Factors Influencing Sitting Comfort and In-chair Movement
in the Office Environment

by

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ABSTRACT

Seated subjects move (i.e. fidget) in reaction to prolonged, fixed postures. The hypothesis that this seated movement correlates with perceived discomfort (PD) has not been rigorously tested. The purpose of my doctoral research was to measure in-chair movement (ICM) as an objective correlate of sitting discomfort and examine the effect of workplace factors and ergonomic interventions on ICM and PD in an on-site study of healthy, computer-based telephone operators. I measured ICM by tracking the center of pressure (COP) at the buttock-chair interface with an interface pressure mat. Perceived exertion, workload, and PD were measured with validated rating scales. Data were tested ($\alpha = .05$) with repeated measures MANOVA, regression analysis, and intraclass correlation coefficients (ICC). My thesis consists of five studies. In study number one, a significant correlation between the interface pressure mat and the force platform was shown for the tracking of COP coordinates on both axes. Next, I established the inter-trial reliability (ICC $> .90$) of both the COP system and the PD scale. In my third study, I found that PD was significantly related to the time-of-day and work pace, while ICM was affected only by work pace. In study four, I showed the following significant effects with short term use of workstation exercises: increased ICM and decreased PD and perceived exertion. In my final study, I found that--compared to a *fixed* (tilt and lock seatpan) chair--use of a *dynamic* (freely tilting) ergonomic chair increased both ICM and sitting comfort. In summary, my results show that movement in reaction to prolonged seated work is related to discomfort. By contrast, movement that was *allowed* by a decrease in work pace, or *promoted* by the use of exercises or a dynamic chair was related to improved comfort. Given the positive relationship between sitting discomfort and future musculoskeletal problems, these results have important implications in ergonomics and health care.

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CHAPTER ONE

Overview and Thesis Introduction

> *She sat bolt upright in her seat, hands clasped in her lap, a finishing school posture which made no concessions towards comfort.*[1]

Overview

In this thesis I examine various facets of the relationship between sitting posture and sitting comfort. Throughout this series of studies, there is, however, a central, recurring quest: to determine the effect of upright, immobile postures on comfort.

Introduction

Workplace automation and office computerization have changed the sitting habits of workers. Sitting is no longer the exclusive domain of rulers and royalty, but is the common work posture in developed regions, such as North America, where two-thirds of the workforce sit (Grieco, 1986). Sitting, now considered a characteristic human posture (Grandjean, 1988), is expected to become increasingly prevalent as office computerization increases (Sauter, 1984).

Common though it may be, sitting is uncomfortable, especially when prolonged. More than half of seated workers report musculoskeletal discomfort

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[1] Elizabeth George: A Great Deliverance. Bantam, 1992, Pg 1.

whether working at traditional jobs (Kleeman and Prunier, 1982) or video display unit (VDU) tasks (McPhee, 1990; Bjorksten et al, 1987). Prolonged sitting also may be unhealthy. Based on medical profiles from 1.5 million people, Hettinger (1985) reported that sitting was a stress factor, nearly equal in weight to lifting and vibration in the development of what Hettinger (1985) has termed "industrial disease". Lastly, despite the prevalence of musculoskeletal complaints in seated workers, office and seating guidelines (ANSI, 1988; Canadian Standards Association, 1989) are devoid of suggestions for the prevention of sitting discomfort. This problem is magnified for health care practitioners planning a patient's return to seated work.

These factors--the pervasiveness of seated work postures, the risk of discomfort, the impact of sitting on health, and the absence of comfort promotion guidelines--led me to conduct my doctoral research in the area of sitting comfort. My overall goal was to develop a measure of in-chair movement to use as an objective correlate of sitting comfort, and examine the effect of workplace factors (time-of-day, workload pace) and ergonomic interventions (workstation exercises, dynamic tilt chairs) on in-chair movement, perceived discomfort and perceived workload in seated workers. For these studies I focused on healthy Directory Assistance operators.

This thesis is presented as a series of studies on the following topics: *Development of a Measurement System* (Chapter Two), *Field Reliability* (Chapter Three), and the effects of the *Time-of-Day and Workload* (Chapter Four), *Workstation*

Exercises (Chapter Five), and *Chair Type* (Chapter Six) on comfort and in-chair movement. Each of the five papers contains a specific review of literature, hypotheses, methods, results and discussion. In Chapter Seven, sample size and power are discussed, while Chapter Eight contains a retrospective overview of the thesis. An overview of each chapter now follows as an introduction to the thesis.

Chapter Two: Development of a Dynamic Measure of Sitting Comfort

This chapter reports on the development of a tool for the objective, indirect measurement of sitting comfort. Traditionally, sitting comfort is evaluated with subjective rating scales which are then referenced to an objective measure, such as sitting posture (Bishu et al, 1991) which is measured on a non-continuous (*static*) basis. While researchers have recognized the *dynamic* nature of sitting behaviours and sitting comfort, the *static* nature of most objective correlates of sitting discomfort does not reflect that attribute. Consequently, I have developed a VERG (Vision Engineering Research Group) interface pressure mat (Force Sensing Systems, Winnipeg, MN, R3N 0W4) to measure in-chair movement as a continuous (dynamic) correlate of sitting comfort.

The measurement of in-chair movement with respect to comfort in this research series is not unique; Grandjean et al (1960) examined those very factors. The invasive nature of most motion analysis systems has, however, precluded the measurement of in-chair movement in the field. By contrast, my interface mat measures in-chair movement non-invasively by tracking a subject's center of pressure (COP) at the buttock-chair interface. Chapter Two contains details of the development and validation process of the COP system, laboratory tests of the mat's intertrial reliability for tracking standardized movements, and reports on the relationship between selected trunk movements and resultant COP excursions.

Chapter Three: Field Reliability

Results of the Development Study showed that the COP system was capable of continuous, on-line collection of movement data in the laboratory. The next stage, the evaluation of the COP system in the field, is reported in Chapter Three. The first issue in this chapter was task and site selection. A VDU task was selected because of the universality of computers and the prevalence of sitting discomfort in VDU operators (Sauter, 1984; Evans, 1987; Sauter et al, 1991). Since the COP system was not designed to distinguish between task and non-task movements, the primary consideration in selecting the subject group was that their task movements and workload were standardized. For the above reasons VDU-based telephone operators at the local telephone company were selected.

The stated purpose of Chapter Three was to determine the intertrial reliability of COP data. Inherent in that purpose, however, was the need to determine the most reliable means of analyzing the COP data (e.g. COP distance travelled versus COP variation around the mean) and the most reliable means of sampling the data (e.g.

discrete 5 min blocks versus a series of time blocks). Given the novelty of the COP system, I utilized a stringent test of reliability, the *standard error of measurement* (SEM). By determining the extent of measurement error versus true differences, the SEM also provided a valuable benchmark to make statistical decisions in the three subsequent studies. Field reliability of a standard discomfort scale, the *Body Part Discomfort Scale* (Corlett and Bishop, 1976) also was tested with the SEM.

Chapter Four: Effect of the Time-of-Day and Work Pace on Comfort, Perceived Mental Workload and In-chair Movement

The relationship between time-of-day and comfort is well documented. By contrast, there is limited evidence of circadian effects on perceived mental workload (Hancock, 1988) and in-chair movement (Jurgens, 1980). Therefore, a primary purpose of this study was to measure the effect of the time-of-day on comfort, movement, and mental workload (measured with Wierwille and Casali's (1983) *Modified Cooper-Harter Mental Workload Scale*). Knowledge of those effects was required for the design (e.g. factor control) and interpretation (e.g. generalizability) of subsequent studies in this series.

In retrospective surveys of telecommunications workers, workpace has been linked with musculoskeletal discomfort (Smith et al, 1992). Therefore, the second purpose of my study in this chapter was to compare comfort, mental workload and in-chair movement in Directory Assistance operators working in high pace versus low pace workload conditions.

Chapter Five: A Review of Workstation Exercises and a Study on Their Effect of on Comfort, Perceived Exertion and In-chair Movement

Chapter Five opens with an extended three part rationale for the need to avoid fixed postures while seated, followed by a review of currently available workstation exercises. Several exercise programs have been introduced in the past decade to reduce musculoskeletal discomfort and muscle tension. Field tests of their effectiveness in reducing discomfort are rare (Thompson, 1990; Henning et al, 1993), as are tests of their ability to promote in-chair movement (i.e. reduce postural fixity). The purpose of the intervention study, which is the core of Chapter Five, was to determine if workstation exercises could promote a positive relationship between in-chair movement and sitting comfort. More formally, the purpose was to test the hypothesis that when movement was encouraged by exercises, rather than occurring in reaction to discomfort, subjects would report greater comfort. The second hypothesis I tested was that, when performing workstation exercises, subjects would rate their exertion (*Rated Perceived Exertion*; Borg, 1982) level higher when compared to their normally sedentary (no-exercise) condition.

Chapter Six: Effect of a Dynamic Tilt Chair on Comfort and In-chair Movement

In recent years, chairs with freely tilting seat pans, or *dynamic tilt* chairs (Dainoff et al, 1986) have been introduced. The ability of these chairs to encourage seated movement and improve comfort in the workplace has been only superficially studied (Bendix et al, 1985). In Chapter Seven, I compared sitting comfort (*General Comfort Rating*; Shackel et al, 1969) and in-chair movement between a *traditional* (tilt and lock) chair and a *dynamic* (freely tilting) chair. Subjects also compared chair features between the two chair types using a modified *Chair Features Checklist* (Shackel et al, 1969; Grant, 1991).

Chapter Seven: General Considerations of Sample Size

In this chapter, the projected sample sizes based on a power of .90 are presented. As well, the shortcomings of traditional power determinations are discussed.

Chapter Eight: Summary

Results of this series of studies fall into two areas; technical and applied. From a technical perspective, the COP system was a valid, reliable means to measure seated movement that also was non-invasive, transportable, and adaptable to a variety of chairs. The applied results, although extensive, do have a common theme: movement that was in reaction to prolonged VDU work in sitting was positively related to discomfort. By contrast, movement that was *allowed* by a decrease in workpace, *required* by exercise usage, or *promoted* by the use of a dynamic chair, increased the operators' perceived sitting comfort.

These movement results compliment both the long held theory that discomfort was related to seated movement (Grandjean et al, 1960), and a recent theory that comfort could be promoted by reducing fixed postures (Winkel and Oxenburgh, 1990; Bendix, 1991). On the other hand, results appear to conflict with Pustinger et al's (1985) theory that excessive seated movement is negatively correlated with worker well being. The positive relationship demonstrated here between mobile postures and comfort, has important implications for the long term reduction of musculoskeletal problems in seated workers.

CHAPTER TWO

Dynamic Measurement of Sitting Discomfort: Development, Reliability, Validation and Calibration

Many authors suggest that the measurement of sitting comfort is one of the greatest challenges in comfort research (Lueder, 1983; Corlett, 1990; Zhang and Helander, 1992). By tradition (Shackel et al, 1969; Drury and Coury, 1982; Corlett, 1989), sitting comfort is evaluated with subjective scales, such as the General Comfort Rating (Shackel et al, 1969), which are then referenced to some objective measure of the chair, the occupant, or the task. To date, most objective correlates in comfort studies have been measured using a *static* (i.e. non-continuous) approach. That is, investigators have measured factors, such as spinal posture (Bishu et al, 1991), seated pressure distribution (Yun et al, 1992), or performance (Rogers and Thomas, 1990) as an interrupted time series. While remaining with the traditional subjective/objective approach to measuring comfort, I have broken with tradition by using a *dynamic* (i.e. continuous) correlate of sitting comfort, namely in-chair movement. This paper reports on the development and validation of a system to measure in-chair movement (ICM).

I have taken this dynamic approach for the following reasons. First and foremost, sitting is a *dynamic* activity. In his studies of train commuters, Branton (1966) was the first to show that seated subjects move continuously. Two decades later, under controlled laboratory conditions, Fleischer et al (1987) demonstrated that even subjects performing simple manual dexterity tasks in sitting, moved continually, and moved in excess of the task demands. Second, numerous investigators have shown that sitting comfort is not static, but is in fact, *time dependent* (Grandjean et al, 1960; Laville, 1980; Bhatnager et al, 1985; Schleifer and Amick, 1989). The third reason is what Branton and Grayson (1967) termed, the *cyclic* nature of sitting, meaning that over time, subjects display a variety of postures that are cyclically repeated. The continuous measurement of in-chair movement incorporates each of these three attributes of sitting comfort and behaviour. An additional reason to measure in-chair movement is that it will quantify, not just how much subjects move, but with respect to *fixed postures* (Occhipinti et al, 1991) will show how little subjects move. Measuring seated movement therefore incorporates Corlett's (1989) suggestion that temporal factors are the most important consideration in evaluating sitting comfort.

In-chair Movement

In-chair movement, commonly referred to as fidgets (Jurgens, 1989) or spontaneous movements (Jensen and Bendix, 1992), is an outcome measure previously used to provide a dynamic, time-based measure of sitting discomfort in laboratory studies (Grandjean et al, 1960; Rieck, 1969; Bhatnager et al, 1985; Bendix et al, 1985; Jensen and Bendix, 1992). The underlying hypothesis in these precedent studies was that subjects make few movements when first sitting, but as time passes and discomfort increases, so do in-chair movements. This concept of in-chair movement versus comfort is somewhat enigmatic since some movement is necessary to avoid undesirable static work postures (Winkel, 1987) and some movement is task related. Nevertheless, in most cases, investigators (Grandjean et al, 1960; Rieck, 1969; Bhatnager et al, 1985; Jurgens, 1989) have shown that both discomfort and in-chair movement are positively related to sitting duration.

Comfort versus Discomfort

A basic problem associated with the measurement of sitting comfort is the determination of what is being measured: comfort or discomfort. Researchers generally measure sitting discomfort (Bishu et al, 1991). In the belief that comfort and discomfort are linked on a bipolar continuum (Richards, 1980), these discomfort measures are used to make assumptions about comfort. Those assumptions should be made with caution. Using factor analysis, multidimensional scaling, and cluster analysis, Zhang and Helander (1992) have shown that comfort and discomfort are multidimensional constructs that require independent measurement. Since in-chair movements (or fidgets) have been positively associated with discomfort (Zhang and Helander, 1992; Bhatnager et al, 1985), my thesis focuses on the measurement of discomfort, *operationally defined as the presence of a distracting bodily sensation* (Corlett, 1973).

Field Measurement of Discomfort

Sitting discomfort is best evaluated in the field since it is dependent on the task (Drury and Coury, 1982) and on a variety of workplace factors related to the job (e.g. overtime, peer interactions) and to the individual (e.g. job satisfaction) (Lueder, 1983). Unfortunately, of the studies which have previously quantified seated movement, only one (Bendix et al, 1985) was a field study. The invasive and disruptive nature of most motion analysis systems has precluded them from on-site analysis of in-chair movement. Many systems require the attachment of transducers to the body (Samuelson et al, 1987; Sabelman et al, 1992) that may not be welcome on-the-job or, like electrogoniometers (Marras, 1992), may interfere with sitting. Yet other methods, such as chair mounted accelerometers (Bendix et al, 1985), restrict testing to an experimental chair. In order to test my hypothesis that sitting discomfort is temporally related to in-chair movement in the workplace, a non-invasive measure of seated movement was required.

Therefore, I employed the VERG (Vision Engineering Research Group) interface pressure mat (Force Sensing Systems, Winnipeg, MN, Canada) as a non-invasive means to collect continuous in-chair movement (ICM) data in the field by tracking a subject's center of pressure (COP). In this chapter I report on (i) the development of the VERG COP analysis system, (ii) the validity and laboratory reliability of the system, and (iii) the relationship between trunk movement and COP movement. This research was approved by the Human Ethics Review Committee in the University's Faculty of Graduate Studies.

METHODS

Equipment

VERG interface mat: The VERG interface pressure mat is a 15 by 15 array of 2.54 cm^2 force sensing resistors (FSR). The mat was originally designed to sample at .5 Hz via multiplexers and store data on-line in an IBM compatible computer. The VERG FSR, sensitive to compression only, consists of a force sensitive conductive polymer, interposed between two sheets of Mylar (Knudson and White, 1989). With increasing force, an FSR exhibits a non-linear decrease in resistance (Hedman, 1992) which is linearized with a double antilog amplifier (Mokshagundam, 1987). Each VERG FSR is calibrated by mapping its response characteristics. During sampling, differences due to hysteresis ($< 5\%$) are corrected using the on-line calibration curves.

The 225 mat sensors are embedded in a 2 mm thick rubber mat (Plate 2.1) and encased in a Goretex cover. The mat is flexible and readily adaptable to most chair seats. The VERG, like other interface systems (Drummond et al, 1982), was developed to measure pressure distribution at the buttock-chair interface, store the data on-line, and display pressures ir 3-D grids or isobar maps. The interface mat measures in-chair movement on-line by tracking a subject's center of pressure (COP) at the buttock-chair interface. The COP is calculated on-line by summing the pressure moments about the point (0,0).

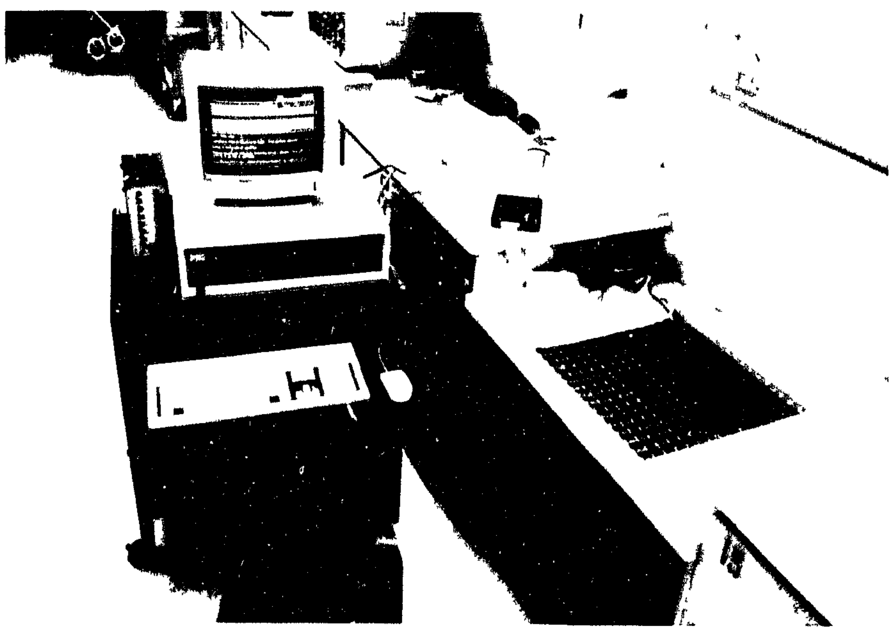


Plate 2.1 The VERG pressure sensing system consisting of: an interface mat composed of a 15 X 15 array of force sensing resistors (cover removed), a data interfacer (black box), and an IBM personal computer.

The COP is defined as the point of application of the resultant force between two contacting surfaces, such as a body and a floor surface. Moreover, when that surface is the only support for the body in static postures (eg feet in standing), the position of the COP actually reflects the position of the center of gravity within a plane parallel to the support surface (Winter, 1990). In the present study, *in-chair movement (ICM) is operationally defined as any movement of the chair occupant (task related or otherwise) that changes the position of the COP.* Validity of the operational definition of ICM requires two underlying assumptions about the COP.

The first assumption is that most of the body weight is supported by the seat, therefore implying that the COP of the forces at the buttock-chair interface reflects the position of the center of gravity (COG). Second, the dynamic component of sitting (i.e. acceleration effects) is assumed to be small compared to the static component, implying that seated positions can be assumed to be a series of static postures--in which case, once again, the COP reflects the COG. COP tracking in sitting is limited by not providing specific information on positions of individual body parts. However, when the two underlying assumptions are met, the COP is affected by the positions of all body parts, especially by the more massive parts, such as the trunk and legs.

Kistler force platform: COP data collected with a Kistler 9281B multicomponent force platform (Kistler Instrument, Eulachstrasse 22 AG CH-8408, Winterthur, Switzerland) were used as the validation standard in the present study. The force platform was sampled at 100 Hz with a Hewlett-Packard Multiprogrammer 6942A (Hewlett-Packard, Fort Collins, CA, 91601). The force platform's four triaxial transducers are sensitive to three orthogonal forces: compression and two forms of shear. The COP is located by dividing the measured moment on each axis (in newton-meters) by the vertical reaction force (in newtons) (Grabiner et al, 1993). The validity of the force platform in tracking the COP has been previously documented (Goldie et al, 1989; Thyssen et al, 1982).

Data Analysis

The present study involved method comparisons; that is, (i) COP calculations were compared between an interface pressure mat and a force platform, and (ii) COP movement was compared to a subject's trunk/spinal movement. Following Altman and Bland's (1983) recommendations, visual plots and regression analysis (SPSS, Chicago, IL, 60611) were used to compare data.

1. Development Studies

Sample Rate Determination: At 0.5 Hz, the VERG sample rate was considered too slow for detecting changes in seated posture (Winter, 1990). Therefore, the frequency of seated movements was determined in order to set an appropriate sample rate for detecting COP changes. A female subject (Ht 176 cm, Wt 62 Kg) sat on a chair mounted on the force platform. With the subject's feet resting on the platform, random in-chair movements (weight shifts, slouching, reaching etc.) were performed for 10 minutes. For an additional 5 minutes, the subject repeated her common movements at maximum and minimum speeds. The force platform outputs were sampled at 100 Hz and the signal was analyzed with a Nicolet 660A Fast Fourier Transformation Spectral Analyser to determine the component frequencies present in the seated movements.

Creep Test: All conductive polymer force sensors will show continued deformation under constant load (i.e. creep), especially during initial loading (Mokshagundam, 1987). In this test, the extent of creep (in %) and the time required to reach steady state for the VERG mat were evaluated. The mat was positioned on an office chair and loaded with a 22.5 Kg weight centered on the mat. To simulate human interface conditions, an air-filled rubber ring was interposed between the mat and the weight. The VERG X and Y coordinates of the COP were sampled for 5 secs every min for two hrs.

2. Validation Study

Dynamic Validation: The purpose of this experiment was to determine if there was any difference between the VERG mat and the force platform in the determination of (i) the COP coordinates and (ii) tracking velocity (defined as the distance moved by the COP between samples divided by the time between samples; or $d-d_1/t-t_1$ in cm/sec).

With the VERG mat superimposed on the force platform, COP coordinates were simultaneously tracked with a female subject (Ht 160 cm, Wt 51 Kg) positioned in long sitting with the legs (below mid-thigh) off the platform (Plate 2.2). For each of the four, 15 sec tests, the subject bent (i.e. moved) to her point of comfort and returned to upright. During each of four successive movements, the subject's direction of movement changed. That is, the subject's upper body movement described a four pointed star. The subject either moved as quickly as possible, or moved and held the bent position. Regression analysis was used to compare the force platform and interface mat results.

3. Reliability Study

Introduction: Data management software programs were developed in-house (Appendix 2.1 MTT Program; Appendix 2.2 FINAL Program) to calculate (in cm) the total excursion of the COP (COP distance) and the average distance from the mean COP position (COP variation). The purpose of this study was to determine the intertrial reliability of the VERG mat in measuring COP distance and variation for standardized movements.

Subjects: The volunteers were students (3F, 1M) in good health with no history of musculoskeletal pain. The subjects, who ranged in age from 21 to 27, all gave their informed consent. Mean height was 171.3 cm (SD 10.1) and mean weight was 67.8 Kg (SD 12.0).

Plate 2.2 Dynamic Validation: Subject positioning for the purpose of simultaneous recording of movement by the floor mounted force platform (grey), and the interface pressure mat (black) superimposed on the force platform.

Protocol: The test chair (Harter Furniture, Guelph, ON, Canada), devoid of back and arm rests, was secured to the floor. With the mat centered on the seat, the chair height was adjusted to achieve a 90^0 knee angle for each subject. Three motion barriers were placed equidistant (20 cm) from the sides and front edge of the chair. A fourth motion barrier w .s placed 10 cm from the back edge of the chair. During the 15 sec tests, subjects maintained their maximum lordosis and bent to touch each barrier in turn. The subjects' movement speeds were maintained by a metronome and allowed, for example, 2 sec for the subject to complete each of the four upright-barrier-upright movement sequences. Tests were repeated one week later. COP distance and variation were compared between trials by regressing Trial 1 results on Trial 2.

4. Calibration

Gross trunk motion: To assist in the interpretation of the COP movement, changes in trunk posture were compared to COP changes measured by the interface mat. Two volunteers from study #3 (Reliability) acted as subjects: a male, age 21, Ht 186 cm, Wt 84 Kg; a female, age 27, Ht 165 cm, Wt 61 Kg). The test chair and VERG mat set-up was identical to the reliability study. Markers were placed on the center of rotation (COR) of the hip and shoulder joints. Spinal motion markers were fixed perpendicular to the spine (Plate 2.3), level with the first thoracic (T_1), first lumbar (L_1) and first sacral (S_1) vertebrae (Fenety and Kumar, 1992). VERG COP data and trunk movement were captured simultaneously during two tests: to the limits of sagittal flexion and extension, and to the limits of bilateral side flexion.

Plate 2.3 Calibration Test: Subject positioning for the purpose of simultaneous recording of COP movement with the VERG mat, trunk inclination measured with center of rotation markers (white squares) and spinal movement measured with motion markers (striped).

Trunk motion was filmed in the sagittal and frontal planes at 30 Hz with two VHS video cameras. An on screen light emitting diode signalled the start and end of each trial to facilitate motion analysis. Using a video cassette player with a frame grabber, motion was analyzed at 3 Hz. The following angles were measured with a goniometer: (1) trunk inclination (i.e. flexion or extension), or the angle subtended by a plumb line and a line joining the shoulder and hip CORs, (2) thoracic kyphosis, or the angle between the spinal marker at T_1 and the spinal marker at L_1, (3) lumbar lordosis, or the angle between the spinal markers at L_1 and S_1 (Figure 2.1), and (4) lateral trunk flexion, or the angle at L_5S_1 subtended by a plumb line and a line joining the motion markers at T_1 and S_1. Measures (2) and (3) have been shown to be valid (Troup et al, 1967; Bryant et al, 1989) and reliable (Fenety and Kumar, 1992) representations of the angles between the superior surfaces of the respective vertebrae. The test-retest reliability of the four angular measures (r^2=.88 to r^2=.92) was established by analyzing one film twice. The relationship between the VERG COP measures and trunk ROM was evaluated with regression analysis.

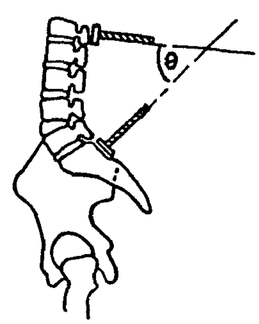


Figure 2.1 Determination of lumbar lordosis (θ), or the angle between the superior surface of L_1 (first lumbar vertebra) and S_1 (first sacral segment) using motion markers (striped).

RESULTS

1. Development Studies

Sample Rate Determination: Power spectral density analysis of the subject's seated movements showed that the maximum component frequencies present were 0.475 Hz in the sagittal plane and 0.362 Hz in the frontal plane. Nyquist theory suggests that sample rates be set at least twice the rate of the measured phenomena. Consequently, the mat developers (Force Sensing Systems, Winnipeg MN) set the dynamic collection rate for the VERG COP system at 10 Hz and ran the data through a low pass filter with a cut-off of 3 Hz. In this dynamic mode, the VERG collected COP coordinates in either a continuous or time batch (cycle on/cycle off) manner.

Creep: Maximum creep in the VERG COP coordinates for a static load mat was 5.3% and occurred at the 10 min mark of the test. Creep stabilized at min 12, such that further fluctuations were <1% of original (time zero) values.

2. Validation Study:

Dynamic Validation: COP coordinates versus time for the Kistler and VERG systems are plotted for the Y axis (Figure 2.2). Since the reference (or true) zero of the force platform (geometric center) differs from the interface mat (left rear corner), the VERG mat coordinates were transformed to center at zero (i.e. subtract average position from each coordinate) in Figure 2.2.

Tracking velocities (COP distance ÷ time between reads) of the Kistler and VERG systems were highly correlated on both the X ($r=.99$; $r^2=.99$, $p<.001$) and Y ($r=.89$; $r^2=.80$, $p<.001$) axes (raw data in Appendix 2.3 Speed Tests X,Y Axes). Similarly, COP coordinates measured by the Kistler and VERG systems were correlated on the X ($r=.99$; $r^2=.99$, $p<.001$) and Y ($r=.97$; $r^2=.95$, $p<.001$) axes (raw data for one of four trials in Appendix 2.4 Dynamic Validation Study).

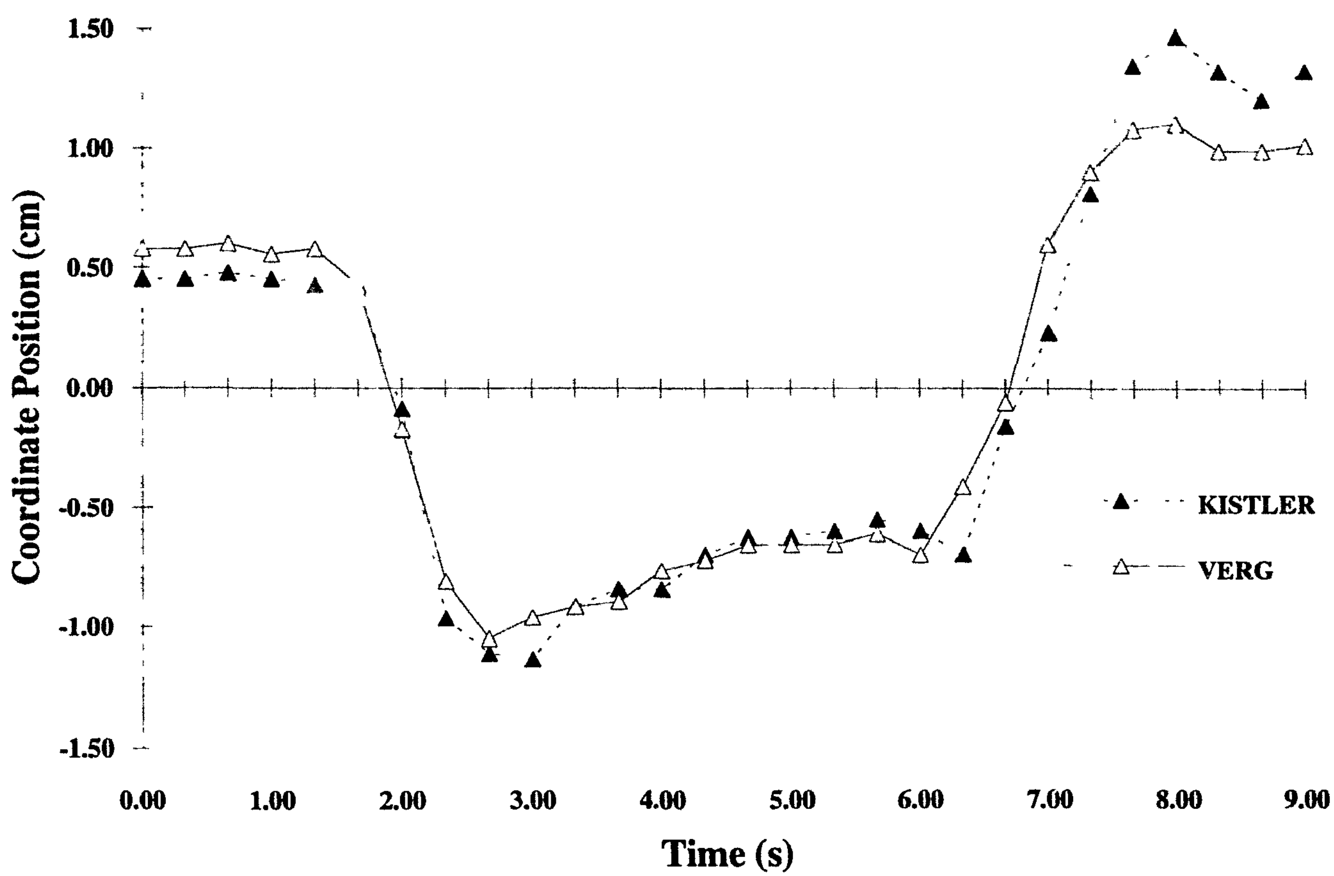


Figure 2.2 Validation plots of the COP "Y" coordinates versus time recorded simultaneously by a VERG mat and a Kistler force platform over 9 secs for a seated subject moving in the sagittal plane.

3. Reliability Study

For the standardized movements, COP distance was significantly correlated between trials ($r= 0.98$; $r^2=.96$; $p<.01$). However, while correlation between days was high for COP variation ($r^2= 0.81$), the effect was not significant ($p=.09$). Figure 2.3 contains one subject's COP tracings for both trials.

4. Calibration Study

During trunk flexion in sitting, lumbar lordosis ranged between 0^0 and 3^0 for both subjects. Changes in the angle of thoracic kyphosis were less than 10^0 and were unrelated to the COP ($r =.60$). Trunk inclination, however, was positively correlated with changes in the COP ($r=.98$; $r^2=.97$; $p<.001$) (raw data in Appendix: Calibration Trials). Figure 2.4 contains regression plots for trunk inclination (upper plot) and left lateral flexion (lower plot) versus COP position. For both subjects, left and right lateral flexion were significantly correlated ($r>.93$, $p =.001$) with COP motion (Appendix: Calibration Trials). Motion from upright to full left lateral flexion (33^0 F, 29^0 M) resulted in a 10 cm shift in the COP for both subjects.

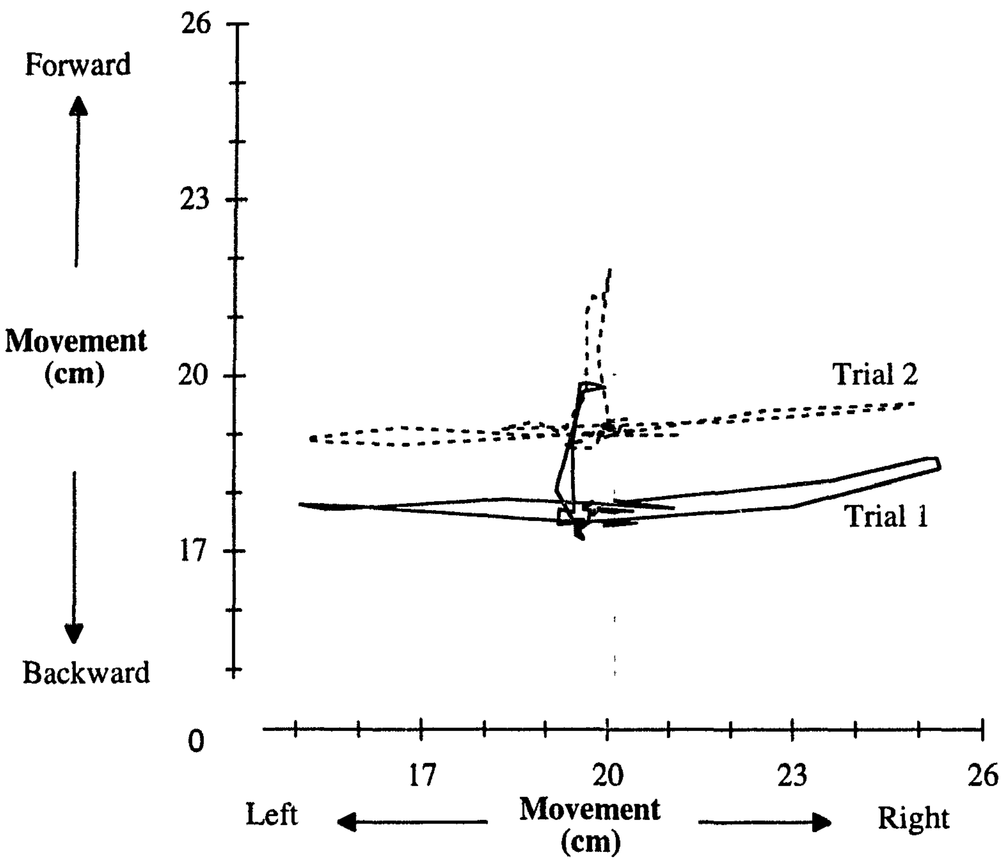


Figure 2.3 Trial 1, Trial 2 COP traces for a subject's standardized movements in 15 sec. trials, providing visual confirmation of the inter-trial reliability. Note that the subject's initial position on the mat differed between trials.

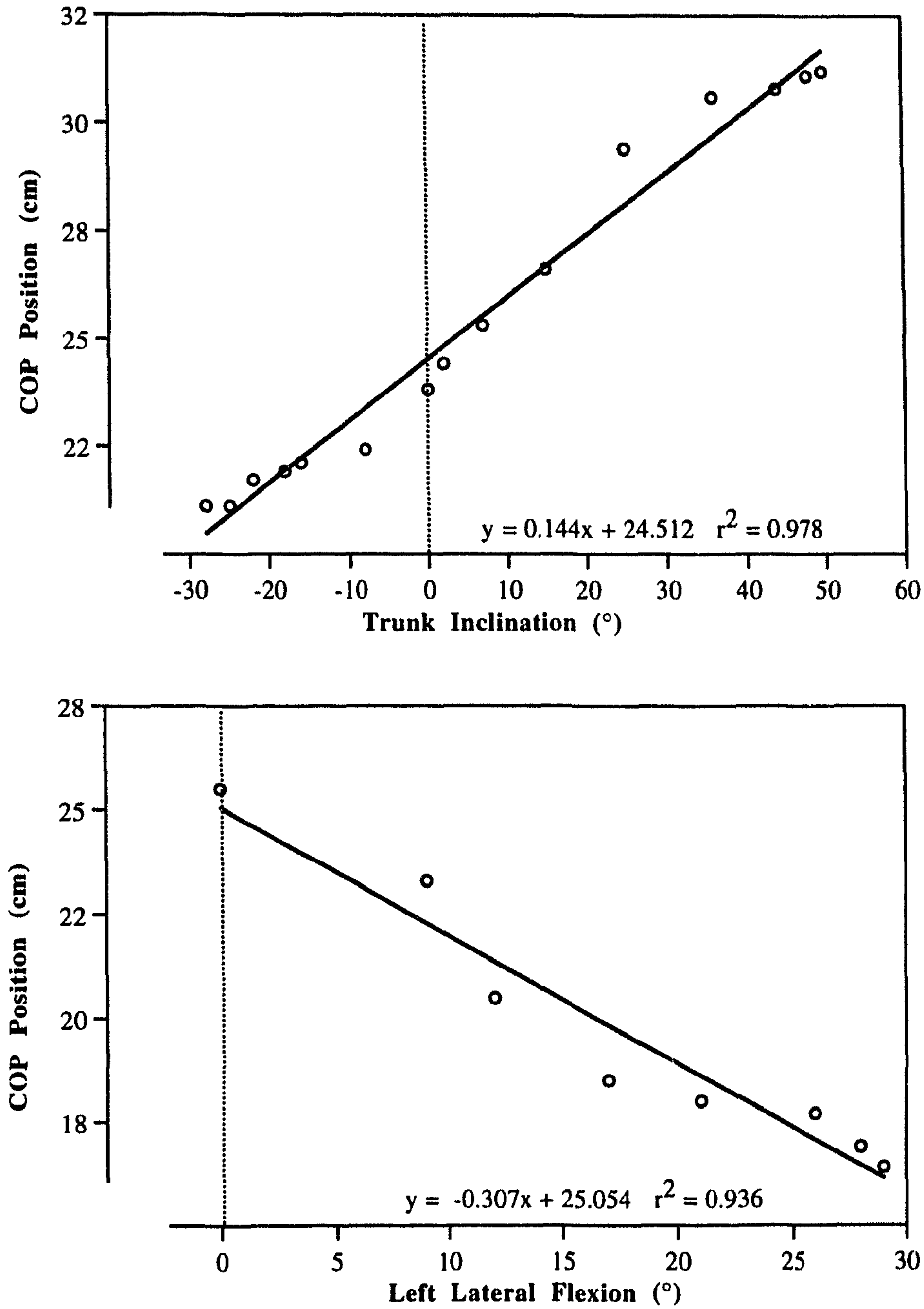


Figure 2.4 Regression plots of COP motion (cm) versus trunk angle (in °) in sitting, for trunk inclination (upper plot) and left lateral flexion (lower plot) for the female subject, demonstrating linearity and a high proportion of explained variance in both cases.

DISCUSSION

Results of this study established the validity and laboratory reliability of the VERG COP system. Furthermore, this study showed that because the VERG system required no body attachments or chair adaptations, it was a suitable tool for the next stage of testing; the evaluation of sitting discomfort in the workplace. Calibration curves based on trunk movements have established a relationship between body movement and COP movement that will assist in interpreting COP movement in on-site studies.

Dynamic Validation:

In spite of the difference in sample rates between the Kistler (100 Hz) and the VERG (3 Hz), there was no difference between the two systems in measuring COP coordinate velocity. That result confirms results of the power spectral density analysis and further validates the selection of 3 Hz for the VERG sample rate. Figure 2.2 provides graphic evidence of the ability of the VERG sensors to respond to directional changes in movement and to define COP coordinates. Regression results also showed that the VERG was less accurate in measuring COP velocity in the Y direction than in the X direction, a result of the manufacturer's multiplexing protocol which favors X axis collection.

Study results further show that the VERG COP system was reliable between days for tracking the COP under controlled movement conditions. Correlations were high in spite of the absence of strict controls on initial sitting position and posture (i.e. lumbar lordosis).

Calibration

The two calibration curves provide graphic interpretation of the COP changes with respect to trunk movement. Regression results demonstrated a linear relationship between the COP and the angles of trunk inclination and lateral flexion; knowledge that will assist in the interpretation of COP movement in future studies. As expected, the taller, heavier male produced greater COP excursion per degree of trunk inclination. However, as a result of the greater trunk flexibility of the female subject, sagittal plane COP movement in both subjects equalled 10 cm. In lateral trunk flexion, the COP excursion (10 cm) was similar for both subjects, not surprising considering the similarity of the average (50th percentile) bi-ischeal distances in males (12 cm) and females (13 cm).

While the zero to three degrees of lordosis reported here for upright, unsupported sitting differs from a published report of $5.8^0 \pm 5.98^0$ (n=25) (Bridger et al, 1989), the small sample size in the present study may have contributed to the discrepancy. Given the influence of weight and height on COP movement, the present results suggest that COP studies should utilize within subjects designs or control for anthropometric differences between subjects. Also, in future field studies, the influence of task motions (e.g. reaching) and behaviours (e.g. slouching) on COP movement requires quantification.

Interface Pressure Mapping

Interface pressure mapping was developed to evaluate pressure distribution at the buttock-chair interface in spinal cord injured patients and reduce the risk of pressure sores by detecting and eliminating pressure peaks (Ferguson-Pell, 1980). More recently, pressure mapping studies in ergonomics have demonstrated a positive relationship between equalized pressure distribution and lumbar support usage (Shields and Cook, 1992), seat angle changes (Riley and Bader, 1988), sitting posture (Reinecke et al, 1987), and subjective sitting comfort (Yun et al, 1992). These ergonomic applications of interface mapping take one or more static 'snapshots' of the entire pressure distribution. By contrast, utilization of the center of pressure in the VERG system is unique in its dynamic (i.e. continuous) representation of the pressure distribution.

Benefits and Limitations

The principal benefits of the VERG COP system in measuring seated movement in field studies are that it is non-invasive to the subject and non-disruptive to the workplace. Unlike force platforms (Rieck, 1969) or spring loaded platforms

(Grandjean et al, 1960), the interface mat is readily transportable and adaptable to any seat surface. Benefits of the computer interface are the ability to provide rapid data analysis and collect data on-line with collection periods restricted only by hard drive storage space. In the future, the VERG system also may assist in determining *when* a posture becomes prolonged or fixed and assist in the development of risk indices for postural fixity (Occhipinti et al, 1991).

The VERG COP system has limitations, but none is considered major. First, the lack of sensitivity of force sensing resistors (FSR) to shear loads is a drawback for the COP system. However, since compression is the predominant form of loading at the buttock-chair interface (Bader, 1990) the restriction is likely minor. Second, by measuring at the buttock interface, only indirect information on leg movement is obtained. The mat, however, readily detects movement in the trunk--a common source of sitting discomfort (Sauter et al, 1991). Similarly, no specific information on arm and head motion is available, although the system could be augmented with devices, such as accelerometers. Third, all interface pressure transducers interfere with (i.e. perturb) the interface they are mapping (Ferguson-Pell, 1980). Nevertheless, none of these three limitations restrict my application of the VERG mat, since each subject will serve as his/her own control (i.e repeated measures design). A fourth limitation is the creep exhibited by each FSR. This effect can be minimized in the main studies by pre-loading the mat for 5 to 7 min (pre-test) and eliminating the subject's first five minutes of data.

The measurement of in-chair movement in the field has the potential to overcome the two principle weaknesses of traditional objective measures of comfort: the need for continuous, time-based comfort measures and the need to reference comfort to field tasks. Subjective comfort measures still are considered the standard against which objective sitting comfort measures are validated (Shackel et al, 1969; Corlett, 1989). In-chair movement will be compared with subjective (i.e. perceived) discomfort in the next component of this research series: field reliability.

CHAPTER THREE

Field Reliability of In-chair Movement and Perceived Discomfort Measures

Ergonomists' interest in seated movement covers both ends of the movement spectrum. Excessive in-chair movement has been linked to sitting discomfort (Grandjean et al, 1960), while too little movement is associated with postural fixity (Bendix, 1991). Postural fixity (Hettinger, 1985) and perceived sitting discomfort (Sauter, 1984) are risk factors in the development of musculoskeletal problems in prolonged seated postures. Reliable measures of perceived discomfort (PD) and in-chair movement (ICM) are therefore needed to evaluate interventions aimed at reducing those musculoskeletal risks.

Despite their widespread use, reliability of PD scales has either been largely ignored or reported for short term laboratory tests which have limited generalizability to field situations. Of the variety of methods used to measure seated movement, such as force platforms (Rieck, 1969), transduced chairs (Bendix et al, 1985), and video analysis (Jurgens, 1989), inter-trial reliability has been suggested, but not supported with statistics. The absence of statistical confirmation notwithstanding, reliability is rarely generalizable between studies because of changes in field conditions or measurement techniques. In this study I report on day-to-day reliability of the PD and ICM measures developed for future intervention studies. The subjects in this study were seated for two hours in a fully operational field situation: VDU-based Directory Assistance Operations at a local telephone company.

Perceived Discomfort

Corlett and Bishops' (1976) Body Part Discomfort Scale (BPDS) is the most widely used scale for the evaluation of perceived sitting comfort (Corlett and Bishop, 1978; Drury and Coury, 1985; Ulin et al, 1993; Wiker, 1989). Recently, a second scale termed localized muscular discomfort (LMD), was presented by van der Grinten (1991), as an adaptation of Borg's (1982) CR-10 scale of rated perceived exertion. To rate discomfort, subjects first localize the sensation using a body map that divides the body into two halves in the sagittal plane, thereby creating 40 (LMD: van der Grinten, 1992; See Appendix 3.1 Discomfort Scale and Map) or 27 (BPDS: Corlett, 1990) body parts. Perceived discomfort is rated from "no discomfort" (= 0) to "extreme discomfort" (= 5 on BPDS, or = 10 on LMD scale).

Reliability of PD Measures

In contrast to numerous reports of BPDS validity (Corlett and Bishop, 1976, 1978; Wiker, 1989), there is only one reported test of inter-trial reliability of discomfort ratings. That test was performed on the LMD method (van der Grinten, 1991), where the greatest inter-trial reliability was reported, for regional scores (e.g. pelvis/leg region) which were composed of scores from functionally related body parts (e.g. buttock + thigh + knee + lower leg). The subjects in van der Grinten's

(1991) discomfort trials held static postures at controlled angles (such as head flexion in sitting, or trunk flexion in standing) with no external loads, over short (2 to 3 min) test durations. In spite of that, Pearson correlation coefficients (r_P) for the regional variables appear moderate at best (18 of 30 r_P coefficients less than .75), however, significance levels were unreported. van der Grinten and Smitt (1992) later reported that reliability was improved by reducing the number of body parts rated for discomfort from 40 to 19. For the BPD scale, reliability is often inferred, but not documented (Wiker, 1989; Ulin et al, 1993). To its credit, the BPD scale is linear at low static loads common to seated tasks (Corlett, 1990) and was proven sensitive to comfort changes in seated subjects over 3 hr test periods (Bhatnager et al, 1985).

In-chair Movement

Perhaps due to the invasive nature of most motion analysis systems, seated movement studies have been conducted in laboratories (Grandjean et al, 1960; Rieck, 1969; Bhatnager et al, 1985; Jurgens, 1989), with only two exceptions (Branton, 1966; Bendix et al, 1985). To allow field testing, I used the VERG (*V*ision *E*ngineering *R*esearch *G*roup) interface mat (Force Sensing Systems, Winnipeg, Canada) as a non-invasive method to monitor continuously ICM. The VERG mat tracked subjects' center of pressure (COP) as they sat in a chair (Reference, Validity Study). The COP, defined as the point of application of the resultant ground reaction force, provides an instantaneous summary (i.e. resultant) of the subject's in-chair movements. It does not, however, provide information on individual body part movement.

In a previous study, inter-trial reliability of the VERG ICM system was established in the laboratory for standardized movements of 15 sec duration (reference: Validation Study). Conditions in a field study differ, in that ICM is composed of required task movements and extraneous movements, often referred to as spontaneous movements (Jensen and Bendix, 1992) or fidgets (Branton, 1966). Regardless of stringent experimental controls, in real life situations, day-to-day variations in tasks and extraneous movements may be great (Jurgens, 1989). The first problem of measuring ICM out of the laboratory, is actually a problem of determining a representative sample and a reliable method of data analysis.

Sampling Techniques in Seated Motion Analysis

A review of methods previously used to measure seated movement shows considerable variety in test periods and sampling techniques. While some authors agree that movement data should be collected continuously (Pustinger et al, 1985; Jurgens, 1989), the time periods selected for actual data analysis are divergent and dependent on study design. In comparing subjects' total movement at two VDU workstation settings (adjustable versus fixed), Pustinger et al (1985) analyzed the entire 3 hr block of data. In a similar workstation comparison ("best case versus worst case"), Mark et al (1985) used interrupted sampling (30 sec every 30 min) to measure variability of movement over a 6 hr work period. By analyzing 5 min blocks of movement data every 15 min, Jensen and Bendix (1992) evaluated four chair/desk settings, but were unable to detect a time trend in seated movements. In contrast, temporal trends have been shown when seated movement data were analyzed as 15 (Rieck, 1969) or 30 min blocks (Grandjean et al, 1960; Bhatnager et al, 1985) over a minimum two hr test period. Therefore, in order to detect temporal changes (i.e. trends) in ICM, analysis periods of 15 or 30 min appear more suitable than 5 min, however, the comparative reliability of these longer sample periods has not been reported.

The appropriate length of analysis period is not the only unknown. The literature contains no clear direction on the most reliable method of data analysis. For example, data could be analyzed as the total seated movement over a 30 min period (Bhatnager et al, 1985), however, reliability can be improved by an alternative protocol. From sampling theory, Kroll (1967) suggested treating large (e.g. 30 min) blocks as composites of smaller blocks (e.g. ten, 3 min blocks) and analyzing them as trials. For optimum reliability, the mean of the smaller blocks can be used (Kroll, 1967), provided no time trend is evident within the sets of blocks (Sanford et al, 1993). Unfortunately, the literature on seated movement provides no clear direction in determining an appropriate, minimum duration of these short blocks. Research in a related field, posture recording, suggests that the shortest sample period for detecting postural changes contain "several work cycles" (Keyserling, 1986). Considering the cyclic nature of posture (Genaidy et al, 1994), the variability of in-chair (i.e extraneous) movements (Jurgens, 1989) and the sole precedent in the literature (Jensen and Bendix, 1992); I selected 5 min as the minimum block length in my study and will compare the reliability of single 5 min blocks versus the means of three (3x5 = 15 min) (Rieck, 1969) or six (6x5 = 30 min) (Grandjean et al, 1960) 5 min blocks.

Reliability Methods

Ideally, the purpose of reliability studies is to identify and reduce sources of error, thereby improving decisions in future studies. In practice, investigators in reliability studies often take the classical approach that reliability is best expressed as a ratio of variances, commonly the ratio of among subjects' variance to total variance. An alternative approach, based on measurement error, defines reliability as stability (Mitchell, 1979) or consistency (Rothstein, 1985) between trials.

Classical Reliability Methods: While the most common classical method, the Pearson Product Moment correlation, can determine the existence of a linear relationship, it does not reflect agreement between trials (Altman and Bland, 1983). Notwithstanding, high Pearson r_P values are reported erroneously as measures of reliability, when they are simply measures of mutual covariance. A second form of classical reliability, the intraclass correlation coefficient (ICC), has eliminated the misinterpretation of linear relationships for agreement by not "assuming away" (Bland and Altman, 1990) errors in the ICC variance ratio, defined as (among-group variance) / (among group variance + error variance) (Streiner and Norman, 1989). The ICC can measure intrinsic accuracy of instruments (Burdock et al, 1963), however, it is limited by its tendency to be a biased estimator of consistency when subjects are heterogenous (Bland and Altman, 1990; Matyas, 1993). Stratford (1989) showed that while data sets with the highest among-groups variance had the highest ICC values, they had the poorest day-to-day consistency, as determined by the standard error of measurement (SEM).

Standard Error of Measurement: The SEM, an alternative form of the ICC (Anastasi, 1988), can determine inter-trial consistency, defined as small trial-to-trial differences (Stratford, 1989). In contrast to the *relative* reliability provided by the r_p and ICC, the SEM is an index of *absolute* reliability (Verducci, 1980). As the square root of the absolute error variance, the SEM is not biased by heterogeneity in among-groups variance (Roebroeck et al, 1993). While calculation of both the ICC and SEM require that each source of variance (e.g. different raters) be identified in an appropriate ANOVA (Shrout and Fleiss, 1979), the similarities end there. The ICC approach combines the error variances to determine a single ICC coefficient, while an SEM approach allows the researcher to quantify each error of interest; in the present study, the error attributed to trials. An obvious benefit of the SEM is its expression in the metric unit of the measurement. The SEM is, however, limited in that, unlike the ICC, it has no lower limit of acceptance attached to it.

SEM Confidence Intervals: By assuming a normal distribution of errors, a 95% confidence interval ($\pm$ 1.96 x SEM) can be built around the SEM for measurements taken on one occasion. The SEM then can be used to compare the reliability of parallel test forms, for example, single versus averaged scores (Stratford et al, 1989). The principal advantage of the SEM, however, is its application in studies based on the initial reliability study (Roebroeck et al, 1993). To compare measurements taken on two occasions (pre- and post-test), multiplying the 95% SEM confidence interval by $\sqrt{2}$, gives the *smallest detectable difference* (sdd), or the amount of test-to-test difference, significant at the .05 level, that is due to *measurement error*, not to *true* differences between tests (Anastasi, 1988; Ottenbacher et al, 1988; Nitschke, 1992).

Selection of Appropriate Reliability Statistic: Numerous sources of known and unknown variation can be expected in a field study. In this case, the expectation of similar movements occuring at similar times from day-to-day may be unrealistic if data are analyzed in small portions (e.g. 5 min blocks). In addition, many non-work (fatigue, family issues) and work (mental workload, employer-employee relations) factors influence perceived discomfort. Witness the moderate r_P values in van der Grinten's (1991) reliability study for very short holds and highly standardized tasks. Therefore the problem is not to determine *if* there is variation in ICM and PD measures, but to determine *how much* inter-trial variation exists. The most appropriate measure of reliability for this ergonomic field study appears therefore to be the smallest detectable difference (sdd), based on the 95% confidence interval of the standard error of measurement.

Study Purposes

The first purpose of my study--to evaluate the inter-trial reliability of perceived discomfort (PD) measures--arose from the absence of precedents of stringent PD reliability tests and the need to establish their field reliability. Given the novelty of the ICM assessment techniques and the absence of guidelines on the sampling and analysis of seated movement, the second purpose of my study was to evaluate the reliability of the various COP data sampling periods (5, 15 and 30 min). The third purpose of this study was to quantify inter-trial errors, and thereby improve the likelihood of detecting true differences in future studies in this research series. My final purpose was to confirm the numerous laboratory reports that ICM (Grandjean et al, 1960; Rieck, 1969; Jurgens, 1989) and perceived discomfort (Bhatnager et al, 1985; Drury and Francher, 1985; Schleifer and Amick, 1989) increase over time, by testing subjects under field conditions proposed for future ergonomic studies.

METHODS

Subjects:

The subjects were volunteers (1M, 7F) ranging in age from 23 to 45 years (mean 38.1, SD 7.95) who had been employed as Directory Assistance (DA) operators for an average of 12 (SD 4.6) years. Their mean height was 166.8 (σ 7.3) cm and their mean weight was 71.4 (SD 12.7) kg.

During the study subjects worked exclusively on day shifts in DA operations. Volunteers were excluded if they (a) were over the age of 45, (b) used bifocal lenses, (c) were pregnant, (d) had any minor health problems related to the urogenital or buttock region (e.g. haemorrhoids), (e) failed to meet height criteria based on furniture restrictions (see below), (f) required a screen viewing distance outside the recommended range of 50 to 80 cm (Akbari and Konz, 1991), or (g) in the course of completing a workplace screening form (Nordic questionnaires; Kuorinka et al, 1987), they reported any musculoskeletal problem in the preceding seven days or any significant musculoskeletal problem in the preceding year that prevented them from doing their "normal work" (n=4).

The study was introduced to the operators in the positive context of *factors that contributed to their musculoskeletal comfort*, not discomfort. Subjects were shown how the VERG mat collected interface pressures, but were blinded to the fact that movement would be derived from these recordings. Subjects were allowed to assume any posture, except those which brought the feet in contact with the mat. All subjects gave their signed, informed consent (Appendix 3.2 Informed Consent). Research was approved by the Human Ethics Review Committee of the University's Faculty of Graduate Studies.

Task Description:

The subjects and task were chosen following an extensive ergonomic analysis of Operator Services at the local telephone company that included evaluations of operator tasks, as well as their work environment (i.e. indoor climate) and furniture (Appendix 3.3 MT&T On-Site Conditions). The VDU task selected, Directory Assistance, was chosen because the areas of task, workload, environment, and furniture were standardized.

The operators' task, centered on a VDU and a headset, required no movements other than keyboarding, screen viewing and speaking to customers. The operators' workload (i.e. calls/operator/hr) was maintained at a relatively constant standard because the telephone company adjusted the number of on-line operators in proportion to the total volume of incoming calls. Analysis of variance of random samples of operator workloads over the preceding 12 months showed that the only significant change in workload was a decrease early on weekend mornings ($p < .001$). Testing was therefore restricted to weekdays. The maximum continuous work period allowed under the terms of the collective agreement was 120 min, a period considered sufficient to detect changes in comfort (Bhatnager et al, 1985) and ICM (Jurgens, 1989). One of three formal breaks (two, 15 min rests; one, 30 min meal) followed each 2 hr work period.

Operators could occupy any available workstation and changed stations frequently throughout a shift, making standardization of the indoor climate and equipment crucial in this study. In terms of the indoor climate of the DA room, operators had rheostat control over lighting levels and partial control of temperature (within $\pm$ 2^0 C). Air flow rates and humidity met the ASHRAE (1985) standards. The operators' equipment, including VDU's, workstations and chairs (Concentrix, Steelcase, Grand Rapids MI), was standardized throughout the entire office (Plate 3.1). The keyboard and screen were not height adjustable. In view of the effect of operator/workstation fit on in-chair movement (Mark et al, 1985; Pustinger et al, 1985) subjects were excluded if, while seated, they: (a) could not achieve a 90^0 angle in either the knee or elbow joints, or (b) tilted their head above the horizontal or more than 60^0 below the horizontal to view the screen.

Equipment:

In-Chair Movement: The COP was tracked at the chair-buttock interface as subjects sat on a VERG interface mat, a 45 cm^2 flexible array of force sensing resistors. For each 2 hr test, customized software allowed continuous on-line (Packard Bell 486SX-20) collection of COP data in the form of twenty-four, 5 min blocks. Using post-collection software, the total COP track (COP distance) and the average distance from the mean COP position (COP variation) was calculated for each 5 min time block. Customized graphics software provided two-dimensional COP plots (Figure 3.1), to assist with direct, visual interpretation of the COP data.

Perceived Discomfort: Perceived discomfort (PD) was evaluated using a combination of the BPD and LMD methods. For reasons previously discussed, PD was scaled with Corlett and Bishop's (1976) BPDS scale from 0 (no discomfort) to 5 (intolerable discomfort). PD was mapped with van der Grinten's (1991) LMD map, based on the results of a pilot study which showed that subjects (n=4) were more accurate in localizing their body parts on the LMD map, and preferred the option of rating back discomfort by side (i.e. left or right). Subjects individually learned the discomfort rating techniques during a 20 minute training session and practised twice during work time.

Plate 3.1 Standardized workstation and chair in Directory Assistance operations, showing fixed height shelves for the VDU screen and keyboard.

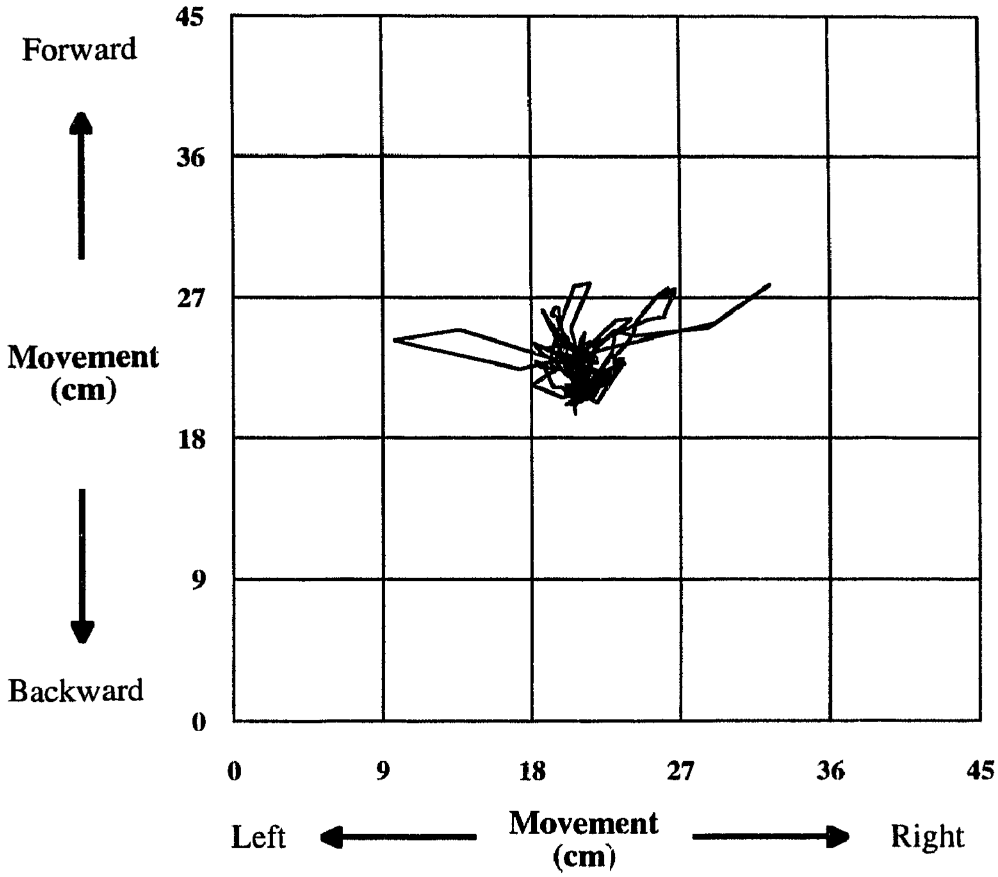


Figure 3.1 Sample of a seated subject's center of pressure path recorded from minute 5 to min 10 by the 45 cm x 45 cm VERG mat.

Test Procedure:

Tests were 2 hour long and took place exclusively during weekday mornings at the start of the shift. Subjects began each test with the chair (height, backrest angle, seat tilt) and screen distance set at their pre-determined preferred position, but were allowed to re-adjust any setting in the course of their work. Prior to the start of each test, subjects were asked to report any recent changes in their health (e.g. colds, headaches) or personal life (e.g. marital or job issues). As subjects sat on the mat, COP data were collected continuously for 120 minutes. Perceived discomfort was rated at minute 5, following which subjects logged on-line to work. Subjects signed off to rate their perceived discomfort at minute 65 and at the 115 min mark. Tests were repeated one day later at the same workstation set at each subject's preferred position. Figure 3.2 contains the test protocol on a time-base.

With the subjects' knowledge, their workload (calls/hour) was electronically monitored every hour during the tests to determine if their workload varied by more than 15% (i) from their peers (i.e. the system average), or (ii) from day-to-day. The system average also was monitored for day-to-day variations in workload.

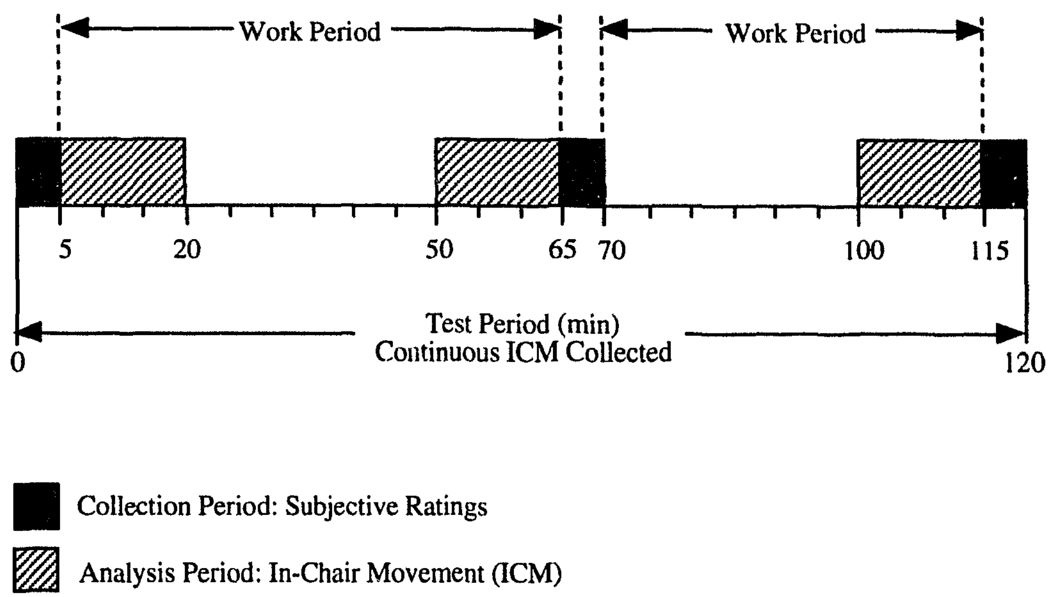


Figure 3.2 Test protocol in two hr tests of field reliability showing continuous ICM data collection (0-120 min) and three collection periods for subjective ratings of perceived discomfort (PD) at 0-5, 65-70, and 115-120 minutes.

Data Analysis: Movement data were not analyzed during blocks 1, 14 and 24 when subjects were doing study related tasks such as workstation adjustments and subjective ratings (i.e. PD). COP data were analyzed as the means of three (or six) 5 min blocks in the following sample periods: the start of the test (5-20 or 5-35 min); at the end of hour one (50-65 or 35-65 min); and at the end of hour two, (100-115 or 85-115 min).

The BPDS data were analyzed by combining individual scores into regional scores (van der Grinten and Smitt, 1992) of: whole body, shoulder/arms, back/neck, and pelvis/buttocks.

Calibration Study

In a previous laboratory study, COP movement was plotted with respect to measured trunk motion in the frontal and sagittal planes (reference: Validity Study). The purpose of this field calibration study was to measure the influence on COP movement, of the common field tasks and behaviours identified in a previous ergonomic analysis (Appendix 3.3). Subjects (n=4) started in an upright posture (90^0 at hips, knees) and performed each of the following 9 movements as the COP was tracked during a 10 sec trial: lean on left elbow, place both feet on a footrest, tilt the chair back from 100^0 to 115^0, move arms from armrest to keyboard, slouch (see

Grandjean et al, 1983), stretch legs and cross ankles, and look behind while (i) twisting their entire trunk, (ii) swivelling their chair, or (iii) turning only their head.

Experimental Design and Analysis:

ICM (distance and variation) and PD variables were screened for inter-trial linearity with the Pearson 'r' correlation coefficient. A Subject x Block repeated measures MANOVA was used to compare the reliability of the 15 and 30 min ICM protocols and evaluate time trends within these protocols. Intraclass correlation coefficients (ICC: Shrout and Fleiss, 1979) and the smallest detectable differences (sdd: Roebroeck et al, 1993) were calculated for single blocks [ICC (2,1)] and for the mean of 3 [ICC (2,3)] or 6 [ICC (2,6)] 5 min blocks at each of 3 sample periods (start, hr 1, and hr 2; see "Test Procedure"). The ICC acceptance level was set at .75 following Burdock (1963). Inter-trial reliability of PD scores was tested for each of 4 regional variables, with a Subject x Day repeated measures MANOVA. ICC (2,1) and the sdd were calculated for sum and average PD scores at min 5, 65, and 115.

The within-days and between-days effect of time on in-chair movement and perceived discomfort was tested with a Day (2) x Time (3) repeated measures MANOVA. The time conditions selected as independent variables were: Within-days (3); at the start of the test, and the end of hrs 1 and 2, and Between days (2); two consecutive weekdays. Outcome measures used to evaluate the experimental conditions were: PD measured at min 5, 65, and 115 and COP distance, analyzed using the most reliable COP protocol identified in the Subject x Block tests. Actual between trials differences for ICM and PD were compared to the sdd values calculated in the Subject x Block tests (ICM) and the Subject x Day tests (PD).

The within (3 times: min 5, 65, 115) and between days (2 consecutive days) effect of time on the number of body parts reporting discomfort (NBPD) was analyzed with a Friedman Day (2) x Time (3) ANOVA and multiple comparisons. All analyses were conducted at the .05 α level with SPSS (SPSS, Chicago, IL, 60611). Where sphericity tests showed significant deviations ($p < .05$) Huynh-Feldt epsilon was used to correct the degrees of freedom in the MANOVA tests.

RESULTS

Analysis of the Nordic Questionnaire data showed that the percentage of study subjects reporting a musculoskeletal "discomfort, ache or pain" at least once in the preceding year, by region was: 50% (neck), 66% (low back) and 38% (shoulder). Analysis of the workload data showed that at no time during the study did a subject's workload vary by more than 15% from the system average or from day-to-day. On one occasion, a test was re-scheduled due to a 25% increase in the system average resulting from a snowstorm.

In-Chair Movement

A. *Calibration Results*

Descriptive results (mean, SE) of COP distances for the nine calibration movements are presented in Figure 3.3. Results showed that the greatest contributions to COP movement were made by movements involving the hips (slouch, turn body) and legs (ankle cross, reach to foot rest).

B. *Correlation Analysis: 5 min blocks*

Inter-trial linearity for the 21 five min blocks of COP data (blocks 1, 14 and 24 excluded) was evaluated using the Pearson r_P. For COP distance, day 1 scores had a significant (.05), linear relationship to day 2 scores in 16 of 21 blocks. Conversely, for COP variation, r_P correlation coefficients had a wide range of variability (e.g. -.40, .00, .87), and were generally insignificant (20/21 blocks).

C. *Protocol Analysis*

Due to the lack of inter-trial agreement (i.e. r_P tests), COP variation was dropped as a dependent variable. In Table 3.1, results of protocol comparisons for COP distance shows that regardless of time period, reliability coefficients (ICC) for the means of 3 (and 6) trials were greater than those based on a single trial. Similarly the SEM is greater for any single measure than for its corresponding average (3 or 6 trials). The relationship between the sdd, the ICC and time, graphed in Figure 3.4, illustrates the improved reliability (ICC) and consistency (sdd) with averaged blocks for the 15 min protocol. While the highest ICC and lowest sdd values are for the 30 min means, the 6 trials were not stable over time, as evidenced by the significant ($p < .01$) linear trend (Table 3.1). Consequently, the 30 min protocol was dropped from further analysis. The 15 min protocol was therefore evaluated in the Day x Time analysis. A sample of the data and equations required to calculate the SEM and sdd for single and mean protocols (Table 3.1) for one 15 min block (5-20 min) are contained in the ANOVA summary (Table 3.2).

D. *Day x Time Results*

Figure 3.5 illustrates the results of the Day (2) x Time (3) analysis for ICM (COP distance) measured in 15 min blocks: 5-20, 50-65, and 100-115. While MANOVA showed a significant increase in COP distance with time regardless of day ($p < .01$), there was no difference between days ($p = .15$). For COP variation, Day and Time results were comparable to those for COP distance (Table 3.3). Table 3.4(A) illustrates that the actual differences between trials for mean COP distance (15 min) did not exceed the measurement error (i.e. the sdd).

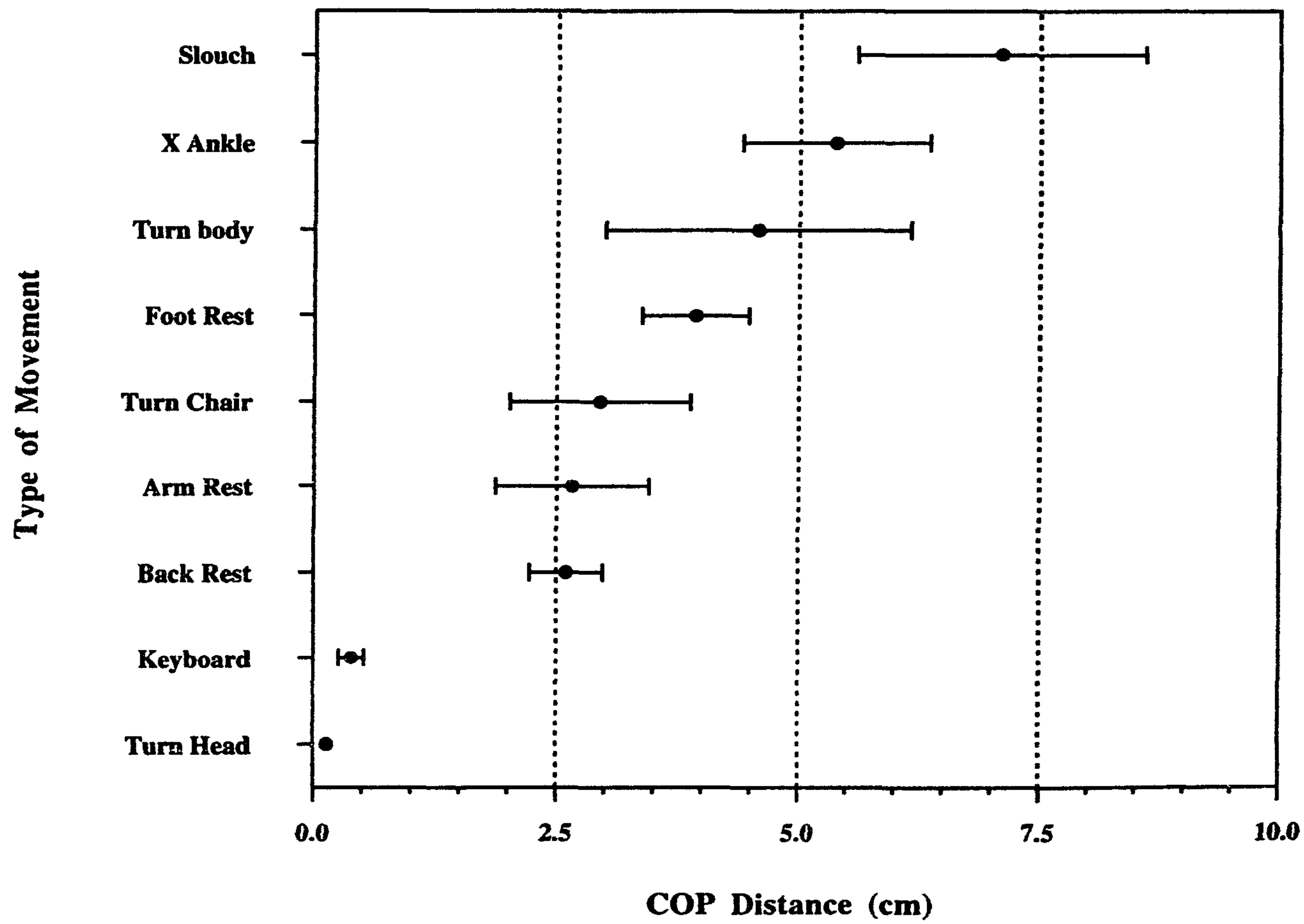


Figure 3.3 Calibration Tests: Average COP movement (mean, SE in cm) in 10 sec trials for 9 movements in the calibration trials (n=4).

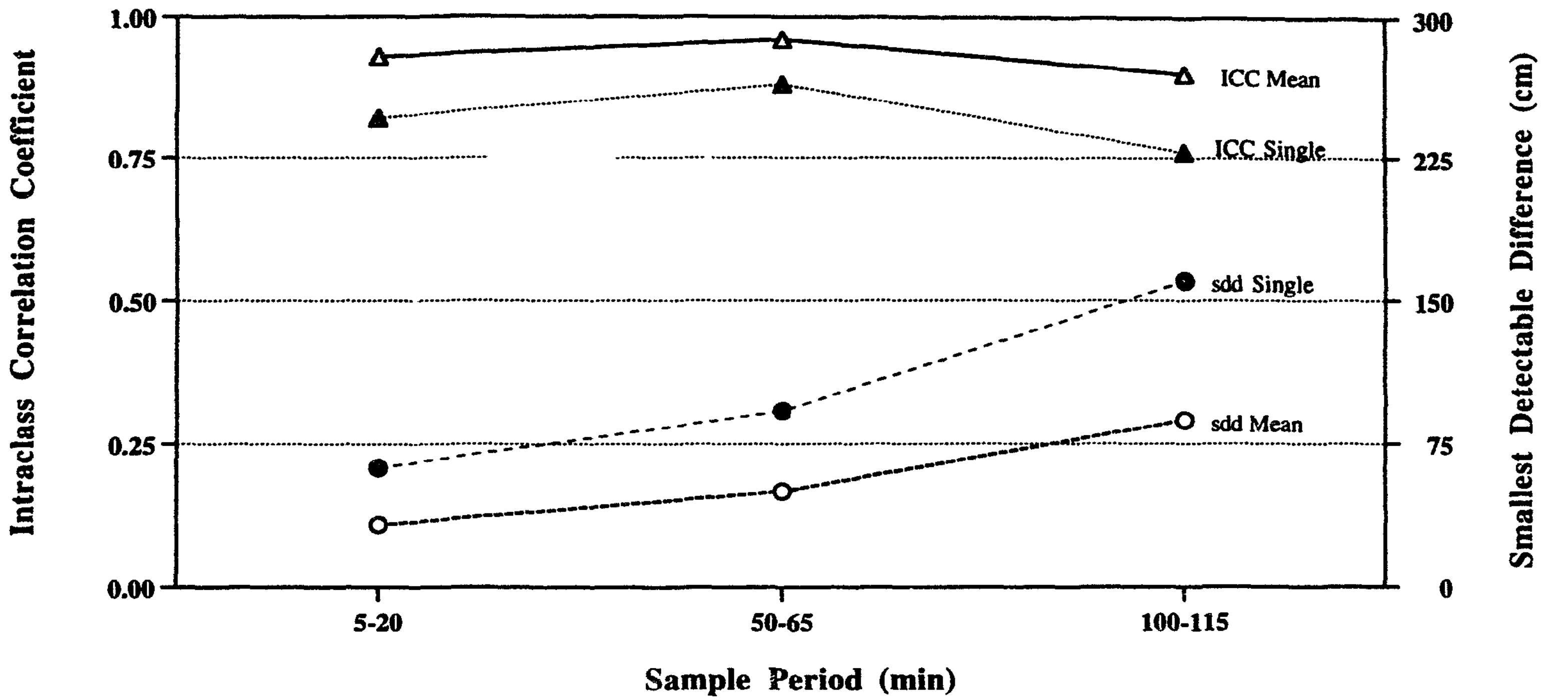


Figure 3.4 Reliability Protocols: Intraclass Correlation Coefficients and smallest detectable difference at three sample periods (5-20, 50-65, 100-115) for single versus mean protocols, showing improved reliability for COP data analyzed as the *mean* of three, 5 min blocks compared to a *single* 5 min blocks.

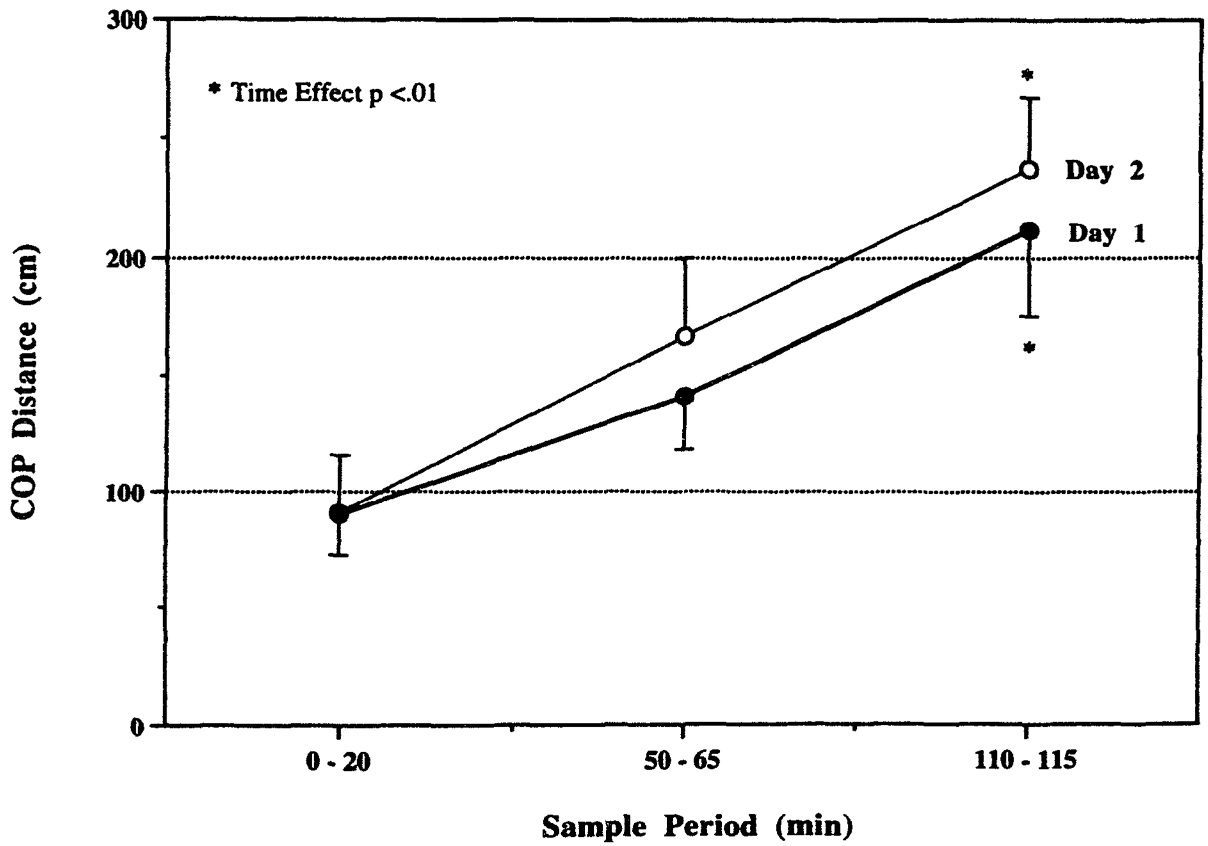


Figure 3.5 Reliability: In-chair movement versus time (Mean, SE) at three sample periods (5-20, 50-65, 100-115) showing a time effect independent of day, but no difference between days.

Table 3.1 Protocol analysis for ICM (COP distance). Comparison of error estimates (SEM & sdd in cm) and ICC for 3 analysis protocols: (a) single block, (b) 3 block mean (15 min), and (c) 6 block mean (30 min) in 3 time periods (min): 5-20 or 5-35 (start), 50-65 or 35-65 (end Hr 1) and 100-115 or 85-115 (end hr 2). Based on Day 1 Subject X Block MANOVA results (n=8).

	15 Minutes			30 Minutes	
Sample Period (min)	Single 1 Block ICC (2,1)	Mean 3 Blocks ICC(2,3)	Sample Period (min)	Single 1 Block ICC (2,1)	Mean 6 blocks ICC (2,6)
5-20			5-35		
ICC	.82	.93	ICC	.92	.97
SEM *	22.5	13.0	SEM *	23.5	9.6
sdd **	62.4	36.1	sdd **	65.0	26.6
Trend (p)	-	(.15)	Trend (p)	-	(<.01)
50-65			35-65		
ICC	.89	.96	ICC	.71	.88
SEM	33.4	19.3	SEM	52.9	21.6
sdd	92.7	53.6	sdd	146.7	59.9
Trend (p)	-	(.28)	Trend (p)	-	(<.01)
100-115			85-115		
ICC	.76	.90	ICC	.82	.93
SEM	57.0	32.9	SEM	60.7	24.8
sdd	158.1	91.3	sdd	168.2	68.6
Trend (p)	-	(.64)	Trend (p)	-	(<.01)

* SEM = standard error of measurement (cm)

** sdd = smallest detectable difference (cm) = $\sqrt{2}$ x 95% CI SEM (Roebrocke et al, 1993)

Table 3.2 Subject x Block MANOVA summary for single versus mean of 3 blocks of COP data for the 15 min protocol (5-20 min), where the F value for 'Constant' denotes a significant between subjects effect.

Source	df	SS	MS	F	p value
Constant	1	195,453.4	195,453.4	26.62	<.01
Among	7	51369.1	7338.4		
Within	16	8110.5	506.9		
Blocks	2	1930.7	965.4	2.19	.15
Residual	14	6179.8	441.4		

$$SEM_{single} = \sqrt{MS_{error}} = \sqrt{((SS_{blocks} + SS_{residual}) / df_{error})}$$

$$SEM_{mean} = \sqrt{MS_{error}} / \sqrt{N} \quad \text{(where N = \# blocks)}$$

Table 3.3 Summary of Day (2) x Time (3) MANOVA results for (A) sum and average PD in whole body, back/neck, pelvis/buttocks and shoulder regions and (B) 15 min blocks of COP movement (distance, variation).

Significance Levels MANOVA: Day (2) x Time (3)

(A) Cluster PD Scores

Variable	Day	Time	Day x Time
Whole Body			
Sum	.98	.01	.30
Average	.65	.01	.10
Back/Neck			
Sum	.58	.01	.77
Average	.17	.01	.25
Pelvis/Buttocks			
Sum	.83	.01	.90
Average	.38	.01	.89
Shoulder			
Sum	.95	.49	.28
Average	.24	.43	.57

(B) COP Movement

Variable	Day	Time	Day x Time
COP Distance	.16	.01	.49
COP Variation	.42	.01	.17

Table 3.4 Comparison of actual inter-trial differences (Day x Time Test) and smallest detectable differences (Subject x Time Test) for (A) COP distance (cm) and (B) average whole body PD (PD units).

(A) COP Distance

Differences	Min 5-20	Min 50-65	Min 110-115
Actual (cm)	.89	25.9	25.6
sdd	36.1	53.6	91.3

(B) Average Whole Body PD

Differences	Min 5	Min 65	Min 115
Actual (PD units)	.12	.07	.01
sdd	.44	.36	.35

Perceived Discomfort

A. *Reliability*

Reliability and consistency results for the four regional PD variables (sum and average) at min 65 and 115 are presented in Table 3.5. Due to a high rate of zero discomfort responses, results at min 5 are incomplete and are not reported. Regardless of time, reliability was higher and sdd values were lower for all averaged PD scores compared to sum scores, with the exception of the pelvis/buttock region. Also, both the back/neck and pelvis/buttock scores (sum or average) failed to meet the .75 reliability ICC standard. Furthermore, the back/neck and pelvis/buttock scores had the highest sdd values. Finally, the shoulder/arm scores were most reliable, but the absence of a time trend (see above, Table 3.3) shows that this region is not heavily loaded in this task. Therefore, the most reliable, consistent indicator of temporal changes in discomfort for these test conditions were the whole body average scores (ICC=.89 at min 65, and .90 at min 115).

Table 3.5 Summary of inter-trial reliability and measurement errors (SEM, 95% CI, sdd) for perceived discomfort (sum & average) in the shoulder, back/neck, pelvis/buttock and whole body regions at 65 and 115 mins. Based on Subject x Day MANOVA (n=8). The lower limit of ICC acceptability is .75.

Body Part Time (min) Sum, Average	SEM	95% CI SEM * (±)	sdd	ICC (2,1)
Shoulder				
65	.30 .03	.59 .06	.83 .08	.90 .99
115	.50 .08	.98 .15	1.38 .22	.92 .99
Trunk				
65	1.11 .45	2.17 .88	3.07 1.25	.67 .67
115	1.13 .45	2.21 .88	3.13 1.25	.68 .77
Pelvis				
65	1.01 .60	1.97 1.17	2.80 1.66	.72 .63
115	.57 .44	1.11 .86	1.57 1.22	.89 .71
Whole Body				
65	.75 .13	1.47 .25	2.07 .36	.75 .90
115	1.17 .12	2.29 .24	3.24 .35	.88 .89

* 95% CI SEM = 95% confidence interval of SEM

B. *Day x Time Results: Discomfort, Number of Body Parts*

Figure 3.6(A) illustrates the results of the Day (2) x Time (3) analysis for average whole body PD measured at min 5, 65, and 115. MANOVA showed a significant increase in whole body discomfort with time ($p < .01$) regardless of day, but no day-to-day differences ($p = .98$). As summarized in Table 3.3, no DAY effect was present for any of the 4 regional PD scores (sum or average), and all scores increased significantly ($p < .01$) over time, except for the shoulder/arm region. Table 3.4B shows that the actual between trials differences for PD were also not true differences, meaning they did not exceed the sdd. As seen in Figure 3.6B, the reported number of body parts experiencing discomfort (NBPD) increased at minutes 65 and 115 ($p < .01$). Results of the Friedman tests also showed no DAY effect ($p = .33$) for the number of uncomfortable body parts.

DISCUSSION

Overall results support the central hypothesis that in-chair movement (ICM) and perceived discomfort (PD) measures are reliable between trials. However, of the ICM and PD measures which were tested, not all were equally reliable, nor did all increase with time. The essence of this study is the establishment of field condition stability and test measure reliability; two conditions required prior to conducting on-site intervention studies.

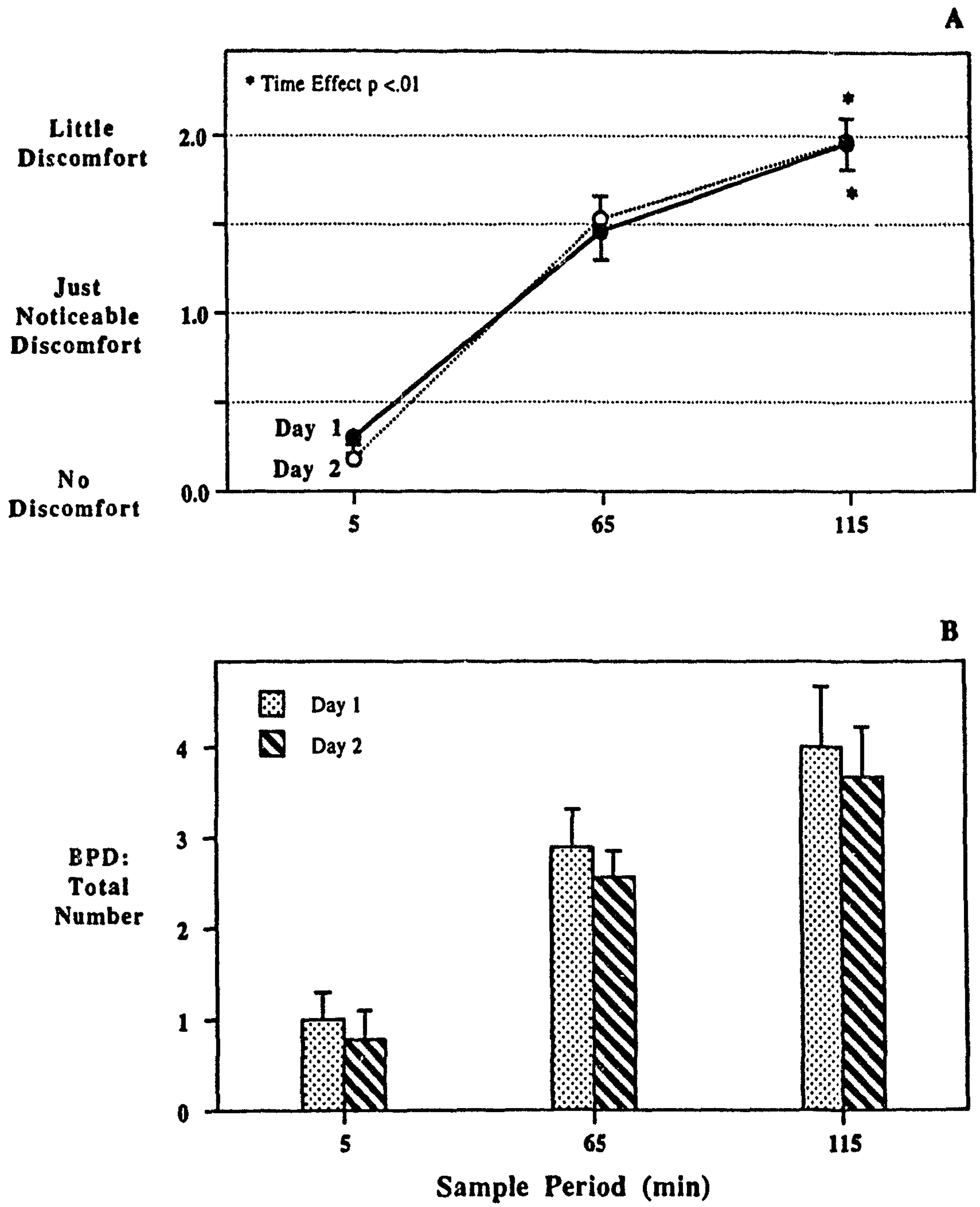


Figure 3.6 Reliability: (A) Whole body perceived discomfort (Mean, SE) and (B) number of uncomfortable body parts (whole body) versus time at 5, 65, and 115 min, showing time, but not day effects, for both discomfort (A) and number (B).

Nordic Musculoskeletal Questionnaire

Musculoskeletal survey results in this study are comparable to other studies of telephone operators (Starr et al, 1982) where discomfort reported 'within the preceding month' for a sample of 23 men and 122 women was 65% (neck), 63% (low back) and 48% (shoulder). However, since operators with moderate to severe symptoms were excluded from the sample results in the present study, the actual percentages in this telephone company are likely higher than reported here.

In-chair Movement: Time Effect

In terms of in-chair movement, the present field study supports numerous laboratory studies which have shown that seated movement (termed fidgets, restlessness, etc.) increased with time spent in sitting (Grandjean et al, 1960; Rieck, 1969;; Bhatnager et al, 1985; Jurgens, 1989; Swanson and Sauter, 1993a). Unlike the COP method used in this study, the older laboratory studies used a variety of techniques (e.g. force platforms) that were not suited for field use or that required excessive data reduction (e.g. video analysis). The tasks in most laboratory studies--easy chair reading (Grandjean et al, 1960), automobile driving (Rieck, 1969) and computer simulated boat piloting (Jurgens, 1989)--were unrelated to traditional office work, with two exceptions. In a chair comparison study by Michel and Helander (1994), subjects performing VDU tasks increased their in-chair movement six-fold in the first 30 min of a two hr laboratory test. Using video motion analysis, Swanson and Sauter (1993a) reported increased posture changes ($p < .001$) in the afternoon compared to the morning in a laboratory study of data 32 entry clerks.

Temporal increases in seated motion have previously been shown in the field, but under limited conditions. Branton (1966) studied two train passengers, while the tasks in Bendix et al's. (1985) study varied between paperwork and typing. Although many investigators have evaluated in-chair movement, this is the first study with a report on inter-trial reliability of ICM.

The above results also show that tracking the COP with an interface mat is non-disruptive and suitable for field use. The hardware performed well in detecting time trends in ICM for seated VDU operators. The temporal increases in ICM demonstrated here were due, in part, to factor control (task, environment, time-of-day), screening standards (health and workstation fit) and a repeated measures design (control of inter-individual differences). Nevertheless, the increase in COP movement over time was significant ($p < .01$).

In my calibration study, results showed that, as expected, the greatest contribution to COP excursion involved movements of the hips and legs, rather than head and arm movements. Results of my previous trunk motion calibration study showed that trunk movement in either the sagittal or frontal planes resulted in large

(10 cm) COP excursions. Interestingly, the body regions known to suffer the greatest discomfort in seated operators, the trunk, and buttocks (Karlqvist and Bjorksten, 1990; Sauter et al, 1991), made the greatest contribution to COP movement. The COP system is therefore capable of detecting movement (or the lack thereof) in body parts at greatest risk of discomfort.

Correlation Analysis: COP Variation

Whether the data were analyzed in 5 min blocks with a Pearson r_p or in 15 min blocks with an ICC (2,1), COP distance measures consistently met the inter-trial reliability standards (ICC=.75, r_p significant at $p < .05$), while COP variation consistently did not. There appears to be day-to-day stability in the amount of movement, but not in how the movement took place (i.e. large movements versus a series of smaller movements). As a result COP variation was dropped as a dependent variable and may require refinement or a larger sample size in future applications.

In-chair Movement: Protocol Analysis

Continuous data collection with the VERG COP system provided the opportunity to select time periods for analysis. Given the uniqueness of the COP measures and the absence of any guidelines in the literature, a primary goal of this research was to determine the most reliable, consistent protocol for data analysis. Results clearly showed that, compared to the use of a single 5 min block, averaging consecutive 5 min blocks improved both reliability and consistency of the COP measures. Although Kroll (1967) suggested using all available trials, the limitation of averaging is that only stable trials can be used (Stratford et al, 1989). Therefore, in spite of having the highest reliability, all 30 min blocks (5-35, 35-65 and 85-115) had a significant within-blocks time trend and were inappropriate for the averaging protocol.

Protocol analysis results support the treatment of 5 min blocks as discrete trials and the analysis of 15 min blocks (i.e. mean of 3, 5 min blocks) for the three sample periods (5-20, 50-65 and 100-115 min). These protocol results are credible considering that behaviour, in this case seated movement, can be expected to vary daily and larger blocks accommodate those fluctuations. Jensen and Bendix (1992) failed to detect a time trend in 'spontaneous' seated movements when they analyzed data every quarter hr as single, discrete 5 min blocks; a result that supports the use of larger, averaged blocks.

The smallest detectable difference (sdd) for trial-to-trial differences has been established in this study as a benchmark for my future studies with this methodology. As an example, for the 15 min block from min 5-20, only inter-trial differences in COP distance greater than 36.1 cm are outside the limits of measurement error and should be considered true differences.

Perceived Discomfort: Time Effect

Results of the present study support numerous reports in the literature of a positive relationship between perceived musculoskeletal discomfort and the length of time one is seated (Shackel et al, 1969; Corlett and Manenica, 1980; Helander et al, 1987; Schleifer and Amick, 1989; Michel and Helander, 1994). In studies where sitting discomfort was reported by region, shoulder and arm discomfort was generally time sensitive (Schleifer and Amick, 1989), a result in contrast to the present findings. Given the high prevalence rates for upper limb discomfort in female VDU operators reported by McPhee (1990) and Evans (1987), the absence of a time trend in the shoulder/arm regional scores is peculiar in this study. In seeking an explanation, the effect of the type of VDU usage (Elias et al, 1980) on physical symptoms should be considered, since the Directory Assistance data base is arranged to require minimal keystrokes per customer request. Further, the operator/workstation fit, a contributing factor in upper limb discomfort (Dainoff and Dainoff, 1986), was controlled in this study.

For the neck/back and pelvis/buttocks regional scores, the significant time effect ($p < .001$) was expected. Wachsler and Learner (1969) reported that buttock comfort was the principle determinant of overall sitting comfort. Furthermore, back and neck discomfort is a leading complaint reported by VDU operators in many musculoskeletal surveys (Evans, 1987; Sauter et al, 1991).

The temporal increase in the number of uncomfortable body parts in seated workers shown here has been reported elsewhere by numerous researchers (Bhatnager et al, 1985; Drury and Francher, 1985; Wiker et al, 1989; Bishu et al, 1991). For each of the four regional variables, the time trends were similar for sum and average scores. Therefore, by implication, as total discomfort scores increased, so did the number of uncomfortable body parts, an assumption corroborated by results from the Friedman test. These coincident increases in uncomfortable body parts and total discomfort confirms other findings (Corlett and Manenica, 1980; Wiker et al, 1989), and follows a basic law of psychophysics; that increasing the area of stimulation results in an increase in the perceived severity of the stimulus (Coren and Ward, 1989). In this study, the relationship between time and the frequency of reported discomfort was not affected by the use of van der Grinten's (1991) LMD map in which the body was divided into fewer anatomical parts than the BPDS map.

Perceived Discomfort: Reliability

The shoulder/arm regional scores had the highest ICC coefficients at minutes 65 and 115. Thus the absence of a time trend in the shoulder/arm region, although unusual, was consistent across the two test days. While some inter-trial reliability scores for the back and neck and pelvis and buttocks were below the .75 standard, whole body discomfort scores were consistently reliable. Results of the SEM and sdd analyses mirror the reliability results. Therefore, these results suggest that the *site* of discomfort may have varied by region from day-to-day, but the total *amount* of discomfort and the *number* of uncomfortable body parts were both consistent. Just as rated perceived exertion (Borg, 1982) is deemed to measure gestalt (i.e. general) perceptions, the reliability of the whole body scores alludes to a similar phenomenon in perceived discomfort. The present results suggest that PD data be collected by body part, but evaluated as whole body scores.

Van der Grinten (1991) also reported that inter-trial correlations were highest in the shoulder/arm region, moderate for the other regional variables, and that the highest correlations were the whole body discomfort ratings. The parallels with the present study are striking given that van der Grinten's (1991) tests were conducted 2 weeks apart with subjects performing non-dynamic work (2 to 3 min static holds) in sitting and standing.

Results of the error analysis for PD show that the minimum trial-to-trial differences (sdd in PD units) for whole body discomfort are .36 and .35, at minutes 65 and 115, respectively. No SEM reports are available for comparison in the literature. Reduction of measurement error may be accomplished for VDU-based subjects by moving from paper-based to computer-based discomfort ratings (Zwahlen et al, 1984; Saldana et al, 1994). Other suggestions to reduce PD errors (Bonney et al, 1990) or improve sensitivity (Stuart-Buttle, 1994) include transforming absolute scores to relative proportions, but result in ordinal data with its concomitant restrictions.

Inter-trial variations in sitting discomfort and in-chair movement may be explained by individual factors, such as mood, general well-being or stress. An essential requirement of repeated measures design is stability of test conditions and subjects. In spite of the task and environment control present in this study, Directory Assistance is a service-based industry in which operators deal with the variable, often unrealistic expectations of the public (Armistead, 1987). Consequently, inter-trial variations in discomfort may be due to variations in the operators' mood or mental workload.

In-chair movement and perceived discomfort also may be influenced by the effect of many other variables not measured in this study, such as job stress related to electronic productivity monitoring (Carayon, 1993), the loss of control due to external work pacing (Frankenhaeuser, 1991) and general tiredness (Boissin et al, 1991). In addition, the literature on perception deals primarily with the contribution of physiological factors (e.g. work load, heart rate) to perceived discomfort and exertion. Research in rated perceived exertion (RPE) shows that at least 33% of the variance in RPE is due to psychological factors (Morgan, 1973). No such estimate is available for perceived discomfort.

Caution must be exercised in interpreting the temporal increases in-chair movement reported here. An increase of 121 cm of seated movement per 5 min block (averaged over 15 min) from the start to the end of the two hr test is significant. The relevance, however, is not clear. Considering the calibration results (Figure 3.3), several large movements are required to produce 121 cm of COP movement. There is however, no certainty that this movement increase will reduce postural fixity (Grieco, 1986) or decrease the risk of musculoskeletal problems (Bendix, 1991). Although ICM and PD increased concurrently over the test period, presently there is no method to determine if the movement is in reaction to the discomfort. Neither is it possible to determine if the subjects' movement limited the increase in their perceived discomfort. Finally, researchers (Pustinger et al, 1985; Swanson and Sauter, 1993a) have questioned the value of seated movements, citing negative correlations between movement and productivity.

My PD and ICM results can be generalized with the following provisions. Not only is the sample size small, it is predominantly female. Jurgens (1980) has suggested gender related differences exist in seated "restlessness". Generalizability is also limited by the singularity of the subjects' task, controls on the environment (time-of-day, workload) and screening standards (health and workstation fit).

Conclusions

While this study has not identified and quantified all sources of variation in ICM and PD measures, the results provide benchmark measures of a major source of error, the *standard error of measurement*. Results have clearly identified that the greatest reliability and smallest measurement errors were for in-chair movement (COP Distance) analyzed as three, 5 min blocks and for perceived discomfort (PD) evaluated as a whole body score. This study also showed temporal increases in ICM and perceived discomfort for all regional variables except the shoulder/arm region. Finally, for both ICM and PD, the absence of day-to-day differences (Day x Time tests) and the reliability of most variables (Subject x Day, Subject x Block tests) establishes the suitability of the test conditions for my remaining studies in this research series.

CHAPTER FOUR

Effects of Time-of-Day and Work Pace on In-chair Movement, Perceived Musculoskeletal Discomfort and Mental Workload in Telephone Operators

Since early attempts to quantify seated restlessness with the *wrigglemeter* (Branton, 1966), researchers have used in-chair movement as an objective measure of sitting discomfort (Grandjean et al, 1960; Rieck, 1969; Bhatnager et al, 1985). While there is renewed interest in the phenomenon of in-chair movement (Swanson and Sauter, 1993a; Fenety, 1993; Shalin et al, 1994), other than perceived discomfort, workplace factors that may influence in-chair movement (ICM) are largely unexplored. Researchers have suggested that two such workplace factors are the *time-of-day* (Jurgens, 1980; Swanson and Sauter, 1993a) and *workload pace* (Jurgens, 1989). Both factors are evaluated in the present study, the first purpose of which was to evaluate the effect of the time-of-day and workload pace on in-chair movement.

In terms of perceived discomfort (PD), time-of-day effects have had minimal documentation in field studies in the electronic office (Bishu et al, 1991; Schleifer and Amick, 1989). Also, the positive effect of workload pace on PD has been measured, but only in retrospective studies (DiTecco et al, 1992; Sauter et al, 1992; Smith et al, 1992). Therefore, the second purpose of the present study was to utilize a prospective design to measure the effect of the time-of-day and workload pace on perceived discomfort.

For video display unit (VDU) operators, external work pacing by electronic means (i.e. computerized control of task pace) is becoming increasingly common (Smith et al, 1992). Yet little is known of its effect on perceived mental workload. Similarly, there is little known of the effect of the time-of-day on mental workload (Hancock, 1988). Therefore, my final purpose in the present study was to determine the effect of the time-of-day and workload pace on subjective ratings of mental workload in electronically paced workers. The subjects in the present study were Directory Assistance (DA) operators seated on-site at a VDU task for two hours. The following discussion includes a review of the effects of the time-of-day and workload pace on both in-chair movement and perceived discomfort, followed by an introduction to the *Modified Cooper-Harter* mental workload scale.

Time-of-Day Effect on Comfort and In-chair Movement

Time-of-day effects on perceived discomfort: Sleep, alertness and autonomic functions are among the variety of human body functions that fluctuate daily with respect to the time-of-day. Musculoskeletal discomfort also has been shown to fluctuate over the course of the day in a variety of occupations, office workers included (Shackel et al, 1969; Bishu et al, 1991; Schleifer and Amick, 1989). In a field study of clerical workers, Shackel et al (1969) tested subjective comfort in 20 subjects on each of 8 chairs over a full work day. Though no statistical support was given, perceived discomfort (PD) reportedly increased in the afternoon compared to the morning (Shackel et al, 1969). In laboratory studies of VDT operators, both Bishu et al

(1991) and Schleifer and Amick (1989) demonstrated significant ($p < .01$) afternoon increases in musculoskeletal discomfort.

Notably, after the mid-day break, discomfort did not return to early morning levels in any of the three full-day studies (Shackel et al, 1969; Schleifer and Amick, 1989; Bishu et al, 1991). Corlett and Manenica (1980) have suggested that the failure to recover pre-lunch discomfort levels is due to the cumulative effects of fatigue. They further suggest that, with respect to musculoskeletal discomfort, the end of a workday (e.g. afternoon) cannot be considered a repetition of the start of the workday (e.g. morning), regardless of the task or the worker (Corlett and Manenica, 1980).

Time-of-day effects on in-chair movement: In-chair movement (ICM) has been variously called fidgets (Branton, 1966), spontaneous movements (Jensen and Bendix, 1992), restlessness (Jurgens, 1980), body movements (Jurgens, 1989), and posture changes (Swanson and Sauter, 1993a). In general, the numerous researchers who have demonstrated a positive relationship between ICM and time, have done so in 2 to 3 hr tests (Rieck, 1969; Bhatnager et al, 1985; Jurgens, 1989); periods that fall well short of an 8 hr workday.

Three notable exceptions exist. In Grandjean et al's (1960) laboratory study, subjects ($n=7$) were each tested in 4, two hour blocks that covered the period of 0800 to 1800 hrs. Although no statistical tests were done, the authors concluded that ICM was affected by the time-of-day. Similarly, in a laboratory study of data entry clerks (n=32F), Swanson and Sauter (1993a) reported increased posture changes ($p<.001$) in the afternoon compared to the morning. Conflicting evidence has been shown in 8 hr field tests with typists (n=12) where Bendix et al (1985) showed that the temporal patterns of ICM apparently did not differ from morning to afternoon, although again, no statistical evidence was presented. So, while the short term effects of time on ICM are documented, time-of-day effects over a full workday remain equivocal. Since time-of-day effects must be considered in defining the relationship between ICM and sitting discomfort, more stringent tests of the time-of-day effects on ICM are therefore required.

Effects of Mental Workload and External Workload Pacing on Health Complaints and In-chair Movement

Mental workload: Increasing workplace automation and complexity has meant that workers use their physical resources less and their mental skills (e.g. perception, vigilance, and problem solving) more (Wierwille and Casali, 1983). Measurement of the workload imposed by these mental factors has become an ergonomic priority for reasons of health, wage compensation and performance (Meshkati et al, 1990). Jex (1988) defines mental workload as the worker's perception of the margin between their *motivation* to do the work and the current *task demands*, while at the same time achieving *adequate* task performance. In simple terms, an operator's mental workload is a tradeoff between what they *want* to do, what they *have* to do, and their perception of *acceptable* performance. Moray (1982) suggests that time stress is an absolute prerequisite for the creation of mental workload. Time stress commonly occurs at work when jobs are externally, rather than self-paced.

External workload pace: While external job pacing is more common in production line work, computerized tasks lend themselves to external pacing in tasks involving data entry, communications and vigilance (Dainoff and Dainoff, 1986). Job control in the workplace can be evaluated using Karasek and Theorell's (1990) a model that combines job control (what will I do next?) and job demands (what should I do next?). Whether the nature of the pacing is electronic (computer paced) or automated (e.g. assembly line), paced work falls into Karasek and Theorell's (1990) *low control-high demand* category, a time stress condition that contributes to mental workload (Moray, 1982).

There is conflicting evidence about the relationship between external pacing and mental workload. That is, high mental workload demands have been linked to both external pacing (Manenica and Golias, 1991), and self pacing (Salvendy, 1975). While task pacing has been shown to affect both the physiological and psychological responses of workers (Knight and Salvendy, 1981), there are few prospective field studies of the effect of electronic external pacing on mental workload and perceived discomfort.

Effects of workload pace on health complaints: Three groups of researchers have measured the effects of electronic pacing in the telecommunications industry (DiTecco et al, 1992; Sauter et al, 1992; Smith et al, 1992). A retrospective survey of 225 DA operators, 229 service representatives and 266 clerks showed that electronically paced DA operators had higher ($p < .01$) psychological strain measures (e.g. boredom, anxiety) and somatic health complaints (musculoskeletal discomfort, headaches, fatigue, etc) than self-paced telephone company service representatives and clerks (Smith et al, 1992).

In the second study with telecommunications workers ($n=533$), the National Institute of Occupational Health and Safety (NIOSH) evaluated the relationship between upper extremity *disorders* (defined as musculoskeletal complaints later confirmed by physical examination) and electronic pacing (Sauter et al, 1992). Using multiple logistic regression, the NIOSH group showed that increases in work pressure and calls handled by DA operators were related to upper extremity disorders (Sauter et al, 1992). The third study, conducted on telephone operators ($n=704$) at Bell Canada, showed that 45% of the operators felt that job pressure was 'high to very high' due to electronic workload pacing (DiTecco et al, 1992).

These three telecommunications studies have a common feature: each utilized retrospective questionnaires. Even though musculoskeletal complaints were confirmed by examination in the NIOSH study, none of the DA operators in the Smith et al

(1992) and Sauter et al (1992) telecommunications studies rated their musculoskeletal discomfort on-the-job. So, while all three studies have the advantage of large sample size, they did not measure discomfort or workload directly. Consequently, prospective studies of the effects of workload pacing on perceived discomfort are required to validate the retrospective findings of Sauter et al (1992), Smith et al (1992), and DiTecco et al, (1992).

Effects of workload pace on in-chair movement: In a comprehensive review of factors the influenced ICM, Jurgens (1980) suggested there were distinct peaks in seated "habitual restlessness" that appeared to be related to individual daily peaks in activity levels. Interestingly, these activity peaks, referred to as one's position on the "morning-to-evening continuum" (Monk, 1990), have been shown to coincide with peak performance (Campbell, 1992). In a simulated boat piloting study, Jurgens (1989) later tested the hypothesis that ICM (i.e. restlessness) was associated with the level of task difficulty. Jurgens (1989) created three levels of difficulty by increasing the pace of potential piloting errors (e.g. boat crashes) in the simulation sequence. Results showed that time spent in sitting, not workload pace demands, determined the amount of body movement. To date, Jurgen's (1989) laboratory study remains the only test of ICM versus workload pace.

Effects of Time-of-day on Mental Workload

Hancock (1988) evaluated performance in a mental workload task in 24 subjects (12F, 12M) at 0800, 1200, 1600 and 2000 hrs and found no significant time-of-day effect, a result the author termed surprising in view of circadian variations in performance. The failure to detect time-of-day differences was attributed by Hancock (1988) to a number of factors such as, similarity of the task on the 4 occasions, failure to cover the 24 hr day, and an inability to counterbalance the order effects. This review of the literature uncovered no other studies involving the time-of-day and workload pace, regardless of the outcome measure (ICM, PD or performance). That deficiency is puzzling, considering the host of cognitive factors that have been shown to vary throughout the day, such as working memory (Folkard, 1975), memory strategies (Oakhill, 1986) and perceptual motor performance (Smith, 1992).

Assessment of Mental Workload

The assessment of mental workload falls into three basic categories: physiological reactions (e.g. heart rate, eyeblink frequency), secondary task performance (e.g. tapping while problem solving), and subjective scaling techniques. Sheridan (1980) argued that not only are subjective ratings the most direct measure of mental workload, they are unobtrusive, sensitive and quick.

The Modified Cooper-Harter (MCH) is a subjective mental workload scale designed to measure loads in mental, rather than motor or psychomotor tasks

(Appendix 4.1 MCH Scale). By incorporating a decision tree, the MCH scale directs the rater to one of four sectors on the 1 to 10 mental workload scale: impossible (10), maximum (7 to 9), moderate (4 to 6) and low (1 to 3). MCH validation tests demonstrated a strong correlation with objective workload (< .01) as well as linearity throughout the 10 point range (Wierwille and Casali, 1983; Wierwille et al, 1985a). Wierwille et al (1985b) strongly recommend use of the MCH scale for tasks which are 'communications oriented in nature and involve verbal input and output', a relevant consideration in the present study.

Rated high in sensitivity, the MCH has proven capable of detecting differences with as few as 8 subjects (Wierwille et al, 1985a). In addition, the MCH is not intrusive, and because of its single rating structure, the MCH requires minimal time to complete (15-30 sec) (Hill et al, 1993). The MCH is an ordinal scale, although the developers (Wierwille and Casali, 1983) have tested results with both parametric and non-parametric techniques. While Jex (1988) suggested transforming the ordinal MCH data in order to achieve sufficient homeoscedascity for parametric tests, the transformation requires a large (n=80) sample size.

Study Hypotheses

The primary null hypothesis in the present study of Directory Assistance operators was that in-chair movement (ICM) would not affected by either the time-of-day (morning versus afternoon) or the workload pace (high versus low). A second null hypothesis was that neither the time-of-day nor the workload pace would affect perceived discomfort (PD). A final hypothesis was that perceived mental workload would not be affected by either the time-of-day or the workload pace.

The first alternate hypothesis is that ICM is greater in the afternoon compared to the morning and, greater when the workload is low, compared to high. Regarding PD, the alternate hypothesis is that PD will be greater in the afternoon compared to the morning and greater under high workload pace conditions. The final alternate hypothesis is that perceived mental workload will be higher in the afternoon and greater under a high workload pace.

METHODS

Subjects

The subjects (3M, 6F), ranged in age from 23 to 40 years (Mean 28.6, SD 6.5). All had been employed as Directory Assistance operators for 59 (SD 52) months, and all were members of a collective bargaining unit. Their mean height and weight were 171.4 (SD 9) cm and 72.8 (SD 8.5) kg, respectively.

The subjects, all in good health, were screened on multiple health and anthropometric factors (details in Chapter 3; Reliability). All subjects gave their signed, informed consent. The research was approved by the Human Ethics Review Committee of the University's Faculty of Graduate Studies.

Task Description

The VDU-based Directory Assistance task was selected because the workload and environment (including furniture) were standardized. Details of the environmental controls and screening based on workstation fit are contained elsewhere (Chapter 3: Reliability).

The operators in this study dealt primarily with requests for directory assistance, and to a lesser extent, handled intercepts on disconnected or out-of-service numbers. DA information was released in voice simulation via an Automated Voice Response System (AVRS), unless the customer requested a spoken response or asked for multiple listings. By adjusting the number of on-line operators, the telephone company maintained call volumes (calls/operator/hr) at a relatively constant rate, with one exception. My analysis of random samples of DA workloads from the previous year, showed that call rates decreased significantly ($p < .001$) early on weekend mornings (0700 to 1000 hrs).

When the DA system reached peak capacity, CW (call waiting) was posted on-screen. The DA operators had constant on-line access to their up-to-date average work time (AWT), defined as their average work time per call, and to the group work times (GWT), defined as the average work time per call for the entire DA office. DA operators could therefore self-monitor their work pace at will.

Equipment

Perceived Discomfort: Perceived Discomfort (PD) was rated using the BPD (Corlett, 1990) 5 point scale (0 = no discomfort, to 5 = intolerable discomfort) and localized with the LMD body map (van der Grinten, 1991). Previous results (reference: Reliability Study) showed that inter-trial reliability for PD ratings was greatest for average whole body scores. That is, for each subject at each rating period, the sum of their individual body part PD scores was averaged over their number of uncomfortable parts.

In-chair movement: ICM was measured by tracking center of pressure (COP) changes at the buttock chair interface as subjects sat on a VERG (Vision Engineering Research Group) pressure sensing mat. On-line data were collected continuously and stored as 24, five min blocks. Post collection software calculated the total COP distance travelled in each block. Based on results of my Reliability Study (Chapter 3), ICM data were analyzed as three block means, defined as the average of three consecutive 5 min blocks of COP distance. Subjects were shown how the mat collected interface pressure, but were blinded to the fact that movement would be derived from the data.

Mental Workload: Perceived mental workload was evaluated after each test with the Modified Cooper-Harter (MCH) scale. Following Wierwille and Casali's (1983) suggestions, subjects trained and practised on-the-job, and performed the ratings immediately after each test session.

Calls Handled: With the subjects' knowledge, their actual workload (calls/hr), average work time (AWT) and group work time (GWT) were recorded on-line.

Test Procedure

The independent variables evaluated in this study were time-of-day (n=2) (AM/PM; *morning* and *afternoon* of the same day) and work pace (n=2) (High/Low; *weekday mornings*, with a consistent, high workload pace and *weekend mornings*, with a variable, low workload pace).

The test duration was two hrs, the maximum period of continuous work allowed under the terms of the operators' collective agreement. All subjects were tested exclusively during day shifts on three occasions: Trial 1 began at the start of a weekday shift (AM-high), while trial 2 finished at the end of the same weekday shift (PM-high). Trial 3 began at the start of a weekend shift (AM-low). To control order effects in the work pace tests (high, low), the design was counterbalanced with respect to work pace (Wierwille and Casali, 1983). That is, 4 subjects were first tested on a weekday, and 5 on a weekend.

Based on the results of my reliability study (Chapter 3), subjects rated their PD at the 5, 65, and 115 minute marks. In order to evaluate seated movement trends that coincided with ratings of perceived discomfort, ICM was analyzed as the mean of three blocks at the *start* of the test (min 5-20), at the end of *hour 1* (min 50-65), and the end of *hour 2* (min 100-115). Subjects rated their mental workload at the 115 min mark of each test. The time periods (in min) of on-line work, ICM collection, ICM analysis and performance of subjective ratings (PD, MCH) are identical to those presented in Figure 3.1 (Chapter 3; Reliability).

Test Design

Of the four independent variables (AM/PM, High/Low pace), only three combinations were tested (as trials) in the present study. The effect of trials (AM-high, PM-high, AM-low) and time (start, hr 1, hr 2) on in-chair movement was measured with a Trial (3) x Time (3) repeated measures MANOVA. The main effects of trials and time (hr 1, hr 2) on perceived discomfort and calls/hr were evaluated with a Trials (3) x Time (2) repeated measures MANOVA.

Analysis of simple main effects (Nichols, 1993a), and nonorthogonal contrasts (Nichols, 1993b) were used to evaluate the levels of the two independent variables (Am/Pm, High/Low work pace) nested within the trials effect for ICM, PD and calls. Friedman two-way ANOVA with post-hoc tests was used to evaluate differences in mental workload (Modified Cooper Harter) with respect to the Am/Pm and High/Low workload conditions. All analyses were conducted at the $\alpha = .05$ level (SPSS Chicago, IL 60611).

RESULTS

Time, Time-of-Day Effects

In-Chair Movement: ICM increased over 2 hrs in all tests; however, the effect was only significant ($p < .01$) under high pace (weekday) conditions (AM-high, PM-high) (see Figure 4.1). Time-of-day tests showed that, regardless of the time (65, 115 min), afternoon increases in ICM were insignificant ($p = .18$).

Perceived Discomfort: Perceived discomfort at minute 5 was excluded from analysis due to the number of zero responses. The increase in PD from min 65 to min 115, shown in Figure 4.2, was significant ($p < .01$) in all three trials (AM-high, PM-high, AM-low). Nonorthogonal contrasts showed that, on weekdays, PD was greater ($p < .01$) in the afternoon (PM-high) for both test periods (65, 115 min).

Calls Handled: As seen in Figure 4.3, tests of simple main effects for weekday trials showed neither time, nor time-of-day effects. That is, the rate of handling calls did not change from hr one to hr two in the morning ($p = .14$) or in the afternoon ($p = .38$). Neither did the call rate change from morning to afternoon ($p = .54$).

Mental Workload: Friedman ANOVA showed no difference between AM and PM trials ($p=.32$) in the MCH ratings of perceived mental workload. Table 4.1 contains the means and standard errors of the MCH ratings for the three trials.

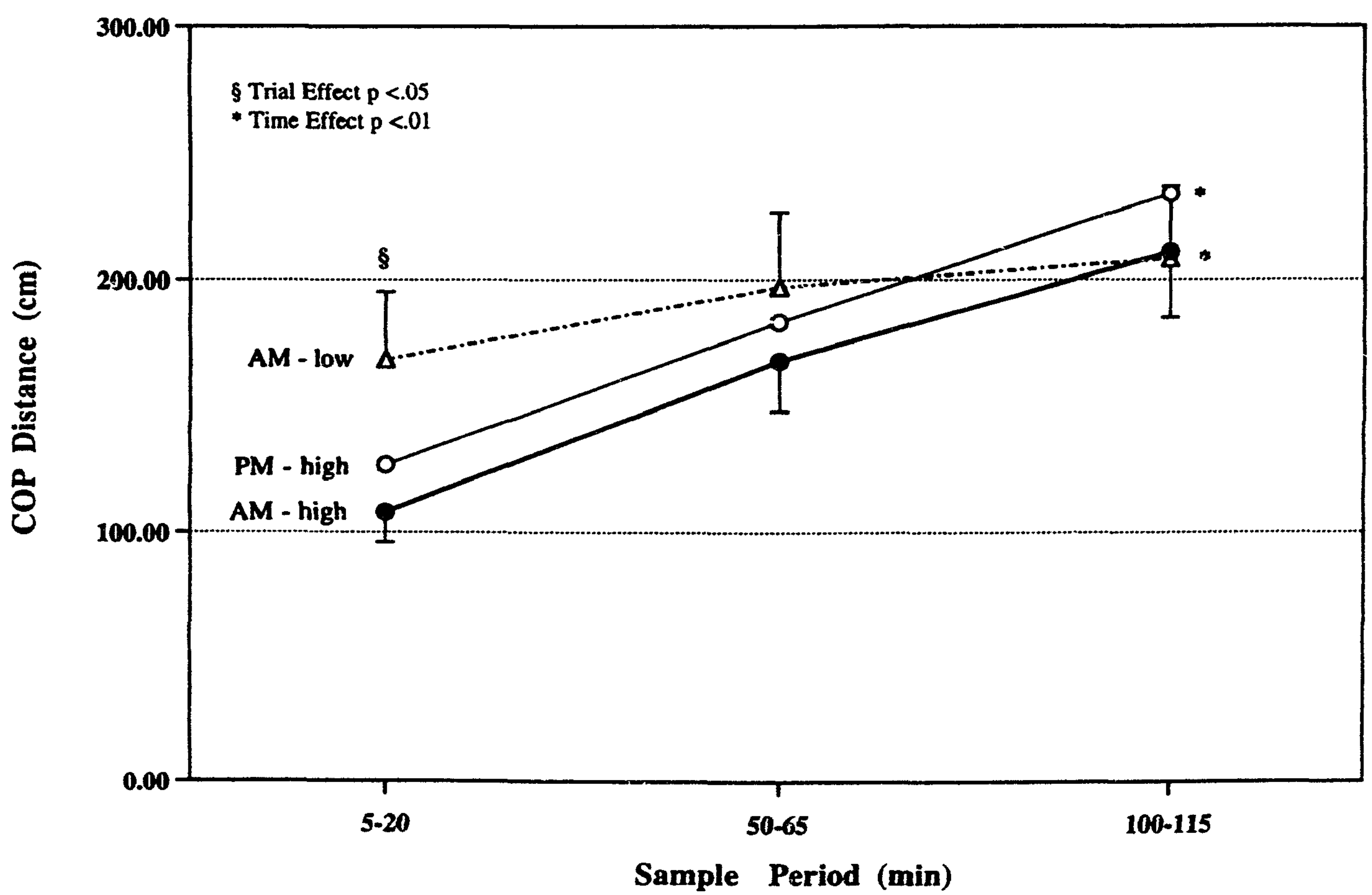


Figure 4.1 Day Study: In-chair movement versus time (Mean, SE) showing that under high pace conditions (weekdays), ICM increased over 2 hr tests, but not from morning (AM-high) to afternoon (PM-high). In comparing low pace (AM-low) to high pace (Am-high) conditions, ICM was greater from min 5-20, and did not increase over 2 hrs.

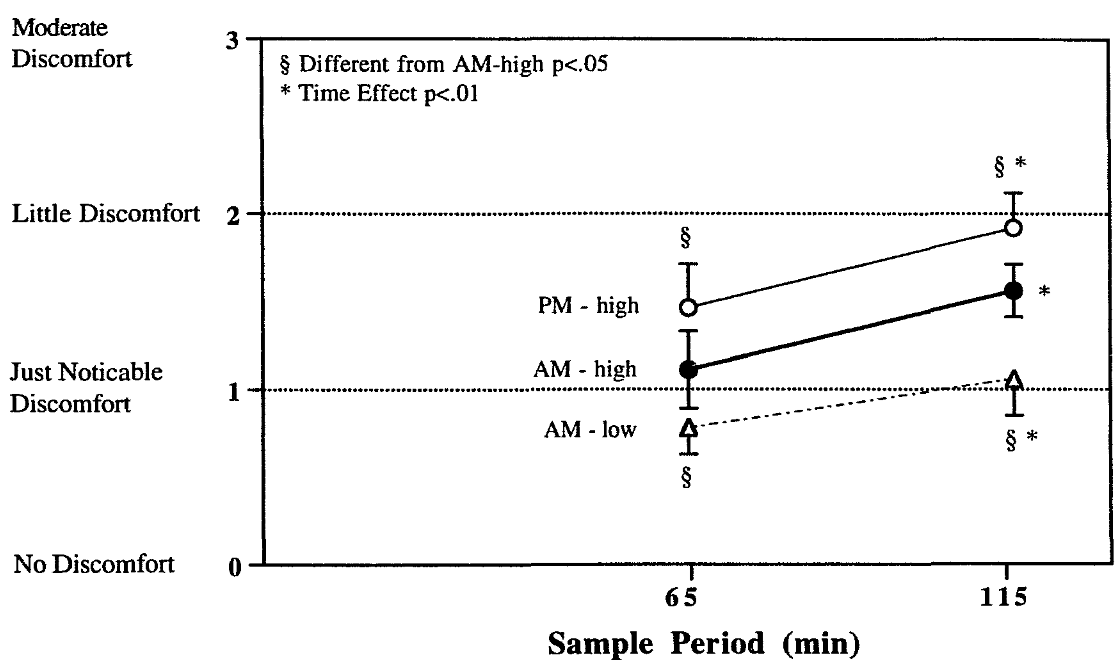


Figure 4.2 Day Study: Perceived Discomfort (PD) versus time (Mean, SE) showing that PD increased from min 65 to min 115 in all 3 trials. Compared to weekday mornings (AM-high), PD was greater in the afternoon (PM-high) and lower on weekend mornings (AM-low) at 65 and 115 mins.

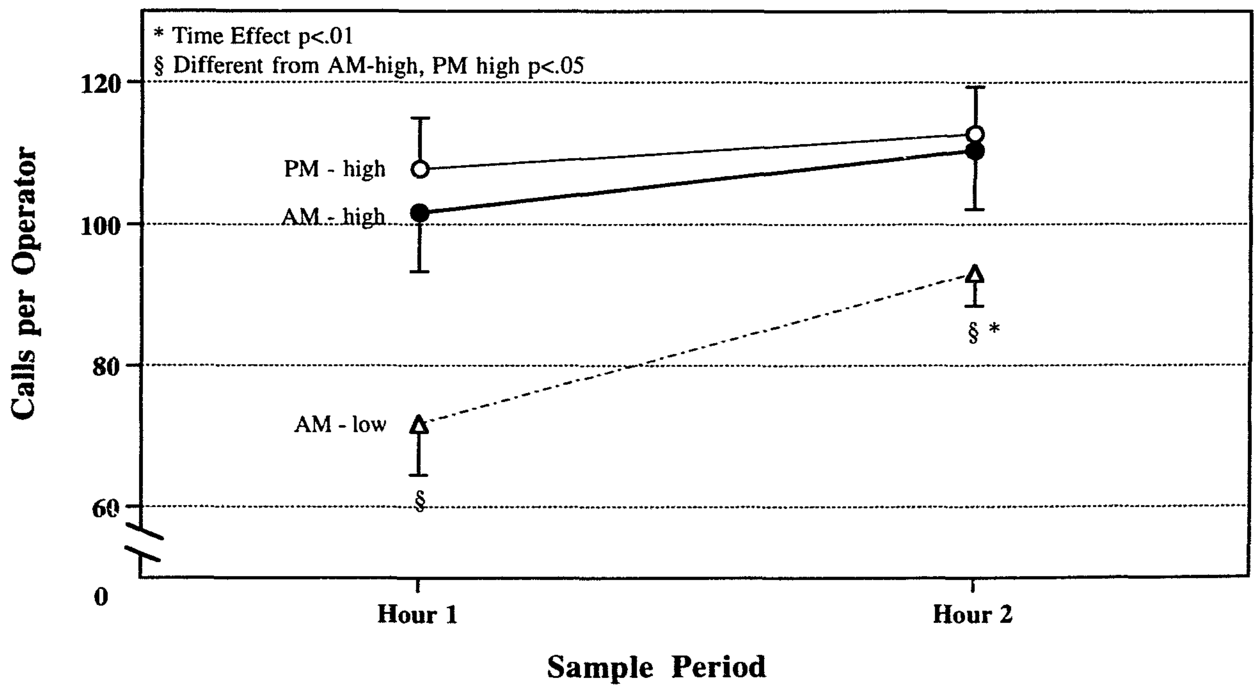


Figure 4.3 Calls per operator per hour (Mean, SE) showing consistent call rates on weekdays (AM-high, PM-high), lower call rates on weekends (AM-low), and a significant ($p<.01$) increase over the test period on weekends.

Table 4.1 Mental workload ratings (Mean, SE) at the 115 min mark using the Modified Cooper Harter scale, showing no significant difference between the three trials (AM-high, PM-high and AM-low) using the Friedman two-way ANOVA.

MCH Rating	AM-high	PM-high	AM-low
Mean (SE)	2.1 (.31)	2.4 (.28)	2.0 (.26)

Work Pace Effects

In-Chair Movement: Figure 4.1 shows that under low pace conditions (AM-low), ICM was significantly greater ($p=.03$) in the first time period (5-20 min), compared to high pace conditions (Am-high). By the end of hr 2, however, there was no difference ($p=.43$) in ICM between the high (AM-high) and low (AM-low) work pace conditions.

Perceived Discomfort: Figure 4.2 illustrates that, regardless of the test period, perceived discomfort was significantly lower ($p=.02$) on the weekends (AM-low) compared to weekday conditions (AM-high).

Calls Handled: Comparison of AM-high to AM-low workloads showed (Figure 4.3) that calls/operator/hr were lower on the weekends ($p<.05$). Unlike the weekday tests, the number of calls handled increased significantly ($p<.01$) from hr one to hr two.

Mental Workload: There were no differences (p=.74) in perceived mental workload between the weekday (high) and weekend (low) work pace conditions (see Table 4.1).

DISCUSSION

Time, Time-of-Day Effects

Perceived Discomfort: Perceived discomfort (PD) data support the alternate hypothesis that PD is greater in the afternoon than in the morning. The increases in PD shown here over an 8 hr shift, support similar findings in seated train occupants (Branton, 1966), easy chair occupants (Shackel et al, 1969), industrial workers (Corlett and Manenica, 1980), VDU data entry clerks (Schleifer and Amick, 1989) and secretaries (Bishu et al, 1991). Testing was restricted to day shifts (0700 to 1800) in these cited studies, as well as the present study. There is, therefore, no way to determine if the time-of-day effects in these studies related to the actual time-of-day (endogenous effects) or to the duration of the shift (fatigue effects). In the present study, the work pace (calls/operator/hr) did not change from morning to afternoon. Therefore, the afternoon increases in PD are likely due to fatigue from the cumulative workload (i.e. calls/shift), although that effect was not specifically tested.

In-Chair Movement: In-chair movement data support my primary hypothesis that ICM was similar from morning to afternoon. The present results appear to agree with Bendix et al (1985) who showed similar morning and afternoon discomfort patterns in a descriptive field study of 12 typists. At first glance, my results disagree with Grandjean et al's (1960) report of afternoon increases in PD. However, I tested raw data of ICM taken from Grandjean et al's (1960) study of subjects seated on 2 chairs (wood, easy) at two time periods (AM, PM) for time-of-day effects using a Time-of-Day (2) x Chair (2) repeated measures MANOVA. Results showed no significant time-of-day effects for the independent variables that corresponded to those tested in the present study (i.e. early AM, late PM).

Corlett and Manenica (1980) argued that PD is greater at the end of a shift because of failure to recover from fatigue effects. The absence of an afternoon increase in ICM might imply that, unlike perceived discomfort, in-chair movement is not affected by fatigue. Just as Zwahlen et al (1984) reduced the end-of-shift increases in PD by inserting hourly rest breaks for VDU operators, the physiological stimuli that affect ICM may recover during the Directory Assistance operators' scheduled breaks or during their spontaneous breaks (Grandjean, 1988) that occur when there are no calls waiting (CW). The stimuli behind the temporal increases in ICM are unknown and likely include a combination of physiological factors, such as muscle fatigue (Sjogaard et al, 1988), muscle pain (Edwards, 1988), decreased lower limb circulation (Winkel and Jorgensen, 1986), decreased synovial fluid movement in weight-bearing joints (Paul, 1974), low back discomfort (Magora, 1972), and distortion of buttock tissue (Bader, 1990), as well as psychological factors, such as anxiety (Jurgens, 1980) and the level of cortical stimulation (Marek and Noworol, 1986). Given the variety of physical stimuli that may have influenced ICM, and the narrow range of test periods evaluated, an unequivocal interpretation of the time-of-day effects is difficult in the present study.

While results of this study are far from conclusive, they suggest that endogenous factors do not play a major role in the promotion of ICM. The morning to afternoon similarity in ICM patterns may, however, be explained on the basis of the activity peaks (i.e. morning-to-evening activity continuum) noted by Jurgens (1980). It is possible that the paced nature of the DA operators workload may have masked the peaks. Alternatively, the activity peaks of the subjects may have been mixed between morning and afternoon, effectively cancelling each other out. A greater range of test periods throughout a 24 hr day is therefore required to better evaluate the effects of endogenous factors on ICM. While the work pace effects (high/low) were counterbalanced, order effects in my time-of-day tests were not because of the possibility of introducing changes related to individual (mood, sleep) and task (call rates) factors. Where possible, in any future studies of endogenous factors, these individual and task factors should be controlled and the test order counterbalanced (i.e. AM/PM, PM/AM).

Mental Workload: Given the weekday standardization in call rates found in this study, the inability to detect changes in mental workload from morning to afternoon is not surprising. These results support Hancock's (1988) findings, although he tested over a broader time range (0800 to 2000). A number of factors may be cited to explain the similarity of mental workload ratings from morning to afternoon in the present study. First, the AM/PM tests were separated by only 6 hrs and were exclusive to day shifts. Second, the task and physical workload of the DA operators (i.e. call rates) was unchanged from morning to afternoon. Since Smith (1992) has suggested that time-of-day effects interact with auditory vigilance, memory and perceptual motor skills performance, mental workload effects may have been masked by changes in any of these factors. Finally, the likelihood of finding differences may have decreased due to an inherent problem in repeated measures design, namely the carryover effect of learning between trials (Poulton, 1982).

Work Pace Effects

Perceived Discomfort: Perceived discomfort and the call pace were both significantly lower on the weekend test, and both increased over the test duration. In the literature, considerable emphasis has been placed on the influence of the *type* of workload on sitting comfort (Branton, 1966; Drury and Coury, 1982). The present study is unique in demonstrating that changes in the *pace* of a task has a significant effect on PD. Sauter et al (1992) showed retrospectively that psychosocial and physical workload factors were predictive of musculoskeletal strain. The relationship between the number of calls handled (work pace) and PD demonstrated in this prospective field study, corroborates Sauter et al's (1992) findings.

In-Chair Movement: During weekdays when the calls handled remained steady (AM-high, PM-high), ICM increased significantly over time. However, in the presence of a decreased workload on weekend mornings, temporal increases in ICM were no longer significant. In fact, as early as the first test period (min 5-20), the mean and the variance of the ICM data increased on the weekend when the operators could set the job pace. Since both the number of calls decreased (physical workload) and therefore the call pace (mental workload) dropped, it is not possible to ascribe the changes in ICM with certainty to either physical or mental factors related to the DA operators' tasks.

In a broad sense, these results parallel those of Cohen et al (1991), who used factor analysis to show that decreased mental stress was positively correlated with increased freedom to move on-the-job. The present results also are similar to Bendix et al's (1985) report that ICM was influenced by changing from typing to non-typing tasks. In contrast to the present findings, Jurgens (1989) found that seated movement was not influenced by the mental workload level in a paced boat piloting task, but only by the time spent in sitting.

Mental Workload: Perhaps the most unexpected finding in this study was that a drop in work pace (calls handled) did not result in decreased mental workload ratings. Given the wealth of literature linking external pacing to mental workload or stress

(Manenica and Golias, 1991; DiTecco et al, 1992; Sauter et al, 1992; Smith et al, 1992; Carayon, 1993), the results are perplexing. Several explanations are offered.

In answer to the final question on the Modified Cooper Harter Scale decision tree, "Is the mental workload acceptable?", the subject is directed either to a low (1 to 3) or moderate (4 to 6) mental workload rating. For the 9 subjects, only 2 of 27 total MCH ratings in these three trials were in the moderate range. Thus, the failure to find mental workload differences may be attributed to a similarity between weekday (high pace) and weekend (low pace) workload levels of the DA operators. While subjects were required to have worked for a minimum of 3 months, they in fact averaged approximately 5 years experience as DA operators. Therefore, just as Hancock (1988) attributed similar mental workload ratings to the repeated use of similar test workloads, the operators may have perceived that the weekday/weekend differences were not novel and rated their mental workload accordingly.

Design of this study called for an assumption that differences in work pace (high/low) would reflect a change in mental workload. Although relevant and topical, mental workload measurement is complex, relatively new, and rife with confounding influences. The lack of distinction between the high/low work pace conditions therefore may be explained by re-examining the mental workload model. In light of recent interpretations by Gaillard (1993), it appears that the Directory Assistance tasks may not require *mental effort*, since memory requirements are not high and operators neither perform multiple tasks nor priorize tasks. If Gaillard's (1993) theory is accepted, then DA operations would then be classified in *regular performance*, a situation in which mental workload is below individual capacity. In other words, the DA operators may be understimulated, a condition which is aggravated on weekend mornings (Braby et al, 1993).

Another possible explanation for the absence of a workload effect is the choice of mental workload scale. While the authors (Wierwille and Casali, 1983) report high sensitivity for the MCH scale, others (Hill et al, 1993) have questioned its ability to detect differences in tasks involving low mental workloads. The multidimensional *Subjective Workload Assessment Technique* (SWAT) (Reid and Nygren, 1988) or the *NASA Task Load Index* (TLX) (Hart and Staveland, 1988) scale therefore may have been more appropriate for this application, given the ability of these two tools to differentiate between workloads related to time, mental effort and stress (Hill et al, 1992). Neither was selected because the time required for completion of the TLX and SWAT (5-10 min) exceeded the available time in the present study.

Meshkati et al (1990) have identified the following three groups of factors that influence mental workload assessment: *long term memory* of similar tasks, *background factors* such as personality and aspirations, and *momentary conditions* such as fatigue, stress and motivation. Thus, although no mental workload differences were detected from high (AM-high) to low (AM-low) conditions, there are likely many influences on the mental workload of the Directory Assistance operators that simply were not measured. For example, according to DiTecco (1992) while DA operators were expected to complete calls as quickly as possible, they could increase their time on particular calls in order to satisfy their personal needs for job satisfaction. At some point, the same operators would have to speed up (i.e. increase their time stress) to keep their AWT (average work time) down. That potential conflict between the employer's expectation of quantity and the employees' need for quality, predicted by DiTecco (1992), was not detected in my study with the mental workload scale. Ergonomists recognize, however, that clear differentiation between mental workload related to task and that associated with time is not possible in the presence of time stress (Phillip et al, 1971). Measurement of mental workload may have been confounded by time stress in this study. Thus, specific measurement of stress, for example with the Occupational Stress Questionnaire (Elo et al, 1992) may have complimented the present study.

Final explanations for the similarity in mental workload between the high (weekday) and low (weekend) pace conditions involve subject selection. Operators with underlying musculoskeletal problems were not accepted into the study. Given the link between job stress and musculoskeletal disorders (Sauter et al, 1992; Smith et al, 1992), the operators experiencing the greatest stress may have been those excluded from the study. That hypothesis can be evaluated in another context. DiTecco (1992) hypothesized that since the GWT (Group Work Time) was the office average, at any given time half the operators would be above the GWT (and not under time stress), while the other half were below the GWT (and under stress to improve). In light of the mental workload results, random selections of each subject's AWT were compared to the corresponding GWT. Results showed that the AWT was consistently higher than the GWT (i.e. time stress) for 4 operators and consistently lower (i.e. decreased time stress) for 5 operators. If DiTecco's hypothesis is correct, the operators experiencing high/low time stresses are counterbalanced in this study. These results imply that the test group was representative of the group at large and that failure to find mental workload differences was not due to a biased sample of DA operators who did not experience time stress.

Generalizability

Numerous controls and selection standards preclude general application of these results to other test groups under different test conditions. For example, subjects in this study were screened on a host of factors, such as health, workstation fit, and eyewear. Furthermore, ICM results were dependent to a large extent on the task and environment controls in this study, since few movements were actually required of DA operators. Finally, broader application of these time-of-day results will require more in-depth testing of endogenous effects.

Conclusions

The main purposes of the present study were to test the effects of three independent variables: *time* (within a test period), *time-of-day* (AM/PM) and *work pace* level (high/low) on three dependent variables: *perceived discomfort* (PD), *in-chair movement* (ICM) and *perceived mental workload*. Results for the psychophysical (i.e. perceived) factors were divergent: PD was influenced by the time-of-day and the level of work pace, while mental workload was insensitive to both. ICM, the physiological measure, was affected by work pace, but was relatively constant across a weekday shift. During the 2 hr tests, temporal increases in ICM that were seen during high pace tests (weekdays), disappeared in the low work pace conditions (weekend mornings). In closing, in-chair movement (or fidgets) has been traditionally linked to perceived discomfort. Results of this study suggest that future studies of in-chair movement should take into account cognitive (e.g. work pace) and endogenous (time-of-day) factors.

CHAPTER FIVE

Effect of Workstation Exercises on In-chair Movement, Perceived Musculoskeletal Discomfort and Perceived Exertion in Telephone Operators

Extended work with video display units (VDU) is associated with two factors predictive of musculoskeletal problems: fixed (i.e. immobile) postures (Hettinger, 1985) and sitting discomfort (Sauter, 1984). Several workstation exercise programs have been introduced to VDU operators to reduce muscle tension and musculoskeletal discomfort. Tests of the effectiveness of these exercise programs in reducing discomfort are rare in field studies (Thompson, 1990; Henning et al, 1993) and non-existent under paced workload conditions. The seemingly obvious claim that workstation exercises promote in-chair movement also has not been substantiated. Neither has the effect of workstation exercises on perceived exertion at VDU task been measured. All three issues are addressed in the present field study, the purpose of which was to determine the effect of workstation exercises on in-chair movement, musculoskeletal discomfort, and perceived exertion in Directory Assistance (DA) operators working at a paced VDU task. I begin with a review of the rationale for the use of workstation exercises, followed by a review of workstation exercises and intervention studies, plus an introduction to the Borg (1982) scale of perceived exertion.

RATIONALE FOR THE USE OF WORKSTATION EXERCISES

The following is a three part rationale for the use of workstation exercises:

Part 1. Continued Sitting Discomfort Following Ergonomic Interventions.

In the last decade, efforts to decrease musculoskeletal discomfort in seated VDU operators centered upon improving ergonomic design and the worker-workstation fit (Winkel, 1987). In two laboratory experiments, Dainoff (1990) demonstrated that subjects ($n=13, 14$) reported less neck, shoulder and back discomfort ($p<.01$) working under optimum workstation settings, compared to sub-optimal conditions (fixed furniture, screen glare, etc.). Ong (1984, 1990) reported similar decreases in discomfort after furniture and lighting interventions in two field studies of VDU data entry clerks. Yet, in each of these cited interventions, discomfort was not eliminated.

Indirect evidence of the persistence of musculoskeletal discomfort in the face of ergonomic improvements comes from the North American telecommunications industry. The Occupational Safety and Health Department of the American and Canadian Communications Workers of America (CWA) conducted musculoskeletal surveys in 1989 and 1992 with approximately 8,000 members per survey (LeGrande, 1993). The first CWA survey (1989) showed that two-thirds of Directory Assistance (DA) operators had an upper limb complaint, while 84% reported neck and back pain. As a result, most employers instituted ergonomic improvements in furniture and the office environment. The 1992 follow-up survey revealed that musculoskeletal discomfort rates had, somewhat paradoxically, increased slightly (LeGrande, 1993). LeGrande (1993) concluded that "in and of itself, improved physical ergonomics does not significantly reduce....health symptoms and disorders." LeGrande's (1993) large scale field evidence confirms Dainoff's (1990) and Ong's (1984, 1990) controlled results; postural discomfort occurs even when ergonomic furniture and environment guidelines are followed for VDU offices.

Continued musculoskeletal discomfort following furniture interventions is due, in part, to the fact that discomfort increases over the workday, regardless of task (Corlett and Manenica, 1980; Schleifer and Amick, 1989). An alternative explanation is based on the fact that seated postural stress is equivalent to the product of the musculoskeletal load times the duration of the posture (Winkel, 1987). Any advantage gained by improved ergonomic *design* (i.e. decreased musculoskeletal load) might therefore be offset by an increase in *duration*, since comfortable subjects move less often (Grandjean et al, 1960; Branton, 1966; Bendix, 1991). Strong support for the *design-duration* hypothesis comes from Cantoni et al (1984) who showed that replacing traditional telephone operators' equipment with VDUs resulted in a theoretical 35% decrease in the L_3 intervertebral disc load (kg/hr), accompanied by a significant decrease in operator movement ($p<.01$). Consequently, Winkel and Oxenburgh (1990) recommend that "physical stress be optimized rather than minimized" in sedentary office work. One means to achieve that end has been to introduce exercises to reduce postural fixity and thereby reduce musculoskeletal discomfort.

Part 2. Physiological Benefits of Workstation Exercises:

Exercise as a component of health promotion is a widely accepted idea that has moved into the workplace (Ivancevich et al, 1990). On-site exercise programmes are commonly aerobic and anaerobic group exercises aimed at effecting improvements in general (Haskell, 1991) and psychological (Long and Flood, 1993) health. Individual, rather than group exercise programs have been introduced in the past decade to reduce musculoskeletal discomfort in computer operators. Since muscle stretching is a principal component of most computer workstation exercise programs, stretching benefits are now reviewed to evaluate claims that workstation exercises increase flexibility (Gore and Tasker, 1986), improve musculoskeletal comfort (Joyce and Peterson, 1985a) and decrease both fatigue (Pearce, 1984) and muscle tension (Austin, 1984).

The specific effects of stretching exercises have commonly been evaluated for rehabilitation (Zachazewski, 1989) or athletic (Stanish and Curwin, 1989) applications, and only rarely in ergonomic studies (Hansford et al, 1987). Most research centers on determining the relative effectiveness of the following three types of stretching exercises: *static* stretches, in which muscles are stretched to a point of comfortable muscle tension and held (Zachazewski, 1989), *ballistic* stretches with quick, bobbing motions (Stanish and Curwin, 1989) and *proprioceptive neuromuscular facilitation (PNF)* techniques in which a muscle is contracted isometrically prior to being stretched (McLure, 1993). Stretching programs in humans have been evaluated using one or more of four outcome measures: improved joint flexibility, decreased muscle tension, increased peripheral circulation, and decreased muscle pain. Stretching effects also have been measured using animal models.

Increased flexibility: According to some authors (Stanish and Kozey-Hubley, 1989; Taylor et al, 1990), the primary objective of stretching programs is to increase the length of the musculo-tendinous unit. Consequently, a common index of stretching effectiveness is to measure muscle length indirectly by determining the range of motion (ROM) at the joint over which the muscle passes. In healthy college students, deVries (1962) showed that trunk and shoulder ROM improved over a five week period ($p < .01$), whether subjects used ballistic or static stretching exercises. Tanigawa (1972) showed, however, that after four weeks of either PNF or static stretching techniques, subjects showed steady, but insignificant ($p < .10$), increases in hip flexion ROM.

Decreased muscle tension: A second means of evaluating stretching effectiveness is to measure electromyography (EMG) signals, on the assumption that stretching decreases muscle tension (Condon and Hutton, 1987). By integrating the EMG signal (IEMG), Prentice (1982) showed that PNF and static stretches were equally effective in decreasing the IEMG of hamstring muscles in healthy subjects who had exercise-induced muscle soreness. Moore and Hutton (1980) used surface recordings of integrated EMG activity in the hamstring muscles, as well as ROM measures, to compare the effectiveness of PNF versus static stretching techniques in producing muscle relaxation. Results from 23 female gymnasts were somewhat paradoxical; PNF techniques resulted in maximum hip ROM combined with maximum, not minimum, EMG activity (Moore and Hutton, 1980). Similar conflicting ROM and EMG results were reported by Condon and Hutton (1987) in a comparison of ankle joint ROM versus soleus muscle IEMG activity. The findings of Moore and Hutton (1980) and Condon and Hutton (1987) were later questioned by Ethnyre and Abraham (1988), who found that maximum ROM did coincide with reduced EMG (maximum relaxation) when EMG was recorded with intra-muscular electrodes.

Increased circulation: Hansford et al (1987) compared the effectiveness of a 5 min rest break versus simple wrist stretching exercises in restoring radial and ulnar artery blood flow in 16 female production line workers after 1.5 hrs of repetitive work. Results showed that blood flow in both arteries, as measured by Doppler shift signals, was significantly reduced after production line work ($p < .01$), and that exercises were more effective than rest ($p < .01$) in re-establishing circulation.

Decreased muscle pain: A trigger point is a focus of irritability in muscle, hypothesised to be due to vasoconstriction (Travel and Simons, 1983). Considering the above documented improvements in muscle-tendon length (ROM outcomes), muscle relaxation (EMG measures) and circulation, it is not surprising that stretching has been commonly prescribed to relieve trigger point tenderness and muscle pain (Simons, 1976). Mechanical stress at work due to prolonged immobility, poor posture and misfitting furniture have been cited as perpetuating factors in trigger point production and subsequent muscle pain (Travel, 1968). Yet, the effectiveness of stretching in reducing muscle discomfort is centered on evidence from patient populations (Travel and Simons, 1983). In spite of the high frequency of musculoskeletal complaints in VDU workers (Evans, 1987; LeGrande, 1993), in ergonomic field studies there has been no confirmatory evidence of pain reduction through muscle stretching. As a final point, stretching and range of motion exercises may reduce musculoskeletal discomfort for reasons other than reducing trigger point irritability. Wyke (1981) has theorized that joint movement, such as gentle oscillations, reduces pain by stimulating joint mechanoreceptors.

Comparative studies of stretching effectiveness: Direct effects of stretching exercises have been evaluated using animal models. For most of this research, muscles were subjected to prolonged immobilization (Hnik et al, 1985; Williams, 1988). Taylor et al (1990) evaluated stretching protocols that more closely resemble those prescribed to improve flexibility in healthy humans. In two separate experiments, extensor digitorum longus muscle tendon units from New Zealand white rabbits were excised and stretched 10 times at a constant rate in a materials testing apparatus. Muscles (n=8) repeatedly stretched to a set *length* showed a progressive, significant decrease in muscle tension ($p < .05$) which peaked after four repetitions. When muscles (n=12) were repeatedly stretched to a set *tension* and held for 30 sec, tension versus time curves showed that relaxation increased significantly in the first three repetitions and then plateaued ($p < .05$). The techniques used by Taylor et al (1990) eliminated the protective influence of stretch reflexes, thereby limiting clinical inferences. Nonetheless, these animal results suggest that stretching increases length and decreases tension in whole striated muscles. Also clinically relevant is the fact that the length and tension changes reached their peak after only three or four repetitions.

Standardization of stretching protocols: The greatest difficulty in comparing outcomes (e.g. ROM, EMG) of these stretching studies is the absence of standardization in three components of the stretching protocols: program duration, the number of stretches per session and the duration of each stretch. Based on this review, there are no clear guidelines in determining program duration or the lower limit of required repetitions for maximum benefit, although as just noted, Taylor et al's (1990) animal model provides a minimum guideline of 3 or 4 repetitions.

A component of stretch protocols that has been evaluated is the stretch duration required to increase muscle flexibility. To increase hip ROM, Madding et al (1987) have shown that one passive hip abduction stretch held for 15 secs was as effective as a stretch held for 45 or 120 secs. More recent evidence from a 6 week stretching program (Brandy and Irion, 1994) has shown that maximum hamstring flexibility may require 30, not 15 seconds per stretch as suggested by Madding et al (1987).

There is, however, a notable gap in the literature, namely that the stretch duration required to decrease muscle tension has not been determined. Unlike stretching protocols in rehabilitation or athletic settings, stretching exercises in the workplace have time constraints, particularly for paced workers. The total *effect* of each set of stretching exercises is a product of the number of *repetitions* times the *duration*. The ideal in ergonomics would be to get maximum effect with minimum loss of work time by optimizing the *repetition* times *duration* formula. At present there is insufficient evidence to develop such a formula.

Summary of stretching effectiveness: Generally, results show that compared to control groups, subjects benefit from performing any of the three types of stretches. However, not all types of stretching exercises are suited to the workplace, and not all are safe. For example, *PNF* techniques, though shown to be an effective means to increase flexibility (Moore and Hutton, 1980), require a partner and are not suited to individual use at VDT workstations. *Ballistic* stretches can be more effective than static stretches (deVries, 1962), but carry the risk of exceeding the limit of muscle extensibility (Schultz, 1979). Not surprisingly, static stretches are the common type of workplace stretching exercises.

Based on this review, there is support for the claims that workstation exercises can improve muscle flexibility and can decrease muscle discomfort and tension. At present, there is no evidence that workstation stretching exercises decrease fatigue. However, post-stretch EMG has not been measured on the job, nor have EMG fatigue parameters been sampled over an entire workday in workers performing workstation exercises.

Part 3. Workplace Postures: Their Physiological Implications and Susceptibility to Change with Workstation Exercises.

Previous results have shown that DA operators most often reported musculoskeletal discomfort in the upper neck, lower back and buttock regions (Reliability, Day Studies). Based on those studies and results from an ergonomic survey in the DA office (Appendix 3.3), three workplace factors that could contribute to those specific complaints were identified. Analysis of the first factor, work organization, showed that DA operators sat for prolonged periods (up to 2 hrs) in relatively fixed postures. Examination of the second factor, work postures, showed that the two most common postures were *upright* with a forward head posture and *slouched* with the hips forward. In terms of factor three, furniture, all DA office chairs were standardized and had a non-adjustable lumbar support that precluded changes in lumbosacral posture, except by slouching. In the following sections, the implications of those three workplace factors on the production of neck, back and buttock discomfort are discussed in detail, as are the potential of workstation exercises to alter these physical factors.

Physiological implications of forward head posture on neck pain: The normal, or "orthostatic" resting position of the head on the neck is clinically evaluated as the horizontal distance from the mid-cervical spine to a plumb line that runs tangentially through the apex of the thoracic spine (Rocabato, 1983). Subjects with horizontal distances greater than 6 cm are considered to be in a *forward head posture*, although there is considerable debate on that figure (Rocabato, 1983; Hanten et al, 1991). Sixty-two % of surveyed physical therapists stated that forward head postures were associated with neck pain (Enwemeka et al, 1986a), but clinical results have failed to find any significant correlation between the two factors (Caneta and Brown, 1988). While the clinical implications of forward head postures are largely unproven, there is evidence that an anterior head position increases the EMG activity in the trapezius muscle in sitting and standing (Enwemeka et al, 1986b). In fact, movement of the head from neutral to a forward position was shown by Harms-Ringdahl et al (1986) to increase the trapezius and erector spinae load up to 6% of the muscles' *maximum voluntary capacity* (MVC). In prolonged work, the forward head position therefore poses a problem, since the recommended upper limit for static muscle activity over an 8 hr day is 3.6% of the MVC (Sjogaard, 1986). While there is no evidence that forward head postures cause neck pain, reduction of those postures was shown to decrease neck pain. An exercise program that emphasized a McKenzie (1983) *head-*

retraction-in-sitting exercise was successful in reducing neck and arm pain in one third of office workers presenting with neck and shoulder pain that was accompanied by mild neurological signs (Patkin, 1990).

Physiological implications of prolonged seated postures on low back pain: The problems with prolonged sitting go beyond the fact that any seated posture increases the intervertebral disc pressure compared to standing (Andersson and Ortengren, 1974; Andersson et al, 1975). Prolonged sitting in fixed (i.e. immobile) postures poses the additional risk of compromising disc nutrition since nutrition via fluid flow (Bogduk and Twomey, 1987), and diffusion (Adams and Hutton, 1983), rely on posture changes. By contrast, movement has been demonstrated to improve intervertebral disc nutrition (Krämer, 1977; Krämer et al 1985; Holm and Nachemson, 1983). While the contribution of decreased disc nutrition to the pathogenesis of spinal pain is conjectural, reduction of low back pain with spinal movement has been shown in physiotherapy patients (Martin et al, 1986).

In spite of the efforts of chair designers, individuals generally adopt a flexed to slightly lordotic posture of the lumbar spine in sitting (Bridger et al, 1989). Shah (1978) showed that lumbar flexion compresses the anterior disc wall causing the nucleus pulposus to migrate posteriorly, thereby increasing the strain on the posterior annulus. In addition, the posterior spinal ligaments and the capsular ligaments of the facet joints are under tension in flexed seated postures (Bogduk and Twomey, 1987).

Accordingly, for people who sit for prolonged periods, McKenzie (1981, 1985) advocates regular reversal of lumbar flexion with spinal extension exercises to alleviate strain on the posterior spinal elements and to encourage anterior migration of the nucleus pulposus. McKenzie extension exercises are commonly performed either as *extension-in-standing* or as a *prone push-up* (upper trunk only) exercise. Both these exercises are presumed to be passive (i.e. require no erector spine activity), although that hypothesis has recently been disputed (Fiebart and Keller, 1994).

Support for the McKenzie protocol comes from the rehabilitation literature. A four week McKenzie extension stretching program in healthy college students (18M,18F) was shown to increase spinal extension in males ($p<.05$), but not in females (Smith and Mell, 1987). During the study, the control group lost range of motion (ROM), leading Smith and Mell (1987) to conclude that the extension exercises at the very least, prevented loss of extension ROM in these students who sat for several hours per day. The McKenzie protocol also has been shown to significantly increase spinal ROM in extension, decrease low back pain and increase sitting tolerance (i.e. time) in patients reporting mild, short duration low back pain ($p<.001$) (Ponte et al, 1984). The effectiveness of McKenzie (1981, 1985) extension exercises in reducing discomfort in seated postures requires further evaluation.

Physiological implications of prolonged sitting on pelvis and buttock pain: In seated postures, the gluteus maximus muscle slides superolaterally off the ischial tuberosity, leaving only skin and subcutaneous fat to bear the body weight transmitted through the ischial tuberosities (Daniel and Faibisoff, 1982). These protective tissues are compressed in sitting and localized peaks of pressure can occur near the ischial tuberosities for a variety of reasons, such as inadequate chair seat padding (Hertzberg, 1972), using a backrest without a lumbar support (Diebschlag and Muller-Limmroth, 1980), sitting for long periods with no pressure relief (Bader, 1990) or sitting in a slouched posture (Babbs, 1979). Regardless of their etiology, pressure peaks contribute to sitting discomfort (Zacharkow, 1988; Yun et al, 1992). In-chair posture changes are unlikely to alleviate discomfort since, as shown by my earlier center of pressure results (Reliability Study), movement only increases pressure elsewhere in the buttocks. Prolonged sitting also reduces the synovial fluid film between the weight bearing surfaces of joints, such as the hip (Mow et al, 1989). Standing is an ideal means to alleviate the high tissue pressures, localized discomfort and reduced synovial fluid film that occur in prolonged sitting (Zacharkow, 1988; Mow et al, 1989).

Workstation Exercises: Programs and Intervention Studies

Exercise programs, specifically for VDU operators, were initially introduced to compliment ergonomic furniture interventions. These programs reportedly reduced muscle tension (Austin, 1984) and fatigue (Pearce, 1984), principally in the eye, wrist, shoulder, and neck regions. More extensive exercise programs have since been developed. Joyce and Peterson (1985a, 1985b) introduced Dataspan® as a comprehensive program to improve "the comfort, health and effectiveness' of VDU operators. The Dataspan® program has three components: workstation consultation (e.g. furniture adjustments), job task skills (memory, audio skills), and exercises that include relaxation and stretching for the shoulder, neck and wrist regions.

A competitor to Dataspan® is the Pause Gymnastics™ program (Gore and Tasker, 1986), which, unlike Dataspan®, is exclusively exercises and contains strengthening, as well as stretching components for sedentary workers. Besides having a greater variety of exercises (46 compared to 15), the Pause Gymnastics™ program differs from the Dataspan® in a philosophical sense. The onus for performing Dataspan® exercises is on the individual (Joyce and Peterson, 1985a; 1985b), whereas the Pause Gymnastics™ program is designed to be an "office" break for group-style exercises.

Subjective Evaluation of Workstation Exercises

Many of the workstation exercises from the multitude of available programs have been subjectively evaluated with respect to usability (specificity, workplace suitability, conspicuousness, and ease of performance) and therapeutic suitability (exacerbation of pre-existing conditions, replication of task demands, and safety) (Lee et al, 1992; Lee and Waikar, 1991). Of the 127 exercises evaluated, the authors concluded that most met their criteria, but one third were conspicuous (and likely to cause embarrassment in the office), one half were disruptive, and a number of exercises either loaded joints or imitated stressful work postures (Lee et al, 1992; Lee and Waikar, 1991). Lee's reviews (Lee et al, 1992; Lee and Waikar, 1991) are unique and contain comprehensive details such as the original instructions for each exercise. Neither Lee et al's reviews nor the original programs, however, addressed the central issue of whether the VDU workstation exercises were effective in reducing musculoskeletal discomfort.

Workstation Exercise Interventions

Three studies have addressed the preceding issue. In order to "reduce musculoskeletal strain," Thompson (1990) had 85 data entry operators at a utility company perform stretching exercises for 5 min, twice per day or as discomfort arose. After one-year, Thompson (1990) reported that comfort improved and that productivity increased by 25%. Swanson and Sauter (1993b) tested 37 female data entry clerks over the course of a 445 min workday in a National Institute of Occupational Safety and Health (NIOSH) laboratory study. In addition to their 45 min lunch break, all subjects in this NIOSH study took 6, three min breaks; 2, ten min breaks; and approximately 32, thirty second breaks. Under the experimental design, half the operators in the NIOSH study simply rested during the breaks, while the other half performed stretching exercises. Discomfort ratings, which were performed 8 times per day, showed there was no difference in discomfort between the two conditions (exercise breaks versus and breaks-only) and that discomfort increased with time, regardless of condition (Swanson and Sauter, 1993b).

Henning et al (1993) field tested the same NIOSH break versus exercise protocol (Swanson and Sauter, 1993b) on 20 VDT insurance claim clerks with the following 9 week test schedule: 3 weeks of baseline (two, 10 min breaks/day and no exercises), 3 weeks of NIOSH breaks (6 x 3 min, 2 x 10 min and 32 x .5 min) and no exercises, and 3 weeks of NIOSH breaks plus exercises. Using a repeated measures MANOVA, analysis of discomfort ratings (early morning, pre-lunch, late afternoon) showed that the only improvement in comfort occurred in the leg region during the three week exercise component, but the increase was insignificant (Henning et al, 1993).

Critique of Exercise Intervention Studies

Based on my review of exercise intervention studies (Thompson, 1990; Swanson and Sauter, 1993b; Henning et al, 1993), workstation exercises appear to be ineffective in reducing musculoskeletal discomfort, but each of these three studies has limitations. A thorough evaluation of any intervention intended to reduce musculoskeletal discomfort should include two elements of design. First, the comfort levels between intervention and no intervention conditions should be compared. Second, considering that discomfort increases over time (Corlett and Manenica, 1980;

Schleifer and Amick, 1989) the effect of the intervention on the temporal growth of discomfort should be measured.

None of the three exercise intervention studies evaluated both design elements. Swanson and Sauter (1993b) performed a baseline test on all subjects, but did not compare baseline results to either the *exercise* or *breaks only* conditions. Henning et al (1993) measured discomfort across the day, but did not report if exercises affected temporal patterns of discomfort. Finally, subjects in Thompson's (1990) study did not, in fact, rate their discomfort at any time. Reports of decreased discomfort were based on informal interviews with the VDT operators, conducted at an unspecified time after the exercises were introduced (Thompson, 1990).

Additional considerations limit the generalizability of the three exercise intervention studies. In each of the three studies, exercise programs were developed by exercise specialists. The exercise programs, however, may have failed to reduce discomfort because they were based on the specialists' perceived demands of the operators' tasks, rather than on specific problems identified from subjective discomfort ratings by the VDT operators. Still, the lack of significant results is surprising, especially in the Henning et al (1993) and Swanson and Sauter (1993b) studies, since the work/rest schedule, which provided 22% of the workday for breaks, is considered generous by traditional (10-15%) standards (Grandjean, 1988).

Not all exercise (or rest) breaks, however, may have been taken, implying that compliance may have affected the outcomes of these intervention studies. In support of that hypothesis, the many correlates of exercise compliance are not well understood, even in seemingly well motivated physical therapy patients under regular follow-up schedules (Sluijs et al, 1993). While Swanson and Sauter (1993b) had ready access to their subjects, no mention of monitoring and compliance was made by Thompson (1990) or Henning et al (1993). A final point regarding these studies is that compliance and specificity aside, the exercise programs themselves may have been inadequate in terms of stretch duration, repetition frequency, comprehensiveness, etc.

Additional Considerations in Evaluating Workstation Exercises

This review identifies other gaps in the literature. Silverstein (1988) has pointed out that, for paced workers, gains from an exercise program may be "overshadowed by increasing productivity demands...in the remaining work time." Paced worker's face conflicting demands: the desire to perform exercises, versus the need to maintain productivity. Since none of the subjects in the reviewed studies were paced, the effectiveness of workstation exercises under paced conditions requires measurement. Finally, while the extent of postural fixity imposed by VDU operators has been acknowledged (Grieco, 1986; Winkel, 1987), the effect of workstation exercises in decreasing postural fixity (by increasing seated movement), has yet to be measured. So while workstation exercises appear to have little benefit, their effects in reducing musculoskeletal discomfort and postural fixity have not been thoroughly explored.

PERCEIVED EXERTION

By tradition, rated exertion during work (or exercise) symbolizes a subject's perceived integration of local (exercising muscles and joints) and general (cardiopulmonary system) physiological sensations (Ekblom and Goldbarg, 1971). More recent models now include the contribution of psychological factors in rated perceived exertion (RPE). While Morgan (1973) has suggested that psychological and social factors account for a least one-third of the unexplained variance in RPE, others (Pandolf, 1983; Watt and Grove, 1993) suggest the actual contribution is much higher, especially in field studies. Consequently, according to Pandolf (1983), what matters most in RPE may not be what workload a subject is doing, but rather "what the individual *thinks* he/she is doing".

Borg CR-10 Scale of Rated Perceived Exertion

The most frequently used perceived exertion scale is the Borg (1970) 15 point RPE scale which related workload (on a cycling ergometer) with subjective ratings of exertion. Borg (1982) later produced the CR-10, a 10 point scale which ran from 0 (no exertion at all) to 10 (maximal exertion) (Appendix 5.1 RPE Scale). The CR-10 was introduced as a category scale with ratio properties that allowed inter-individual comparisons of factors other than perceived exertion, such as pain (Borg, 1982). The original Borg (1970) scale also has been validated to rate subjective *difficulty* in cognitive tasks such as visual tracking tests and standardized Swedish intelligence tests (Borg et al, 1971). Consequently, I consider the Borg CR-10 RPE scale appropriate for use in VDU tasks where the principal component is cognitive, rather than physical.

Perceived Exertion in Ergonomics

Interest in perceived exertion is high in ergonomics, particularly in the area of safe lifting limits. In the 1981 NIOSH guide for manual lifting, the principal considerations were physical factors, such as the vertical load heights. However, research also has shown that the risk of back injuries in lifting tasks increases as the *perceived* load increases (Snook et al, 1978). Herrin et al (1986) later showed that the perception of exertion in lifting can be used to predict the incidence and severity of musculoskeletal injuries. Thus the relationship between reality (actual workload) and perception (subjective load: RPE) is a determining factor in the risk of musculoskeletal problems in a variety of tasks, possibly including seated VDU work.

In a pilot test, results showed that when the DA operators' actual workload (i.e. rate of taking calls) was constant, RPE was unchanged over a 2 hr work session (Fenety, unpublished). Kuorinka (1983) has suggested that subjects rating exertion may actually be rating discomfort. That suggestion conflicts with the pilot study results which showed that, although RPE was constant, discomfort increased over time. While the application of perceived exertion is growing rapidly in ergonomics, the effect of workstation exercises on RPE to date is untested in normally sedentary VDU workers (Winkel, 1987).

Study Hypotheses:

Based on my review of the literature, the primary null hypothesis tested in this study was that there was no difference in perceived discomfort, in-chair movement, and perceived exertion between *exercise* and *no exercise* conditions. A second null hypothesis also was tested; that there is no correlation between ratings of exertion (RPE) and whole body perceived discomfort (PD) under *exercise* or *no exercise* conditions.

The following alternate hypotheses were tested: Compared to no exercise conditions, electronically paced Directory Assistance (DA) operators performing regular workstation exercises: (i) would decrease their postural fixity by increasing their in-chair movement, (ii) would not experience temporal increases in musculoskeletal discomfort over the 2 hr test period, (iii) would have decreased musculoskeletal discomfort in the whole body, and more specifically, in the back/neck and pelvis/buttocks regions. Directory Assistance (DA) operators performing regular workstation exercises: (iv) would experience insignificant increases in RPE from hr 1 to hr 2 under *exercise* and *no exercise* conditions, and (v) would, compared to the *no* *exercise* condition, report increased perceived exertion when tested with *exercises*. The final alternate hypothesis was (vi) that the correlation between ratings of exertion (RPE) and whole body perceived discomfort (PD) under *exercise* or *no exercise* conditions would be significant and positive.

METHODS

Subjects

Eleven subjects (3M, 8F), who had been employed as Directory Assistance operators for an average of 78 (SE 18.6) months participated on a volunteer basis. The subjects ranged in age from 22 to 41 yrs (Mean 29.5, SE 1.9) and had a mean height and weight of 172.9 (SE 2.1) cm and 69.6 (SE 3.9) kg, respectively. Subjects, all in good health, were screened on multiple health and anthropometric factors (details covered in Reliability Study). Each gave their signed, informed consent. The research was approved by the Human Ethics Review Committee of the University's Faculty of Graduate Studies.

Task Description

The VDU-based Directory Assistance task was selected because the workload and environment (including furniture) were standardized. Details of the environmental controls and screening based on workstation fit are contained elsewhere (Reliability study). The operators in this study dealt primarily with requests for directory assistance, and to a lesser extent, handled intercepts on disconnected or out-of-service numbers. Performance of the DA task required keyboard entry, screen viewing and voice communication with customers.

Equipment

Perceived Discomfort: Perceived Discomfort (PD) was rated using the BPD (Corlett, 1990) 5 point scale (0 = no discomfort, to 5 = intolerable discomfort) and localized with the LMD body map (van der Grinten, 1991). For each rating period, the PD data were analyzed for two body regions (pelvis/buttock and back/neck) and for whole body scores (i.e. the sum of the pelvis/buttock, back/neck, and shoulder/arm scores averaged over the number of uncomfortable parts). Shoulder/arm scores were not analyzed separately because previous results (Reliability study) showed that the region had a low musculoskeletal load (i.e. high rate of zero discomfort scores) regardless of time (start, end hr 1, end hr 2).

In-chair movement: ICM was measured by tracking center of pressure (COP) changes at the buttock chair interface as subjects sat on a VERG (Vision Engineering Research Group) pressure sensing mat. On-line data were collected continuously and stored as 24, five min blocks. Post collection software calculated the total COP distance travelled in each block. Based on results of my reliability study (reference: reliability study), ICM data were analyzed as three block means, defined as the average of three consecutive 5 min blocks of COP distance. Subjects were shown how the mat collected interface pressure, but were blinded to the fact that movement would be derived from the data.

Perceived Exertion: At the end of hr 1 and hr 2, subjects rated how hard they worked in the preceding hour by marking the Borg (1982) CR-10 scale (Appendix 5.1), at a point which corresponded to their perceived exertion from 0 (no exertion) to 10 (extremely hard exertion).

Exercise Program

Dataspan® Exercises: Four years prior to the start of this study, the telephone company had introduced the Dataspan® "Ergonomic Skills Training Program", which included a series of stretching, range of movement and eye relaxation exercises (Joyce and Peterson, 1985a). In the interim, the compliance rate for the exercises had dropped to nearly zero among the operators. Six months prior to the start of the study, I conducted a series of small group discussions with 30 DA operators who had been in the Dataspan® program. There was consensus among the operators that the exercises made them "feel better". In spite of that, they cited several reasons for exercise non-compliance, such as feeling conspicuous or silly, dislike of particular exercises (e.g. seated pelvic tilt), difficulty remembering exercises and having too little time to do the exercises. Of the eleven DA operators in the study, 4 had been employed at the time the Dataspan® exercises were originally introduced, but none was doing the Dataspan® exercises.

Review of Dataspan® Exercises: As previously noted, the greatest discomfort (per body region) for Directory Assistance operators was in the upper neck, lower back and buttock regions. Examination of the Dataspan® exercise program revealed limitations regarding those three regions. First, the only exercise for the buttock region, the *glute clench*, would not likely decrease buttock pressure. Second, the Dataspan® exercise specific to the upper neck, the *cable stretch*, encouraged an upright sitting posture, but did not require subjects to stretch the upper neck extensor muscles (e.g. suboccipital muscles; Rocabado, 1983). Third, the operators found the *seated pelvic tilt*--an exercise that temporarily changed lumbosacral posture--objectionable, conspicuous and difficult to do in their chairs which had built-in lumbosacral supports.

Exercise Revisions: Based on the operator's criticisms to the Dataspan® exercises and my review of the program, the Dataspan® exercise program was revised as follows (Appendix 5.2 Modified Dataspan® Program): The *seated pelvic tilt* and *glute clench* exercises were replaced with a McKenzie (1985) *extension-in-standing* exercise; standing to decrease buttock pressure, and extension to reverse the effects of prolonged flexion on the spine. To compliment the Dataspan® neck range of motion exercises (*head turn, head tip*), a McKenzie (1983) *head-retraction-in-sitting* exercise was added to stretch the upper cervical extensors (Rocabado, 1983).

In terms of reorganization, the exercises were divided into 5 groups by body region: low back/pelvis, eye, neck, shoulder and extremities (wrist/ankle). These exercises were printed in pamphlet format and given to each subject for ready access. Except in the low back/pelvis region (*extension-in-standing* exercise), operators were given two or three exercises to choose from within each region for each workstation exercise break. In full knowledge that 30 second holds are required to increase muscle flexibility (Bandy and Irion, 1994), and that 3 to 4 repetitions are required to decrease muscle tension (Taylor et al, 1990), time constraints to a large extent, dictated the protocol. During the exercise breaks, subjects were asked to perform two repetitions of each exercise and to hold each stretch for 5 seconds only.

Implementation: The revised program was introduced to the operators on an individual basis in 45 min sessions. At each session, the possible physiological benefits were introduced with two general themes: increased relaxation (muscle and eye) and decreased stiffness (joint and muscle). Reduction of musculoskeletal discomfort was not discussed as a benefit. Throughout the introductory session the emphasis was placed on prevention, that is, the operators doing exercises before they felt stiff or before their eyes felt tired. Since the original Dataspan® exercises had been introduced, new workstations had been added that afforded greater privacy. If operators still felt conspicuous, exercise alternatives were offered. For example, the Dataspan® wrist stretch called for both arms to be stretched away from the body. The alternative was to stretch one arm at a time with the arm hanging down at the side of the body.

It was more difficult to address the operators' concerns about time pressure, especially when the telephone system was at full capacity and the "call waiting" symbol was posted on-screen. Performing some exercises, such as *palming* (i.e. eye relaxation), required operators to sign off (i.e. to withhold calls). This practice put the operators' desire to perform exercises in conflict with company performance standards that were electronically monitored. The first step was to ask subjects, where possible, to perform all exercises except *palming* and *extension-in-standing* while taking calls. Second, I reiterated to the DA operators that the exercise program was initiated by management in full recognition that some of the revised Dataspan® exercises required work stoppage. Subjects also were told that by improving productivity and health, the exercise breaks could benefit both the employee and employer.

Subjective Comments: At the completion of the second test, subjects were given a questionnaire to complete and return under separate cover (Appendix 5.3 Exercise Questionnaire). Subjects were asked to: (1) comment on the *ease* or *difficulty* of: performing the exercises, doing the exercises without disrupting work, remembering to do the exercises, and doing the exercises without feeling conspicuous, (2) comment on the number and variety of exercises, (3) identify any problems encountered with particular exercises, and (4) provide general comments and suggestions.

Test Procedure

Subjects were tested twice, each test lasting two hrs. Tests were conducted exclusively during day shifts, with each subject's first and second tests taking place at the same time-of-day. Given the influence of the time-of-day on discomfort (Shackel et al, 1969; Bishu et al, 1991; Schleifer and Amick, 1989), the design was counterbalanced. That is, 6 subjects were tested at the start of a morning shift and 5 were tested after lunch. Subjects were first tested before the introduction of the exercises (baseline). At the end of that test, the revised Dataspan® program was presented, including explanations (benefits and precautions), as well as demonstrations and practice of the exercise and relaxation techniques. The second test took place after the operators had worked from three to five day shifts, during which they were expected to take one workstation exercise break every 30 min. For the exercises, subjects were instructed to stretch until they felt a comfortable sensation of muscle tension, and hold for 5 seconds.

The **minimum** requirement for a break consisted of two repetitions of the *extension-in-standing* exercises. The **preferred** requirement for a break consisted of one exercise from each of the five regions. During the exercise tests, subjects were observed for compliance with the **minimum** requirement. Follow-up was provided on-site during at least one of the days between the first and second tests, and as requested by the subjects. A third test, a one month follow-up to test effectiveness and compliance, was cancelled because site conditions changed when the workstations were converted by the addition of a type-in-standing option.

Test Protocol

In previous tests (Reliability Study, Day Study), subjects initially rated their discomfort at minute five. However, the number of zero discomfort responses occasionally resulted in insufficient variance to test for differences using the 5 min scores. Therefore, assuming a greater risk of discomfort over time, the initial perceived discomfort (PD) rating was changed to minute 30. PD was subsequently rated at the 65 and 115 minute marks. For each perceived discomfort rating, subjects were asked to close their eyes and evaluate discomfort by briefly focusing on each body part in turn.

In order to evaluate seated movement trends that coincided with ratings of perceived discomfort, ICM was analyzed as the mean of three blocks at the *start* of the test (min 5-20), at the end of *hour 1* (min 50-65), and the end of *hour 2* (min 100-115). Subjects rated their perceived exertion at the 65 and 115 min mark of each test. Subjects signed off the computer to rate their exertion (RPE) and discomfort (PD). The order of presentation of the RPE and PD scales was randomized.

During the *exercise* test, subjects were not told to take an exercise break. At 35, 65 and 90 minutes, however, subjects were cued visually that 30 mins had passed. The 30 min cues were intentionally placed to follow the time period during which in-chair movement data were collected. [illegible]tors were inconspicuously observed for compliance regarding the *extension-in-standing* exercise during the exercise tests.

Test Design

The independent variables evaluated in this study were workstation exercises (*exercise, no exercises*) and *time* within each test. The effect of *exercises* and *time* (start, hr 1, hr 2) on ICM and PD was measured with an *exercises* (2) x *time* (3) repeated measures MANOVA. To determine if the exercises were effective in reducing discomfort in specific body regions, PD was evaluated regionally (back/neck, pelvis/buttock) and for the whole body. The main effects of *exercises* and *time* (hr 1, hr 2) on RPE were evaluated with an *exercises* (2) x *time* (2) repeated measures MANOVA. In the presence of non-zero, two-way interactions, the analysis of simple main effects (Nichols, 1993a) was used to evaluate the effects of each independent variable at each level of the other independent variable (e.g. the effect of *exercises* at hr 1 and hr 2). Pearson correlation coefficients were used to measure correlation (or more precisely, mutual covariance) between RPE and whole body discomfort at hr 1 and hr 2 during the *exercise* and *no exercise* tests.

The effect of repeated trials on PD and in-chair movement was determined in a previous study (Reference: Reliability) using the standard error of measurement (SEM). Therefore, in this study, only differences between *exercise* and *no exercise* conditions that exceed the SEM will be reported as actual differences. All analyses were conducted with SPSS (SPSS Chicago, IL 60611) at the $\alpha = .05$ level.

RESULTS

Exercise Performance

All but one of 11 subjects performed the required *extension-in-standing* exercises every 30 minutes during the exercise test. During the 3 to 5 day introductory period, informal observations showed that no DA operators ever completed a "**preferred**" break (5 exercises).

In-chair Movement

The effect of *exercises* and *time* (within trials) on in-chair movement (ICM) are presented in Figure 5.1. The main effects were significant for *exercises* ($F_{(10,1)} = 8.74$, $p = .01$), *time* ($F_{(10,1)} = 12.29$, $p < .01$), and the *exercises* x *time* interaction ($F_{(20,2)} = 4.1$, $p = .03$). Tests of simple (i.e. interaction) effects of *exercises* revealed that movement was greater with *exercises* in the first (5-20 min) ($F_{(10,1)} = 8.63$, $p = .02$) and second (50-65 min) ($F_{(10,1)} = 6.75$, $p = .03$) periods, but not in the final 15 minutes ($p = .92$). Results of tests on the simple effect of *time* showed that in-chair movement increased significantly over the two hr test period in the *no exercise* condition ($F_{(20,2)}$= 15.6, p<.01). However, because ICM was consistently high (i.e. greater than 175 cm) throughout the *exercise* test, there were no temporal increases in ICM when *exercises* were used ($F_{(20,2)}$ =.84, p=.45).

Perceived Discomfort

The effect of *exercises* and *time* on perceived back/neck discomfort are presented in Figure 5.2A. Main effect tests of *time* showed that, regardless of the trial (*exercises, no exercises*) back/neck discomfort increased over time ($F_{(20,2)}$= 8.5, p<.01). Tests for the main effect of *exercises* showed that back/neck discomfort was lower with exercises ($F_{(10,1)}$= 7.73, p<.05). Once again simple effects tests clarified the results: Back/neck discomfort was significantly lower with *exercises* only at min 115 ($F_{(10,1)}$= 8.12; p<.05), although it approached significance at the min 65 ($F_{(10,1)}$= 4.77; p=.054).

In the pelvis/buttock region (Figure 5.2B), MANOVA tests for the main effect showed that, in the *exercises* condition, pelvis/buttock discomfort was reduced ($F_{(10,1)}$= 9.42, p<.05). Simple (interaction) tests revealed that, like the back/neck region, discomfort was lower only at min 115 in the *exercise* condition ($F_{(10,1)}$= 6.78; p<.05). Unlike the back/neck region, pelvis/buttock discomfort did not increase over *time* with ($F_{(20,2)}$= 1.96, p=.17) or without ($F_{(20,2)}$= 3.06, p=.07) *exercises*.

In Figure 5.2C, the effects of *exercises* and *time* on whole body perceived discomfort (PD) are presented. For each sample period (30, 65, 115 min), whole body PD was less when subjects exercised ($F_{(9,1)}$= 18.26, $p<.01$). Main effects revealed that perceived discomfort increased over *time* ($F_{(18,2)}$= 10.9, $p<.01$). However, simple effects tests revealed that increases in whole body discomfort over time were highly significant in the *no exercise* condition ($F_{(18,2)}$= 14.7, $p<.01$), but only approached significance in the *exercise* condition ($F_{(18,2)}$= 3.51, $p=.06$).

Perceived Exertion

Figure 5.3 illustrates that between min 65 (hr 1) and min 115 (hr 2), perceived exertion (RPE) increased over time in the *no exercise* condition and decreased under *exercise* conditions, although in neither condition was the *time* effect (hr 1- hr 2) significant ($F_{(10,1)}$= .31, $p=.15$). Tests also showed that, when subjects exercised, RPE was lower at hr 2 ($F_{(10,1)}$= 6.7, $p<.05$).

Correlation (Covariance)

Regardless of the *time* (hr 1, hr 2) or the condition (*exercise* or *no exercise*) there was no significant covariance between perceived exertion and perceived discomfort. Pearson correlation coefficients ranged from $r=-.10$ to $r=.44$.

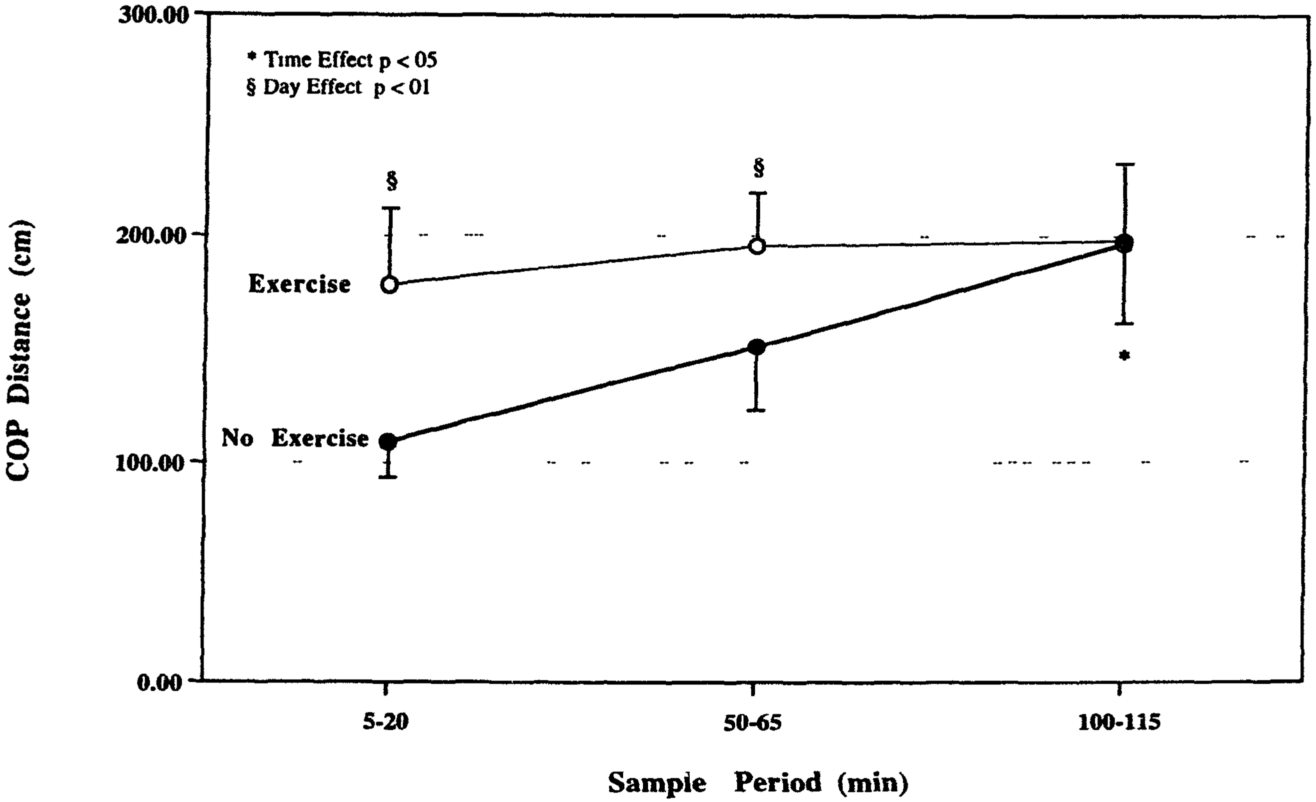


Figure 5.1 Exercise: In-chair movement vs time (Mean, SE): start (5-20 min), end of hr 1 (50-65 min) and end of hr 2 (100-115 min). In the *no exercise* condition, ICM increased over time ($p < .05$). With *exercises*, the time effect was removed, since ICM was high over the entire two hours. Compared to the *no exercise* condition, movement was greater with *exercises* in the first (5-20 min) and second (50-65 min) sample periods, but by the end of the 2 hrs, there was no difference ($p = .92$) between the two conditions.

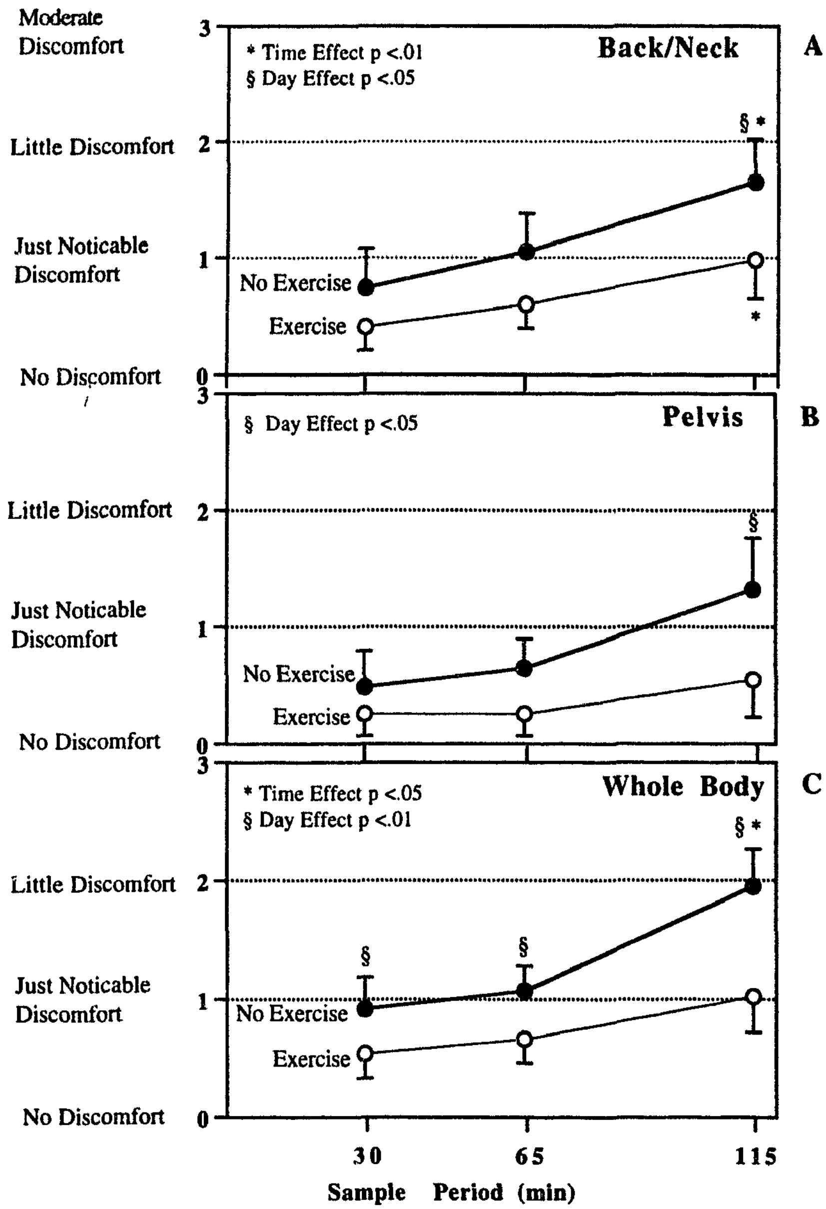


Figure 5.2 Exercise: Average perceived discomfort vs time (Mean, SE): 30, 65, and 115 mins for the back/neck (**A**), pelvis/buttock (**B**) and whole body (**C**) regions. Figure **5.2A** shows significant ($p<.05$) temporal increases in back/neck discomfort in both the *exercise* and *no exercise* conditions, and that discomfort was lower ($p<.05$) with *exercises* at the end of the test (min 115) compared to the *no exercise* condition. Figure **5.2B** shows that with or without *exercises*, pelvis/buttock discomfort did not increase over time. Compared to the *no exercise* condition, pelvis/buttock discomfort was significantly lower at the end (115 min) of the *exercise* tests. Figure **5.2C** shows significantly greater whole body discomfort at each sample period in the *no exercise* condition. Over time, whole discomfort increased in both conditions, but was significant only in the *no exercise* condition ($p<.01$).

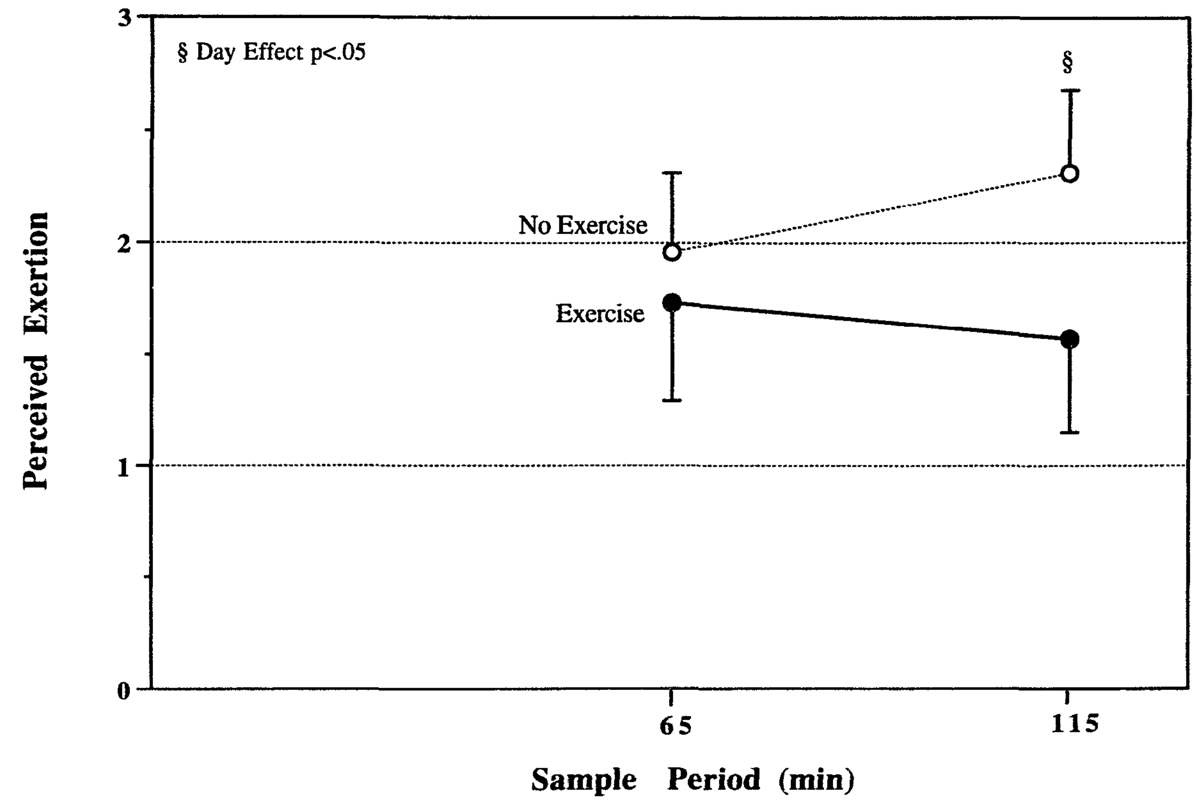


Figure 5.3 Exercise: Perceived exertion at hr 1 (65 min) and hr 2 (115 min) (Mean, SE) in the *exercise* and *no exercise* conditions. The ascending time trends in the *no exercise* condition and descending time trends in the *exercise* condition, were not significant. Compared *no exercises*, perceived exertion was significantly lower at hr 2 with *exercises* ($p<.05$).

Questionnaire Results

Results of the questionnaire showed that the DA operators found the exercises did not make them feel conspicuous (10/11), nor were they difficult to perform (10/11). The number and variety of exercises were reported as satisfactory (11/11), but 3 DA operators reported minor discomfort with the exercises; 2 with *wrist flexion*, and 1 with the *extension-in standing* exercise. Correlation of the perceived discomfort results with questionnaire results was precluded by subject anonymity regarding the questionnaires. The primary problem reported by the operators, however, was difficulty remembering (6/11) or finding time (7/11) to perform the exercises, particularly when "calls waiting" was posted. With one exception, the DA operators reported that the exercises made them feel better, or less tired at day's end.

DISCUSSION

In this study I revised and re-introduced a program of VDT workstation exercises and measured their short term effects on the comfort, in-chair movement (ICM) and perceived exertion of Directory Assistance operators. This study is unique in demonstrating significant increases in seated movement after introduction of workstation exercises. Results also showed that, when using workstation exercises, operators rated their musculoskeletal discomfort and exertion lower compared to the *no exercise* conditions. In a post-study questionnaire, DA operators reported that the greatest problem with the program was difficulty finding time to perform the exercises.

Effect of Exercises on In-chair Movement

The alternate hypothesis regarding in-chair movement was upheld by the results of this study. Following three to five days of the workstation exercise program, operators showed significant increases in ICM during the first (5-20 min) and second (50-65 min) test periods. The increases in ICM are important in terms of reducing postural fixity. For the following reasons I believe that the recorded movements are only indirectly due to the movements associated with actual exercises. In the first place, many of the neck and arm movements that were part of the exercises have been shown to produce negligible changes in the center of pressure in seated subjects (Reference: Reliability Study). Secondly, no movement was recorded by the VERG pressure mat while subjects were standing to perform the *extension-in standing* exercises. Finally, the 30 min time cues were intentionally delayed until after the first (5-20 min) and second (50-65 min) periods of ICM data collection. Although subjects could do the exercises at will, they rarely did them before the 30 minute cues.

The movement increases may be attributable to any of the following three study factors. The first is the rationale presented to the operators regarding the exercises. During those introductory sessions, biomechanical loads associated with poor postures (Harms-Ringdahl, 1986) and physiological problems related to immobility (e.g. buttock pressure or decreased circulation) were increased. The solution put forth to the operators was to move and the means was through workstation exercises. Quite possibly, the DA operators acted on both messages: the need to move and the need to exercise. A second explanation is that the exercises generated their own impetus for in-chair movement. For the operators, meeting any of the objectives of the exercise program (muscle relaxation, improved circulation, etc) would provide positive feedback that movement was beneficial, whether achieved by exercises or otherwise.

The third explanation involves the issue of breaks from an externally paced task. The shape of the movement-versus-time graph for the *exercise* condition (Figure 5.1) bears a strong resemblance to results obtained previously (Day Study). In the Day study, in-chair movement was evaluated under two work pace conditions: on weekends when incoming calls were irregular (low pace) and on weekdays when calls were virtually non-stop (high pace). When the pace was low, subjects received frequent, random breaks and, just as in the *exercise* condition, in-chair movement was high throughout the 2 hr tests. Under high paced conditions, the movement-versus-time graph showed a positive linear growth that resembled the *no exercise* slope (Figure 5.1) in the present study. In the Day study, operators moved because they had the opportunity through random breaks. In the present study operators were encouraged to create their own (i.e. exercise) breaks. Regardless of how the breaks were obtained, they appear to discourage the fixed postures commonly seen in DA operators in high pace conditions.

Effect of Exercises on Musculoskeletal Discomfort

Both alternate research hypotheses regarding musculoskeletal discomfort were supported by study findings. That is, short term usage of workstation exercises curbed the temporal growth of discomfort over the two hr tests and resulted in significantly less discomfort in the body as a whole and by region (back/neck, pelvis/buttock).

Temporal growth of musculoskeletal discomfort: While discomfort increased over the two hr test period in both conditions, the effect was not significant when subjects were using workstation exercises. The workstation exercises had their greatest effect in minimizing the rapid growth of discomfort in the second hour, as seen in the whole body scores (Figure 5.2C). The reduced temporal increases in whole body discomfort seen in this study are restricted to the two hr test period. While Directory Assistance operators were tested in the morning and afternoon, the time-of-day was counterbalanced. Consequently, it cannot be determined if the exercises could diminish the morning-to-afternoon increases in discomfort previously demonstrated in

DA operators (Reference: Day Study). Therefore, the present findings cannot be compared to Swanson and Sauter's (1993b) report that exercises were ineffective in reducing the morning to afternoon increases in discomfort in VDU operators.

If, as Grandjean (1988) has suggested, temporal increases in discomfort are due to cumulative fatigue, then it appears that three short (30 to 60 secs) exercise breaks, whether taken in the morning or afternoon, were sufficient to decrease cumulative fatigue over two hrs in the present study. Evidence to the contrary was presented by Sjogaard et al (1988), using a muscle fatigue model based on potassium homeostasis in static muscle work. Compared to non-stop work, subjects taking intermittent rest breaks had a higher rate of muscle potassium loss, leading Sjogaard et al (1988) to question the benefits of these breaks in reducing fatigue. Therefore, exercise breaks likely improve comfort, not just by reducing fatigue, but by affecting other causes of discomfort, such as job stress and anxiety. For example, in a prospective, cross sectional cohort study of a variety of workers (n= 902), Leino (1989) reported that a subject's mean stress scores in the years 1973 and 1978 both predicted clinical musculoskeletal discomfort in 1983. In general, workplace exercise programs have been shown to reduce anxiety in workers (Long and Flood, 1993). Similar psychological mechanisms may underlie the effectiveness of workstation exercises in decreasing discomfort. However, stress and anxiety were not measured in the present study. In the future, interpretation of exercise benefits would be assisted by self-ratings of stress with a scale such as the Occupational Stress Questionnaire (Elo et al, 1992).

Whole body musculoskeletal discomfort: In the only other study which evaluated exercise and no exercise conditions in VDU operators, Henning et al (1993) found that the only change after three weeks of exercises was a non-significant decrease in leg discomfort. In order to determine possible factors that contributed to the discrepancy between the present study and Henning et al's (1993), the methodologies of the two were compared with respect to work/rest schedules, subject selection, study duration and the nature of the VDT tasks.

The work/rest schedules in the *no exercise* tests were identical in both studies: 120 minutes of continuous work with no breaks. By comparison, during the *exercise* tests, the insurance clerks of Henning et al's (1993) study received nine breaks compared to the DA operators' three. However, if that disparity had any effect, it should have been to increase the likelihood of improved comfort for the insurance clerks. Subject selection also distinguished the two studies. Henning et al (1993) did not select on the basis of musculoskeletal problems, whereas DA operators were excluded if they had any musculoskeletal problems in the previous 3 months. Therefore, musculoskeletal discomfort in the DA operators was not chronic and more likely to be influenced by exercises. The two investigations also differed in duration.

Although compliance was never mentioned, three weeks may have been sufficient time for exercise compliance (correctness, frequency, etc.) to have declined in the Henning et al (1993) study. By contrast, it is unlikely that three to five days was sufficient time for boredom, complacency or forgetfulness to develop for the DA operators.

Lastly, differences between the two studies in detecting changes in comfort, may be attributable to the limitations of psychophysical scaling. Data entry and Directory Assistance operations both use VDU's. However, Directory Assistance operations are distinctly different. Whether due to electronic pacing (DiTecco, 1992), electronic performance monitoring (Smith et al, 1992), or shiftwork (Ursin et al, 1988), the prevalence and severity of musculoskeletal discomfort in DA operators exceeds that commonly reported by other VDU users, data entry clerks included (Evans, 1987; Sauter et al, 1991; Smith et al, 1992; LeGrande, 1993). Assuming the DA operators and data entry clerks benefitted equally from the exercises, the difference between the two groups may be explained by a ceiling effect in psychophysical scaling. Given their risk of musculoskeletal discomfort, the DA operators in this study--even under the *no exercise* conditions--rated their discomfort in the lower half of the scale, leaving little latitude to lower their discomfort scores in the *exercise* condition. Assuming that perceived discomfort in data entry clerks under *no exercise* conditions was lower than that reported by DA operators, Henning et al's

(1993) subjects may have encountered the ceiling, or more aptly, the floor effect. That is, the insurances clerks may have been so comfortable before exercising that they were unable to further lower their perceived discomfort during the exercise tests.

Another limitation of psychophysical scaling is what Poulton (1975) referred to as unspecific bias, defined in this case as rating discomfort according to expectation. Discomfort reduction was not mentioned to the operators as a possible benefit. The reported links between exercise and health, however, are ubiquitous in the media and would have affected subjects in the present study and the Henning et al (1993) study. Since unspecific bias may have therefore contributed equally to both studies, it would not account for the differences in study findings.

Regional musculoskeletal discomfort: Results of the main effects MANOVA tests showed overall significant decreases in discomfort in the back/neck and pelvis/buttock regions. However, in both cases, discomfort was significantly lower only at the final rating. Nonetheless, the exercises, customized in response to specific musculoskeletal complaints in DA operators, were effective in reducing discomfort in the back/neck and pelvis/buttock regions.

Summary of the effects of exercises on musculoskeletal discomfort: Whether determined from a union commissioned questionnaire (LeGrande, 1993) or in a randomized cross-sectional survey (Smith et al, 1992), DA operators report high rates of musculoskeletal discomfort in regions such as the back (80-84%) and neck (67-72%). Those results emphasize the importance of my key finding, namely that discomfort can be reduced by workstation exercises. Unfortunately, although reduced, discomfort nonetheless persisted. Just as ergonomic furniture has not eliminated discomfort, neither did workstation exercises. Based on Henning et al's (1993) and Swanson and Sauter's (1993b) results, more breaks are not likely the answer either. Discomfort may be reduced by increasing the number of stretching repetitions or the stretch durations to recommended standards. In the interests of decreasing discomfort, more research is required to determine standards for rest break lengths (Henning et al, 1993) and to develop stretching programs that are preventative. A variety of other options have been suggested to increase comfort including job rotation (Wærsted and Westgaard, 1991), increased task variety (Winkel, 1987) and relaxation of muscles not involved directly in tasks (Edwards, 1988). It appears that the reduction of musculoskeletal discomfort will require a multi-faceted approach.

Perceived Exertion

Study results regarding the fourth alternative hypothesis are mixed. While there was nc significant time effect on perceived exertion (PE) in either test condition, the direction of the effect differed. Over the two hr tests, PE increased in the *no exercises* condition and decreased with *exercises*. The fifth alternate hypothesis, however, was not supported. With *exercises*, PE was lower, not higher than *no exercise* tests. My exercise-versus-PE hypothesis was based on two assumptions. The first was that exercises would require more effort than sedentary VDU work. Second, I assumed that, after an exercise break, operators would have to make up for lost time by increasing their pace to meet productivity standards (Silverstein et al, 1988). Rejecting the exercise-versus-RPE hypothesis does not mean the assumptions are incorrect. Rather, it implies that RPE was influenced by at least two other issues which are now discussed: psychological factors and non-specific subjective ratings.

In field tests, RPE may be influenced by psychological variables, such as anxiety and mood state (Morgan, 1973; 1994); two factors that may be altered by the use of exercises (deVries et al, 1981; Long and Flood, 1993). While the actual benefits of workstation exercises are not defined, some general benefits are assumed, including psychological effects. Therefore, the psychological benefits of exercise may have influenced the perception of exertion, resulting in no increase in RPE over time in the *exercise* condition.

Non-specific subjective ratings of PE refers to Kuorinka's (1983) suggestion that subjects may be rating perceived discomfort when asked to rate perceived exertion. His hypothesis is based on his report of "similar ascending trends" in integrated EMG signals and general (whole body) discomfort ratings in manual workers (Kuorinka, 1983). In the present study, the absence of a statistical relationship between perceived discomfort and perceived exertion lends no support to Kuorinka's (1983) suggestion. Results of the present study are, however, equivocal since the study was based on a small sample of one occupational group and the duration was short. Furthermore, Morgan (1973) has presented analogous evidence supporting a link between perceived exertion and general well-being. Individuals who scored 1.5 to 2.0 standard deviations above published norms on measures of neuroticism and anxiety, overrated their perceived exertion in bicycle ergometer tests (Morgan, 1973). If the converse is true, that a state of well-being decreases perceived exertion, then discomfort may be related to perceived exertion.

Regardless of whether perceived exertion is mediated by psychological or physiological factors, results of my study lead to one of two conclusions about the Borg RPE scale. Either the Borg CR-10 RPE scale was sensitive to low levels of hysical effort experienced by VDU operators, or the RPE scale was measuring task ulty (Borg et al, 1971) or discomfort (Kuorinka, 1983). Results of my study, although preliminary, also suggest that workstation exercises can decrease a subjects' perception of effort at their primary task. The exact implications of this finding are unknown, but may parallel findings in ergonomic lifting studies in which the risk of musculoskeletal injuries decreased as the perception of effort decreased (Snook et al, 1978; Herrin et al, 1986). RPE has been valuable in setting safe lifting guidelines to prevent musculoskeletal injury. In the future, RPE may prove equally useful in less strenuous tasks for setting guidelines for sitting duration or work/rest ratios.

General Considerations of Workstation Exercises

Methodology: My use of a revised Dataspan® exercise program over the course of 3 to 5 days, resulted in measured improvements in comfort and in-chair movement. Since benefits of workstation exercises have not previously been reported, possible reasons for the program's short term success will be discussed. First, the program may owe its success to the fact that the program revisions were based on specific musculoskeletal complaints made by the DA operators in previous studies (Reliability, Day studies). Second, the program's content and administration are possible contributors to its success. For example, in terms of content, only 11 exercises were used, and these were readily available in a simplified brochure. Administratively, the exercises were reviewed and reinforced for each subject, at least once during their 3 to 5 days in the program. Also, the **minimum** exercise break (i.e. *extension-in-standing*) required only 20 to 30 seconds to complete.

A final possible reason for the success of this program is that the operators benefitted, not just from the exercises, but from the break itself. Zwahlen et al (1984) have presented descriptive evidence that regular rest breaks curb the temporal growth of musculoskeletal discomfort. In this study, the effects of taking a rest break therefore may be confounded with the effects of taking an exercise break. To date, no researcher has distinguished those two effects. Using the NIOSH break protocols, neither Swanson and Sauter (1993b) nor Henning et al (1993) were able to demonstrate any difference in perceived discomfort between *rest-breaks-only* and *rest-breaks-plus-exercises*. However, the NIOSH breaks were very extensive and possibly so effective in limiting the growth of musculoskeletal discomfort that the exercises produced no further effect. In order to distinguish the effects of rests from exercises, in the future, I would add a *rest-breaks-only* condition to my methodology.

Compliance: A common reason cited for the failure of long term (one year or more) workplace exercise programs is that discomfort patterns are resistant to change (Silverstein et al, 1988). That was not the case in the present study, where changes occurred in less than a week. Long term exercise programs therefore may fail for other reasons, such as exercise non-compliance. Using a survey, Silverstein et al (1988) reported that a one year program to reduce discomfort in industrial workers was unsuccessful in spite of the fact that two-thirds of workers claimed participation that ranged from "some to daily". Full compliance, however, means that exercises are done correctly and done daily at the requested repetition rate. Questionnaires alone cannot confirm complete compliance.

The quality and frequency of compliance factors can be monitored, but generally require human resources, such as team leaders (Joyce and Peterson, 1985b).

In spite of that, at the local telephone company, the original Dataspan® program still failed using small groups and team leaders when introduced four years previously. Thompson (1990) similarly reported that the workstation exercise program "deteriorated for lack of management....after a year, or so." In both the Silverstein et al (1988) and Thompson (1990) studies, subjects reported feeling better with exercises, yet in both cases, compliance declined. If, as it appears, exercise compliance requires repeated follow-ups and on-going program modifications, the cost of workstation exercises may be high. Nonetheless, those costs may be offset by the exercise benefits demonstrated in this study, namely the potential to decrease discomfort: a risk factor in the development of musculoskeletal problems (Sauter, 1984; Hagberg and Wegman, 1987). Ultimately, to determine their ergonomic value a cost-benefit analysis of workstation exercises would be required, including measures of productivity and long term health effects.

Conflict: Exercises versus Job Performance: Long term exercise effects and compliance rates could not be assessed in my study because of furniture changes in Directory Assistance operations. Nonetheless, answers to the questionnaire did identify a potential problem. Seven of eleven operators reported difficulty in finding (or making) time to do the exercises. Based on those results, it is likely that long term compliance of the revised Dataspan® program also would decline unless some organizational changes took place. Whereas my results show that exercising reduced discomfort, nonetheless, the operators found it difficult to stop and do the exercises, particularly when they were under time pressure (i.e. when calls were waiting). Thus a primary need of the operators is alleviation of their conflicting demands of job performance and exercise breaks.

The solution to this conflict may be to shift the responsibility for "making time" for a break from the operator to management. The telephone company could accomplish this by programming on-line exercise prompts or by signalling breaks with light emitting diodes (LED) mounted on each computer (Henning et al, 1993). The change in responsibility would address three problems. First, subjects would not "forget" to take a break. Second, the prompts, in a sense, would signal a sanctioned break, removing the onus from the operators. Third, since the operators were never observed to take a full (i.e. **preferred**) break of 5 exercises, the length of time that the signal was on could define the minimum length of the break. Shorter-than-allowed breaks are not exclusive to my study. In a laboratory study using a paced VDT task, Henning et al (1989) found that worker-terminated breaks were too short, and therefore ineffective in improving operator well-being and performance. The drawback to management versus operator-controlled breaks is the loss of an element of job control. However, prior to the start of this study the exercise compliance rate was nearly zero. That is, the DA operators were not exercising their freedom to take exercise breaks.

Specific exercise problems: Minimal problems with the exercises were reported. Two operators reported discomfort during wrist stretching suggesting that, in spite of the low rate of wrist discomfort reported by DA operators (Reference: Reliability, Day Studies), there may be underlying muscle length changes (Travel, 1983) made obvious by the stretching exercises. Only one operator reported discomfort with the *extension-in-standing* exercise. This incidence was lower than expected, considering that the exercise was novel, had a high rate of compliance, and moved the spine into the range of extension; a position rarely encountered in daily life (McKenzie, 1981).

No problems were reported by subjects with respect to the duration of the muscle stretches. Prior to data collection, available evidence suggested that a 15 second duration was required to stretch muscles. Nevertheless, 5 second stretches were used in my study to reduce the operators' time away from work and thereby encourage their compliance. Recent evidence (Brandy and Irion, 1994) showed hamstring stretches maintained for 30 secs were more effective in increasing muscle length than stretching for 15 seconds. Effective stretching should influence the viscoelastic response of both the contractile (muscle) and non-contractile (collagen, elastin) components of the muscle-tendon unit (Walker, 1994). Unfortunately, the ideal stretch duration for influencing connective tissue is unknown (Taylor et al, 1990; Walker, 1994). Given the time constraints in Directory Assistance operations, long duration stretches (15 or 30 secs) for each muscle group would be unrealistic for workstation exercises. As noted earlier, subjects in Brandy and Irion's (1994) study increased joint range of motion by performing the 30 sec stretches only once per day. Therefore, in future I suggest that the short duration workstation stretching exercises be continued, but augmented with one daily set of prolonged (30 sec hold) stretching exercises.

Generalizability: The following caveats should be taken into account in making inferences from this study to other VDU operators: Study subjects were not representative of general office populations since they were screened on the basis of musculoskeletal health. Subjects also represented only one occupational group, Directory Assistance (DA) operators, a group in which musculoskeletal discomfort rates exceed general rates (Smith et al, 1992; LeGrande, 1993). Computer usage by DA operators also distinguishes them from most VDU operators. For example, compared to data entry clerks, DA operators use fewer keystrokes per hr (Smith et al, 1992) and are more likely to be electronically monitored and paced (DiTecco, 1992). The DA operators reported difficulties in making time to perform exercises, a less likely scenario for unpaced VDT operators. Finally, results of this study cannot be generalized to long term applications, since compliance will likely vary across time.

CONCLUSIONS

In summary, results of my study are preliminary, in that only short term effects were examined on a small sample of subjects with no recent history of musculoskeletal problems. Nonetheless, the reduction of musculoskeletal discomfort, perceived effort and postural fixity with exercises has positive implications for VDU users. Results of the present study suggest that workstation exercises may provide a means to improve comfort and decrease postural fixity in DA operators, thereby decreasing the risk of future musculoskeletal problems. Therefore, exercises in the hands of VDU operators, may be preventative tools.

CHAPTER SIX

Effect of Chair Design on In-chair Movement and Musculoskeletal Discomfort in Telephone Operators

Complex definitions of good posture abound, however, Gregg and Corlett (1991), have defined a good sitting posture as simply "one that can be changed". As an obvious corollary, Helander et al (1987) contend that a good chair design is one that enables postural change. While numerous physiological reasons exist to support Gregg and Corlett's (1991) argument, putting Helander et al's suggestion into practice is one of the greatest challenges presently facing chair designers. That challenge, according to Dainoff and Mark (1989) and Gregg and Corlett (1991), arises from the conflicting requirements of chair occupants: stability versus mobility. Chairs therefore need to provide an optimal level of sitting support, below which, occupants have to support themselves, and above which, posture changes are restricted.

One means to achieve that middle ground in chair design has been to introduce chairs which have the traditional physical supports (armrests, backrests, contours, etc.), but which have freely tilting (i.e. *dynamic*) seatpans (Bendix, et al, 1985) that reportedly facilitate seated posture changes (Bendix et al, 1986). While subjects have rated these *dynamic* tilt chairs as acceptable (Bendix et al, 1985), to date there is limited evidence of their effect on the promotion of in-chair mobility. The primary purpose of the present study was to determine the extent to which *dynamic* tilt chairs promote seated posture changes.

Despite the importance of comfort in chair design (Corlett, 1989), there is no evidence that *dynamic* tilt chairs promote sitting comfort. Therefore a second purpose of this study was to measure the effect of *dynamic* tilt chairs on sitting comfort in VDU based Directory Assistance (DA) operators. A third purpose of this study was to compare specific design features between ergonomic chairs with tilt mechanisms that are *dynamic* (free tilt) and those which are *fixed* (i.e. locked). Below I will present a rationale for seated posture changes, a review of the literature on *dynamic* tilt chairs and introduce the proposed chair evaluation methodology.

The Case for Postural Changes in Sitting

The need for seated mobility centers on two issues, both of which have been reviewed in a previous study (Exercise Study), and which are presented here in outline only. First, a case for in-chair mobility arises from the physiological implications of not moving. Results of previous studies (Appendix 3.3; Reliability Study) showed that DA operators were largely immobile in sitting, and that the two common trunk postures were slouched, or upright with the head forward. The implications of these postures include: neck muscle fatigue (Harms-Ringdahl et al, 1986; Sjogaard, 1986), decreased disc nutrition (Holm and Nachemson, 1983), increased strain on the posterior spinal elements (Bogduk and Twomey, 1987), buttock discomfort (Yun et al, 1992), reduced synovial fluid film in the hip joint (Mow et al, 1989) and reduced lower limb circulation (Winkel and Jorgensen, 1986). For each of these factors, movement has been shown, directly or indirectly, to reverse their short term effects.

The second issue deals with the fact that ergonomic furniture interventions have had minimal effect in reducing musculoskeletal sitting discomfort in laboratory, as well as in small and large scale field studies (Ong 1984, 1990; Dainoff, 1990; LeGrande, 1993). Winkel (1987) and Bendix (1991) have both suggested that the reason for the failures are that improved ergonomic furniture design has been self-defeating. That is, as furniture provided more comfort, subjects moved less often. There is ample evidence from Grandjean et al (1960), Jurgens (1989) and my previous studies (Reliability, Day and Exercise Studies) to support the converse of that hypothesis; that subjects move more as they become uncomfortable.

A positive relationship has, however, been demonstrated between seated movement and comfort. Results from a previous study (Exercise Study) showed that, when using workstation exercises, subjects were more comfortable ($p<.01$) and moved more often ($p<.05$) during the two hr work sessions. In the exercise study mentioned above, the stimuli to movement were the exercises. In a post-program questionnaire, problems with exercise as a movement stimulus were noted by the subjects who reported difficulties finding time (7/11) or remembering (6/11) to perform the exercises, particularly at peak workloads.

In recognition of the need to move and the difficulties associated with workstation exercises, other movement stimuli were explored in the area of work organization. For VDU operators, job rotation (Wærsted and Westgaard, 1991) and the regular interjection of short term, non-VDU tasks (Winkel and Oxenburgh, 1990) are the commonly recommended solutions for encouraging posture changes in seated workers. Neither was considered a viable solution in DA operations since all tasks were exclusively VDU-based. In view of their concerns about instability in *dynamic* tilt chairs, Dainoff and Mark (1989) recommended more education in both the use of adjustable chairs and the benefits of posture changes. As cited above, results of a previous study (Exercise) showed that compliance with voluntary exercise programs was threatened when subjects were busy. Considering the difficulties associated with many recognized movement stimuli, and the failure of traditional chairs to improve sitting comfort, a *dynamic* tilt chair was introduced for the purpose of facilitating posture changes in the DA operators.

Dynamic Tilt Chairs

In this study, Dainoff et al's (1986; 1987) chair classification system is used Chairs with freely tilting seatpans (i.e. passive, or tiltable chairs) are classified as *dynamic* tilt chairs, whereas those with seatpans that tilt and lock are termed *fixed* tilt chairs. Bendix et al (1986), define a *dynamic* tilt chair as one in which the seatpan tilts easily around a transverse axis in both positive (front chair edge down) and negative (front edge up) directions. *Dynamic* tilt chairs were designed to follow the occupant's sagittal plane movements, whether the movements were planned or not. In the *dynamic* tilt chair tested by Bendix and various colleagues (Bendix, 1984; Bendix et al, 1985; 1986), tilt resistance was preset at 160 Nm/rad and was linear throughout the range.

To accommodate subjective preferences and anthropometric differences, the tilt resistance in newer *dynamic* tilt chairs is under the occupant's control and can vary from zero (free tilt) to maximum (locked). The transverse tilt axis of the chairs tested by Mandal (1976, 1981), Bendix (1984) and Dainoff et al (1986) was located near the center of the seat. That particular axis location presented a problem, since any degree of seat tilt changed the effective height of the seat (i.e. the front edge height). More recent chair models have eliminated the problem by adopting a *knee tilt mechanism*, defined by manufacturers as an anterior tilt axis that approximates the occupant's knee joint.

Mandal (1976, 1981) introduced chairs with tilting seatpans for the purpose of improving spinal posture. In the first thorough investigation of that hypothesis, Bendix (1984) evaluated *dynamic* tilt chairs in a laboratory study with 10 subjects who spent 2 weeks accommodating to the tilt chair. Spinal posture was evaluated after 15 minutes sitting in each of three seatpan settings: *fixed* in a -5^0 tilt (front edge up), *fixed* in a +5^0 tilt (front edge down), and *dynamic* tilt from -10^0 to +30^0. Results showed no sign..icant differences between the three settings in either spinal posture or subjective acceptability (Bendix, 1985).

Next, Bendix et al (1985) altered the test chair's tilt angles and compared subjective acceptability and surface electromyographic (EMG) signals from the erector spinae between the following three settings: *dynamic* tilt (-8^0 to +20^0) and seatpans *fixed* in a +10^0 tilt and a -5^0 tilt. While EMG did not differ between chair settings, the *dynamic* tilt chair was rated as more acceptable ($p<.01$) in the one hr laboratory trials. In recognition of the need to avoid fixed postures, Bendix et al (1986) transduced the seatpan to continuously monitor tilt frequency as an indirect measure of the occupant's movement. Results showed that increased chair height increased the frequency of seatpan tilts ($p<.001$) (Bendix et al, 1986).

Since the transducer methodology was restricted to the tilting chair, Bendix and colleagues could not initially compare posture change frequency in chairs with *dynamic* versus *fixed* tilt seatpans. Subsequent video motion analyses later allowed Jensen and Bendix (1992) to perform such a laboratory study. The number of body segment movements per 5 min block were compared between four chair/desk settings: a *dynamic* tilt seatpan (range unspecified) with a (i) flat and a (ii) tilted desktop, and a flat desktop with the seatpan *fixed* at (iii) +5^0 and (iv) -5^0). Results showed that regardless of body part (head/neck, trunk, thigh and lower leg), movement was not greater in the *dynamic* tilt chair for the 10 subjects who were reading during each of the 4, hour long tests.

Since occupants of *dynamic* tilt chairs have the freedom to select and readily change their seatpan angle, researchers have been interested in evaluating their behaviour with respect to tilt angle selection. Dainoff and colleagues transduced the seatpan to record tilt angles during 90 min VDU tasks (Dainoff et al, 1986). Pilot study results (Dainoff et al, 1986) showed that when the seat height was fixed, subjects (n=2) showed a consistent preference for a forward tilt position, regardless of task (data entry or data editing). The authors later suggested (Dainoff et al, 1987) the fixed seat height may have influenced the results, since the height was fixed in a position whereby the feet were only in contact with the floor when the chair was tilted forward.

In another laboratory study, Dainoff et al (1987) compared tilt movement patterns between subjects (n=6) sitting in a chair with the seatpan in *dynamic* mode (freely tilting from 6^0 forward to 8^0 backward) versus *fixed* mode (locked anywhere from $+6^0$ to -8^0). Subjects were allowed to change seat height at will during the 90 min VDU tasks. In the *fixed* mode, results showed that subjects tilted forwards for data entry tasks and backwards for data editing. In the *dynamic* mode, subjects spent from 78 to 100 percent of their time in backwards tilt, regardless of task. In spite of suggestions that posture is improved with forward tilt chairs (Mandal, 1981; Bendix, 1984), Dainoff et al's (1986; 1987) results suggest that, when given the option, subjects prefer to lean backwards. The preceding statement should be considered in light of the fact that these results (Dainoff et al, 1986; Dainoff et al, 1987 were obtained with a small sample size.

The *dynamic* chair concept is not without drawbacks, since in-chair mobility in tilt chairs is gained at the expense of stability (Dainoff et al, 1989). Depending on the degree of tilt resistance, some minor posture changes can result in seatpan tilts which may be unexpected by the occupant. Dainoff and Mark (1989) have therefore suggested that *dynamic* tilt chairs are not suited for VDU tasks that require excessive visual tracking and high speed keying. These were not considered limiting factors in this study. First, keystroke rates in DA operators are considered low (< 15,000/hr) (Smith et al, 1992). Second, DA operators have only one visual target, the VDU screen. By contrast, other VDU operators, such as data entry (DE) clerks, frequently change their focus from document to VDU screen. DE clerks could therefore potentially be disrupted by a shifting frame of body reference (i.e. chair tilts) that occurred as they were changing their visual target. Conversely, DA operators with a single visual target should be less bothered by a posture change, whether or not it is expected.

The improvement of seated mobility through chair design is not restricted to *dynamic* tilt chairs. Instead of tilting the seatpan, Graf et al (1993) modified the seatpan contours to support the ischial tuberosities yet increase the trunk/thigh angle. They used video analysis to determine posture changes in subjects (9F, 9M) seated on the modified and traditional seatpans performing VDU tasks and assembly tasks for 1 hr each. Graf et al (1993) showed three important results in their laboratory study. First, subjects moved more often in the modified chair ($p=.05$) and second, subjects moved more often at assembly work, regardless of chair type ($p=.10$). Third, with the modified chair, improvements in perceived discomfort were non-significant.

In summary, the acceptability of *dynamic* tilt chairs, the spinal postures associated with their usage, and the preferred tilt angles, have been documented. By contrast, the evaluation of perceived comfort in passive tilt chairs is notably absent in this review of the literature. Finally, limitations of the Jensen and Bendix (1992) study suggest that the influence of *dynamic* tilt chairs on the promotion of posture changes requires further exploration. While recognizing that *dynamic* chair designs may not be the exclusive answer to improved seated mobility, the present study focuses on measuring their ability to facilitate posture changes and improve comfort in a field setting.

Ergonomic Furniture Evaluations

Given the multitude of factors that influence chair evaluation, a thorough investigation of office seating should cover the requirements of the *task* (vision, reach, force requirements etc.), the *sitter* (desk clearance, musculoskeletal loads, comfort, acceptability etc.) and the *seat* (height, shape, ingress/egress, etc.) (Corlett, 1989). In reality, most researchers follow evaluation guidelines which are based on Branton's (1966) suggestion that a principal component of chair evaluation should be the measurement of sitting comfort. Shackel et al (1969), Branton (1969), and Drury and Coury (1982) have proposed that, in the absence of objective measures of chair comfort, simple, unstructured rating scales should be used to rate comfort by body part (*Body Part Discomfort Scale*; Corlett and Bishop, 1976), to rate comfort in relation to the chair (*General Comfort Rating Scale*; Shackel et al, 1969) and to evaluate specific chair features (*Chair Features Checklist*; Shackel et al, 1969). The present study utilizes each of these three scales, of which one, the *Body Part Discomfort Scale*, has been previously introduced (Reliability Study).

The *General Comfort Rating* (GCR), introduced by Shackel et al (1969), is an eleven item, 10 interval scale of rank ordered statements regarding chair comfort and discomfort (Appendix 6.1 General Comfort Rating). After testing for content validity, Shackel et al (1969) introduced the GCR as an ordinal scale containing equal intervals. In spite of that psychophysical ambiguity, most researchers use parametric statistics to test for differences in *General Comfort Ratings* (Drury and Coury, 1982;

Helander et al, 1987; Bishu et al, 1991; Thomas et al, 1991). By asking subjects to "rate the chair on their feelings now", the GCR evaluates *seat* comfort, not the *occupant's* comfort. The GCR scale has been used to rate pre and post-test comfort (Helander et al, 1987), or comfort at specific intervals, such as every 30 (Drury and Coury, 1982) or 60 minutes (Bishu et al, 1991) of a test.

While the GCR has been recommended for its sensitivity (Corlett, 1990), other investigators have been unable to distinguish comfort between various chair types using the scale (Daley et al, 1985). Helander and colleagues suggested (Helander et al, 1987) and later proved (Zhang and Helander, 1992) that the major problem with comfort scales, like the GCR, was its complicated, multidimensional nature. Despite its drawbacks, the GCR remains widely used in chair evaluations (Drury and Coury, 1982; Corlett, 1989; Thomas et al, 1991). Furthermore, results of a previous intertrial reliability study (collected during Reliability Study, analyzed for this study) showed that the GCR was reliable between trials ($ICC_{1,2} > .98$) and sensitive, considering its standard error of measurement was .2 (on the 10 point scale).

Shackel et al (1969) also introduced the original *Chair Features Checklist* (CFC) to identify specific chair features "which might produce local comfort or discomfort". The original CFC required subjects to select one of three statements about each feature. For example, chair height could be too high, correct, or too low. In the modified CFC (Drury and Coury, 1982), subjects rate each feature on a continuous 9 cm line that spans the extremes (e.g. too high to too low). In order to evaluate features not widely available at the CFC's inception, Grant (1991) has further modified the CFC by adding scales to rate arm rests, backrest inclination and seatpan tilt features. Using results from 250 subjects, Grant (1992) has confirmed the content correlation of the revised scale items ($p < .05$) and shown predictive validity between CFC ratings and subsequent chair rankings.

The CFC is generally administered at the end of chair fitting trials (Shackel et al, 1969) or research interventions (Bishu et al, 1991), although the duration of chair use prior to measurement is highly variable. In multiple chair comparisons, Helander et al (1987) found the modified CFC (Drury and Coury, 1982) to be more informative than either the *Body Part Discomfort* or *General Comfort Rating Scales*. While Shackel et al (1969) suggested the CFC ratings were ordinal in nature, researchers nonetheless treat CFC ratings using parametric statistics (Daley et al, 1985; Helander et al, 1987; Bishu et al, 1991). Of the multitude of researchers using the CFC ratings, only Grant (1992) has reported validity.

The three recommended scales for chair evaluation (BPDS, GCR, and CFC) share two features: None produce objective data, and none acknowledge the dynamic nature of sitting. To address those issues, I have developed a system to measure changes in seated posture by tracking a subject's center of pressure (COP) as they sit on an interface pressure mat (Reliability Study). Using the COP system, changes in seated posture have been shown to result in changes of the COP. These changes are operationally defined as in-chair movements (ICM) (Reliability Study). Measurement of the COP distance travelled over time has provided an objective means to indirectly evaluate chairs by directly measuring dynamic sitting behaviour. Unlike video motion analysis (Jensen and Bendix, 1992), the interface mat was unobtrusive and welcome in on-site studies (Day Study); two features that will allow the unique evaluation of *dynamic* tilt chairs in the field.

Study Hypotheses

The primary null hypothesis in this study was that, for VDU-based DA operators, there would be no difference in their in-chair movement (ICM), specific body discomfort by part (*Body Part Discomfort Scale*) and general comfort (*General Comfort Rating Scale*) between the experimental (*dynamic*) tilt chair and a traditional (*fixed*) tilt chair. It was further hypothesized that regardless of chair, there will be no increase in discomfort (specific or general) over time. A final null hypothesis was that there would be no difference in chair feature ratings between chair types.

In terms of ICM data (i.e. posture changes), the alternate hypothesis was that ICM would be greater when subjects use the *dynamic* tilt chair. The second alternate hypothesis was that comfort would be greater in the *dynamic* tilt chair over the entire test period, whether measured in general, or by specific body part. A third alternate hypothesis was that discomfort would increase over time in both chairs and achieve significance only in the *fixed* tilt chair. The final alternate hypothesis was that, in rating the chair features which most distinguish the two chairs (seat shape and tilt features), subjects would show a greater preference for the *dynamic* tilt chair over the *fixed* tilt chair.

METHODS

Subjects

Nine subjects (8F, 1M) who had been employed as Directory Assistance operators for an average of 92.4 (SE 21.2) months volunteered for the study. The subjects, all in good health, ranged in age from 23 to 40 yrs (Mean 28.9, SE 2.2) and had a mean height of 169.4 cm (SE 3.3) and a mean weight of 69.8 kg (SE 4.1). Details of subject screening on health and anthropometric factors are contained elsewhere (Reliability Study). Each subject gave their signed, informed consent. The research was approved by the Human Ethics Review Committee in the University's Faculty of Graduate Studies.

Task Description

Details of the Directory Assistance operations are contained in preceding studies (Reference: Reliability).

Equipment

Details of the following scales and measures used in the present study are contained elsewhere:

Perceived Discomfort (Reliability Study)

In-chair Movement (Reliability Study)

Shackel's General Comfort Scale: Using the General Comfort Scale (GCR), subjects were asked to "rate the chair on your feelings now" at the 5 (pre-test) and 115 (post-test) min marks of each test.

Chair Features Checklist: Appendix 6.2 Chair Features Checklist contains the modified CFC form used in my study. In this modified checklist, Shackel et al's (1969) original Chair Features Checklist for *seat* (height, width, depth, slope and shape) and *backrest* (height, fit and curvature) features was augmented with 4 scales from Grant's (1991) checklist. Although the modified CFC form used in the present study was not tested for content validity, each its 12 individual features was evaluated by Grant (1992). Subjects completed the modified checklist for each chair at min 115 of the test session.

Test Chairs: A *fixed* and a *dynamic* chair were each tested in this study. The *fixed* chair, a Concentrix® (Steelcase Corp, Grand Rapids, MI, 49509), was a traditional tilt that was already in use in Directory Assistance operations (see Plate 3.1, Chapter 3). The *dynamic* chair, a Dharma Swivel Tilt chair (Teknion, Downsview, ON, M3J 2J5) was the experimental chair tested in this study (Plate 6.1). Both the test chairs had tilting seat pans, were adjustable for seat height and had reclinable backrests. Unlike traditional *dynamic* tilt chairs (Bendix, 1984; Dainoff et al, 1986), the Dharma chair did not tilt forward (i.e. front edge down).

The two chairs differ primarily in the methods of changing the seat tilt and backrest angles. In terms of seat tilt, the angle is under active control of the operator in the *fixed* chair. That is, each time an operator chose to change seat tilt, they manually adjusted and *fixed* (i.e. locked) the seat tilt anywhere from 4^0 backwards (front edge up) to 3^0 forwards (front edge down). By comparison, the tilt mechanism in the *dynamic* seat passively tilts the seat from 0^0 (neutral) to 20^0 backwards by following an operator as he/she moved in the sagittal plane. The degree of tension in the *dynamic* chair tilt mechanism was adjustable for body weight and user preference. In addition, the *dynamic* chair locked in a neutral seatpan position.

The backrest adjustments also differentiated the chairs. Again, subjects in the *fixed* chair were required to actively adjust and lock the backrest angle in one of two fixed positions: 100^0 or 140^0 from the horizontal line of the seat pan. The *dynamic* chair back was linked to the chair body via a flexible glass fibre attachment that allowed the chair to passively follow subjects as they twisted or leaned back from upright (100^0) to full backwards tilt (140^0). The energy stored as subjects leaned backwards assisted them back to upright. The two chairs also were distinguished by the degree of contour support. Where the *fixed* tilt chair had a full lumbar support, the *dynamic* chair had none; and where the *fixed* tilt chair had a deeply contoured seatpan, the *dynamic* chair had minimal curvature in all planes.

Plate 6.1 Lateral view of the *dynamic* tilt chair. Note the tension adjustment knob on the undersurface (open arrow), the narrow glass fibre chair back attachment (solid arrow), and the non-contoured seatpan and chair back.

In comparisons with industry (Canadian Standards Association: CSA, 1989; American National Standards Institute: ANSI, 1988) and research (Grandjean, 1988) standards, both chairs met most criteria for dimension and control features. Of note, both the *dynamic* and the *fixed* chairs failed to meet standards in the backrest/lumbar support areas. As opposed to ANSI (1988) standards and Grandjean's (1988) recommendations, the *dynamic* chair did not have a lumbar support. Neither was the *dynamic* backrest tilt under tension control (CSA, 1989). In the *fixed* chair, the peak of the lordosis support (non-adjustable) was 100 mm lower than standards (CSA, 1989; Grandjean, 1988). Furthermore, in the upright position, the *fixed* chair failed to meet another CSA standard: an open space between the base of the backrest and the top of the seat.

Test Procedure

The tests, two hours in duration, took place exclusively during day shifts. The Directory Assistance (DA) operators were tested once in each chair, with each subject's tests conducted at the same time-of-day. Given the influence of test order in within-subjects designs (Drury, 1990), the design was counterbalanced, with 5 subjects first tested in the *dynamic* chair, and 4 in the *fixed* chair. Also, given the influence of the time-of-day on comfort (Corlett, 1989), 5 subjects were tested in the morning and 4 in the afternoon. Since subjects in the present study receive attention not provided to their counterparts, there is a risk of introducing the Hawthorne effect (Pennock, 1930). In order to minimize that possibility, this study took place during a period when a series of minor office alterations furniture changes were taking place.

The *dynamic* chair was introduced to the DA operators in individual 20 minute sessions that included demonstrations of the *dynamic* chair features and discussions of physiological benefits, such as varied muscle usage and decreased stiffness (joint and muscle). Neither improved comfort nor increased movement were mentioned as benefits. Subjects then sat in the *dynamic* chair and practised adjusting the chair controls.

Following the introduction, subjects returned to work using the *dynamic* chair. The operators were asked to use maximum tilt resistance on the first day and thereafter experiment to find their preferred seatpan tilt resistance in the *dynamic* tilt chair. Tests in the *dynamic* chair took place after subjects had worked three day shifts over a three to five day period, during which they used the *dynamic* chair exclusively. During the tests with the *dynamic* chair, subjects were free to select the desired seatpan tilt resistance. Subjects were given a *Chair Use Form* and asked to complete both usage and comments on a daily basis (Appendix 6.2 Chair Use Form).

Test Protocol

The DA operators signed off the computer to rate their perceived discomfort (PD) at the 30, 65 and 115 min marks. As in previous studies (Reliability, Day, Exercise), in-chair movement (ICM) was measured continuously over the test period, but was analyzed as the mean of three blocks at the *start* of the test (min 5-20), at the end of *hour one* (min 50-65), and at the end of *hour two* (min 100-115). At the completion of each test, subjects completed the modified *Chair Features Checklist* (CFC). Perceived discomfort, though rated by body part, was analyzed as an average whole body score (i.e. sum of all discomfort scores averaged over the number of uncomfortable body parts).

Test Design and Analysis

The independent variables evaluated in this study were *chair* (*dynamic* and *fixed*) and *time* within each test. The effects of *chair* and *time* (*start, hr 1, hr 2)* on ICM and PD were measured with a *chair* (2) x *time* (3) repeated measures MANOVA. In the presence of non-zero interactions, the analysis of simple main effects was used to evaluate the effects of each independent variable at each level of the other independent variable (Nichols, 1993b). The effect of *chairs* on the CFC ratings was tested with the Wilcoxin matched-pairs signed ranks tests.

RESULTS

From the four studies in this thesis, the present study was chosen to present detailed raw scores and MANOVA commands/results to illustrate the general statistical methodology. Appendix 6.3 (SPSS Results - Chair Study) contains the in-chair movement (COP), perceived discomfort (whole body), General Comfort Rating and Chair Features Checklist results.

In-chair Movement

In Figure 6.1, the effects of *chair* and *time* on in-chair movement (ICM) are presented. The main effects were significant for *chairs* ($F_{(8,1)}$= 12.1, $p<.01$) and *time* ($F_{(8,1)}$= 9.9, $p<.01$), but not for the *chair* x *time* interaction ($F_{(16,2)}$= 2.2, p= .14). Tests for simple (i.e. interaction) effects revealed that ICM was significantly greater with the experimental *(dynamic)* chair only in the second test period (50-65 min) ($F_{(8,1)}$= 12.3, $p<.01$), although differences approached significance in the third test period (100-115 min) ($F_{(8,1)}$= 5.1, p=.054). It is also evident in Figure 6.1 that there was clearly no difference in ICM between chairs at the end of hr 1 ($F_{(8,1)}$= .00, p=.96). Simple effects tests also revealed that ICM increased over time in both the traditional *(fixed)* ($F_{(16,2)}$= 26.6, $p<.01$) and *dynamic* ($F_{(16,2)}$= 5.6, $p<.01$) chairs.

Perceived Discomfort

The effect of *chair* and *time* on whole body perceived discomfort are presented in Figure 6.2. Discomfort increased over time in the *fixed* chair ($F_{(16,2)}$= 8.8, $p<.01$), but not in the *dynamic* chair ($F_{(16,2)}$= 3.1, p=.07). Although the main effect for *chair* was not significant ($F_{(8,1)}$=4.8, p=.06), compared to the *fixed* tilt chair, discomfort was lower in the *dynamic* chair in the final sample period (100-115 min) ($F_{(8,1)}$= 7.2, $p<.05$).

General Comfort Rating

Pre and post-test GCR results are presented in Figure 6.3. Main effects were significant for *chair* ($F_{(8,1)}$= 12.5, p<.01), *time* ($F_{(8,1)}$= 22.2, p <.01) and the *chair* x *time* interaction ($F_{(8,1)}$= 11.6, p<.01). Simple effects tests revealed that subjects were more comfortable in the *dynamic* chair compared to the *fixed* chair on both the pre-test ($F_{(8,1)}$= 5.7, p<.05) and post-test ($F_{(8,1)}$= 18.5, p<.01) GCR scores. In both chairs, discomfort increased over time (p<.05).

Chair Features Checklist

Table 6.1 contains the means and standard errors for each of the twelve features evaluated with the Chair Features Checklist. Results of the Wilcoxin matched-pairs signed ranks tests showed that both seat shape and backrest fit were significantly poorer in the *fixed* chair (p<.05). Also, while subjects rated the *ease of chair tilt* (item 11, Table 6.1) as below adequate in both chairs, it was significantly lower in the *fixed* chair compared to the *dynamic* tilt chair. In three features (seat slope, backrest position, backrest curvature) the differences approached significance (i.e. p<.07). These differences were termed trends and further confirmed that subjects preferred the backrest characteristics of the *dynamic* tilt chair.

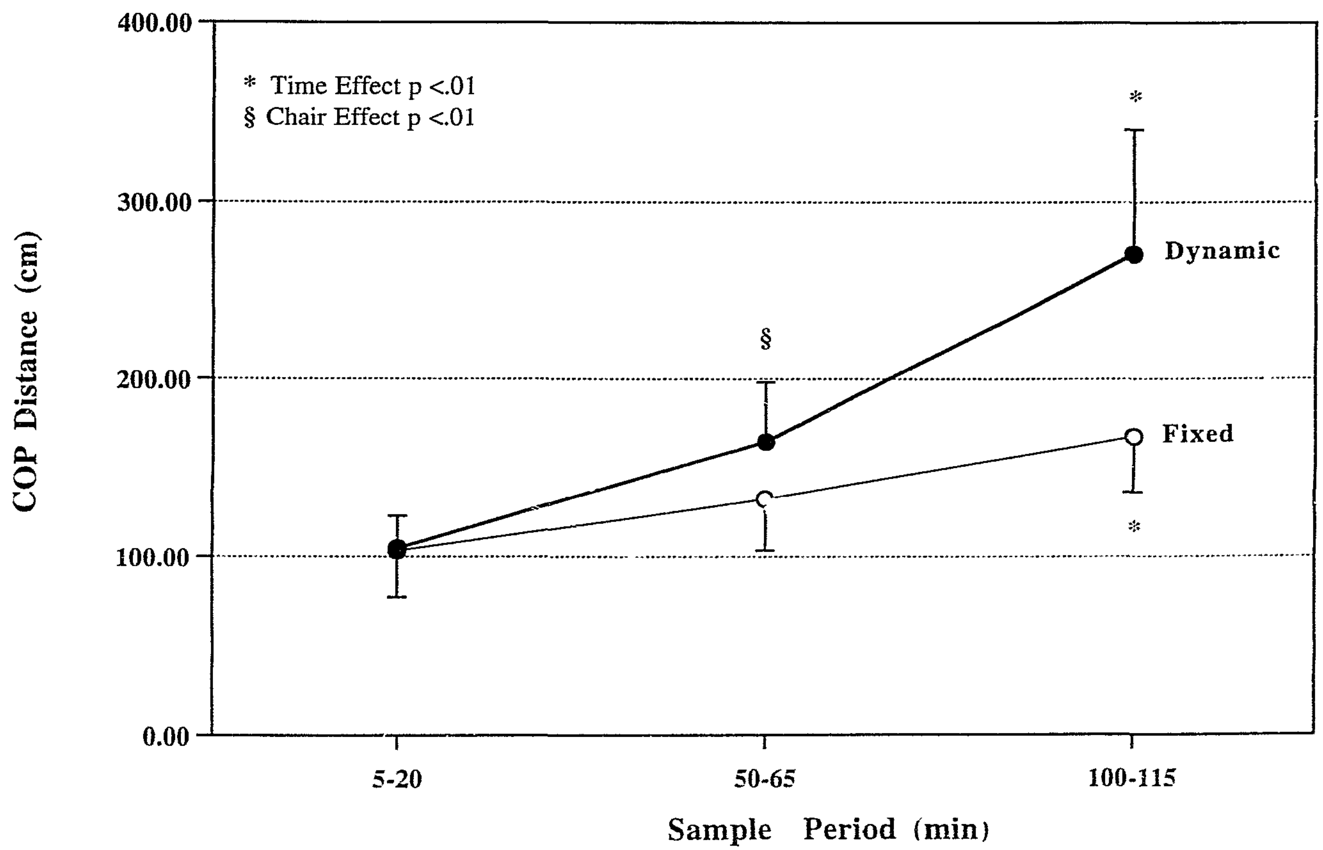


Figure 6.1 Chair: In-chair movement vs time (Mean, SE): start (5-20 min), end of hr 1 (50-65), and end of hr 2 (100-115 min). ICM increased over time ($p<.01$) in both the *dynamic* and *fixed* chairs. Compared to the *fixed* chair, ICM Was higher in the *dynamic* chair at hr 1 ($p<.01$), but differences at hr 2 only approached significance due to the high variance in *dynamic* results in that sample period.

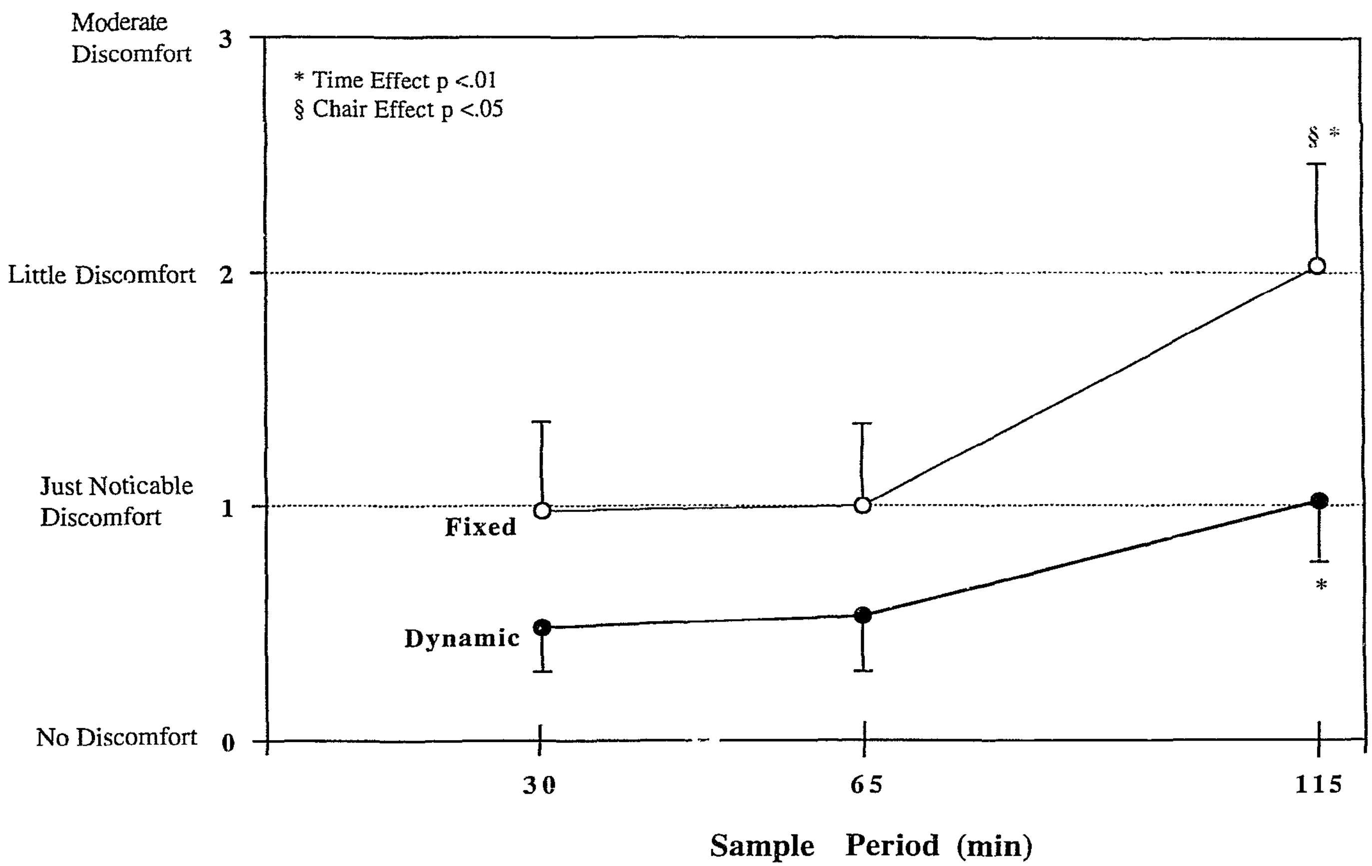


Figure 6.2 Chair: Average whole body discomfort vs time (Mean, SE): 30, 65, and 115 mins, showing that discomfort increased over time in both chairs ($p < .01$) and that discomfort ratings were significantly less in the *dynamic* chair in the final sample period (hr 2).

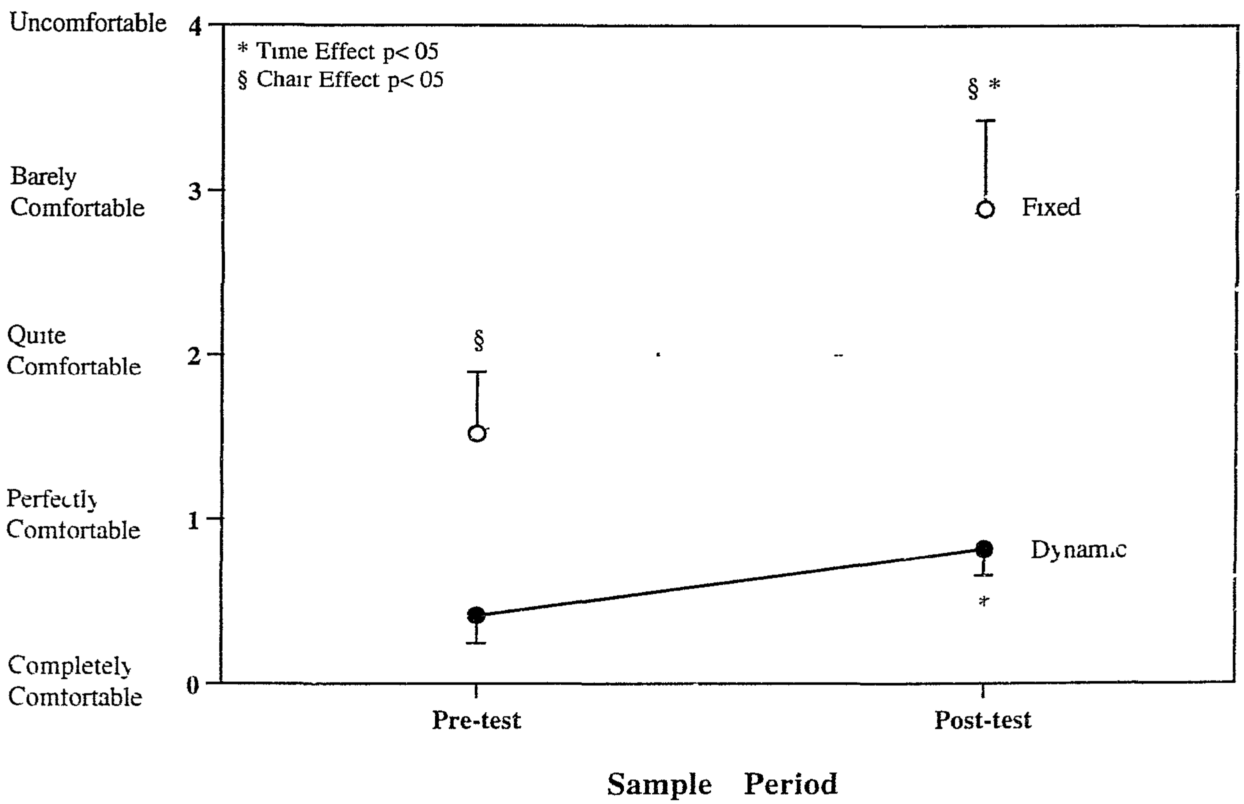


Figure 6.3 General Comfort Ratings at min 5 (pre-test) and min 115 (post-test) (Mean, SE), showing that, discomfort was significantly reduced in the *dynamic* chair at both sample periods ($p<.05$), and that discomfort increased over time, regardless of chair type ($p<.05$).

Table 6.1 Chair Features Checklist results for the *dynamic* tilt and *fixed* tilt chairs on a 0 to 4 scale in which 2 signifies adequate or correct. Below each variable name, the verbal anchors on the 0 to 4 scale is contained in brackets. Significance refers to the Wilcoxin matched-pairs signed ranks test, where: * is significant at $p < .05$ and § is a trend at $p < .07$.

Reference Variable (verbal anchors: 0, 4)	Dynamic Tilt Mean	(S.E.)	Fixed Tilt Mean	(S.E)	Signif
Seat height (too high, too low)	1.96	(.03)	2.01	(.32)	ns
Seat length (too long, too short)	2.17	(.18)	2.09	(.17)	ns
Seat width (too narrow, too wide)	1.99	(.08)	1.99	(.01)	ns
Seat slope (too far back, forwards)	1.97	(.08)	2.40	(.21)	§
Seat shape (poor, good)	2.48	(.23)	1.39	(.25)	*
Backrest position (too high, too low)	2.02	(.02)	2.50	(.22)	§
Backrest fit (poor, good)	2.78	(.22)	1.10	(.28)	*
Backrest curvature (too curved, too flat)	1.94	(.09)	1.06	(.30)	§
Arm rest height (too high, too low)	2.21	(.22)	2.29	(.36)	ns
Backrest angle (too upright, too inclined)	1.90	(.10)	1.83	(.32)	ns
Ease of chair tilt (too easily, too hard)	1.68	(.22)	.76	(.25)	*
Chair tilt range (too far, not enough)	1.60	(.19)	1.18	(.31)	ns

DISCUSSION

In this study, I introduced a *dynamic* tilt chair and measured its effect on the promotion of posture changes and sitting comfort in VDU-based DA operators. In spite of widespread interest in methods to promote of mobile postures, this study is the first to show that chair design can positively influence in-chair movement. My study also supported the contention that use of a *dynamic* tilt chair promoted perceived sitting comfort. Results of the *Chair Features Checklist* showed that differences between *fixed* and *dynamic* tilt chairs were centered on support (e.g. seat shape) and chair tilt characteristics, rather than on chair dimensions, such as seat length. Below, results of the ICM, comfort and chair features measures are discussed in detail. Given the wealth of factors which influence sitting comfort, study limitations also are presented.

Seated Mobility

Results of main effects tests supported the alternate hypothesis. That is, the *dynamic* chair significantly increased in-chair movement (ICM) in the DA operators compared to the traditional (*fixed* tilt) chair. Closer examination of results, however, showed that the effect of chairs on mobility was inconsistent across the test period. For example, at the start of the test there was marked similarity in the means. At the second and third (final) sample periods, movement was greater with the *dynamic* chair. The trend of these ICM results implies that the chair, per se, may not have fostered spontaneous movements (Jensen and Bendix, 1992), but instead made posture changes easier when subjects became restless over time.

An interesting comparison can be made between ICM results of this study and those of a previous intervention with workstation exercises (Exercise Study) in which ICM was measured over 3 sample periods identical to the present study. In the control conditions of the present (*fixed* chair), and the exercise (*no exercises*) studies, subjects' in-chair movements showed steady, temporal increases over two hrs. In the two intervention conditions (*tilt* chair and *exercises*), ICM was greater compared to control conditions. However, with each intervention, there were marked differences in the temporal ICM patterns: With exercises, ICM was greater than the no-exercise condition in the first sample period, stayed high at period 2, and by period 3, the exercise and no-exercise means had converged. Quite the opposite effect was shown when subjects used the *dynamic* tilt chair. In the first sample period, the means for ICM in the *dynamic* and *fixed* chairs were indistinguishable, but over the course of two hrs, ICM was greater with the *dynamic* chair.

Those study comparisons show that the *dynamic* tilt chair and workstation exercises each promote in-chair movement differently. At first glance, it is tempting to suggest that simultaneous use of both the exercises and the *dynamic* chair would increase posture changes over the 2 hr work period, but caution is advised. Given

Dainoff and Mark's (1989) concern about stability, subjects may find exercising on an unstable base difficult and therefore, unappealing.

The positive effect of a *dynamic* chair on posture changes as reported in this study differ from the results of Jensen and Bendix (1992). The absence of an effect of the *dynamic* tilt chairs on posture changes may be attributable to differences between the studies in three factors: data collection protocols, chair design features and data analysis techniques. Each factor is now discussed in turn.

Study differences may be explained by examining Jensen and Bendix's (1992) data collection protocols. In the first place, unlike the seatpan transducer, which recorded continuous motion, the videotaped movements were analyzed as four discrete 5 min blocks spaced over the one hr trial (Jensen and Bendix, 1992). In a previous study with DA operators, I examined the intertrial reliability of in-chair movements that were measured in two hr trials (Reliability Study). My results showed that seated movement behaviours were highly variable and that ICM measured as discrete 5 min blocks of motion data only achieved acceptability with the Pearson 'r' test, a non-stringent test of reliability.

A second protocol difference was that the test duration in the Jensen and Bendix (1992) study was one hour, compared to my 2 hr tests (Reliability Study). Tests in the Jensen and Bendix (1992) study may have therefore been too short, since previous results (Reliability, Day Studies) showed that most DA operators displayed relatively fixed postures in the first hour of sitting. Third, the absence of a chair effect may be due to the task, since work pace and cognitive demands have been shown to influence seated movements (Day Study). Therefore, the demands of reading in the Jensen and Bendix (1992) study may not have created a significant stimulus for posture changes, regardless of chair.

Study dissimilarities also may be explained by differences in chair features. Three principal features distinguish the *dynamic* chair in the present study from that used by Jensen and Bendix (1992). The first is a difference in control over the degree of resistance to seatpan tilt. Where Jensen and Bendix's (1992) chair had pre-set tilt tension, subjects in the present study selected their tension in the experimental chair. The advantage in movement promotion therefore may have been to the experimental chair (Dharma), since pre-set tension would accommodate neither anthropometric differences nor subjective preferences. Second, the direction of seatpan tilt distinguished the studies. Unlike the Jensen and Bendix (1992) chair in which the front edge tilted down (positive tilt) and up (negative tilt), the *dynamic* chair in my study tilted in the negative direction only. The effect of tilt direction on the promotion of ICM is speculative. Since subjects in *dynamic* chairs may prefer the negative tilt range for VDU work (Dainoff et al, 1986), more research is required in the area.

The third chair difference, tilt axis location, impacts on the second factor. The tilt axis in the Jensen and Bendix (1992) chair was centrally located, meaning that a change in tilt angle would require an accompanying change in chair height. Therefore, in order to move from a negative to a positive tilt (or vice versa), subjects seated in the Jensen and Bendix (1992) chair had to adjust their chair height, a requirement which may have negated the benefits of using a *dynamic* tilt chair. By comparison, the experimental chair in this study had an anterior tilt mechanism which allowed any degree of negative tilt with no required seat height change.

Finally, the discrepancy between the present study and the Jensen and Bendix (1992) study, may be attributable to differences in data analysis techniques. Bendix and colleagues analyzed seated movement by determining motion frequency (Bendix et al, 1986, Jensen and Bendix, 1992). In a previous study (Reliability Study), I found that an indirect measure of frequency, the *variation of the COP around the mean*, was not reliable between trials. In the present study, data therefore were analyzed as total movement per designated time block. In summary, a variety of protocol and equipment differences between the present and the Jensen and Bendix (1992) studies may have contributed to the divergence in results, thereby making direct comparisons difficult.

Results of the present study have established that subjects sitting in *dynamic* tilt chairs move more often. Results also exposed a number of unknowns about *dynamic* tilt chairs that warrant future research, including preferred tilt angle, preferred tilt resistance, and the location of the most favourable tilt axis. Finally, this study has introduced an indirect, dynamic method to evaluate chairs by measuring the behaviour of chair occupants.

Because of the influence of task on both the patterns of seated movement (Dainoff et al, 1986) and on posture change frequency (Graf et al, 1993), care should be taken in generalizing these ICM results that were obtained on one occupational group. As seen in comparisons of my results with Jensen and Bendix's (1992), the type of *dynamic* tilt chair also influences results. Therefore, caution also is advised against generalizing ICM results from this experimental chair to other *dynamic* tilt chairs.

Sitting Comfort

Study findings supported both alternate hypotheses regarding sitting discomfort. In the first place, both general and specific body part comfort was greater in the *dynamic* tilt chair. Second, discomfort by body part did not increase over time in the *dynamic* tilt chair.

Body Part Discomfort: This is the first study to compare perceived comfort (*Body Part Discomfort Scale: BPDS*) between *fixed* and *dynamic* tilt chairs, and consequently is the first to demonstrate improved comfort with the short term use (5 days) of *dynamic* tilt chairs. The absence of temporal increases in sitting discomfort with the use of a *dynamic* chair echo results obtained when DA operators used workstation exercises (Exercise Study). In fact, BPDS discomfort patterns with the *dynamic* chair are almost indistinguishable from those with *exercise* usage. That is, regardless of the type of intervention (*dynamic* chair or *exercise*), at each sample period (30, 65, or 115 min) discomfort was decreased by at least 50% compared to control conditions. Unlike the exercise study, however, in which whole body discomfort was lower ($p < .02$) at each sample period, with the *dynamic* chair, differences only achieved significance in the final sample.

General Comfort Rating: Results of the *General Comfort Ratings* (GCR) reinforced the BPDS whole body results (Figure 6.3). With the GCR, both pre- and post-test discomfort ratings were significantly lower in the *dynamic* tilt chair than in the *fixed* chair. Unlike the BPD ratings, however, the GCR scale showed temporal increases in discomfort in both the *dynamic* (and *fixed*) chairs. The GCR scale in the present study clearly discriminated between chairs with respect to comfort, a result that disagrees with other researchers (Daley et al, 1985; Helander et al, 1987).

Chair Features Checklist

Regarding the CFC, one alternate hypothesis (differences in seat shape) was supported and the other (tilt features) was supported in part. In general, results of the Wilcoxin tests showed that in 6 of 12 features, there were no significant differences between the *fixed* and *dynamic* chairs. Subjects displayed a preference for the non-contoured experimental (i.e. *dynamic*) chair by rating the seatpan shape and three backrest features (fit, position and curvature) as poor in the traditional (i.e. *fixed*) tilt chair (Table 6.1). These evaluations followed short term (3 days) exposure to the *dynamic* chair. Over time, subjects may, as suggested by Dainoff and Mark (1989), prefer more stability in the form of additional contour support.

With respect to seat slope (item 4, Table 6.1), results are interesting in light of Dainoff et al's (1986) findings regarding preferred tilt angles. Like the data verification clerks in Dainoff et al's (1986) study, the DA operators in the present study rated the backwards seat slope as preferable to the neutral one. Another tilt feature preferred in the *dynamic* chair was the ease of chair tilt. Of note, even though the ease of chair tilt (item 11, Table 6.1) was under operator control in the *dynamic* chair, subjects still rated the tilt tension as too light (i.e. too easy to tilt). In general, CFC results support the many other authors who found that untrained subjects using the *Chair Features Checklist*, could distinguish design differences between chairs (Shackel et al, 1969; Drury and Coury, 1982; Helander et al, 1987; Bishu et al, 1991).

Study Limitations

In terms of detecting true differences between the chair types with respect to ICM, the present study was limited in part by the type of sensors used to track the

COP. The interface mat is composed of force sensing resistors (FSR), transducers which detect compressive, but not shear, loads. Consequently, as the seatpan tilts in the *dynamic* chair, a proportion of the occupant's weight is not sensed by the FSR transducers. Therefore, since the ICM results for the *dynamic* chair are underestimates, the true differences between the *fixed* and *dynamic* chairs are likely greater than reported.

In the present study, there was a risk of introducing a Hawthorne effect with respect to the experimental chair. The effect may have been minimized by the variety of changes taking place in the DA office. Nonetheless, the introduction of chairs for this study was the only change with respect to seating.

This study also is limited by the fact that features other than the tilt mechanism (contours, backrest adjustment) distinguished the experimental and traditional chairs. Further to that, the DA operators' long term exposure to the traditional (*fixed*) chair gave them ample time to form opinions about it. Consequently, differences in subjective ratings and ICM may be due to physical differences between the two chairs or the novelty of the experimental chair.

Given the wealth of factors that influence sitting comfort and chair evaluations, these results should be generalized with caution. Chair design and task considerations aside, numerous factors influence chair evaluations and therefore restrict generalizability. The list of these factors is extensive and includes: chair appearance (Shackel et al, 1969), the length of the sitting period (Branton, 1966, Bhatnager et al, 1985; Schleifer and Amick, 1989; Fenety, Reliability Study), the length of adjustment period (Bendix et al, 1985), workstation adjustability (Pustinger et al, 1985), gender (Branton, 1966), low back pain (Michel and Helander, 1994), the initial chair adjustment settings (Helander and Little, 1993) and operator characteristics, such as anthropometric fit and ergonomic skills (Dainoff and Mark, 1989).

Nevertheless, results of this study have established that subjects sitting in *dynamic* tilt chairs had greater in-chair movement and comfort. Given the importance of seated mobility, methods such as *dynamic* chairs are needed to foster in-chair movement. However, considering the gaps in the literature and the number of restrictions to generalizability, more research is required before *dynamic* tilt chairs can be strongly endorsed.

CHAPTER SEVEN

General Considerations of Sample Size

MANOVA power determinations done on data from my Reliability Study showed that to achieve a statistical power of .90, on a per study basis, 9 subjects were required for in-chair movement and 10 subjects for whole body comfort. This sample size was met in most, but not all studies, principally because of rapid changes occurring in the telecommunications industry in Canada. Specifically, deregulation of the industry meant that changes this telephone company had planned for 1996 were implemented on short notice. The changes involved moving to a new office, purchase of new workstations, and an amalgamation of Toll Services and Directory Assistance that was accompanied by extensive retraining. Consequently, in each study, data collection periods were shortened to avoid the periods of change in on-site conditions. After each extensive change, a two month minimum break-in period was allowed before data collection was resumed.

Calculation of traditional power is limited in that it does not give the researcher the odds of finding *true* differences (i.e. non-measurement error), rather it gives the probability of finding statistical differences if those statistical differences exist, whether or not those differences are *true*. So, while 9 subjects gave sufficient power in my studies, in each study some so-called differences were not greater than the sdd, and are not reported as statistical differences. For example, in the Exercise study, according to MANOVA results, discomfort (back/neck and pelvis) was significantly less at min 65 when subjects used exercises. However, since the differences did not meet the sdd standard, the differences were reported as insignificant. My thesis results therefore do exemplify a weakness in the reliance on power determinations. In retrospect, sample size estimates likely should have been higher to account for the *standard error of measurement*.

CHAPTER EIGHT

Summary

Results of the first study; Development and Validation, showed the VERG interface mat to be a valid, reliable means to measure in-chair movement (ICM) by tracking the center of pressure (COP) in seated subjects. Furthermore, unlike traditional methods of measuring seated movement, the mat's portability and non-invasive nature made it suitable for on-site testing. Two other benefits of the VERG COP system as tested, were flexible data collection periods and rapid data analysis.

The reliability of assays of in-chair movements (ICM) are rare. My Study is the first published report of ICM reliability, taking into account its variable nature and the fact that ICM is both task and behaviour sensitive. The challenge in my Reliability Study was therefore to determine the *most* reliable method of collecting and analyzing the movement data. Results clearly showed that both reliability and consistency were improved when data were analyzed as the mean of three consecutive 5 min blocks of ICM data, rather than as single five minute blocks.

Reliability Study results also showed that, similar to another reliability report, perceived discomfort (PD) was most reliable when measured as a whole body score. Interestingly, in contrast to other research with VDU operators, telephone operators in my Reliability Study had a low incidence of shoulder and arm discomfort. Finally, PD results were used to determine the smallest detectable difference, or the minimal amount of difference between trials (e.g. exercise, no-exercise) above which differences are *true* (i.e. not due to measurement error).

Of the two independent variables tested in the Day Study (Chapter Four)--work pace and time-of-day--perceived discomfort was influenced by both, a result that supports numerous reports in the literature. On the other hand, ICM was affected only by work pace, a result in contrast to one other reported comparison of ICM versus task difficulty. An unexpected finding in the Day Study was that mental workload ratings were not affected by significant decreases in work pace.

My Exercise Study results are unique in showing that ICM increased with the short term use of workstation exercises. Exercise use also decreased discomfort; a result that disagrees with all other published workstation exercise studies. Since telephone operators have among the highest reported rates of body discomfort in seated VDU operators, the finding of improved comfort in the Exercise Study is noteworthy. A final, and unique finding in the Exercise Study was that when telephone operators were performing exercises, perceived exertion decreased.

Although many parameters of dynamic tilt chairs have been previously studied, my Chair Study is the first to show that perceived comfort was greater in dynamic tilt chairs than in traditional (tilt and lock) chairs. Tilt chair usage also resulted in greater in-chair movement, although only in the final sample period.

Investigators have suggested that the relationship between chairs and sitting comfort is somewhat paradoxical. As furniture has become more comfortable, seated workers have moved less. Enter the paradox. As seated subjects have moved less, they have become more uncomfortable. Results of my study consistently demonstrated the complement of that paradox: whether movement was *encouraged* by the use of tilt chairs or exercises, or was *not discouraged* by a high work pace, sitting comfort was improved when seated postures were mobile.

Future Directions

Results of this series of studies demonstrated that on a small scale, short term use of a passive tilt chair and workstation exercises by VDU based Directory Assistance operators promoted both perceived comfort and in-chair movement. Since musculoskeletal discomfort in VDU operators is predictive of future health problems, my results demonstrate that workstation exercises and dynamic tilt chairs have the potential to reduce short term discomfort and long term musculoskeletal health problems. These results require confirmation using larger sample sizes in a variety of seated occupations.

Furthermore, while exercises, tilt chairs, and decreased work pace all decreased sitting discomfort in these studies, no single factor eliminated discomfort, implying that the reduction of musculoskeletal discomfort will require a multi-faceted approach. In future studies, large sample sizes would facilitate regression analysis to determine the effect of factors such as the time-of-day, workload pace, type of shift, perceived exertion, and age on perceived discomfort.

Several unanswered questions remain. Firstly, since all subjects were interrupted at the end of hour one to rate their discomfort, there is a possibility that the interruption limited the temporal growth of in-chair movement. Secondly, from the results there appears to be a common ceiling on in-chair movement in all studies. That is, the mean COP distance in the final 15 min blocks ranged between 200 and 230 cm, with the exception of the dynamic tilt chair in the Chair Study (270 cm). In the future it may be possible to determine if particular factors limit in-chair movement, such as task demands or the physical constraints imposed by chairs (e.g. armrests).

Third, based on my Chair Study results, universal endorsement of the dynamic tilt chair is not possible due to the number of unknowns, such as actual force required by a subject to change the seat tilt position or the chair's suitability for use in high speed VDU tasks. Finally, in the future, unknowns from the Exercise Study should be addressed. For example, most workstation exercise programs promote a variety of exercises, making it difficult to determine the effectiveness of specific, individual exercises.

In the future, as more people work in seated positions in industry and offices, there will be an even greater risk of sitting discomfort. Ergonomists therefore will need more tools to address the issue of musculoskeletal problems; tools to evaluate office seating and tools to measure the outcome of interventions aimed at reducing discomfort. In this thesis I have developed such a tool. Using an interface pressure mat, I have developed an indirect measure of discomfort: in-chair movement. My thesis results have shown that in-chair movement was indicative of discomfort and sensitive to the effects of the chair and exercise interventions.

GLOSSARY OF THESIS ABBREVIATIONS

ANOVA	Analysis of Variance
ANSI	American National Standards Institute
ASHRAE	American Society of Heat, Refrigeration and Air Engineers
AVRS	Automated Voice Response System
AWT	Average Work Time
BPDS	Body Part Discomfort Scale
CFC	Chair Features Checklist
CI	Confidence Interval
COP	Center of Pressure
COG	Center of Gravity
COR	Center of Rotation
CSA	Canadian Standards Association
CW	Call Waiting
DA	Directory Assistance
EMG	Electromyography
FSR	Force Sensing Resistor
GCR	General Comfort Rating
GWT	Group Work Time
ICC	Intraclass Correlation Coefficient
ICM	In-chair Movement
IEMG	Integrated Electromyography
LMD	Localized Muscular Discomfort
MANOVA	Multivariate Analysis of Variance
MCH	Modified Cooper Harter
MT&T	Maritime Telegraph & Telephone
MVC	Maximum Voluntary Contraction
NBPD	Number of Body Parts [experiencing] Discomfort
NIOSH	National Institute of Occupational Safety and Health
PD	Perceived Discomfort
PE	Perceived Exertion
PNF	Proprioceptive Neuromuscular Facilitation
RPE	Rated Perceived Exertion (Borg, 1982)
ROM	Range of Motion
sdd	Smallest Detectable Difference
SE	Standard Error
SEM	Standard Error of Measurement
SPSS	Statistical Package for the Social Sciences
SWAT	Subjective Workload Assessment Technique
TLX	NASA Task Load Index
VDU	Video Display Unit
VERG	Vision Engineering Research Group

APPENDICES

Appendix 2.1 MTT Program

```
10 ' Program Name : MTT
20 ' Written By   : James Crouse
30 ' For          : Anne Fenety
35 ' Date         : April 30,1993
40 ' Purpose      : reducing FSS data files to comma delimited format
50 ' Remarks      : see comments throughout the program for explanations of
60 '               how the input from the data file is handled.
70 ' Modifications : July 8/93 - added 1.5 min and 2 min block parameters
98 '
99 '
100 KEY OFF : CLS : ' clears the screen for uncompiled versions of this program
198 '
199 '
200 DIM X(1900), Y(1900), T(1900)
210 DIM MAX(2), MAXP(2)
220 DIM MIN(2), MINP(2)
298 '
299 '
400 DIM F$(10)
410 DIM BL$(4) : ' the two sizes of blocks that may have been collected
420    BL$(1) = "5 minute blocks"
430    BL$(2) = "10 minute blocks"
434    BL$(3) = "1.5 minute blocks"
435    BL$(4) = "2 minute blocks"
440 CR$ = CHR$(13) : LF$ = CHR$(10) : 'printer Carriage return & line feed
450 ZC$ = CHR$(0) : ' the program looks for this to indicate the EOF
460 SD$ = "C" : DD$ = "C" : ' set the default SOURCE and DESTINATION drives
498 '
499 '
600 ' set default values and initialise some variables
610 TLIM = 575  : ' set default time limit beyond which data points are read in and discarded
620 DLIM = 1800 : ' set default data point limit beyond which data points are read in and discarded
630 BL = 2      : ' set default for 10 minute blocks of data
640 NB = 12     : ' set maximum number of blocks per data file at 12
998 '
999 '
1000 CLS
1010 PRINT SPC(10); "MAIN MENU"
1020 PRINT SPC(10); "---- ----"
1022 PRINT
1023 PRINT "Block Times available :"
1024 FOR I = 1 TO 4 : PRINT "  ";I;"/ ";BL$(I):NEXT
1030 PRINT
1040 PRINT "[1] Change source drive :          Currently set at drive "; SD$
1050 PRINT "[2] Change the destination drive : Currently set at Drive "; DD$
1060 PRINT "[3] Select Block Time :            Currently set at "; BL$(BL)
1070 PRINT "[4] Enter the name of the file to convert"
1080 PRINT "[5] Quit"
1090 PRINT
1100 LINE INPUT "Enter your option : "; KB$
1105 PRINT
1110 IF KB$ = "1" THEN GOSUB 1500: GOTO 1000
1120 IF KB$ = "2" THEN GOSUB 1600: GOTO 1000
1130 IF KB$ = "3" THEN GOSUB 1700: GOTO 1000
1140 IF KB$ = "4" THEN GOSUB 2000: GOTO 1000
1150 IF KB$ = "5" THEN CLS : LOCATE 10,38 : PRINT "-bye-" : END
1160 BEEP: GOTO 1000
1180 '
1190 '
```

```
1500 LINE INPUT "Enter the new Source Drive (A,B,C,D) : "; SD$
1510 IF SD$ = "a" OR SD$ = "A" OR SD$ = "b" OR SD$ = "B" OR SD$ = "c" OR SD$ = "C" OR SD$ = "d" OR SD$ =
"D" THEN RETURN
1520 BEEP: GOTO 1500
1540 '
1550 '
1600 LINE INPUT "Enter the new Destination Drive (A,B,C,D) : "; DD$
1610 IF DD$ = "a" OR DD$ = "A" OR DD$ = "b" OR DD$ = "B" OR DD$ = "c" OR DD$ = "C" OR DD$ = "d" OR DD$
= "D" THEN RETURN
1620 BEEP: GOTO 1500
1640 '
1650 '
1700 ' toggle the block length between 5 minute and 10 minute
1705 LINE INPUT "Enter the # corresponding to the required block time : ";BTN$
1710 ' IF BL = 1 THEN BL = 2: DLIM = 1800: TLIM = 575 : RETURN
1720 ' IF BL = 2 THEN BL = 1: DLIM = 900:  TLIM = 265 : RETURN
1730 IF BTN$ = "1" THEN BL = 1: DLIM = 900: TLIM = 265 : RETURN
1740 IF BTN$ = "2" THEN BL = 2: DLIM = 1800: TLIM = 575 : RETURN
1750 IF BTN$ = "3" THEN BL = 3: DLIM = 280: TLIM = 89 : RETURN
1760 IF BTN$ = "4" THEN BL = 4: DLIM = 370: TLIM = 119 : RETURN
1770 BEEP : GOTO 1705
2000 ' main analysis loop. Originally set up to do up to 10 files but not any more
2005 ' The FOR-NEXT loop was left intact with the loop limit of NF=1
2010 PRINT : PRINT
2015 LINE INPUT "Enter the name of the file to convert : "; F$
2020 NF = 1
2030 FOR F = 1 TO NF
2040     F1$ = SD$ + ":" + F$
2050     F2$ = DD$ + ":" + LEFT$(F$, LEN(F$) - 2) + "rd" : ' reduced file
2060     F3$ = DD$ + ":" + LEFT$(F$, LEN(F$) - 2) + "tx" : ' text file
2070     OPEN F1$ FOR INPUT AS #1
2080     OPEN F2$ FOR OUTPUT AS #2
2090     OPEN F3$ FOR OUTPUT AS #3
2100     GOSUB 3000
2110     PRINT #2, 0 : ' zero indicates the end of the file (easier for BASIC to check for this than end EOF marker)
2120     CLOSE #1
2130     CLOSE #2
2135     CLOSE #3
2140 NEXT
2150 RETURN
2160 '
2170 '
3000 ' analysis subroutine
3002   ' 4000 : get the overall header at the biginning of the data file
3004   ' 5000 : read in the header for a 5-minute block
3006   ' 6000 : read in data points (x,y,t) until the end of the block is encountered (see 6000 for conditions)
3008   ' 8000 : find the MAX and MIN X and Y within the data block AND their locations in the block
3010   ' 7000 : append then block to the data file
3012 '
3016 GOSUB 4000 : IF EOF(1) THEN RETURN
3018 B = 1
3020   PRINT #3, "=========================================================="
3030   PRINT #3, "Block"; B; " , File : "; F1$
3040   PRINT     "Reducing block "; B; " , File : "; F1$
3050 GOSUB 5000: IF EOF(1) THEN RETURN
3060 IF B = 1 THEN T0 = TS : ' time zero is defined by the start time of the first block
3070   PRINT #3, "       Start Time   :"; TS; "(HMS :"; H; ":"; M; ":"; S; ")"
3080   PRINT #3, "       Elapsed Time :"; TS - T0; "sec"
3090 GOSUB 6000: GOSUB 8000: GOSUB 7000
3100 IF EOF(1)   THEN RETURN
3101 IF EFILE = 1 THEN PRINT #3,"abnormal end of file" : RETURN
3105 B = B + 1
```

```
3110 GOTO 3020
3120 '
3130 '
4000 PRINT "      -> reading overall header"
4010 IF EOF(1) THEN RETURN
4020 FOR I = 1 TO 4
4030     GOSUB 9000
4040 NEXT
4050 RETURN
4060     PRINT "           '"; S$; "'" : ' debug print statement for the loop
4070 '
4080 '
5000 PRINT "      -> reading 5 minute block header lines"
5010 IF EOF(1) THEN RETURN
5020 GOSUB 9000 : T$ = S$ : GOSUB 5090
5030 FOR I = 1 TO 3
5040     GOSUB 9000
5045     PRINT "     '";S$;"'"
5050 NEXT
5060 RETURN
5080 '
5090 ' find the numeric value of the time string
5095    S = VAL(RIGHT$(T$, 5)): T$ = LEFT$(T$, LEN(T$) - 6)
5100    M = VAL(RIGHT$(T$, 2)): T$ = LEFT$(T$, LEN(T$) - 3)
5110    H = VAL(RIGHT$(T$, 2))
5120    TS = 3600 * H + 60 * M + S
5130 RETURN
5140 '
5150 '
6000 PRINT "      -> Reading data points (x,y,t)"
6010 GOSUB 6200
6020    PRINT #3, "      Number of data points (read,saved) : ("; I-1; ","; DNUM ;")"
6030    PRINT  "      Number of data points (read,saved) : ("; I-1; ","; DNUM ;")"
6040    PRINT #3, "      Total Collection time for block .. : ";T(I-1)
6050    PRINT  "      Total Collection time for block .. : ";T(I-1)
6060    PRINT #3, "      Data saved up to ................. : ";T(DNUM); "sec"
6070    PRINT  "      Data saved up to ................. : ";T(DNUM); "sec"
6080 '
6090 PRINT "      -> Correcting the time for Block"; B
6095 ' this is relative to T=0 at the start of block #1
6100    FOR I = 1 TO DNUM
6110        T(I) = T(I) + (TS - T0)
6120    NEXT
6130 RETURN
6140 '
6150 '
6200 ' The final IF statement is true ONLY at the data point where TLIM is exceeded.
6201 'DLIM (chosen in the MAIN MENU via the Block Length) will always be greater than the maximum
6202 ' # of data points the program should have collected. i.e. when exceeded something is wrong
6203 ' with the end of the file
6205 FOR I = 1 TO DLIM
6210     GOSUB 9000
6215     IF EFILE = 1 THEN RETURN
6220     IF LEN(S$) < 10 THEN RETURN
6230     X(I) = VAL(LEFT$(S$, 6))
6240     Y(I) = VAL(MID$(S$, 7, 9))
6250     T(I) = VAL(RIGHT$(S$, 8))
6260     IF (T(I) > TLIM) THEN IF (T(I-1) <= TLIM) THEN DNUM = I-1
6270 NEXT
6280 IF I > DLIM THEN PRINT I;" data points read - there must be something wrong - aborting (sorry) " : END
6290 ' IF B = 2 THEN PRINT I, x(I), y(I), t(I): PRINT "      '"; S$; "'"
6300 '
```

```
6310 '
7000 PRINT "     -> writing data from block"; B; " to "; F2$
7001 ' "WRITE" automatically delimits with commas but number can't be saved in a format
7002 ' as with "PRINT USING".
7003 ' PRINT USING was used due to BASIC's number storage sometimes causing, for example,
7004 ' 7.9 to be printed (unformatted) as 7.900001 or 7.89999
7010   PRINT #2, B
7020   PRINT #2, DNUM
7030   WRITE #2, MIN(1), MAX(1)
7040   WRITE #2, MIN(2), MAX(2)
7050   FOR I = 1 TO DNUM
7060      PRINT #2, USING "##.##_,"; X(I), Y(I);
7070      PRINT #2, USING "####.##"; T(I)
7080   NEXT
7090 RETURN
7100 '
7110 '
8000 PRINT "     -> finding MAX and MIN"
8010 MAX(1) = -1E+20: MAX(2) = -1E+20 : ' set to ridiculous values at first
8020 MIN(1) =  1E+20: MIN(2) =  1E+20
8030 MAXP(1) = 1: MAXP(2) = 1
8040 MINP(1) = 1: MINP(2) = 1
8050 FOR J = 1 TO DNUM
8060    IF X(J) > MAX(1) THEN MAX(1) = X(J): MAXP(1) = J
8070    IF X(J) < MIN(1) THEN MIN(1) = X(J): MINP(1) = J
8080    IF Y(J) > MAX(2) THEN MAX(2) = Y(J): MAXP(2) = J
8090    IF Y(J) < MIN(2) THEN MIN(2) = Y(J): MINP(2) = J
8100 NEXT
8110 PRINT #3, "         x (min,max) : (";
8120 PRINT #3, USING "####.##  "; MIN(1); MAX(1);
8130 PRINT #3, ") @ (";
8140 PRINT #3, USING "####.##  "; MINP(1); MAXP(1);
8150 PRINT #3, ")"
8160 PRINT #3, "         y (min,max) : (";
8170 PRINT #3, USING "####.##  "; MIN(2); MAX(2);
8180 PRINT #3, ") @ (";
8190 PRINT #3, USING "####.##  "; MINP(2); MAXP(2);
8200 PRINT #3, ")"
8210 RETURN
8220 '
8230 '
9000 ' This routine reads characters in 1 at a time. BASIC's string input function would not retain
9001 ' the leading zeros thereby throwing off the expected format. This routine constructs a string
9002 ' which is of known format and can be reliably decomposed.
9003 ' A CR,LF pair indicates the end of a line of data.
9004 ' A ZC$=CHR$(0) indicates an end of file but BASIC doesn't seem to recognise this
9005 ' so we have to check for it
9006 ' The upper limit of C=100 is well past the lenth of any expected string length
9007 ' so if reached something is wrong and this is recorded in the text file before termination.
9010 '
9015 S$ = ""   : ' start with a null string
9020 EFILE = 0 : ' flag to indicate if an abnormal end of file was encountered
9025 FOR C = 1 TO 100
9030    IF EOF(1) THEN RETURN
9035    C$ = INPUT$(1,1)
9040    IF C$ = LF$ OR C$ = CR$ THEN C$ = INPUT$(1,1) : RETURN
9045    IF C$ = ZC$ THEN EFILE = 1 : RETURN
9050    S$ = S$ + C$
9060 NEXT
9070 PRINT "something wrong in read-in routine - sorry"
9075 PRINT "(actually its with the data being read not the program)"
9080 PRINT "Block #:";B
```

```
9090 PRINT "Data Point : ";I
9100 PRINT "Character Count : ";C
9115 GOSUB 9200
9150 PRINT #3,"Block # ....... : ";B
9160 PRINT #3,"Data Point .... : ";I
9170 PRINT #3,"Character Count : ";C
9180 GOSUB 9300
9190 END
9198 '
9199 '
9200 FOR CS = 1 TO LEN(S$)
9210     S1 = ASC(MID$(S$,CS,1)) : S1$ = CHR$(S1)
9220     PRINT "   =>[";CS;"]";S1;",";
9230     IF S1>31 AND S1<127 THEN PRINT "'";S1$;"'" ELSE PRINT
9240 NEXT
9250 PRINT
9260 RETURN
9290 '
9300 FOR CS = 1 TO LEN(S$)
9310     S1 = ASC(MID$(S$,CS,1)) : S1$ = CHR$(S1)
9320     PRINT #3,"   =>[";CS;"]";S1;",";
9330     IF S1>31 AND S1<127 THEN PRINT #3,"'";S1$;"'" ELSE PRINT #3,
9340 NEXT
9350 PRINT #3,
9360 RETURN
```

Appendix 2.2 Final Program

```
10 ' Program Name : FINAL2
12 ' Written By :  James Crouse
14 ' For          : Anne Fenety
16 ' Date         : April 30, 1993
 8 ' Purpose      : analyse data from reduced data files produced by the program 'MTT'
20 ' Remarks      : data are stored in separate data files to facilitate analysis by SPSS
30 '              : defined missing value as -100
48 '
49 '
50 KEY OFF: CLS :  'clears the screen when running uncompiled versions of this program
60 OPTION BASE 1
98 '
99 '
100 DIM STATS(9, 24), XY(2, 2000), T(2000)
110 SID = 0
120 T1 = 0: T2 = 260:   ' 4min 20 sec
130 '
140 '
200 DIM OPTS$(3), OPTS(3), YN$(2), FILENAME$(2), EXT$(7), F$(10)
210 OPTS$(1) = "Px,Py": OPTS(1) = 1
220 OPTS$(2) = "L,Lx,Ly": OPTS(2) = 1
230 OPTS$(3) = "R,Rs": OPTS(3) = 1
240 YN$(1) = "YES": YN$(2) = "NO"
250 FILENAME$(1) = "none": FILENAME$(2) = "none"
260 '
270 EXT$(1) = "px": EXT$(2) = "py"
280 EXT$(3) = "l": EXT$(4) = "lx": EXT$(5) = "ly"
290 EXT$(6) = "r": EXT$(7) = "rs"
300 '
310 '
1000 CLS
1010 PRINT SPC(10); "MAIN MENU"
1020 PRINT SPC(10); "---------"
1030 PRINT
1040 GOSUB 1500
1050 PRINT
1060 PRINT "You may:"
1070 PRINT "    [1] Change the current analysis settings"
1080 PRINT "    [2] Select the files to analyse ........ ("; FILENAME$(1); " , "; FILENAME$(2); ")"
1090 PRINT "    [3] Enter the Subject ID ............... ("; SID; ")"
1100 PRINT "    [4] Select the analysis window ......... ("; T1; ","; T2; ")"
1110 PRINT "    [5] Analyse the selected files"
1120 PRINT "    [6] Quit"
1130 LINE INPUT "Enter your option : "; KB$
1140 IF KB$ = "1" THEN GOSUB 3000: GOTO 1000
1150 IF KB$ = "2" THEN GOSUB 4000: GOTO 1000
1160 IF KB$ = "3" THEN GOSUB 5000: GOTO 1000
1170 IF KB$ = "4" THEN GOSUB 5050: GOTO 1000
1180 IF KB$ = "5" THEN GOSUB 10000: GOTO 1000
1190 IF KB$ = "6" THEN GOSUB 2000
1200 BEEP
1210 GOTO 1000
1220 '
1230 '
1500 PRINT "Current Analysis Settings:"
1510 FOR I = 1 TO 3
1520     PRINT "    ["; I; "] "; OPTS$(I); LEFT$("          ", 10 - LEN(OPTS$(I))); ": "; YN$(OPTS(I))
1530 NEXT
1540 RETURN
1550 '
```

```
1560 '
2000 CLS
2010 LOCATE 10, 38
2020 PRINT "- bye -"
2030 LOCATE 1, 1
2040 END
2050 '
2060 '
3000 CLS
3010 GOSUB 1500
3020 PRINT
3030 PRINT "Enter the number of the option to change"
3040 PRINT "            OR"
3050 LINE INPUT "Enter 0 to return to the MAIN MENU : "; KB$
3060 IF KB$ = "0" THEN RETURN
3070 KB = INT(VAL(KB$) + .1): IF KB < 1 OR KB > 3 GOTO 3000
3080 IF OPTS(KB) = 1 THEN OPTS(KB) = 2 ELSE OPTS(KB) = 1
3090 GOTO 3000
3100 '
3110 '
4000 CLS
4010 LINE INPUT "Enter the name of the 1st file : "; FILENAME$(1)
4020 LINE INPUT "Enter the name of the 2nd file : "; FILENAME$(2)
4030 RETURN
4040 '
4050 '
5000 CLS
5010 INPUT "Enter the Subject's ID : "; SID
5020 RETURN
5030 '
5040 '
5050 CLS
6000 PRINT "NOTE : It will be up to you to make sure that the time interval you select"
6010 PRINT "       is appropriate for the length of the file you are having analysed!"
6020 PRINT
6030 LINE INPUT "Enter the interval Start Time (in seconds) : "; T1$
6040 LINE INPUT "Enter the interval End Time (in seconds)   : "; T2$
6050 T1 = VAL(T1$): T2 = VAL(T2$)
6060 IF T2 <= T1 THEN BEEP: GOTO 5050
6070 RETURN
6080 '
6090 '
10000 CLS
10010 IF FILENAME$(1) = "none" OR FILENAME$(2) = "none" THEN GOSUB 10220: RETURN
10020 IF SID = 0 THEN GOSUB 10170: RETURN
10030 '
10040 BN = 0:  ' ensure the first files' data is seen as starting with block #1
10050    DFILE$ = FILENAME$(1)
10060    GOSUB 11000 : 'analyse this file
10070 BN = 12:  ' ensure the second files' data is seen as starting with block #13
10080    DFILE$ = FILENAME$(2)
10090    GOSUB 11000 : 'analyse this file
10100 GOSUB 16000 : 'save the analysed data
10105 ' reset the contents of STATS to 0 in case another set of files is to be analysed
10110 FOR I = 1 TO 7
10120     FOR J = 1 TO 24: STATS(I, J) = 0: NEXT
10130 NEXT
10140 RETURN
10150 '
10160 '
10170 PRINT "You have not entered the Subject's ID # !"
10180 GOSUB 60000
```

```
10190 RETURN
10200 '
10210 '
10220 PRINT "You must choose the file(s) to analyse first !"
10230 GOSUB 60000
10240 RETURN
10250 '
10260 '
10270 '
11000 ' B = 0 means the end of the data file has been reached
11005 DFILE$ = LEFT$(DFILE$, LEN(DFILE$) - 2) + "rd"
11010 PRINT "File to b  analysed : "; DFILE$
11020 OPEN DFILE$ FOR INPUT AS #1
11030 INPUT #1, B: IF B = 0 THEN CLOSE #1: RETURN
11050   BN = BN + 1
11060   GOSUB 17000 : 'read the data and check for values outside the range
11070   IF OFLAG = 0 THEN GOSUB 11200 : 'data are fine - do stats
11080   IF OFLAG = 1 THEN GOSUB 11300 : 'data bad - set stats values as missing values i.e. -100
11110   PRINT
11120   GOTO 11030
11130 RETURN
11140 '
11150 '
11199 '
11200 GOSUB 12000
11210 IF OPTS(1) = 1 THEN GOSUB 13000 : ' find the mean and SD of X and Y
11220 IF OPTS(2) = 1 THEN GOSUB 14000 : ' find the mean and SD of L, Lx and Ly
11230 IF OPTS(3) = 1 THEN GOSUB 15000 : ' find the mean and Sd of the Radius
11240 PRINT
11250 RETURN
11299 '
11300 FOR C = 1 TO 9
11310    STATS(C,BN)=-100
11320 NEXT
11330 RETURN
11998 '
11999 '
12000 PRINT "      => finding data points for time window ("; T1; ","; T2; ")"
12010 TA1 = T(1) + T1: DA1 = 1
12020 TA2 = T(1) + T2: DA2 = DNUM
12030 FOR I = 1 TO DNUM
12040   IF T(I) < TA1 THEN DA1 = I
12050   IF T(I) < TA2 THEN DA2 = I
12060 NEXT
12070 NPTS = DA2 - DA1 + 1
12080 PRINT "         => Start (t,d) : ("; TA1; ","; DA1; ")"
12090 PRINT "         => End   (t,d) : ("; TA2; ","; DA2; ")"
12100 RETURN
12110 '
12120 '
13000 PRINT "      => finding mean and sd of X and Y"
13010 FOR C = 1 TO 2:  '1=X, 2=Y
13020    S1 = 0: S2 = 0
13030    FOR I = DA1 TO DA2
13040       S1 = S1 + XY(C, I) ^ 2: S2 = S2 + XY(C, I)
13050    NEXT
13060    STATS(C, BN) = S2 / NPTS
13070    STATS(C + 7, BN) = SQR((S1 - (S2 ^ 2) / NPTS) / (NPTS - 1))
13080 NEXT
13090 PRINT "         => mean (x,y) : ("; STATS(1, BN); ","; STATS(2, BN); ")"
13100 PRINT "         => SD   (x,y) : ("; STATS(8, BN); ","; STATS(9, BN); ")"
13110 RETURN
```

```
13120 '
13130 '
14000 PRINT "     => finding the line length"
14010 L = 0: LX = 0: LY = 0
14020 FOR I = DA1 TO (DA2 - 1)
14030    D1 = XY(1, I + 1) - XY(1, I): D2 = XY(2, I + 1) - XY(2, I)
14040    L = L + SQR(D1 ^ 2 + D2 ^ 2): LX = LX + ABS(D1): LY = LY + ABS(D2)
14050 NEXT
14060 STATS(3, BN) = L: STATS(4, BN) = LX: STATS(5, BN) = LY
14070 PRINT "        => line length (total) : ("; L; ")"
14080 PRINT "        => line length (x,y)   : ("; LX; ","; LY; ")"
14090 RETURN
14100 '
14110 '
15000 PRINT "     => finding Radius mean and std dev"
15010 IF OPTS(1) = 2 THEN GOSUB 13000
15020 S1 = 0: S2 = 0
15030 FOR I = DA1 TO DA2
15040    R = SQR((STATS(1, BN) - XY(1, I)) ^ 2 + (STATS(2, BN) - XY(2, I)) ^ 2)
15050    S1 = S1 + R ^ 2: S2 = S2 + R
15060 NEXT
15070 STATS(6, BN) = S2 / NPTS
15080 STATS(7, BN) = SQR((S1 - (S2 ^ 2) / NPTS) / (NPTS - 1))
15090 PRINT "        => mean radius : ("; STATS(6, BN); ")"
15100 PRINT "        => SD   radius : ("; STATS(7, BN); ")"
15110 RETURN
15120 '
15130 '
16000 PRINT "  => saving the analysed data"
16010 SID$ = STR$(SID)
16020 FOR F = 1 TO 7
16030    F$(F) = LEFT$(FILENAME$(1), LEN(FILENAME$(1)) - 2) + EXT$(F)
16040    PRINT "     => writing to "; F$(F)
16050    OPEN F$(F) FOR OUTPUT AS #1
16060    PRINT #1, RIGHT$(SID$, LEN(SID$) - 1)
16070    I1 = 1: I2 = 6: GOSUB 16150
16080    I1 = 7: I2 = 12: GOSUB 16150
16090    I1 = 13: I2 = 18: GOSUB 16150
16100    I1 = 19: I2 = 24: GOSUB 16150
16110    CLOSE #1
16120 NEXT
16130 RETURN
16140 '
16150 ' ensure the data are delimited by a single space (for SPSS)
16155 FOR I = I1 TO I2
16156    IF ABS(STATS(F, I)) < .0001 THEN STATS(F, I) = -100
16160    S$ = STR$(STATS(F, I))
16170    IF STATS(F, I) < 0 THEN S$ = " " + S$
16180    PRINT #1, S$;
16190 NEXT
16200 PRINT #1,
16210 RETURN
16220 '
16230 '
17000 PRINT "  => reading data from "; DFILE$; " block #"; BN; " ("; B; ")"
17010 INPUT #1, DNUM
17020 INPUT #1, XMIN, XMAX
17030 INPUT #1, YMIN, YMAX
17040 FOR I = 1 TO DNUM
17050    INPUT #1, XY(1, I), XY(2, I), T(I)
17060 NEXT
17070 OFLAG = 0
```

```
17080 FOR I = 1 TO DNUM
17090     IF XY(1, I) < 0 OR XY(1, I) > 45 THEN OFLAG = 1: RETURN
17095     IF XY(2, I) < 0 OR XY(2, I) > 45 THEN OFLAG = 1: RETURN
17100 NEXT
17110 RETURN
17380 '
17390 '
60000 PRINT
60010 LINE INPUT "Press return to go back to the MAIN MENU"; KB$
60020 RETURN
```

Appendix 2.3 Speed Tests X, Y Axes

Instantaneous speed in cm/sec calculated for the X and Y axes from the X and Y coordinates measured during the Dynamic Validation tests and centered around zero

SAMPLE	VERG1_X	KIST1_X	VERG2_Y	KIST2_Y
1.00	.05	.04	.00	.00
2.00	.79	.74	.02	.02
3.00	4.66	4.67	.04	.02
4.00	.82	.73	.02	.03
5.00	5.35	5.40	.15	.02
6.00	.11	.13	.50	.49
7.00	.35	.41	.63	.78
8.00	3.37	3.41	.25	.14
9.00	1.71	1.81	.09	.02
10.00	.20	.14	.05	.12
11.00	2.88	2.88	.02	.07
12.00	2.07	2.06	.13	.15
13.00	.55	.54	.04	.00
14.00	.36	.30	.13	.07
14.00	.52	.49	.00	.00
15.00	.70	.68	.00	.03
16.00	3.10	3.07	.04	.04
17.00	.88	.92	.08	.04
18.00	.33	.30	.28	.20
19.00	.06	.08	.35	.54
20.00	.02	.04	.66	.49
21.00	.07	.11	.31	.58
22.00	.13	.15	.18	.32
23.00	.20	.05	.02	.05
24.00	1.93	1.95	.00	.12
25.00	2.51	2.42	.02	.02

Appendix 2.4 Dynamic Validation Study

Dynamic Validation Tests: Raw Data of COP position recorded simultaneously by the force platform (in cm) and the interface mat (in inches, converted to cm) for the: 1. X axis and 2. Y axis.

1. X Axis Test:

(A) *Kistler Force Platform*
File: Ann7_FP.3Hz

Time,	Ax,	Ay
0.00000,	3.275,	-.490
0.33333,	4.395,	-.550
0.66667,	3.262,	-1.290
1.00000,	3.262,	3.382
1.33333,	3.262,	4.111
1.66667,	3.290,	-1.292
2.00000,	3.262,	-1.421
2.33333,	3.241,	-1.830
2.66667,	3.241,	1.582
3.00000,	3.241,	3.390
3.33333,	4.395,	3.252
3.66667,	4.297,	.369
4.00000,	3.226,	-1.692
4.33333,	4.053,	-1.154
4.66667,	3.226,	-.848
5.00000,	3.299,	-.361
5.33333,	4.048,	-1.040
5.66667,	4.048,	2.031
6.00000,	4.024,	3.011
6.33333,	4.048,	2.712
6.66667,	4.072,	2.58[illegible]
7.00000,	4.072,	2.632
7.33333,	4.072,	2.518
7.66667,	4.370,	2.672
8.00000,	4.395,	2.717
8.33333,	3.290,	.772
8.66667,	3.712,	-1.530
9.00000,	3.639,	-.889

(B) *VERG System*
File: Ann7_mat.3Hz

Time,	X,	Y
0.00,	9.01,	9.36
0.33,	8.99,	9.23
0.66,	8.63,	8.97
1.00,	10.75,	9.14
1.33,	11.12,	9.04
1.66,	8.69,	8.93
2.00,	8.64,	8.93
2.33,	8.48,	8.95
2.66,	10.01,	8.98
3.00,	10.79,	8.91
3.33,	10.70,	8.66
3.66,	9.39,	8.61
4.00,	8.45,	8.42
4.33,	8.70,	8.49
4.66,	8.86,	8.67
5.00,	9.10,	8.75
5.33,	8.78,	8.77
5.66,	10.19,	8.88
6.00,	10.59,	8.93
6.33,	10.44,	8.93
6.66,	10.41,	8.83
7.00,	10.42,	8.84
7.33,	10.39,	9.00
7.66,	10.45,	8.81
8.00,	10.54,	8.35
8.33,	9.66,	8.71
8.66,	8.52,	8.91
9.00,	8.85,	8.98

2. Y Axis Test:

(A) *Kistler Force Platform*
File: Ann2_FP.3Hz

Time,	Ay,	Ax
0.00000,	-1.685,	5.688
0.33000,	-1.685,	5.664
0.66000,	-1.660,	5.664
1.00000,	-1.685,	5.688
1.33000,	-1.709,	5.640
1.66000,	-1.733,	5.664
2.00000,	-2.222,	5.493
2.33000,	-3.101,	5.322
2.66000,	-3.247,	5.322
3.00000,	-3.271,	5.371
3.33000,	-3.052,	5.371
3.66000,	-2.979,	5.371
4.00000,	-2.979,	5.347
4.33000,	-2.832,	5.396
4.66000,	-2.759,	5.420
5.00000,	-2.759,	5.420
5.33000,	-2.734,	5.420
5.66000,	-2.686,	5.493
6.00000,	-2.734,	5.493
6.33000,	-2.832,	5.420
6.66000,	-2.295,	5.640
7.00000,	-1.904,	5.737
7.33000,	-1.318,	5.835
7.66000,	-0.781,	6.079
8.00000,	-0.659,	6.128
8.33000,	-0.806,	6.128
8.66000,	-0.928,	6.006
9.00000,	-0.806,	6.030

(B) *VERG System*
File: Ann2_mat.3Hz

Time,	X,	Y
0.00,	9.95,	8.71
0.33,	9.95,	8.71
0.66,	9.96,	8.71
1.00,	9.94,	8.71
1.33,	9.95,	8.72
1.66,	9.88,	8.74
2.00,	9.61,	8.77
2.33,	9.32,	8.70
2.66,	9.21,	8.70
3.00,	9.25,	8.67
3.33,	9.27,	8.66
3.66,	9.28,	8.67
4.00,	9.34,	8.66
4.33,	9.36,	8.65
4.66,	9.39,	8.61
5.00,	9.39,	8.64
5.33,	9.39,	8.63
5.66,	9.41,	8.62
6.00,	9.37,	8.63
6.33,	9.50,	8.60
6.66,	9.66,	8.61
7.00,	9.96,	8.63
7.33,	10.10,	8.56
7.66,	10.18,	8.54
8.00,	10.19,	8.56
8.33,	10.14,	8.59
8.66,	10.14,	8.57
9.00,	10.15,	8.57

Appendix 2.5 Calibration Trials

(1) Trunk Inclination: Sagittal Plane Flexion (positive ROM) and Extension (negative ROM)

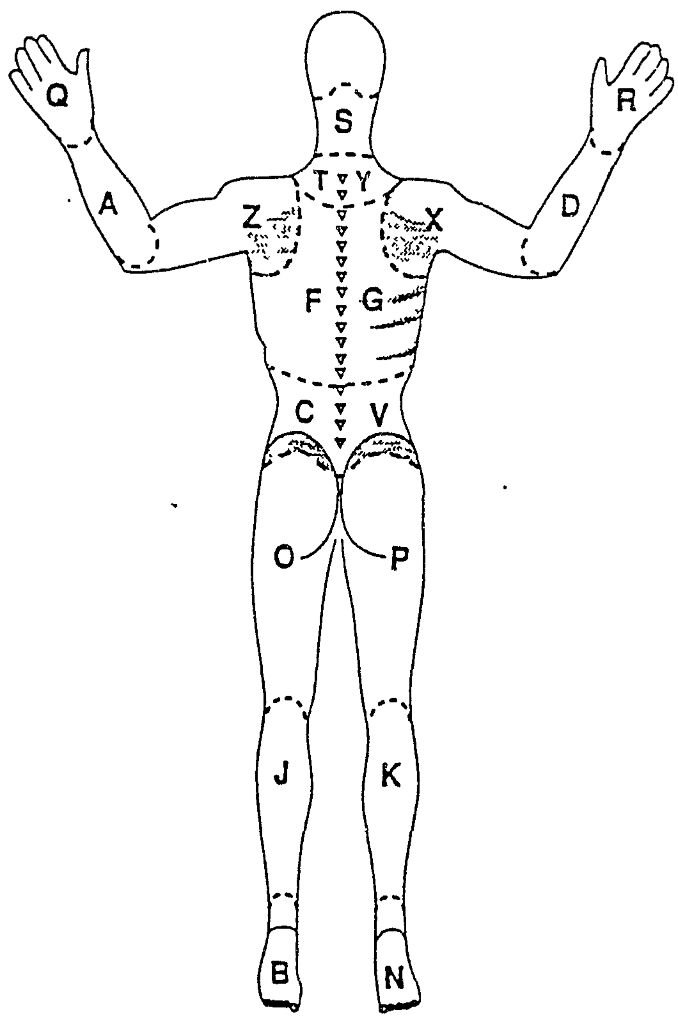
Male		Female	
COP	ROM^0	COP (cm)	ROM^0
18.4	-28	21.1	-28
18.7	-24	21.1	-25
19.1	-18	21.7	-22
19.2	-12	21.9	-18
19.7	-9	22.1	-16
20.6	-6	22.4	-8
21.7	0	23.8	0
22.4	8	24.4	2
22.6	15	25.3	7
23	24	26.6	15
23.5	35	29.4	25
24.9	44	30.6	36
25	52	30.8	44
26.9	62	31.1	48
28.4	66	31.2	50

(2) Lateral Trunk Flexion:

Male		Female	
COP	ROM^0	COP (cm)	ROM^0
25.5	0	24.2	0
23.3	9	24.0	2
20.5	16	21.2	12
18.5	21	18.6	17
18	26	17.3	21
17.7	27	17.2	26
16.9	30	16.6	28
16.4	33	16.5	29

Appendix 3.1 Discomfort Map, Scale

This map, the *Localized Muscular Discomfort (LMD)* map (Van der Grinten, 1992), was used by subjects to localize their body part discomfort. After localizing their discomfort and identifying it by the appropriate letter, subjects rated it on the 0 to 5 *Body Part Discomfort Scale*, shown here under the LMD map.



0	1	2	3	4	5
No Discomfort	Just Noticeable Discomfort	Little Discomfort	Moderate Discomfort	High Discomfort	Intolerable Discomfort

Appendix 3.2 Informed Consent for Research Study

"Factors influencing sitting comfort in the workplace"

This consent form is a detailed explanation of the workplace sitting comfort study which is scheduled to take place at Maritime Telephone & Telegraph (MT&T) beginning in October, 1992. The information is contained in three Sections: -A- Introduction, -B- Test Procedures and -C- Signed Consent.

You are asked to read each section carefully. Feel free to ask any questions about the nature of the study and the requirements of you as a participant. If you choose to volunteer, your initials are required after Section B and your signature is required at the end of the consent.

Principal Investigator:	Anne Fenety, MScPT 494-2524 (W)
Advisors:	Joan Walker, PhD 494-2524
	Richard Wassersug, PhD 494-2244
Date:	August 25, 1992

SECTION -A- INTRODUCTION

Overview

Today's workplace has undergone many changes. Heavy, manual labor has been replaced by light tasks and desk work. This has led to more workers spending prolonged periods of their day in sitting.

In this study, my main interest is the effect that prolonged periods of sitting have on worker comfort. Other possible work-related influences on sitting comfort will be evaluated such as chair design, time of day and workload. The last factor to be evaluated is the effect that regular performance of 'Dataspan' exercises has on your comfort.

Study Purposes

The purposes of the study in which you are asked to participate are as follows. As you sit working at your computer terminal for periods of up to two hours, I would like to measure the effects that:

1. the amount of time spent in continuous sitting
2. the time of day tested (AM or PM)
3. the type of chair (standard versus experimental)
4. the use or non-use of the Dataspan exercises
5. variations in incoming call volume

have on:

1. your rating of body comfort
2. your rating of how hard you worked
3. objective comfort rating (measured by the pressure mat)
4. your rating of chair comfort ('new' versus 'standard' chair)
5. your call counts measured over the test period.

Participation in this study is entirely voluntary. The benefits to volunteers are not financial, but include such things as changes in your regular routine, learning about comfort and participating in a study which could benefit a variety of computer based workers. All participants have the right to withdraw at any time, for any reason with no recrimination on the part of the researcher or MT&T.

This research is wholly independent of MT&T management and was developed by me with the cooperative efforts of the Atlantic Communication & Technical Workers Union (AC&TWU) and the management of MT&T. This study is designed as pure research only and making recommendations to MT&T based on the results is not an intent of this study. The Human Ethics Review Committee of Dalhousie University has reviewed and approved this project.

Study Measurements

Pressure Distribution: As you sit, the downward pressure of your trunk is carried on a chair by your hip bones and thighs. In this study, a pressure sensing mat, which is the size of the chair seat will be used to monitor changes in your seated pressure distribution at regular intervals (1 min ON; 1 min OFF). The pressure mat will be placed between you and your chair seat.

You will be asked to evaluate your sitting comfort by rating the comfort of the chair and your own body. Your perceived work intensity, which is defined as how hard you think you worked in a given time period, is also rated on a scale.

Rating Scales: To rate body comfort, chair comfort or perceived work intensity requires you to make a mark on a line graded from zero to three (or from unacceptable to acceptable) at the point that represents your rating of comfort or work intensity. Completion of each of these scales should require 15 to 45 seconds each.

SECTION B: Testing Procedures

Up to 60 volunteers who have met the admission criteria and agreed to participate in the study will be randomly assigned to at least one of the following three test groups: Group 1 REPEAT TESTS, Group 2 AM/PM TESTS or Group 3 CHAIR TESTS. Volunteers who wish to participate in more than one group should notify me.

Prior to the start of the test sessions, you will be given a health questionnaire that will take 15 minutes to complete. The information received in this questionnaire will remain confidential and will only be used to determine your study eligibilty. In addition, you will be introduced to the three rating scales you will use to rate your comfort, the comfort of the chair and your perceived work intensity.

GROUP 1: Repeat Tests

The purpose of these tests will be to establish the day-to-day <u>repeatability</u> of the three ratings scales (your comfort, chair comfort and perceived work intensity) and the pressure mat readings.

If you are selected for this group you will be tested twice while seated at your workstation performing your regular duties. You will sit for one hour on the pressure mat from which recordings of pressure distribution will be obtained at regular intervals.

You will be asked to complete the three rating scales at the start and again at the end of the one hour test. At the completion of the test, the mat will be removed and you will return to work. The second test session will be held one day later and will be identical to the first test session.

GROUP 2: AM/PM Tests

The purpose of the <u>AM/PM tests</u> is to determine if the time of day (morning or afternoon) or the work intensity (i.e. call volume) affect your comfort, perceived work intensity and pressure distribution.

If you are selected for this group you will be tested three times while seated at your workstation performing your regular duties. Your pressure distribution will be recorded while you sit for two hours on the pressure mat. You will rate your comfort and work intensity at the start of the test session and again after 60 and 120 minutes.

The three test sessions will be scheduled as follows. During a weekday shift, you will be tested at the start of the morning shift and then later that same day in the afternoon. Your third test will take place during a morning weekend shift. All of your testing will be completed in one week.

One quarter of the Group 2 subjects will be randomly selected to be tested on a fourth occasion. The fourth test will take place on the afternoon of test day three.

GROUP 3: Chair Tests

The purpose of the Chair Tests is to determine if the Dataspan exercise routine and the use of an experimental chair affect your sitting comfort, pressure distribution and perceived work intensity. The experimental chair which you will evaluate is a 'passive' ergonomic chair, so named because the chair follows the movements of the operator. The Dataspan exercise routine is that presently in use at MT&T and includes eye relaxation, general movement, limbering and massage.

If you are selected for this group you will be tested three times while seated at your workstation performing your regular duties. Your pressure distribution will be recorded while you sit for two hours on the pressure mat. You will rate your comfort and work intensity at the start of the test session and again after 60 and 120 minutes.

The three test sessions will be conducted, where possible, on the same day of the week for three consecutive weeks. The first test will take place while you are sitting in an MT&T 'Concentrix' chair. The second test will take place after you have used the experimental ('passive') chair for one week. Prior to your third test, you will attend an inservice to learn standardized Dataspan breaks. During the one week period preceding the third test you will be asked to perform one 3 minute Dataspan break per hour. All of your testing will take place within a 14 day period.

One quarter of the Group 3 subjects will be randomly selected to be tested on a fourth occasion. This fourth test will be scheduled for the week following your third test session. All of the testing for subjects in this group will take place over a 21 day period.

Scheduling Procedures

I will attempt to fit your test dates around your work schedule. I ask that you advise me if there are conflicts with extended holidays or days off.

In spite of the best efforts at scheduling, I expect some problems to arise. Any of the scheduled tests may be re-scheduled if you have sustained any injury or health problem that affects your sitting ability or comfort. Similarly, the test will be re-scheduled if you feel that you would be unable to remain seated for the 2 hour test.

Requests to Volunteers

I will require the cooperation of all volunteers in two important areas. My first request is that during your test period (which varies from 2 to 21 days) you refrain from performing any strenuous activities such as spring cleaning or moving heavy furniture. Neither should you begin any new exercises or sports, nor dramatically increase the training level of any sport that you presently play. These requests are to ensure that your comfort is not affected by any aches or pains caused by these new activities. In the event that you can not avoid any of these activities, please notify me prior to your next test session.

My second request involves a change in your normal work organization. For the test sessions ONLY, I need you to extend the length of your work period (prior to break) by 15 minutes (from 105 to 120 min). That will allow me test over the two hour period recommended as the maximum duration of seated work.

Risks to Volunteers

The only risks involved could be minor muscle soreness associated with performing the Dataspan exercises with slightly greater frequency than you do at present. There are two possible inconveniences. The first is the temporary use of a new type of chair. The second is the extension of your maximum work period by 15 minutes.

I do hereby acknowledge that I have read Section -B- including Testing Procedures for Groups 1, 2 and 3 as well as Scheduling Procedures, Requests and Risks to Volunteers. These sections have been verbally explained to me and I have had my questions answered regarding these procedures.

______ initials

SECTION C: Signed Consent

I, ____________________, freely and voluntarily agree to participate in the research project "Factors Influencing Sitting Comfort in the Workplace" to be directed by Anne Fenety, Physiotherapist under the supervision of Joan Walker, PhD and Richard Wassersug, PhD and conducted at the Maritime Tel & Tel Directory Assistance Center in Halifax, beginning October, 1992.

I acknowledge that the nature and purpose of the study, the required procedures and the possible risks and benefits have been provided to me in writing and explained by the investigator. Any and all questions that have arisen have been answered to my satisfaction and I understand that I may ask questions regarding this study at any time.

I understand that participation is entirely voluntary and that no compensation is available to volunteers. I further understand that I have the right to withdraw from this study at any time, without sustaining any form of penalty.

The investigator has assured me that all records and photographs will be kept confidential and that access to my records will be restricted to those researchers directly related to this study. I understand that my written permission will be required to release any information or photographs that would reveal my identity, now and at any time in the future. I have been assured that my face will be concealed in any published photographs. As a participant I understand that I will receive a synopsis of the results.

In the unlikely event that any physical injury is sustained during this study, I understand that no compensation is available and that normal MT&T on-the-job accident protocols will be followed.

If concerns or questions regarding this project arise during or after this study, I understand that I may contact the investigator, Anne Fenety at 494-2524 (work) or 425-3169 (home) or Dr. Walker (494-2524) or Dr. Wassersug (494-2244). I have read and understand the contents of this form. I understand I will receive a copy of this signed consent form.

____________________ ____________________

Participant Date Witness Date

I have explained in detail the study procedures to which the subject has consented to participate.

____

Researcher Date

Appendix 3.3 MT&T On-Site Report

DATED: July 13, 1992

This document contains the results of evaluations of the North & Agricola (Halifax) MT&T Operator Services worksites from July 8 to 13, 1992. These measurements and analyses were performed to determine the feasibility of conducting on-site ergonomic studies at MT&T beginning in October, 1992 as part of my doctoral research at Dalhousie University.

This report consists of three parts. **Part A**: Work Observation (task requirements, postures, workstation variability, schedules, breaks, productivity and exercises), Operator Requirements, On-Site Considerations, Experimental Design Factors, Union Considerations and Statistics; **Part B**: Worksite measurements versus ergonomic standards (computer, chair, workstation and environment) and **Part C**: Summary and Feasibility.

PART A

1. WORK OBSERVATION:

A. Task Types in Directory Assistance:

(i) Relay Operators perform hearing impaired translation services in a separate room that holds 6 work stations. The work intensity is extremely variable.

(ii) Directory Assistance: AVRS (Automated Voice Response System). These DA operator's (Directory Assistance Operators) handle local and long distance enquiries as well as intercepts (errors, number changes, disconnects). The work intensity is maintained at a consistent pace by varying the number of operators with respect to the call volumes.

B. Task Requirements:

(i) Audio acuity: for incoming calls: volume levels, pronunciation and familiarity of the speaker with English is extremely variable.

(ii) Keyboard skills: There is no pre-employment screening for this. The level of touch-typing skills was variable among the operators who were observed during a 4 hr period.

(iii) Physical Requirements: The initial request for information to the operators is received through their headset. To answer the requests, data is retrieved exclusively from computer data bases. Therefore the only manual task is keyboard entry. The work intensity (i.e calls handled per 15 min period) is based on productivity and workload patterns from the previous year. Brenda Munroe (BM) has supplied statistics on actual traffic volumes.

The eye-to-screen viewing distance selected by operators was highly variable. There is a pre-employment visual acuity test and the Occupational Health and Safety Department (OHSD) screens employees who report vision problems.

(iv) Other skills: (a) Spelling and phonetic voice recognition (operators type the requested name as it is spoken). (b) Memory of a variety of names and spellings between successive screens of information. (c) Politeness in the face of any customer behavior.

C. Usual Work Posture:

Note: In the brackets, the numerator is the number of observed postures; the denominator is the number of operators working during each survey. The survey was conducted under the guise of performing other measurements (e.g. furniture dimensions, light levels etc.). The technique used was a form of posture sampling. That is, dividing the DA work area into 6 segments and sampling behavior frequencies over a two minute period.

July 8:
During the late morning peak (1130 to 1145), the common posture was upright (18/22) versus chairback in full 20^0 recline (4/22). Of the 18 upright postures, 14 operators sat in a *forward-head* posture (tragus of the ear forward of the shoulder's center of rotation in the sagittal plane). Other postures noted were: (i) non-utilization of the backrest (4/21), (ii) use of the provided footrest (10/21), (iii) standing for a rest (1/23), (iv) sitting with one leg tucked up on the seat (2/22), and (v) sitting upright, occasionally swivelling the chair (2/22). Two operators wearing bifocals viewed the screen with their chins elevated approximately 15^0 above the horizontal.

July 9:
From 0900 to 0915 hrs (highest traffic load), the common posture was again upright (23/27), in a *forward-head* posture (16/23). Only one operator (1/27) sat in full recline and 3 of 27 sat upright away from the backrest. Other

posture variations were (i) footrest usage (12/25) and (ii) anterior tilt of the seatpan (1/27).

D. Workstation Variability:

The 31 standardardized workstations consist of a two shelf desk unit (fixed heights), computer with attached monitor and a separate keyboard. Due to the staggering of shifts, breaks and meal times, operators do not sit at the same workstation throughout the day. Also, 45 standard Steelcase chairs are available for use. Detailed chair analysis in Part B.

E. Movement Patterns Over Time:

Given the staggering of breaks it was difficult to determine any trend of increasing movements.

F. Breaks:

On all shifts, DA operators cannot work any longer than 120 min. The break is usually taken at between 90 and 105 min, but the work period does on occasion extend to the 120 min mark.

For the the proposed study the DA operators would be asked to delay their first break until the 120 min mark, if possible. The day managers would have to: (i) attempt to leave the study subjects on duty for the 2 hrs and (ii) not pull them off in the event of a work slow-down or shift them to another work area. That would imply that the only reasons that an operator would leave their seat would be for illness or a washroom break.

G. Work Schedules:

These are very diverse. For example, for the July '92 schedule there are 37 different shifts (known as tours) for full time employees. Start and end points are staggered throughout the day to accommodate the heavy volumes of traffic (eg. peaks occur at the start of business hours from 0830 to 0930). Re-testing subjects in the same time slot each day (Reliability Study) will require the cooperation of the union and the subjects. The company can change schedules with two weeks notice, but, to interfere as little as possible with the scheduling, the test/re-test schedule will require careful planning.

H. Variations in Productivity and Intensity:

MT&T reported that their performance measures were lower at the start of evening shifts compared to the start of day shifts for the following possible reasons: (i) customers (i.e. non-business at that time of day) are less sure of what they want and are less direct in their requests. (ii) Since operators have already been up for 8 to 10 hrs, there is no means of knowing what work/leisure activities were done prior to work.

In spite of scheduling efforts, variations in intensity do occur, for example on Saturday and Sunday when call volumes are lower in intensity, particularly in the mornings. MT&T has provided a random sample of work intensities for weekend/weekday and morning/afternoon differences for the period July, 1991 to June, 1991.

I. Dataspan* Exercises:

No subject was observed doing the exercises during the observations. Since MT&T estimated less than 1% of DA operators regularly do them, the exercises are a possible intervention variable.

J. Additional Operator Services:

Sections A through I above are specific to the DA operations on the fifth floor. In addition, there are three other operator functions performed on the third floor:

(i) Toll Operators handle operator-assisted long distance calls in an open area that holds 30 computerized workstations.

(ii) Special Operator Services Traffic (SOST) contains 4 traditional manual switchboards to handle marine and mobile traffic.

(iii) Teleconferencing Services has 4 computer terminal positions.

Work intensity is extremely variable in both Teleconferencing and SOST. The additional physical requirements for SOST operators is the manual (i.e. non-computer) switching of calls. These Operators exercise their option of occasionally standing to perform their tasks.

The Toll workstations are not adjustable for screen or keyboard height. An additional problem is that the keyboard is wired into the shelf and is therefore immoveable. Similar to DA Ops, work intensity in the Toll Operations is maintained by varying the number of operators present. At present, a sit/stand workstation is being evaluated in the Toll section.

2. OPERATORS:

• The task has no apparent anthropometr. .tations and the operators represented a variety of heights and weights.
• Job training: Most new operators are now drawn from another area of the company (Toll Operations) which is downsizing due to technology advances. The training required to move into DA service is 5 days: 3 days in AVRS and 2 days in Relay.

• Average experience: There is a range of 25 years.

• Age (range 20 to 58 yrs) and gender (F:M ratio is 8:1).

• Dress code: There are no restrictions and clothing varies from shorts and slacks to dresses.

3. ON SITE CONSIDERATIONS:

Use of a room on-site: The fifth floor training room may be used for measurement, pre-screening and the administration of consent forms. There is no area of secure equipment storage, so valuables will have to be transported.

4. EXPERIMENTAL DESIGN FACTORS:

A. Comparison of data entry and operator tasks:

While four operators are trained to cross-over and perform the two tasks, the comparison is not feasible for two reasons: (i) either the four data entry workstations nor the tasks are standardized and (ii) the data entry tasks require movement around the office.

B. Comparison of DA tasks with SOST or Toll tasks:

These comparisons are not possible for the following reasons:

(i) SOST Operators

- Work intensity in SOST is uncontrolled
- SOST operators frequently stand

(ii) DA Operations:

• Computers in Toll are hard-wired into non-adjustable workstations which are not comparable to those in DA.
• though Toll Operators work intensity is controlled, it is consistently lower than DA Operators.

C. Work intensity as an independent variable:

The work volume is slower on the weekends meaning it is possible to compare high (weekdays) and low (weekends) work intensities.

D. Location of workstation test site:

Operators were observed to frequently change their workstations in the course of the shift (i.e. after breaks or meals). Yet, all operators appeared to have their own area (or seat) preference within the room. Therefore, no single workstation may be the designated test site.

The room is laid out as four open circles of workstations and one lazy 's' configuration. Not all of the 31 workstations are suitable locations for testing since the VERG computer will be a traffic flow hazard. Therefore, several possible test sites acceptable to both staff and research needs will have to be selected.

5. UNION CONSIDERATIONS:

• I presented an outline of the research proposal to the Atlantic Communication & Technical Workers Union (AC&TWU), the union representing all the MT&T operators. There were no objections raised to the research.

• Points discussed that I felt were important for the union: included: (a) The union agreed to submit a letter of support for the research to the ethical review committee. (b) In the event that participation in the study does diminish a subjects productivity, there will be no recourse taken by the company in the short term or later in contract negotiations, (c) It is understood that the purpose of this study is not to make recommendations to management, though the results may be used to improve on-site conditions and (d) The union was assured that this research is wholly independent of MT&M management.

• In reply to a union enquiry, I told them that the design would not detect differences in comfort between day and night tours, since all testing was restricted to day shifts.

7. STATISTICS:

• MT&T has been assured that all statistics released will be pooled and, where possible, will relate to intensity and productivity during the study with minimal reference to pre-study 'norms'.

PART B

1. FEATURES CHECKLIST: Computer, Chairs and Workstation

Note: (STD) denotes that the feature meets ergonomic standards as defined by Grandjean (1988) or the Canadian Standards Association (1989).

(a) Computers

(i) VDT Monitor

- removeable anti-glare screens are in use (STD)
- character height 3.5 mm (Caps), 2.5 mm (small)
- adjustability:

  screen height is fixed at 20 mm above desk surface

  screen tilts 5^0 upwards and 15^0 downwards

  horizontal distance (screen to desk edge) varies from 480 mm to 580 mm.

  monitor and computer are not separable
- screen dimensions are 170 mm X 235 mm

(ii) Keyboard (meets industry specifications):

- is detached and fully moveable (STD)
- thickness at front edge is 25 mm (STD)
- QWERTY layout (STD)
- key size, spacing and resistance meet STD

- numeric keypad is separate (STD)

- in additicn there are 22 function and 13 special keys

- keyboard tilts to 2 positions: 10^0 (STD) and 20^0

(b) Chair Evaluation:

- 45 standardized Steelcase Concentrix, adjustable task chairs.

- MT&T began purchasing Concentrix chairs 7 years ago, and replaces them as needed.

- Chair upholstery is woven polyester (STD)

- Control functions:

  types: height (pneumatic), seat tilt (no adjustment below neutral) and backrest (upright vs. recline)

  control accessibility: below STD due to location (recessed) and difficulty of push button action

  shape: buttons and slides instead of paddles. Therefore, do not meet STD.

  ease of adjustment; poor and several were broken

- Suitability for VERG mat (45 mm X 45 mm) with respect to dimensions:

  overall seat size 50 mm X 49 mm

  chair arms arise in rear corners and may interfere with the mat for obese subjects

- Arm Rests:
  - dimensions: 250 mm X 60 mm. Do not meet STD (too large)
  - length from backrest to front edge: 290 mm

- Backrest:
  - maximum indentation at peak of lordotic support: 25 mm (STD)

• peak curve occurs at 150 mm (STD is 200-250 mm)

• no open space at base of back rest (STD requires an opening 120-200 mm from the top of seat to the bottom of the backrest)

• is not adjustable horizontally. Does not meet STD

• angle is either fixed at 100^0 from horizontal (STD) or rocks back under spring tension to 140^0, but does not have fixed adjustments through range.

(c) Footrest:

• dimensions: front edge 60 mm high, length 315 mm and angle from horizontal 15^0

• covering: rubber, non-slip tread

(d) Workstation:

• shelf heights are not adjustable

• comparison of dimensions to STD:

• height of keyboard: 690 mm (STD range 550 to 750 mm)

• height of screen shelf: 780 mm (STD 720 mm for 'fixed' height)

• knee clearance: 560 mm (exceeds STD of 460 mm)

• foot clearance: no restrictions

2. ENVIRONMENT:

A. Location:

Halifax Directory Assistance Services is located in a secured, access-controlled site at the North & Agricola MT&T building. The room (approximately 21m X 12m) is on the top (fifth) floor and has restricted traffic flow.

B. Indoor Climate:

• acoustic: This has been evaluated by Sheila Douthwright of the MT&T Occupational Health and Safety Department (OHSD). Results (1989) show that the area noise levels do not exceed the office standard of 60 db's. Sheila has agreed to repeat this evaluation during the actual test period if noise is felt to be a confounding variable.

• lighting:

natural: One window on the southwest wall

artificial: Variable levels of lighting in the work areas under the control of the operators via six rheostats.

• temperature: The November through April period is reported as the most stable period for temperature and humidity. The temperature is maintained at $75^0 \pm 2^0$, and meets the standard for seated office work. There is a thermostat in the Directory Assistance workroom that allows changes of $\pm 2^0$ in the room.

• humidity: This is maintained at 45% ± 5%, and meets ASHRAE standards.

• air quality: The air is exchanged at an acceptable 150 ft^3/min.

PART C

1. SUMMARY:

A. **Major positive aspects to testing at MT&T:**

(i) Extent of worksite control:

The major factors which must be controlled in an on-site study are presently under tight control in the DA operations room. These are: physical environment, task types, work intensity, workstation dimensions, computers and work schedules.

(ii) Level of Cooperation:

Directory Assistance management and the AC&TW union have both expressed interest in participating in the study. As well, both are interested in future applications of the results that would promote employee comfort and productivity and minimize the effect of prolonged sitting.

(iii) Possible <u>independent</u> <u>variables</u>:

At this stage of evaluation and discussions with MT&T it appears that the following variables could be manipulated in a study at the telephone company:

- work intensity
- chair tilt
- time of day tested
- Dataspan® exercises **

A unique feature to this setting (i.e. MT&T) is that very few VDT tasks have such tight control over work intensity. In this case, it can be both controlled and manipulated.

** This study would provide MT&T with the first measure of the effectiveness of the Joyce exercises which have been in place for five years.

(iv) Possible <u>dependent</u> <u>variables</u>:

Use of the following variables has been approved by MT&T:

- body comfort/discomfort
- perceived body exertion
- general comfort rating
- in-chair movement (center of pressure with mat)
- chair features checklist
- calls handled

The extent of control inherent to DA operations allows the unique on-site measurement of work intensity (calls handled) and comfort at intervals defined by me.

(v) <u>Standardization</u> of furniture:

All chairs in the DA Op's section are standardized, though not all adjustment features are operable on all chairs. For the study, fully operational chairs would be tagged for use by the subjects. That would ensure that the seating configuration, which would be measured and recorded, would remain constant between trials.

The fixed work surface heights is both a pro and a con. Generally, workers who perform prolonged seated work sit at a workstation committed to, and adjusted for, a single user. That is not possible at this worksite, given the multiple stations each operator sits in each day. So, while ergonomic convention is being defied, testing with a fixed workstation reflects the reality of this job and the factor is well controlled. MT&T is presently attempting to obtain an adjustable-height workstation suitable to evaluate introduction of the same. If obtained, that may be a later stage factor in my study that may interest MT&T. In the short term the difficulty can, in part, be overcome by minimum height restrictions.

B. **Major negative aspects to testing at MT&T:**

(i) Subjects:

The number of full time employees (62) may be insufficient after screening for height and age. Part-time employees may need to be recruited; a situation which would make repeat testing difficult to schedule.

(ii) Work Organization:

Employees will have to be asked to extend their work period prior to taking breaks.

In order to ensure minimal disruption of employees, the test/re-test schedule will have to be carefully planned within the limits of the collective agreement.

(iii) On-site Considerations:

There is no secure storage area for the computer and VERG mat.

(iv) Test Scheduling:

Given the productivity and intensity differences between day and night shifts as well as weekdays versus weekends, testing would primarily take place on weekday day shifts.

2. FEASIBILITY:

The MT&T DA Operations Center is an excellent site with respect to factor control. In addition, there is a variety of possible dependent and independent variables, many of which are unique. However, what is truly without parallel is the possibility of on-site measures of intensity, comfort and productivity in 15 min blocks over a two hour period.

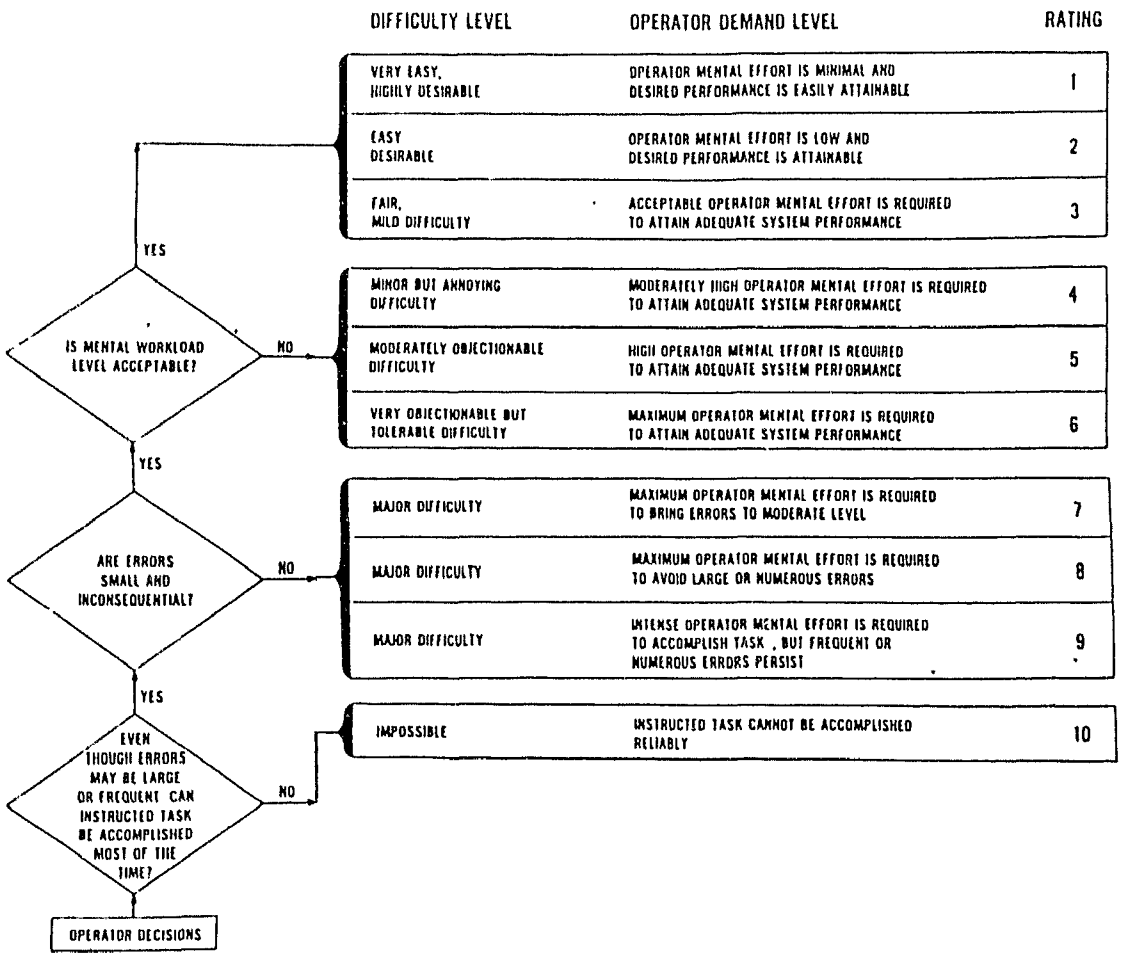
There are numerous applications and benefits to MT&T that range from evaluating comfort versus intensity; productivity versus comfort versus perceived exertion; variations in employee comfort over the shift duration and the evaluation of the mini-break exercise regime currently in place. Also, the present level of cooperation with the study expressed by management and the union add to the study's feasibility.

The major difficulty will be scheduling test dates to meet the needs of the employees, management and test protocol.

My overall impression is that this project is definitely feasible. It will require the continued support of the union and employees, the cooperation of MT&T with respect to their data collection (intensity and performance) and finally, my guarantee of a minimal amount of job disruption.

Appendix 4.1 Modified Cooper-Harter Scale

The Modified Cooper-Harter scale of perceived mental workload. Subjects rate mental workload beginning at operator decisions, are directed by their yes/no responses to one section of the rating scale, and circle the number corresponding to their perceived level of difficulty.



Appendix 5.1 Perceived Exertion

This scale, the Borg CR-10 *Rated Perceived Exertion* (RPE) scale (Borg 1980), was used by subjects to rate their perceived exertion by marking the point on the line which corresponded to their perception of how hard they worked in the preceding hour.

How hard did you work in the past hour?

0	No exertion at all
0.5	Extremely light exertion
1	Very light
2	Light
3	Moderate exertion
4	Somewhat hard exertion
5	Hard exertion
6	
7	Very hard
8	
9	
10	Extremely hard exertion
*	Maximum exertion

Appendix 5.2 Modified Dataspan® Mini-Break Exercises

To get the maximum effect you should take a mini break **every 30 minutes** to be effective. Be a clockwatcher while you get used to the routine.

The exercises are set out in five groups. The **minimum** requirement for an exercise break is that the Group 1 exercise must be done **at least once every half hour**. The **preferred** exercise break consists of one exercise from each of the five groups.

GROUP 1

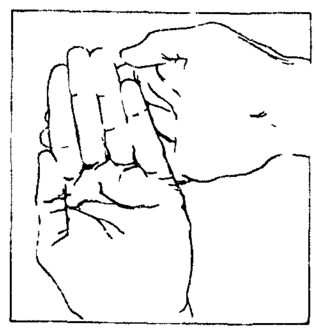
Standing and Stretching

In sitting, there is increased tension in your discs. The act of standing decreases the tension in many of your joints, especially the joints in your spine. Standing provides a chance to relieve pressure under your buttocks as well as to stretch your low back.

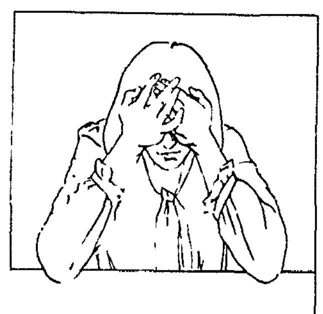
* Place your palms behind you in the small of your back, with your fingers pointing backwards.
* Bend your trunk backwards at the waist as far as you can **comfortably**, using your hands as a fulcrum.
* Hold this position and count to **three** (3).
* Repeat twice.

GROUP 2

Every half hour pick one (1) exercise from this group:



2-1 Palming is one of the most basic and effective exercises for relaxing the eye muscles. If done periodically during the day, it can relieve eyestrain. It serves as a break from light and glare and gives your neck muscles a break from holding up your head.



To do **palming** correctly:
* Place your elbows on the desk in front of you.
* Position the heels of your hands on your cheekbones.
* Place your hands over your eyes so that your fingers rest on your forehead with no pressure on the eye itself and just slight pressure on the surrounding area.
* Move your hands so that no light gets in.
* Lean forward so that you feel no tension in your neck.
* Close your eyes.
* Inhale through your nose and exhale through your mouth four (4) times.
* Expose your eyes to light gradually.

2-2 Yawning and Blinking

Yawning is a response that signals your body's need for oxygen. It also lubricates your eyes, an important benefit when you are concentrating on a computer screen.

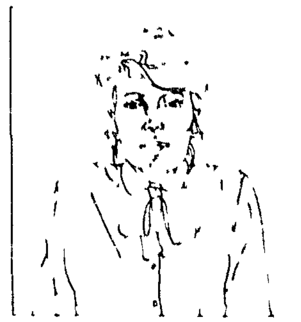
* Drop your jaw and inhale; usually a yawn will result.
* Remind yourself to blink when your work requires concentration.

GROUP 3

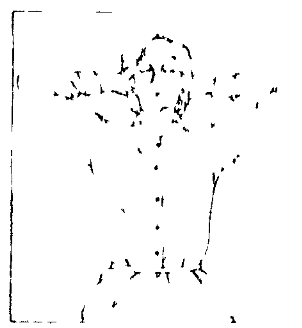
Every half hour pick one (1) exercise from this group:

5-1 Shoulder Shrugs

Your shoulder muscles hold your arms up when you write or use a computer.



* Slowly raise your shoulders upwards to your ears, and then drop them to shoulder level.
* Keep your left shoulder level and let your right one drop until you feel the resistance of muscle tightness. If no tightness is felt, tilt your head sideways to the left until you feel a **comfortable** tension in your neck and shoulder muscles.
* Hold and count to **five** (5) Relax.
* Repeat, stretching your left shoulder.



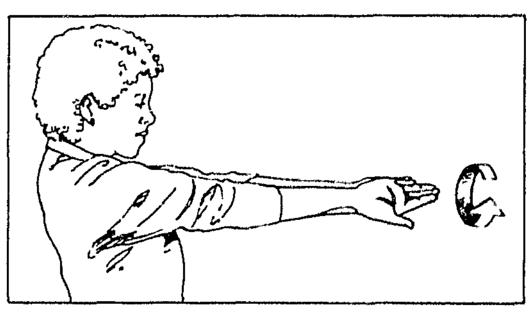
5-2 Shoulder Stretch

* Lock your hands behind your head, pull your elbows wide apart.
* Hold and count to **five** (5). Relax. Repeat two (2) times.

5-3 Shoulders & Arms

* Stretch your arms straight ahead of you at shoulder level.
* Rotate them so the back of your hands face each other.
* Hold for a count of **five** (5).
* Then rotate them so the palms of your hands face upward.
* Hold for a count of **five** (5).
* Repeat three (3) times.

*** Stretch only one arm at a time if you prefer.



GROUP 4

Every half hour pick one (1) exercise from this group:

4-1 Chin Tuck While sitting, computer operators often stretch their heads forward to view the screen (see Figure A). This makes extra work for the neck muscles and may encourage poor posture.

* Imagine a cable attached to the top of your head which is gradually pulling you up, up, up.
* Then pull your whole head **backwards** (see Figure B), not upwards, not downwards, just backwards as though you were tucking in your chin. Hold, and count to **three (3)**.

4-2 Deep Breathing

This routine combines eye rest, limbering and breathing relaxation:

* Let your head drop forward in a relaxed position.
* Close your eyes.
* Slowly roll your head up, breathing **deeply**, until you face the ceiling.
* slowly roll back to the lowered position, breathing out.

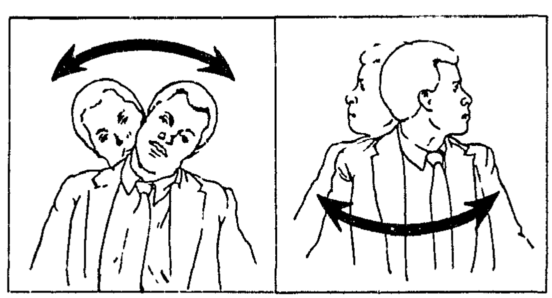
4-3 Neck/Head

The neck needs to be exercised regularly to relieve muscle tension which builds up throughout the workday. Stretching reduces stiffness and discomfort.

* Gently **tip your head** from side to side twice, and stretch upwards as you return to upright.

THEN

* Gently **turn your head** and look over your shoulder, stretching upwards as you go.
* Then **gently** turn and look over your other shoulder.
* Repeat 2 times.

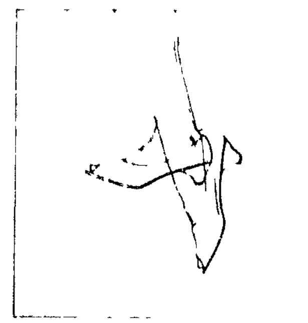


Tip head *Turn head*

GROUP 5

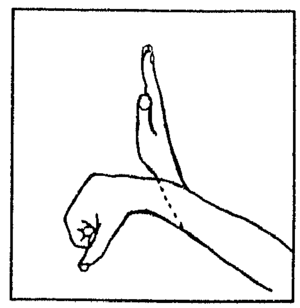
Every half hour pick one (1) exercise from this group:

3-1 Ankles



* While sitting, point toes downward as far as possible.
* Hold for a count of 2 and then point your toes upward as far as possible. Hold for a count of **five** (5).
* Relax. Then repeat with your other foot.
* Do each foot twice.

3-2 Wrist Stretch



* Hold arms straight out in front
* Make a gentle fist.
* Slowly point knuckles to the floor.
* Hold for a count of **five** (5).
* Slowly straighten out your fingers.
* Slowly point your fingers toward the ceiling.
* Hold for a count of **five** (5).
* Repeat 3 times.

Note: The two new exercises which constitute the "modified" portion of this Dataspan® protocol are the: **Standing and Stretching** (GROUP 1) and **Chin Tuck** (GROUP 4) exercises.

Appendix 5.3 Exercise Questionnaire

I would like to hear your comments on the Dataspan exercises. Use the following categories as a guideline. Add any other comments or suggestions at the bottom.

1. Comment on the *ease* or *difficulty* of:

   (A) Performing the exercises as described ______________________________

   (B) Remembering to do the exercises ______________________________

   (C) Doing the exercises without feeling conspicuous ______________________

   (D) Doing the exercises without disrupting work ______________________

2. Comment on the number and variety of exercises ______________________

3. Did you have any problems or experience any discomfort or pain while doing exercises. If yes, which ones?

4. General comments or suggestions______________________________

Appendix 6.1 General Comfort Rating

This scale, the *General Comfort Scale (GCR)* (Shackel et al, 1969), was used by subjects to rate the chair with respect to comfort. Subjects were asked to make a single mark on the 10 cm line which corresponded to their comfort rating.

Please rate the chair on your feelings <u>now</u>

I feel completely relaxed

I feel perfectly comfortable

I feel quite comfortable

I feel barely comfortable

I feel uncomfortable

I feel restless and fidgety

I feel cramped

I feel stiff

I feel numb (or pins and needles)

I feel sore and tender

I feel unbearable pain

Appendix 6.2 Chair Features Checklist

Seat height above floor	Too high	Correct	Too low
Seat length	Too Long	Correct	Too short
Seat width	Too narrow	Correct	Too wide
Slope of seat	Slopes too far towards back	Correct	Slopes too far towards front
Seat shape	Poor	Adequate	Good
Position of backrest	Too high	Correct	Too low
Moulded chair back	Poor fit	Adequate	Fits well
Curvature of backrest	Too Curved	Correct	Too flat
Are the armr	Too high	Just right	Too low
Is the backrest.	Too Upright	Just Right	Too reclined
Does the chair tilt back:	Too easily	Just right	Too hard
Does the chair tilt back:	Too far	Just right	Not far enough

ID # ____ Trial ____ Chair ____ Hour ____

Appendix 6.3 Chair Use Form

Subject ID:_____

Use this form to record: (i) the *length of time* you sat in the the test chair and (ii) your *comments* about the chair. Please try to fill it in at the end of each day. Day 1 is the day you received the test chair.

Under *comments*, please record your reactions (both positive and negative) about any aspect of the test chair. Also, if you are not scheduled to be at work (for example on Day 2), just note that on the comments line. If you need more space write on the back of the page. I would appreciate your returning this form to me on your test day.

DAY 1 Date: _________
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm

Comments: ____

DAY 2 Date: _________
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm

Comments: ____

DAY 3 Date: _________
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm

Comments: ____

DAY 4 Date: _________
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm

Comments: ____

DAY 5 Date: _________
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm
From: ________am/pm To: ________am/pm

Comments: ____

Anne Fenety
April 30, 1993

Appendix 6.4 SPSS Results - Chair Study

This appendix contains the (a) Raw data, (b) descriptive statistics (c) MANOVA or Wilcoxin test results for the (1) Perceived Discomfort, (2) Perceived Exertion, (3) Subject Characteristics, (4) In-Chair Movement, (5) General comfort Rating and (6) Chair Features Checklist variables:

1. Perceived Discomfort (PD)

Data File: B:\spssc\PD_WB_23.CHR

Read-in Variable Names:

SGw2T30 NGw2T30 AGw2T30
SGw2T65 NGw2T65 AGw2T65
SGw2T115 NGw2T115 AGw2T115
SGw3T30 NGw3T30 AGw3T30
SGw3T65 NGw3T65 AGw3T65
SGw3T115 NGw3T115 AGw3T115

Where:

S	= Sum of discomfort scores	
N	= Number of uncomfortable body parts	
A	= Average discomfort score	
w	= Whole Body	
2,3	= Chair type:	2 = Teknion
		3 = Concentrix
T	= Time of rating: 30, 65, 115 min	

(a) Raw Data File Listings PD:

Sum Scores

ID	SGW2T30	SGW2T65	SGW2T115	SGW3T30	SGW3T65	SGW3T115
91.00	.00	.00	1.30	.00	.00	7.40
98.00	.40	1.60	4.80	2.80	4.30	9.60
92.00	.00	.00	.40	1.00	4.00	2.00
99.00	.00	.00	.00	.00	.00	4.00

96.00	2.30	2.40	5.00	12.20	10.80	11.40
95.00	.00	.00	.00	.00	.00	.40
94.00	4.00	.00	9.00	25.00	27.00	47.00
93.00	.90	2.50	2.90	.00	.80	.90
90.00	6.00	4.00	2.00	6.00	5.00	9.00

Number Scores

ID	NGW2T30	NGW2T65	NGW2T115	NGW3T30	NGW3T65	NGW3T115
91.00	.00	.00	1.00	.00	.00	3.00
98.00	2.00	2.00	2.00	3.00	3.00	3.00
92.00	.00	.00	1.00	1.00	4.00	2.00
99.00	.00	.00	.00	.00	.00	2.00
96.00	2.00	2.00	4.00	4.00	4.00	4.00
95.00	.00	.00	.00	.00	.00	1.00
94.00	4.00	.00	7.00	11.00	11.00	11.00
93.00	2.00	3.00	2.00	.00	2.00	2.00
90.00	4.00	2.00	2.00	4.00	5.00	6.00

Average Scores

ID	AGW2T30	AGW2T65	AGW2T115	AGW3T30	AGW3T65	AGW3T115
91.00	.00	.00	1.30	.00	.00	2.50
98.00	.20	.80	2.40	.90	1.40	3.20
92.00	.00	.00	.40	1.00	1.00	1.00
99.00	.00	.00	.00	.00	.00	2.00
96.00	1.10	1.20	1.30	3.00	2.70	2.90
95.00	.00	.00	.00	.00	.00	.40
94.00	1.00	.00	1.30	2.40	2.50	4.30
93.00	.50	.80	1.50	.00	.40	.50
90.00	1.50	2.00	1.00	1.50	1.00	1.50

(b) Descriptive Statistics PD:

Sum Scores

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
SGW2T30	1.51	.72	4.71	.00	6.00
SGW2T65	1.17	.50	2.29	.00	4.00
SGW2T115	2.82	1.00	8.95	.00	9.00
SGW3T30	5.22	2.82	71.65	.00	25.00

SGW3T65	5.77	2.90	75.81	.00	27.00
SGW3T1151	0.19	4.79	206.69	.40	47.00

Number Scores

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
NGW2T30	1.56	.56	2.78	.00	4.00
NGW2T65	1.00	.41	1.50	.00	3.00
NGW2T115	2.11	.73	4.86	.00	7.00
NGW3T30	2.56	1.20	13.03	.00	11.00
NGW3T65	3.22	1.16	12.19	.00	11.00
NGW3T115	3.78	1.02	9.44	1.00	11.00

Average Scores

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
AGW2T30	.48	.19	.34	.00	1.50
AGW2T65	.53	.24	.52	.00	2.00
AGW2T115	1.02	.26	.60	.00	2.40
AGW3T30	.98	.38	1.28	.00	3.00
AGW3T65	1.00	.35	1.08	.00	2.70
AGW3T115	2.03	.44	1.73	.40	4.30

(c) MANOVA Results PD:

Where:
Tek = Teknion (passive) chair
CTX = Concentrix (active) chair

1. Main Effects:

Command:
MANOVA AGW2T30 AGW2T65 AGW2T115 AGW3T30 AGW3T65 AGW3T115
/WSFACTORS CHAIR (2) TIME (3).

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	24.60	8	3.07		
CONSTANT	54.80	1	54.80	17.82	**.003**

WITHIN CELLS	9.67	8	1.21		
CHAIR	5.87	1	5.87	4.85	**.059**
WITHIN CELLS	7.65	16	.48		
TIME	7.32	2	3.66	7.66	**.005**
WITHIN CELLS	2.49	16	.16		
CHAIR BY TIME	.84	2	.42	2.69	**.098**

2. Simple Main Effects of Time on Chair (Tek), (CTX):

Command:

MANOVA AGW2T30 AGW2T65 AGW2T115 AGW3T30 AGW3T65 AGW3T115
/WSFACTORS CHAIR (2) TIME (3)
/WSDESIGN CHAIR, TIME W CHAIR (Tek), TIME W CHAIR (CTX).

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	4.18	16	.26		
TIME W CHAIR (Tek)	1.62	2	.81	3.09	**.073**
WITHIN CELLS	5.96	16	.37		
TIME W CHAIR (CTX)	6.55	2	3.27	8.79	**.003**

3. Simple Main Effects of Chair on Time at:
Time 1 (30), Time 2 (65), Time 3 (115):

Command:

MANOVA AGW2T30 AGW2T65 AGW2T115 AGW3T30 AGW3T65 AGW3T115
/WSFACTORS CHAIR (2) TIME (3)
/WSDESIGN TIME, CHAIR W TIME (1), CHAIR W TIME (2),
CHAIR W TIME 3.

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	2.53	8	.32		
CHAIR W TIME(1)	1.13	1	1.13	3.56	**.096**
WITHIN CELLS	4.53	8	.57		
CHAIR W TIME(2)	.98	1	.98	1.73	**.225**
WITHIN CELLS	5.10	8	.64		
CHAIR W TIME(3)	4.60	1	4.60	7.21	**.028**

---

2. Perceived Exertion (RPE)

Data File: B:\spssc\rate_all.chr

Read-in Variable Names:

PE2T65 PE2T115 PE3T65 PE3T115

Where:
PE= Perceived Exertion
2,3= Chair trial:2 = Teknion
3 = Concentrix
T= Time of rating: 65, 115 min

(a) Data File Listings RPE:

ID	PE2T65	PE2T115	PE3T65	PE3T115
90.00	2.50	.90	3.30	3.30
91.00	.00	.30	.30	.00
92.00	.00	1.70	.90	.90
93.00	.40	.40	.30	.40
94.00	.90	1.70	3.30	4.20
95.00	.30	.50	.20	.60

96.00	.60	.70	2.00	2.30
98.00	3.30	3.50	2.90	3.80
99.00	2.90	3.00	3.90	2.30

(b) Descriptive Statistics RPE:

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
PE2T65	1.21	.44	1.72	.00	3.30
PE2T115	1.41	.39	1.36	.30	3.50
PE3T65	1.90	.50	2.24	.20	3.90
PE3T115	1.98	.52	2.46	.00	4.20

(c) MANOVA Results RPE:

1. Main Effects:

Command:

MANOVA PE2T65 PE2T115 PE3T65 PE3T115
/WSFACTORS CHAIR (3) TIME (2).

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	49.80	8	6.22		
CONSTANT	95.06	1	95.06	15.27	**.004**
WITHIN CELLS	7.30	8	.91		
CHAIR	3.55	1	3.55	3.89	**.084**
WITHIN CELLS	2.91	8	.36		
TIME	.17	1	.17	.48	**.509**
WITHIN CELLS	2.29	8	.29		
CHAIR BY TIME	.03	1	.03	.12	**.741**

2. Simple Main Effects of Chair on Time: (1 = 65 min; 2 = 115)

Command:

```
MANOVA PE2T65 PE2T115 PE3T65 PE3T115
/WSFACTORS CHAIR (2) TIME (2)
/WSDESIGN = TIME, CHAIR W TIME (1), CHAIR W TIME (2).
```

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	3.08	8	.39		
CHAIR W TIME(1)	2.14	1	2.14	5.54	**.046**
WITHIN CELLS	6.50	8	.81		
CHAIR W TIME(2)	1.44	1	1.44	1.78	**.219**

3. Simple Main Effects of Time on Chair: (Teknion, Concentrix)

Command:

```
MANOVA PE1T65 PE1T115 PE2T65 PE2T115 PE3T65 PE3T115
/WSFACTORS CHAIR (2) TIME (2)
/WSDESIGN = CHAIR, TIME W CHAIR (Tek), TIME W CHAIR (CTX).
```

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	2.96	8	.37		
TIME W CHAIR (Tek)	.18	1	.18	.49	**.505**
WITHIN CELLS	2.24	8	.28		
TIME W CHAIR (CTX)	.03	1	.03	.10	**.763**

---

3. Subject Characteristics

Data File: B:\spssc\SPS_CHR.SUB'.

Read-in Variable Names:

Age Employ Height Weight Gender.

(a) Data File Listings:

AGE	EMPLOY	HEIGHT	WEIGHT	GENDER
40.00	189.60	165.00	68.10	1.00
23.00	26.40	163.00	72.00	1.00
29.00	99.60	173.00	95.00	1.00
38.00	156.00	173.00	61.00	1.00
25.00	27.60	190.00	77.00	2.00
23.00	37.20	175.00	75.00	1.00
24.00	36.00	160.00	68.00	1.00
33.00	151.20	158.00	53.00	1.00
34.00	108.00	168.00	59.00	1.00

(b) Descriptive Statistics:

Variable	Mean	S.E.	Variance	Minimum	Maximum
AGE (yrs)	29.89	2.20	43.61	23.00	40.00
EMPLOY (mths)	92.40	21.09	4003.56	26.40	189.60
HEIGHT (cm)	169.44	3.25	95.28	158.00	190.00
WEIGHT (kg)	69.79	4.08	150.15	53.00	95.00

---

4. In-chair Movement (ICM)

Data File: B:\spssc\CHR_L_23.all

Read-in Variable Names:

C2L1 C2L2 C2L3 C2L4 C2L5 C2L6
C2L7 C2L8 C2L9 C2L10 C2L11 C2L12
C2L13 C2L14 C2L15 C2L16 C2L17 C2L18
C2L19 C2L20 C2L21 C2L22 C2L23 C2L24
C3L1 C3L2 C3L3 C3L4 C3L5 C3L6
C3L7 C3L8 C3L9 C3L10 C3L11 C3L12
C3L13 C3L14 C3L15 C3L16 C3L17 C3L18
C3L19 C3L20 C3L21 C3L22 C3L23 C3L24.

Where:
C = Chair
2,3 = Chair type: 2 = Teknion
3 = Concentrix
L = COP Distance in Blocks from 1 to 24

Computation:
Triple Block Means: *Commands*

```
COMPUTE C2T20 = (C2L2 + C2L3 + C2L4) / 3.
COMPUTE C2T65 = (C2L11 + C2L12 + C2L13) / 3.
COMPUTE C2T115 = (C2L21 + C2L22 + C2L23) / 3.
COMPUTE C3T20 = (C3L2 + C3L3 + C3L4) / 3.
COMPUTE C3T65 = (C3L11 + C3L12 + C3L13) / 3.
COMPUTE C3T115 = (C3L21 + C3L22 + C3L23) / 3.
```

(a) Raw Data File Listings ICM:

Where:
T = Time (min): 20 (5-20), 65 (50-65), 115 (110-115)

Triple Block Means:

ID	C2T20	C2T65	C2T115	C3T20	C3T65	C3T115
91.00	50.02	79.20	84.10	38.90	75.41	95.41
92.00	89.62	399.85	762.77	292.31	345.14	383.95
93.00	91.72	145.92	173.38	88.92	113.48	141.80
90.00	98.93	178.43	414.67	105.98	114.11	132.97
98.00	102.59	113.97	135.23	45.80	55.62	63.31
94.00	60.61	88.03	133.98	53.60	82.90	150.92
95.00	192.16	185.20	295.85	150.02	165.31	198.23
99.00	59.51	87.62	170.47	65.17	93.98	120.99
96.00	197.87	205.64	259.95	88.99	146.90	220.08

(b) Descriptive Statistics ICM:

Triple Block Means:

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
C2T20	104.78	18.16	2967.55	50.02	197.87
C2T65	164.87	33.26	9954.71	79.20	399.85
C2T115	270.05	70.22	44372.34	84.10	762.77
C3T20	103.30	26.27	6213.20	38.90	292.31
C3T65	132.54	28.94	7539.38	55.62	345.14
C3T115	167.52	31.38	8863.06	63.31	383.95

(c) MANOVA Results ICM:

Where:
Tek = Teknion (passive) chair
CTX = Concentrix (active) chair

1.Main Effects:

Command:

MANOVA C2T20 C2T65 C2T115 C3T20 C3T65 C3T115
/WSFACTORS CHAIR (2) TIME (3).

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	436233.97	8	54529.25		
CONSTANT	1334042.67	1	1334042.70	24.46	**.001**
WITHIN CELLS	18386.31	8	2298.29		
CHAIR	27883.16	1	27883.16	12.13	**.008**
WITHIN CELLS	96702.56	16	6043.91		
TIME	120427.73	2	60213.86	9.96	**.002**
WITHIN CELLS	87959.08	16	5497.44		
CHAIR BY TIME	24133.86	2	12066.93	2.20	**.144**

2. Simple Main Effects of Time on Chair (Tek), (CTX):

Command:

MANOVA C2T20 C2T65 C2T115 C3T20 C3T65 C3T115
/WSFACTORS CHAIR (2) TIME (3)
/WSDESIGN = CHAIR, TIME W CHAIR (1), TIME W CHAIR (2).

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	179068.18	16	11191.76		
TIME W CHAIR (Tek)	125954.04	2	62977.02	5.63	**.014**
WITHIN CELLS	5593.46	16	349.59		
TIME W CHAIR (CTX)	18607.55	2	9303.77	26.61	**.000**

3. Simple Main Effects of Chair on Time at:
Time 1 (30), Time 2 (65), Time 3 (115):

Command:

```
MANOVA C2T20 C2T65 C2T115 C3T20 C3T65 C3T115
/WSFACTORS CHAIR (2) TIME (3)
/WSDESIGN = TIME, CHAIR W TIME (1), CHAIR W TIME (2),
CHAIR W TIME (3).
```

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	29091.92	8	3636.49		
CHAIR W TIME(1)	9.86	1	9.86	.00	**.960**
WITHIN CELLS	3052.23	8	381.53		
CHAIR W TIME(2)	4704.66	1	4704.66	12.33	**.008**
WITHIN CELLS	74201.24	8	9275.16		
CHAIR W TIME(3)	47302.49	1	47302.49	5.10	**.051**

---

5. General comfort Rating (GCR)

Data File: B:\spssc\rate_all.chr

Read-in Variable Names:

GCR2T5 GCR2T115 GCR3T5 GCR3T115

Where:
GCR = General Comfort Rating
2,3 = Chair trial: 2 = Teknion
3 = Concentrix
T = Time of rating: 65, 1[illegible] min

(a) Raw Data File Listings GCR:

ID	GCR2T5	GCR2T115	GCR3T5	GCR3T115
90.00	.00	.80	3.80	5.30
91.00	.80	.50	1.50	2.30
92.00	.80	.80	.80	1.50
93.00	.60	1.50	.40	2.10
94.00	.00	.80	2.00	4.50
95.00	.20	.20	.60	1.70
96.00	.00	1.10	2.60	3.70
98.00	1.40	1.50	1.50	4.30
99.00	.00	.20	.50	.60

(b) Descriptive Statistics GCR:

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
GCR2T5	.42	.17	.25	.00	1.40
GCR2T115	.82	.16	.23	.20	1.50
GCR3T5	1.52	.38	1.28	.40	3.80
GCR3T115	2.89	.54	2.58	.60	5.30

(c) MANOVA Results GCR:

1. Main Effects:

Command:
MANOVA GCR2T5 GCR2T115 GCR3T5 GCR3T115
/WSFACTORS CHAIR (2) TIME (2).

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	16.31	8	2.04		
CONSTANT	71.97	1	71.97	35.30	**.000**
WITHIN CELLS	14.48	8	1.81		
CHAIR	22.56	1	22.56	12.47	**.008**
WITHIN CELLS	2.54	8	.32		
TIME	7.02	1	7.02	22.16	**.002**
WITHIN CELLS	1.46	8	.18		
CHAIR BY TIME	2.10	1	2.10	11.56	**.009**

2. Simple Main Effects of Chair on Time: (1 = 65 min; 2 = 115)

Command:

MANOVA GCR2T65 GCR2T115 GCR3T65 GCR3T115
/WSFACTORS CHAIR (2) TIME (2)
/WSDESIGN = TIME, CHAIR W TIME (1), CHAIR W TIME (2).

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	7.63	8	.95		
CHAIR W TIME(1)	5.44	1	5.44	5.71	**.044**
WITHIN CELLS	8.30	8	1.04		
CHAIR W TIME(2)	19.22	1	19.22	18.53	**.003**

3. Simple Main Effects of Time on Chair: (Teknion, Concentrix)

Command:
MANOVA GCR2T5 GCR2T115 GCR3T5 GCR3T1152
/WSFACTORS CHAIR (2) TIME (2)
/WSDESIGN = CHAIR, TIME W CHAIR (Tek), TIME W CHAIR (CTX).

Results:

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1.00	8	.13		
TIME W CHAIR (Tek)	.72	1	.72	5.76	**.043**
WITHIN CELLS	2.99	8	.37		
TIME W CHAIR (CTX)	8.41	1	8.41	22.49	**.001**

---

6. Chair Features Checklist (CFC)

Data File: B:\spssc\RATE_CHR.CFC

Read-in Variable Names:

SH_K SL_K SW_K SSL_K SSh_K BrPx_K
BrM_K BrC_K AR_K BRang_K CTez_2 CTfar_K
SH_X SL_X SW_X SSL_X SSh_X BrPx_X
BrM_X BrC_X AR_X BRang_X CTez_X CTfar_X

Where:

_K	=	Teknion
_X	=	Concentrix
SH	=	Seat Height (0 = too high; 4 = too low)
SL	=	Seat Length (0 = too long; 4 = too short)
SW	=	Seat Width (0 = too narrow; 4 = too wide)
SSl	=	Seat Slope (0 = too far backwards; 4 = too far forwards)
SSh	=	Seat Shape (0 = poor; 4 = good)
BrPx	=	Position of Backrest (0 = too high; 4 = too low)
BrM	=	Moulded Chair Back (0= poor fit; 4 = good fit)
BrC	=	Backrest Curvature (0 = too curved; 4 = too flat)
AR	=	Arm Rests (0 = too high; 4 = too low)
Brang	=	Backrest Angle (0 = too upright; 4 = too reclined)
CTez	=	Ease of Chair Tilt (0 = too easily; 4 = too hard)
CTfar	=	Chair tilt distance (0 = too far; 4 = not enough)

(a) Data File Listings CFC:

Teknion Chair:

ID	SH_K	SL_K	SW_K	SSL_K	SSH_K	BRPX_K
90.00	2.00	2.00	2.00	2.40	2.00	2.00
91.00	1.90	1.80	1.90	1.90	3.40	2.20
92.00	2.00	2.00	2.00	2.00	3.20	2.00
93.00	2.00	2.00	2.00	1.40	2.00	2.00
94.00	2.00	2.80	2.00	2.00	2.00	2.00
95.00	1.70	1.50	1.60	2.00	2.30	2.00
96.00	2.00	3.30	2.50	2.00	3.50	2.00
98.00	2.00	2.10	1.90	2.00	1.90	2.00
99.00	2.00	2.00	2.00	2.00	2.00	2.00

ID	BRM_K	BRC_K	AR_K	BRANG_K	CTEZ_K	CTFAR_K
90.00	3.20	2.00	2.00	2.00	2.00	2.00
91.00	3.60	1.90	1.90	1.90	1.90	1.90
92.00	3.10	2.00	2.00	2.00	2.00	2.00
93.00	2.00	1.30	2.00	2.00	.70	1.10
94.00	2.80	2.00	4.00	2.00	.50	.30
95.00	2.80	2.40	2.00	2.10	2.40	1.40
96.00	3.60	2.00	2.00	1.10	2.00	2.00
98.00	1.90	1.90	2.00	2.00	1.60	1.70
99.00	2.00	2.00	2.00	2.00	2.00	2.00

Concentrix Chair

ID	SH_X	SL_X	SW_X	SSL_X	SSH_X	BRPX_X
90.00	2.00	1.60	2.00	2.00	1.10	1.80
91.00	.20	1.90	1.90	3.10	1.90	3.60
92.00	2.00	2.00	2.00	2.00	2.00	2.00
93.00	2.00	2.00	2.00	2.00	2.00	2.00
94.00	2.00	2.00	2.00	2.60	1.00	2.80
95.00	1.70	1.90	2.00	2.00	2.00	2.60
96.00	4.00	3.40	2.00	3.70	.30	3.50
98.00	2.20	2.00	2.00	2.10	2.00	2.00
99.00	2.00	2.00	2.00	2.10	.20	2.20

ID	BRBRC_X	M_X	AR_X	BRANG_X	CTEZ_X	CTFAR_X
90.00	.50	.40	1.70	1.70	.30	.30
91.00	1.90	.70	3.80	2.70	.70	1.30
92.00	2.00	2.00	1.70	2.00	2.00	2.00
93.00	1.40	1.40	1.00	2.60	.60	.60
94.00	.00	.00	1.10	.00	.00	.00
95.00	1.70	2.30	2.40	2.50	.70	2.40
96.00	.40	.50	4.00	.50	.40	1.90
98.00	1.90	2.10	2.00	2.00	.10	.10
99.00	.10	.10	2.90	2.50	2.00	2.00

(b) Descriptive Statistics Ratings CFC:

Teknion Chair:

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
SH_K	1.96	.03	.01	1.70	2.00
SL_K	2.17	.18	.30	1.50	3.30
SW_K	1.99	.08	.05	1.60	2.50
SSL_K	1.97	.08	.07	1.40	2.40
SSH_K	2.48	.23	.46	1.90	3.50
BRPX_K	2.02	.02	.00	2.00	2.20
BRM_K	2.78	.22	.45	1.90	3.60
BRC_K	1.94	.09	.08	1.30	2.40
AR_K	2.21	.22	.45	1.90	4.00
BRANG_K	1.90	.10	.09	1.10	2.10
CTEZ_K	1.68	.22	.42	.50	2.40
CTFAR_K	1.60	.19	.34	.30	2.00

Concentrix Chair:

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
SH_X	2.01	.32	.92	.20	4.00
SL_X	2.09	.17	.26	1.60	3.40
SW_X	1.99	.01	.00	1.90	2.00
SSL_X	2.40	.21	.38	2.00	3.70
SSH_X	1.39	.25	.57	.20	2.00
BRPX_X	2.50	.22	.45	1.80	3.60

Variable	Mean	S.E. Mean	Variance	Minimum	Maximum
BRM_X	1.10	.28	.70	.00	2.00
BRC_X	1.06	.30	.82	.00	2.30
AR_X	2.29	.36	1.18	1.00	4.00
BRANG_X	1.83	.32	.93	.00	2.70
CTEZ_X	.76	.25	.56	.00	2.00
CTFAR_X	1.18	.31	.88	.00	2.40

(c) Wilcoxon Matched-pairs Signed-ranks Tests CFC Ratings:

SH_K with SH_X
Z = -.5345 2-tailed P = .5930

SL_K with SL_X
Z = -.4193 2-tailed P = .6750

SW_K with SW_X
Z = .0000 2-tailed P = 1.0000

SSL_K with SSL_X
Z = -1.8593 2-tailed P = .0630

SSH_K with SSH_X
Z = -2.3805 2-tailed P = .0173

BRPX_K with BRPX_X
Z = -1.8869 2-tailed P = .0592

BRM_K with BRM_X
Z = -2.5205 2-tailed P = .0117

BRC_K with BRC_X
Z = -1.8904 2-tailed P = .0587

AR_K with AR_X
Z = -.2801 2-tailed P = .7794

BRANG_K with BRANG_X
Z = -.2535 2-tailed P = .7998

CTEZ_K with CTEZ_X
Z = -2.3664 2-tailed P = .0180

CTFAR_K with CTFAR_X
Z = -1.5213 2-tailed P = .1282

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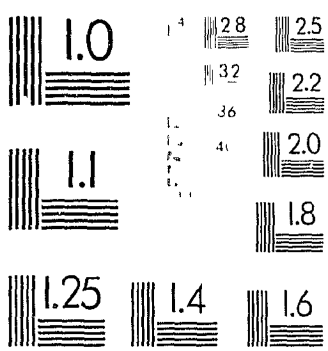
4 OF/DE 4

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT



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