2	6	2	3
7 MHCL	587	0.126	0.2238	0.0768	4	4	2	8	6	1
7 MHCL	246	0.0084	0.0227	0.0362	3	7	2	10	1	2
	406	**0.04927**	**0.1032**	**0.08645**	**2.1667**	**5.167**	**1.333**	**48**	**16**	**7**

7 MLCL	572	0.0783	0.2138	0.0714	2	4	1	4	3	4
7 MLCL	181	0.0508	0.0441	0.0532	2	4	2	7	1	1
7 MLCL	660	0.0291	0.1104	0.0325	3	5	2	10	1	0
7 MLCL	216	0.0242	0.0471	0.0195	4	4	1	10	4	4
7 MLCL	621	0.0872	0.2067	0.061	3	4	2	11	1	1
7 MLCL	192	0.0121	0.0284	0.0195	3	5	2	9	3	5
	407	**0.04695**	**0.10842**	**0.04285**	**2.8333**	**4.333**	**1.667**	**51**	**13**	**15**
8 PREF	421	0.0286	0.193	0.263	0	0.5	0	15	0	6
8 PREF	119	0.0467	0.09	0.1924	0	1	0	10	4	13
8 PREF	425	0.0426	0.2236	0.2924	0	1	0	23	2	4
8 PREF	131	0.0498	0.0555	0.2233	0	2	0.5	9	6	11
8 PREF	506	0.009	0.2355	0.3213	0	2	1	14	3	4
8 PREF	166	0.0509	0.0236	0.2259	2	3	2	12	5	18
	294.7	**0.03793**	**0.13687**	**0.25305**	**0.3333**	**1.583**	**0.583**	**83**	**20**	**56**
8 MLCL	494	0.0642	0.0858	0.2459	0	0.5	0	13	2	0
8 MLCL	148	0.0677	0.0313	0.2248	0.5	1	0	12	0	7
8 MLCL	495	0.0652	0.0416	0.2703	0.5	1	0.5	18	4	6
8 MLCL	150	0.0692	0.0148	0.2585	1	2	1	9	2	7
8 MLCL	512	0.0672	0.0555	0.3311	1	3	1	13	2	4
8 MLCL	176	0.0692	0.0164	0.2946	1	3	1	15	4	3
	329.2	**0.06712**	**0.0409**	**0.27087**	**0.6667**	**1.75**	**0.583**	**80**	**14**	**27**
8 MHCH	436	0.0791	0.2036	0.0682	0	0.5	0	10	1	6
8 MHCH	174	0.0872	0.1219	0.0544	0.5	0.5	0	9	1	13
8 MHCH	503	0.0879	0.282	0.1144	0	0.5	0	13	1	6
8 MHCH	202	0.1004	0.1061	0.0487	0	0.5	0	7	3	10
8 MHCH	482	0.0755	0.2767	0.1615	1	1	0.5	13	2	7
8 MHCH	237	0.104	0.0364	0.0357	1	2	2	5	4	19
	339	**0.08902**	**0.17112**	**0.08048**	**0.4167**	**0.833**	**0.417**	**57**	**12**	**61**
8 MLCH	466	0.1787	0.2403	0.2445	0	0.5	0.5	20	0	7
8 MLCH	188	0.0728	0.231	0.1798	0	0.5	0.5	12	0	10
8 MLCH	569	0.1184	0.2737	0.2874	0.5	1	1	12	2	5
8 MLCH	211	0.0891	0.1928	0.1882	0.5	2	2	6	2	14
8 MLCH	509	0.0473	0.2733	0.3714	1	2	2	16	2	16
8 MLCH	220	0.113	0.042	0.1529	1	2	2	16	3	12
	360.5	**0.10322**	**0.20885**	**0.23737**	**0.5**	**1.333**	**1.333**	**82**	**9**	**64**
8 MHCL	459	0.1102	0.0885	0.1896	0	0	1	16	1	4
8 MHCL	182	0.1067	0.1032	0.1779	0	0.5	1	7	2	12
8 MHCL	469	0.0926	0.119	0.2548	0.5	1	1	8	1	14
8 MHCL	198	0.1023	0.1095	0.2624	1	2	1	9	3	16
8 MHCL	473	0.1508	0.0714	0.2321	1	2	1	13	3	6
8 MHCL	213	0.1931	0.0774	0.1532	2	3	2	10	5	14
	332.3	**0.12595**	**0.09483**	**0.21167**	**0.75**	**1.417**	**1.167**	**63**	**15**	**66**

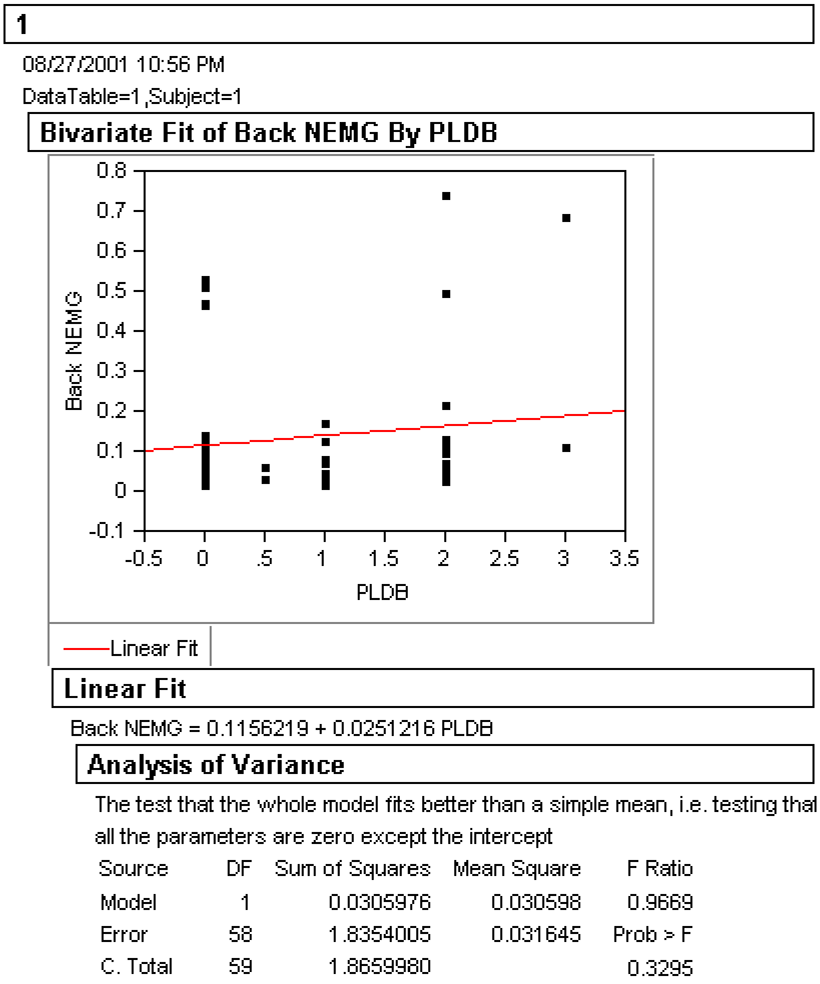
NOTE: All Bold numbers are averages, except for PSN, PSB, and PSF which are frequencies.

2.1 PLD and NEMG Relationship

As mentioned in the results and discussion section, the relationship between PLDB and L1 and L5 NEMG were investigated independently. EMG data for both areas of the low back were combined, noted as Back NEMG, and the relationship between the resultant number and reported PLDB was again analyzed using regression analysis (Supplemental Figures 2.1-2.8). The results from the independent comparison and Back NEMG are presented in Supplemental Table 2.1. Unlike the results found for the independent comparison of L1 and L5 to PLDB, Back NEMG results were significant for only two participants.

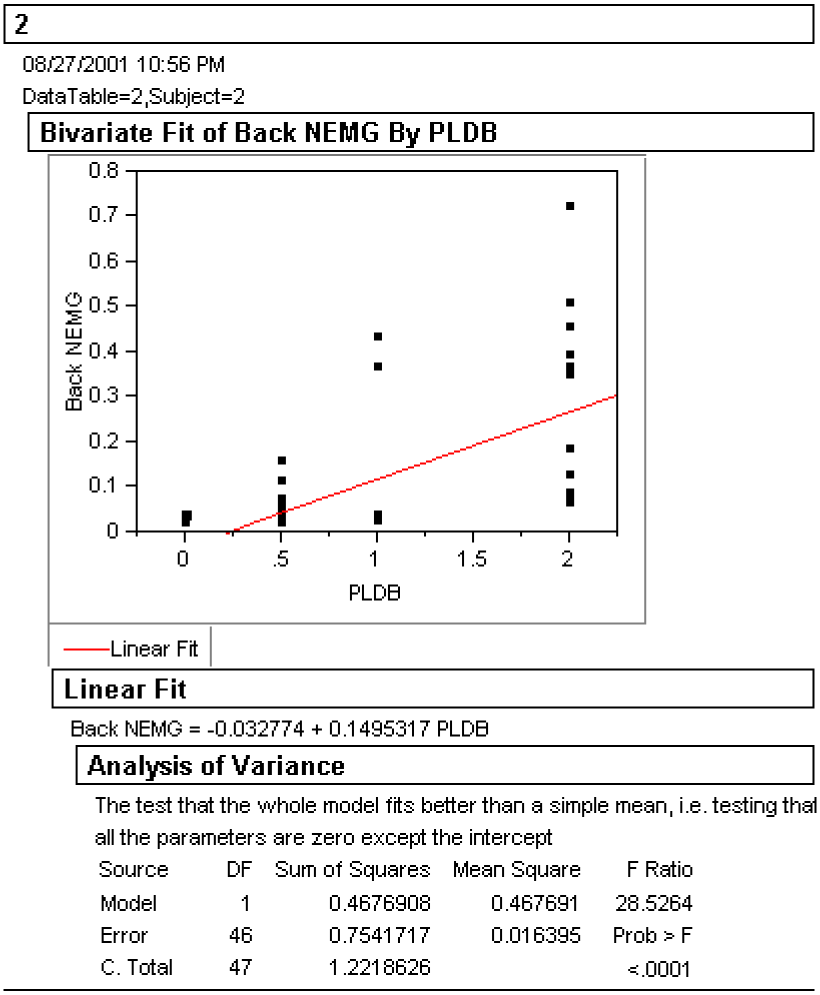
Supplemental Table 2.1 Comparison of relationship between L1 and L5 NEMG and PLDB and between Back NEMG and PLDB.

	L1 and L5 NEMG (from results)		**Back NEMG**	
Participant	**Region (P value)**	**Relationship**	**Back (P value)**	**Relationship**
2	L5 and PLD (0.0001) L1 and PLD (0.001)	Positive Positive	Back and PLD (0.0001)	Positive
6	L5 and PLD (0.045)	Positive	Back and PLD (0.046)	Positive
7	L1 and PLD (0.001)	Negative		
8	L1 and PLD (0.02)	Negative		



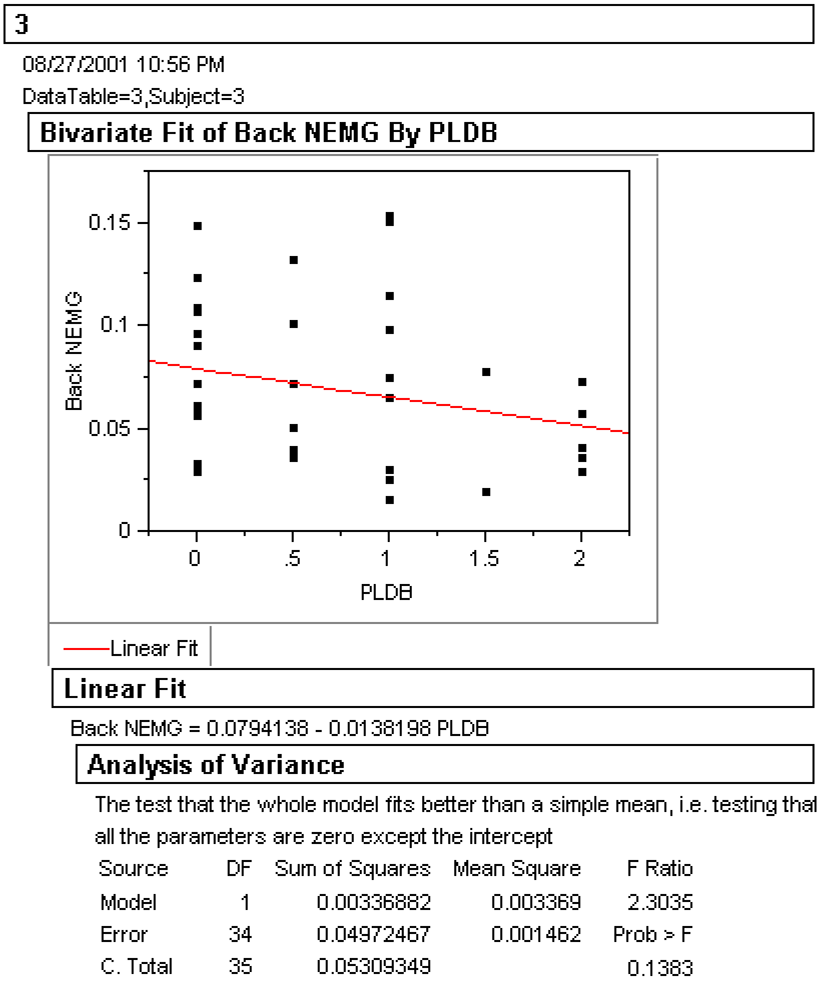
```
1
08/27/2001 10:56 PM
DataTable=1,Subject=1
Bivariate Fit of Back NEMG By PLDB

Linear Fit
Back NEMG = 0.1156219 + 0.0251216 PLDB
Analysis of Variance
The test that the whole model fits better than a simple mean, i.e. testing that
all the parameters are zero except the intercept
Source      DF   Sum of Squares   Mean Square    F Ratio
Model        1        0.0305976      0.030598     0.9669
Error       58        1.8354005      0.031645   Prob > F
C. Total    59        1.8659980                   0.3295
```

Supplemental Figure 2.1 Subject One Back NEMG vs PLDB Relationship



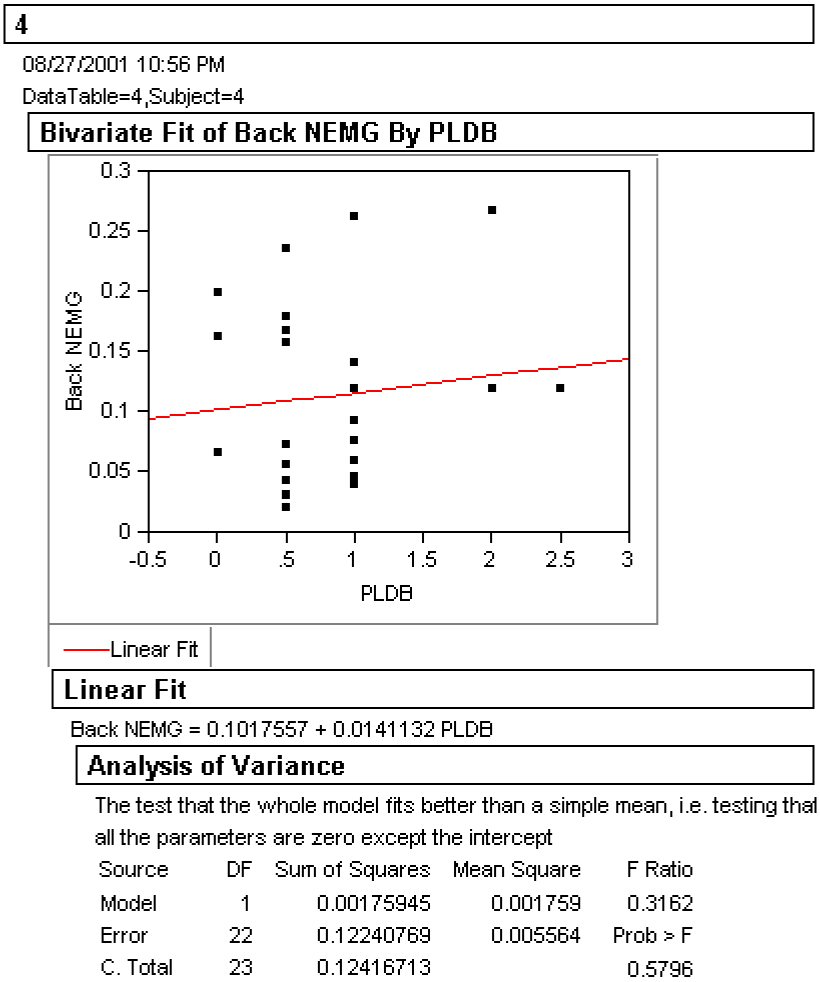
```
2
08/27/2001 10:56 PM
DataTable=2,Subject=2
Bivariate Fit of Back NEMG By PLDB

Linear Fit
Back NEMG = -0.032774 + 0.1495317 PLDB
Analysis of Variance
The test that the whole model fits better than a simple mean, i.e. testing that
all the parameters are zero except the intercept
Source      DF   Sum of Squares   Mean Square    F Ratio
Model        1        0.4676908      0.467691    28.5264
Error       46        0.7541717      0.016395    Prob > F
C. Total    47        1.2218626                   <.0001
```

Supplemental Figure 2.2 Subject Two Back NEMG vs PLDB Relationship



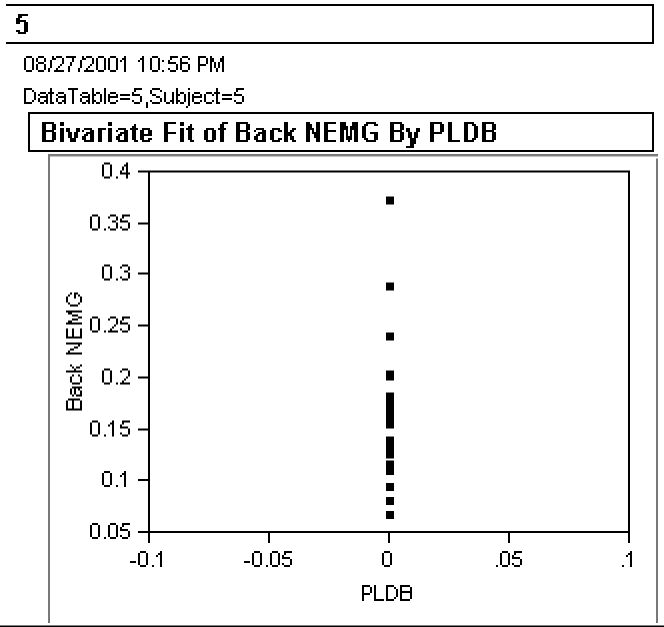
```
3
08/27/2001 10:56 PM
DataTable=3,Subject=3
Bivariate Fit of Back NEMG By PLDB
Linear Fit
Back NEMG = 0.0794138 - 0.0138198 PLDB
Analysis of Variance
The test that the whole model fits better than a simple mean, i.e. testing that
all the parameters are zero except the intercept
Source      DF   Sum of Squares   Mean Square    F Ratio
Model        1       0.00336882      0.003369     2.3035
Error       34       0.04972467      0.001462   Prob > F
C. Total    35       0.05309349                   0.1383
```

Supplemental Figure 2.3 Subject Three Back NEMG vs PLDB Relationship



```
4
08/27/2001 10:56 PM
DataTable=4,Subject=4
Bivariate Fit of Back NEMG By PLDB

Linear Fit
Back NEMG = 0.1017557 + 0.0141132 PLDB
Analysis of Variance
The test that the whole model fits better than a simple mean, i.e. testing that
all the parameters are zero except the intercept
Source      DF   Sum of Squares   Mean Square    F Ratio
Model        1       0.00175945      0.001759     0.3162
Error       22       0.12240769      0.005564   Prob > F
C. Total    23       0.12416713                   0.5796
```

Supplemental Figure 2.4 Subject Four Back NEMG vs PLDB Relationship



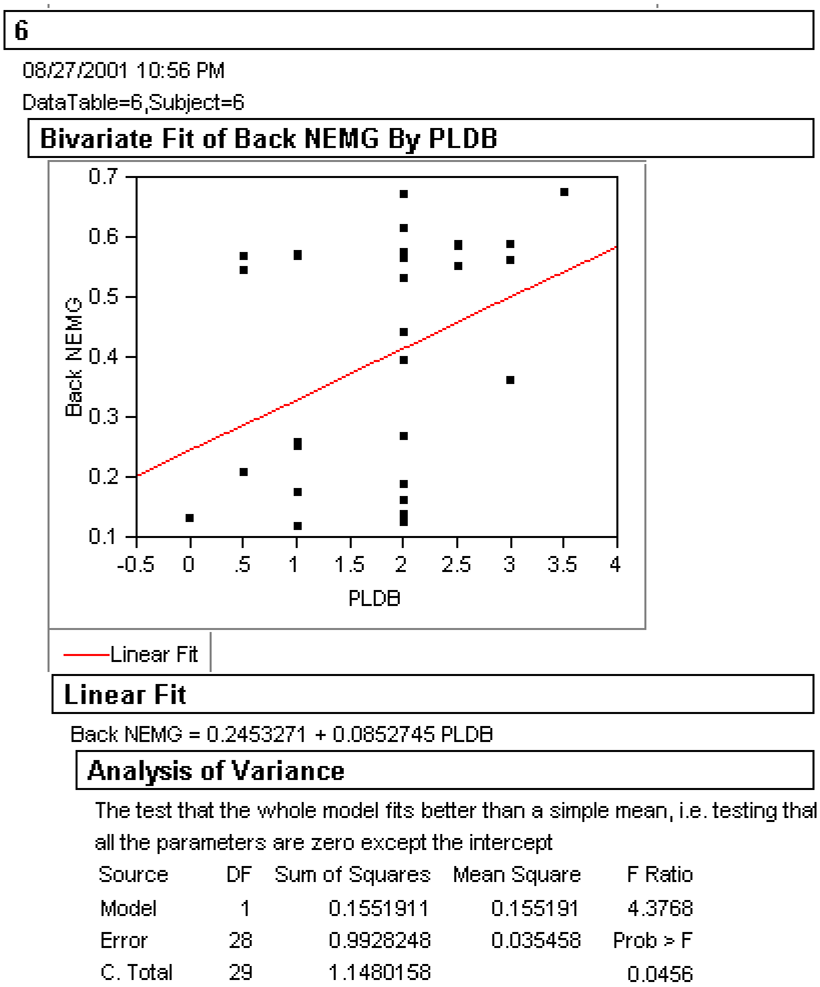
5

08/27/2001 10:56 PM

DataTable=5,Subject=5

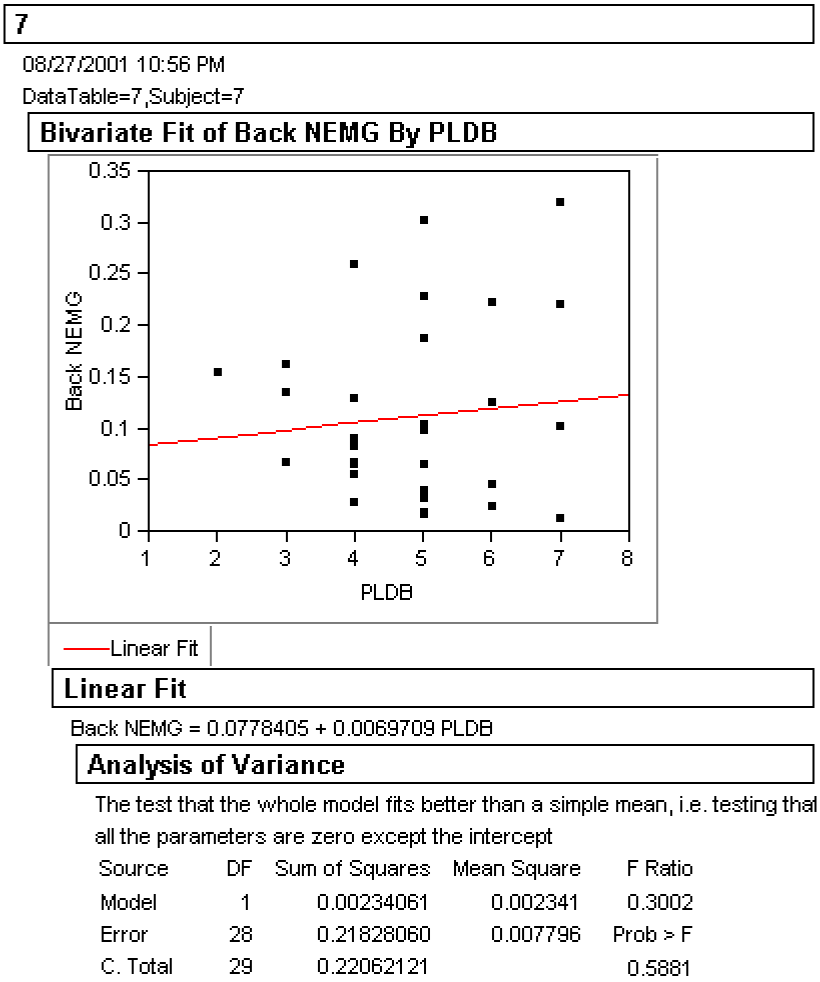
Bivariate Fit of Back NEMG By PLDB

Supplemental Figure 2.5 Subject Five Back NEMG vs PLDB Relationship (no relationship)



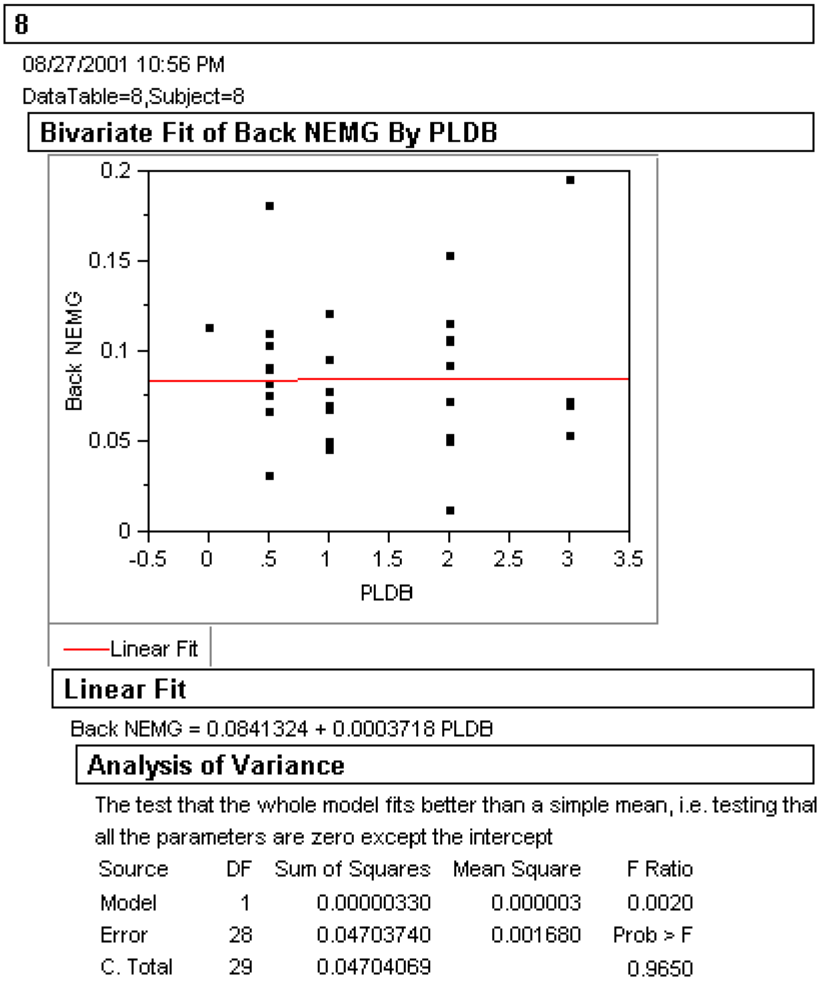
```
6
08/27/2001 10:56 PM
DataTable=6,Subject=6
Bivariate Fit of Back NEMG By PLDB
Linear Fit
Back NEMG = 0.2453271 + 0.0852745 PLDB
Analysis of Variance
The test that the whole model fits better than a simple mean, i.e. testing that
all the parameters are zero except the intercept
Source     DF   Sum of Squares   Mean Square    F Ratio
Model       1        0.1551911      0.155191     4.3768
Error      28        0.9928248      0.035458   Prob > F
C. Total   29        1.1480158                   0.0456
```

Supplemental Figure 2.6 Subject Six Back NEMG vs PLDB Relationship



```
7
08/27/2001 10:56 PM
DataTable=7,Subject=7
Bivariate Fit of Back NEMG By PLDB

Linear Fit
Back NEMG = 0.0778405 + 0.0069709 PLDB
Analysis of Variance
The test that the whole model fits better than a simple mean, i.e. testing that
all the parameters are zero except the intercept
Source      DF  Sum of Squares  Mean Square   F Ratio
Model        1      0.00234061     0.002341    0.3002
Error       28      0.21828060     0.007796  Prob > F
C. Total    29      0.22062121                 0.5881
```

Supplemental Figure 2.7 Subject Seven Back NEMG vs PLDB Relationship



```
8
08/27/2001 10:56 PM
DataTable=8,Subject=8
Bivariate Fit of Back NEMG By PLDB

Linear Fit
Back NEMG = 0.0841324 + 0.0003718 PLDB
Analysis of Variance
The test that the whole model fits better than a simple mean, i.e. testing that
all the parameters are zero except the intercept
Source    DF  Sum of Squares  Mean Square   F Ratio
Model      1      0.00000330     0.000003    0.0020
Error     28      0.04703740     0.001680  Prob > F
C. Total  29      0.04704069                 0.9650
```

Supplemental Figure 2.8 Subject Eight Back NEMG vs PLDB Relationship

APPENDIX D
ANOVA Tables

ANOVAnonpref TABLES

PERFORMANCE

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	979085	139869	20.79	0.000*
Within Participant					
Monitor Height	1	1334.11	1334.11	0.198	0.657
Chair Type	1	3906.25	3906.25	0.581	0.447
Monitor Height*Chair Type	1	534.13	534.13	0.079	0.7784
Order	3	34454	11484.7	1.708	0.167
Task	1	1153476	1153476	171.492	0.000*
Monitor Height *Task	1	1581.26	1581.26	0.235	0.628
Chair Type *Task	1	3987.63	3987.63	0.593	0.442
Sample	1	28240.8	14120.4	2.099	0.126
Monitor Height * Sample	2	1558.32	779.16	0.116	0.891
Chair Type*Sample	2	6348.82	3174.41	0.472	0.625
Task*Sample	2	21749.4	10874.7	1.617	0.202

L5 NEMG

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	1.659	0.237	13.248	0.000*
Within Participant					
Monitor Height	1	0.048	0.048	2.674	0.104
Chair Type	1	0.015	0.015	0.844	0.360
Monitor Height*Chair Type	1	0.039	0.039	2.181	0.142
Order	3	0.351	0.117	6.534	0.001*
Task	1	0.000	0.000	0.011	0.918
Monitor Height *Task	1	0.000	0.000	0.000	0.987
Chair Type *Task	1	0.006	0.006	0.350	0.555
Sample	1	0.069	0.034	1.921	0.150
Monitor Height * Sample	2	0.011	0.005	0.305	0.738
Chair Type*Sample	2	0.060	0.030	1.679	0.190
Task*Sample	2	0.000	0.000	0.008	0.992

L1 NEMG

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	0.434	0.062	7.224	0.000*
Within Participant					
Monitor Height	1	0.035	0.035	4.045	0.046*
Chair Type	1	0.103	0.103	12.021	0.001*
Monitor Height*Chair Type	1	0.085	0.085	9.877	0.002*
Order	3	0.158	0.053	6.148	0.001*
Task	1	0.048	0.048	5.57	0.020*
Monitor Height *Task	1	0.004	0.004	0.454	0.502
Chair Type *Task	1	0.020	0.020	2.296	0.132
Sample	1	0.024	0.012	1.424	0.244
Monitor Height * Sample	2	0.003	0.002	0.186	0.831
Chair Type*Sample	2	0.014	0.007	0.844	0.432
Task*Sample	2	0.005	0.002	0.266	0.767

C7 NEMG

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	0.909	0.129	10.103	.000*
Within Participant					
Monitor Height	1	0.019	0.019	1.502	.222
Chair Type	1	0.004	0.004	0.315	.576
Monitor Height*Chair Type	1	0.166	0.166	12.907	.000*
Order	3	0.073	0.024	1.900	0.132
Task	1	0.025	0.025	1.951	0.165
Monitor Height *Task	1	0.000	0.000	0.026	0.873
Chair Type *Task	1	0.016	0.016	1.247	0.266
Sample	1	0.003	0.001	0.113	0.894
Monitor Height * Sample	2	0.001	0.000	0.024	0.976
Chair Type*Sample	2	0.015	0.007	0.573	0.565
Task*Sample	2	0.001	0.000	0.026	0.974

PLD Neck

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	69.542	9.935	31.035	.000*
Within Participant					
Monitor Height	1	0.250	0.250	0.781	0.378
Chair Type	1	0.191	0.191	0.598	0.441
Monitor Height*Chair Type	1	0.002	0.002	0.005	0.943
Order	3	6.579	2.193	6.851	0.000*
Task	1	1.723	1.723	5.382	0.022
Monitor Height *Task	1	0.333	0.333	1.041	0.309
Chair Type *Task	1	0.021	0.021	0.065	0.799
Sample	1	18.331	9.165	28.632	.000*
Monitor Height * Sample	2	0.336	0.168	0.525	0.593
Chair Type*Sample	2	0.164	0.082	0.256	0.774
Task*Sample	2	0.867	0.434	1.355	0.261

PLD Back

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	404.395	57.771	92.104	0.000*
Within Participant					
Monitor Height	1	0.031	0.031	0.050	0.824
Chair Type	1	1	1	1.594	0.209
Monitor Height*Chair Type	1	1.676	1.676	2.672	0.104
Order	3	2.473	0.824	1.314	0.272
Task	1	0.563	0.563	0.897	0.345
Monitor Height *Task	1	0.220	0.220	0.351	0.554
Chair Type *Task	1	0.012	0.012	0.019	0.891
Sample	1	42.300	21.150	33.720	0.000*
Monitor Height * Sample	2	1.128	0.564	0.899	0.409
Chair Type*Sample	2	1.253	0.626	0.999	0.371
Task*Sample	2	0.164	0.082	0.131	0.878

PLD Eyes

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	109.02	15.574	32.120	0.000*
Within Participant					
Monitor Height	1	0.215	0.215	0.444	0.506
Chair Type	1	0.191	0.191	0.395	0.531
Monitor Height*Chair Type	1	4.298	4.298	8.863	0.003*
Order	3	0.955	0.318	0.657	0.579
Task	1	0.035	0.035	0.073	0.788
Monitor Height *Task	1	0.293	0.293	0.604	0.438
Chair Type *Task	1	0.012	0.012	0.024	0.877
Sample	1	13.792	6.896	14.222	0.000*
Monitor Height * Sample	2	1.385	0.693	1.429	0.243
Chair Type*Sample	2	0.635	0.318	0.655	0.521
Task*Sample	2	0.948	0.474	0.978	0.378

PS Neck

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	1158.62	165.517	15.629	0.000*
Within Participant					
Monitor Height	1	4.304	4.304	0.406	0.525
Chair Type	1	0.563	0.563	0.053	0.818
Monitor Height*Chair Type	1	14.194	14.194	1.340	0.249
Order	3	75.548	25.183	2.378	0.072
Task	1	49	49	4.627	0.033
Monitor Height *Task	1	22.005	22.005	2.078	0.151
Chair Type *Task	1	0.047	0.047	0.004	0.947
Sample	1	53.885	26.943	2.544	0.082
Monitor Height * Sample	2	5.344	2.672	0.252	0.777
Chair Type*Sample	2	7.323	3.661	0.346	0.708
Task*Sample	2	33.635	16.818	1.588	0.207

PS Back

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	90.287	12.898	3.690	0.001
Within Participant					
Monitor Height	1	0.079	0.079	0.023	0.880
Chair Type	1	2.641	2.641	0.755	0.386
Monitor Height*Chair Type	1	1.422	1.422	0.407	0.524
Order	3	15.553	5.184	1.483	0.221
Task	1	8.266	8.266	2.365	0.126
Monitor Height *Task	1	1.880	1.880	0.538	0.464
Chair Type *Task	1	5.005	5.005	1.432	0.233
Sample	1	38.260	19.130	5.473	0.005
Monitor Height * Sample	2	5.760	2.88	0.824	0.441
Chair Type*Sample	2	5.719	2.859	0.818	0.443
Task*Sample	2	7.322	3.661	1.047	0.353

PS Feet

Source	DF	SS	MS	F	P
Between Participant					
Participant	7	1693.99	241.999	32.009	0.000*
Within Participant					
Monitor Height	1	2.621	2.621	0.347	0.557
Chair Type	1	9	9	1.190	0.277
Monitor Height*Chair Type	1	14.734	14.734	1.949	0.165
Order	3	43.850	14.617	1.933	0.126
Task	1	150.062	150.062	19.848	0.000*
Monitor Height *Task	1	8.755	8.77	1.158	0.283
Chair Type *Task	1	0.255	0.255	0.034	0.855
Sample	1	68.260	34.130	4.514	0.012
Monitor Height * Sample	2	18.135	9.067	1.199	0.304
Chair Type*Sample	2	1.073	0.536	0.071	0.932
Task*Sample	2	9.260	4.630	0.612	0.543

ANOVA PREFERENCE TABLES

L1 NEMG

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	0.433	0.072	9.528	.000*
Preference	1	0.0758	0.0758	1.069	0.341
Within Participant					
Configuration	4	0.239	0.059	7.89	0.000*
Configuration*Task	4	0.031	0.008	1.018	0.399
Configuration*Sample	8	0.029	0.003	0.488	0.864
Task	1	0.045	0.045	5.987	0.015*
Task*Sample	2	0.004	0.002	0.242	0.786
Sample	2	0.023	0.011	1.485	0.229
Order	4	0.126	0.031	4.151	0.003*

L5 NEMG

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	2.344	0.391	22.68	0.000*
Preference	1	0.114	0.114	0.299	0.604
Within Participant					
Configuration	4	0.068	0.017	0.984	0.417
Configuration*Task	4	0.026	0.006	0.374	0.827
Configuration*Sample	8	0.096	0.012	0.699	0.692
Task	1	0.000	0.000	0.019	0.891
Task*Sample	2	0.005	0.000	0.014	0.987
Sample	2	0.072	0.036	2.086	0.127
Order	4	0.334	0.084	4.847	0.001*

C7 NEMG

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	0.651	0.109	9.144	0.000*
Preference	1	0.032	0.032	0.296	0.606
Within Participant					
Configuration	4	0.178	0.044	3.738	0.006*
Configuration*Task	4	0.031	0.008	0.651	0.627
Configuration*Sample	8	0.059	0.007	0.621	0.760
Task	1	0.026	0.026	2.188	0.141
Task*Sample	2	0.002	0.001	0.104	0.902
Sample	2	0.004	0.002	0.160	0.852
Order	4	0.156	0.039	3.294	0.012*

PLD Neck

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	68.981	11.497	35.447	0.000*
Preference	1	30.459	30.459	2.649	0.155
Within Participant					
Configuration	4	1.374	0.344	1.059	0.378
Configuration*Task	4	0.610	0.153	0.471	0.757
Configuration*Sample	8	3.081	0.385	1.188	0.308
Task	1	1.378	1.378	4.249	0.041
Task*Sample	2	0.408	0.204	0.630	0.534
Sample	2	19.658	9.829	30.305	0.000*
Order	4	4.616	1.154	3.558	0.008

PLD Back

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	415.698	69.283	117.765	0.000*
Preference	1	95.634	95.634	1.380	0.285
Within Participant					
Configuration	4	1.567	0.392	0.665	0.617
Configuration*Task	4	0.813	0.203	0.345	0.847
Configuration*Sample	8	3.279	0.410	0.697	0.694
Task	1	1.013	1.013	1.721	0.191
Task*Sample	2	0.077	0.039	0.066	0.937
Sample	2	51.377	25.689	43.665	0.000*
Order	4	2.830	0.708	1.203	0.311

PLD Eyes

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	107.265	17.877	35.088	0.000*
Preference	1	59.501	59.501	3.328	0.118
Within Participant					
Configuration	4	2.118	0.530	1.039	0.388
Configuration*Task	4	1.183	0.296	0.581	0.677
Configuration*Sample	8	2.790	0.349	0.684	0.705
Task	1	0.45	0.45	0.883	0.348
Task*Sample	2	0.727	0.364	0.714	0.491
Sample	2	20.315	10.157	19.936	0.000*
Order	4	1.258	0.315	0.617	0.651

PS Neck

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	1344.16	224.026	20.362	0.000*
Preference	1	119.004	119.004	0.531	0.494
Within Participant					
Configuration	4	42.404	10.601	0.964	0.429
Configuration*Task	4	23.233	5.808	0.528	0.715
Configuration*Sample	8	41.975	5.247	0.477	0.871
Task	1	35.113	35.113	3.191	0.076
Task*Sample	2	53.733	26.867	2.442	0.090
Sample	2	45.733	22.867	2.078	0.128
Order	4	35.425	8.856	0.805	0.523

PS Back

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	94.270	15.712	4.760	0.000*
Preference	1	7.748	7.748	0.493	0.509
Within Participant					
Configuration	4	6.392	1.598	0.484	0.747
Configuration*Task	4	10.941	2.735	0.829	0.508
Configuration*Sample	8	17.837	2.230	0.675	0.713
Task	1	20	20	6.059	0.015*
Task*Sample	2	11.359	5.679	1.720	0.182
Sample	2	50.359	25.179	7.628	0.001*
Order	4	43.049	10.762	3.260	0.013*

PS Feet

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	2043.72	340.621	43.015	0.000*
Preference	1	15.504	15.504	0.046	0.838
Within Participant					
Configuration	4	20.483	5.121	0.647	0.630
Configuration*Task	4	14.692	3.673	0.464	0.762
Configuration*Sample	8	38.283	4.785	0.604	0.774
Task	1	154.013	154.013	19.450	0.000*
Task*Sample	2	12.9	6.45	0.815	0.444
Sample	2	99.633	49.817	6.291	0.002*
Order	4	39.435	9.859	1.245	0.293

Performance

Source	**DF**	**SS**	**MS**	**F**	**P**
Between Participant					
Participant (Preference)	6	712789	118798	17.789	0.000*
Preference	1	322740	322740	2.717	0.150
Within Participant					
Configuration	4	7096.47	1774.12	0.266	0.900
Configuration*Task	4	7790.48	1947.62	0.292	0.883
Configuration*Sample	8	19728.7	2466.08	0.369	0.936
Task	1	1436480	1436480	215.097	0.000*
Task*Sample	2	14931.3	7465.66	1.118	0.329
Sample	2	39725.9	19863	2.974	0.053
Order	4	113193	28298.3	4.237	0.003*

VITA

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EDUCATION

Master of Science in Industrial Engineering.
Grado Department of Industrial and Systems Engineering, Virginia Polytechnic Institute, Blacksburg
Major area of specialization: Human Factors Engineering
Dec. 2001

Bachelor of Science in Psychology.
University of Idaho, Moscow
May 1998

Attended.
Montana State University, Bozeman (Industrial Engineering Department)
Aug 1994- May 1996

RESEARCH INTERESTS

Industrial Ergonomics
Prevention and Control of Cumulative Trauma Disorders
Work Design
Occupational Safety and Health
Human Reliability

TEACHING INTERESTS

Industrial Ergonomics

Cognitive Engineering/Ergonomics
Occupational Safety and Health
Human Factors Engineering

TEACHING EXPERIENCE

Virginia Tech, Blacksburg, Virginia. **<u>Teaching Assistant</u>.** *August 2000-May2001.* Aided with undergraduate courses in the area of ergonomics, human factors and industrial systems senior design.

University of Idaho, Moscow, Idaho. **<u>Teaching Assitant</u>.** *August 1997-May 1998.* Taught recitation for undergraduate Psychology courses. This course covered a broad range of Psychology topics.

RESEARCH EXPERIENCE

Identification and Quantification of Video Display Workstation Set Up on Risk Factors Associated with the Development of Low Back and Neck Discomfort. *November 2000-July 2001.* Investigated the gross physiological differences between ergonomic chairs at opposing ends of the spectrum, the correlations between EMG and self reported localized muscle discomfort, and the interaction between chair type and monitor height on low back and neck muscle activity/discomfort.

Visual Perception in Optical Flow Fields, Moscow, Idaho. *August 1997-May 1998.* Undergraduate assistant responsible for conducting and organizing the experiment and aiding in analysis and proofreading. The experiment looked at passive versus active control of different optical flow fields (cockpit simulation).

WORK EXPERIENCE

Micron PC incorporated, Department of Process Engineering. **<u>Process Engineering Intern</u>.** *Jan 1999-Aug 1999.* Responsible for performing various analyses to determine methods for producing higher quality, output, and safety.

HONORS

United Parcel Service Fellowship Recipient (1999)