Thermographic Assessment of the Forearm During Data Entry Tasks: A Reliability Study

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ABSTRACT

Work-related musculoskeletal disorders (WMSDs) negatively impact worker's health, ability to work, and their quality of life. Non-invasive methods for assessing the physiological responses to workload may provide information on physiological markers leading to increased risk of WMSDs. The following study aimed to evaluate the feasibility of using thermography to quantify differences in thermal readings of participants during and following a data entry task and assess the repeatability of thermal readings. Skin surface temperature measurements of the dorsal forearm were obtained from 12 participants (6 females, 6 males) during a data entry task (35 minutes) and a 30-minute post-task period. Participants also reported their perceived forearm discomfort during data entry and recovery. Three forearm analysis regions were analyzed based on statistical findings; Upper Left, Lower Left and Right regions. Temperature trends were found to increase during data entry and decrease during recovery. The Upper Left region was warmer during both data entry and recovery phases in comparison to the other regions. Repeatability of surface temperatures, based on intraclass correlations (ICCs), was found to be fair for magnitudes and trends during data entry, and poor for magnitudes and trends during recovery, despite higher significant correlations in the latter. Positive correlations were evident between subjective feelings of forearm discomfort trends and temperature trends in response to workload. No gender differences were found with regard to temperature measurements. This work contributes to the understanding of surface responses of the forearm during and following an applied stress, and to the literature supporting thermography as a non-invasive evaluative tool for assessing physiological responses during job tasks.

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CHAPTER 1
INTRODUCTION

1.1 Background

Work-related musculoskeletal disorders (WMSDs) continue to be a concern in today's work force. Although the number of reported MSDs is declining, 357,160 new MSD cases were reported in 2006, approximately 30.2% of all nonfatal occupational injuries and illnesses involving days away from work (Bureau of Labor Statistics, 2006). Of these, 50,470 cases involved the upper extremity (Bureau of Labor Statistics, 2006). Upper extremity WMSDs are common among workers that use visual display terminals (VDTs) and keyboards extensively, such as employees in the telecommunications and newspaper industries (Fine, 1996). In 2005, 5,430 injury cases could be linked to jobs that involve data entry tasks (Bureau of Labor Statistics, 2006). Approximately 90.1% of these cases affected the upper extremity and required a median of 20 days away from work for recovery (Bureau of Labor Statistics, 2006). These missed work days resulted in lost wages and decreased productivity for many organizations. Typing is a near universal activity, no longer limited to a business or academic society (Shafer-Crane et al., 2005). This fact makes WMSDs a more widespread problem affecting not only occupational workers, but increasing injury risk to other populations, such as children and adolescents.

Several studies have been performed to understand causes of and contributing factors to WMSDs, though innovative methods for identify pathophysiological mechanism for WMSDs is needed (U.S. Department of Health and Human Services, 2001). Thermography is a non-invasive technique that may provide information about unknown physiological markers associated with injury development during job task performance (Bertmaring, 2006). Thermography has been found to accurately detect the presence of WMSDs for the hand/wrist area (Herrick & Herrick, 1987; Oerlemans et al., 1999; Tchou, Costich, Burgess, & Wexler, 1992). However, its use in an evaluative sense, particularly in occupational settings, is limited.

1.2 Problem Statement

Upper extremity posture and muscle activity during data entry tasks have been identified as contributing factors to WMSDs (National Institute of Occupational Safety and Health, 1997) . Much of the work assessing the forearm during data entry tasks has involved widely accepted and established techniques such as electromyography (EMG) or magnetic resonance imaging (MRI). Studies using thermography to assess task demands are limited, though it has been used to detect WMSDs for select body parts (Feldman & Nickoloff, 1984; Herrick & Herrick, 1987; Oerlemans et al., 1999; Pogrel, McNeill, & Kim, 1996; Sherman, Barja, & Bruno, 1987; Tchou et al., 1992; Zhang, Kim, & Cho, 1999). Also, the reliability of thermographic readings has not been documented. Herrick and Herrick (1987) discuss the importance of verifying a procedure's reliability in terms of reproducibility as well as to produce results comparable to those obtained with established conventional methods, to aid in procedure acceptance.

1.3 Objectives of the Study

The objectives of this study were to (1) evaluate the feasibility of using thermography to quantify differences in thermal readings of participants during and following data entry tasks, and (2) to assess the repeatability of thermal readings. Specific hypotheses that were tested include:

1. Thermal readings of the forearm will increase during the data entry task for all participants, though not at the same rate.
2. Thermal readings will remain elevated following task performance and decrease with time.
3. Thermographic readings will be repeatable and consistent both during and post task for all participants.
4. There will be no significant difference in the thermographic readings of men and women.

1.4 Scope and Limitations of the Study

The current study was restricted to measuring the changes in temperature over the forearm and perceived forearm discomfort as a function of time during and following a typing task. Other physical and subjective responses outside of skin surface temperature and discomfort changes such as muscle activity, heart rate or mental workload were not measured.

Further, the data entry task performed by participants took place on a conventional keyboard. All tasks were restricted to the use of a keyboard. Use of a mouse or other input devices was not considered.

CHAPTER II
LITERATURE REVIEW

2.1 Work-related Musculoskeletal Disorders

NIOSH (1997) defines musculoskeletal disorders (MSDs) as those conditions which involve the nerves, tendons, muscles, and supporting structures of the body. These conditions, which can be caused by work exposures or develop in a workplace setting, are further classified as Work-Related Musculoskeletal Disorders (WMSDs). Examples of WMSDs include, but are not limited to, carpal tunnel syndrome, hand-arm vibration syndrome, and shoulder tendonitis (National Institute of Occupational Safety and Health, 1997).

Despite the fact that no one study will identify all causes of a particular WMSD, multiple studies have shown the relationship between workplace factors and the development and/or increased risk of development of a particular WMSD. The development of WMSDs has strong correlations with a wide variety of physical and psychosocial factors. Common physical factors contributing to WMSDs are repetition force, posture, vibration, and combinations of these factors. Upper extremity WMSDs are commonly found among workers using visual display terminals (VDTs) because of the extensive use of keyboards (Fine, 1996; Gerr et al., 2002). WMSDs are not only a source of lost wages, lost productivity for organizations, but most importantly, negatively affect a worker's health and ability to complete every-day tasks.

2.1.1 Upper Extremity Risk Factors During Data Entry

In a study assessing the effect of upper extremity support on upper extremity posture and muscle activity during keyboard use, Cook et al. (2004) state, "Recent studies have demonstrated that computers are used by more than 25% of the workforce, for more than half of their working day (p.1)." The wide spread use of computers in today's society provides an increased risk for development of musculoskeletal disorders targeting a larger population. Many studies have been performed to address the potential development of musculoskeletal disorders with prolonged computer use. Several risk factors are associated with computer use including: desk, chair and screen heights, working postures, and the use of input devices (Cook et al., 2004).

Pascarelli and Kella (1993) discuss keyboard use as a potential risk factor for carpal tunnel syndrome, epicondylitis, and a host of other musculoskeletal disorders (Keir & Wells, 2002). Awkward working postures of the wrist and forearm during keyboard activities have been associated with the risk of WMSD development. In a study assessing wrist and forearm postures and motions during typing, Serina et al. (1999) show that wrist angular velocities and accelerations were high during typing, despite the appearance of a stationary position. Flexion and extension angular velocities during typing were found to be comparable to industrial worker tasks associated with a high risk of WMSDs. Forearm pronation during typing ranges from 69 degrees to 79 degrees(Honan, Jacobson, Tal, & Rempel, 1996; Honan, Serina, Tal, & Rempel, 1995). Simoneau et al. (1999) have similar findings, reporting means of 62 degrees and 66 degrees for left and right forearm pronation respectively during typing. Reducing pronation can decrease musculoskeletal stresses resulting in a reduction of carpal tunnel pressure and theoretically a lower incidence of carpal tunnel syndrome (Simoneau, Marklin, & Monroe, 1999). As suggested by Serina et al. (1999), "wrist and forearm motions should be evaluated as possible risk factors for musculoskeletal disorders during typing."

Muscle activation and postural loading contribute to the risk of upper extremity disorders. Gerard et al. (1995) found that increased typing speeds resulted in more muscle activity and fatigue (Tittiranonda, Burastero, & Rempel, 1999). The extensor side of the forearm is a common site of problems in typists and industrial workers (Pascarelli & Kella, 1993; Ranny et al, 1995; Keir et al., 2002).

2.2 Thermography

Thermography is the study of human thermal physiology (Pochacz'Aevsky, 1986). Since the first accurate recording of surface body temperature done by Hippocrates in 400 B.C., the capabilities and applications of thermography is a topic of interest continually undergoing research. Thermography is a non-contact method of measuring the surface skin temperature of a particular body-surface area and provides a visual display of these temperatures gradients at a specific time (Feldman & Nickoloff, 1984). Despite common misconceptions, a thermogram is not a "picture of pain," but a visual representation of a physiological response to underlying problems that might be the cause of pain symptoms experienced by individuals. Several thermal sensors are available; however, cutaneous thermal emissions are best studied using infrared thermography and contact thermography (Pochacz'Aevsky, 1986). Infrared thermography is a non-contact method in which electromagnetic thermal energy are captured and converted into video signals, being picked up by a monitor that displays temperature gradients in shades of gray or color. Using a high-speed infrared scanning camera focused on the patient, generated images can be stored using either a Polaroid or a 35-mm picture (Taylor & Warfield, 1985). Some infrared systems use digital recording or computer-assisted machines to record images and can aid in future analysis (Pochacz'Aevsky, 1986; Taylor & Warfield, 1985). Contact thermography uses flexible sheaths made of cholesteric crystals, or "liquid crystals," located in an inflatable box. These sheaths conform to the area of the body of interest and detect heat emissions producing a color display (Pochacz'Aevsky, 1986). Contact thermography can also take the form of probes that are touched directly to the skin surface in order to record heat emissions.

2.2.1 Thermal Symmetry and Abnormalities

The basis of using thermography as a diagnostic aid or an assessment tool is centered in temperature symmetry of the two halves of the body (side to side). A thermal reading of a normal body will exhibit temperature symmetry on a thermal image. The trunk of the body will produce warmer temperatures and the extremities cooler temperatures. In a healthy body, the temperature will decrease as the distance between the trunk and extremities increases (Oerlemans et al., 1999). Asymmetric temperature images are an indication of dysfunction of the soft tissues of the body. This may be an indication of injury or "an underlying pathophysiologic state of vascular, inflammatory, or neurologic origin" as stated by Pogrel et al. (1996). Jacob Green (1987) noted that less than 90 days following an original injury to the peripheral nerve, there is an initial increase in skin surface temperature on that particular side of the body. Approximately 90 day after the injury, there is a decrease in skin surface temperature possibly detectable for years following the injury if the peripheral nerve segment is still affected.

Several standards have been universally adopted, quantifying the limits for asymmetry and the amount of temperature disagreement between skin surface areas that will represent an abnormality. As determined by Felman and Nikoloff (1984), "a thermogram displaying asymmetric temperatures is considered a presumptive indication that an abnormality exists;

however, a 1°C difference in thermal temperature is indicative of a definite abnormality" (p. 248). As this study focuses on the forearms, relative temperature standards are pertinent information. Temperature differences indicating abnormality are slightly different for the forearm. Forearm temperatures are reported to be within 0.9°C (Uematsu & Long, 1976). Differences exceeding 0.9ºC in corresponding areas between the two forearms are labeled as a definite abnormality. Normal "variant" patterns have also been discovered in the dorsal forearm. One pattern consists of coarse mottling diffusely distributed over a wide area (Feldman & Nickoloff, 1984). Another pattern, generalized dorsal forearm hyperthermia is classified as normal because it is thought to involve the dominant extremity of muscular individuals, and the size and shape of the asymmetrically hyperthermic zone is spread, not adhering to a specific dermatome territory, an area of skin whose sensory nerves are supplied from a single spinal nerve root (Marieb, 2001), (Feldman & Nickoloff, 1984). Questions have arisen concerning the reason for temperature asymmetry of the forearms. Feldman and Nickoloff (1984), tested the rationale that hyperthermic dominant forearm, usually the right in majority of cases, is a result of more prominent muscle mass on the dominant side (i.e. right-handed individuals are more prone to develop right-sided hyperthermia). In their study, 94 percent of the 100 relatively asymptomatic actively employed factory workers examined where right-handed. 98% of the right-handed participants did not display any hyperthermia in the dominant forearm, suggesting that asymmetric temperature differences may not be the result of increased muscle mass in the dominant forearm.

2.2.2 Prognostic and Evaluative Thermography

Neurothermography, "a method of assessing the integrity of the peripheral autonomic nervous system," has been shown to detect a host of disorders of the cervical spine and upper extremities of the neurological and neuromuscular nature (Green, 1987). Neurothermography has also had strong correlations with detecting carpal tunnel syndrome (Herrick & Herrick, 1987; Oerlemans et al., 1999; Tchou et al., 1992). Despite the numerous studies that look at thermography and its diagnostic capabilities, there are minimal studies assessing thermography as an evaluative tool assessing task demands on the human physiology (Barker, Hughes, & Babski-Reeves, 2006). Barker et al. (2006) assessed the effects of overhead intermittent work task on thermal readings. In looking at the effects of different task parameters on the middle deltoid and trapezius thermal images during simulated work, thermography was determined to be sensitive to task parameter changes. Barker et al. (2006) conclude that as a result of this sensitivity, "thermography may be useful in quantifying work task demands". The present research investigates forearm activity during a typing task. Forearm activity during tasks is among topics deserving further research and investigation as establishing patterns in muscle activity under normal working conditions can help in identifying abnormalities leading to increased risk for injury development. Sharma et al. (1997) performed a study on thermographic changes in keyboard operators with chronic forearm pain. Looking at asymptomatic and symptomatic participants (those who have diffuse forearm pain for a specified period of time), thermograms showed increased temperature readings in 21 asymptomatic participants, with the exception of four participants, following a five minute typing task, while thermographic readings of symptomatic participants showed significant cooling. Participants were asked to return nine months later to assess repeatability of the results; symptomatic participants again showed cooling in thermographic readings, which were consistent with the results of the first testing phase. However, follow-up information was not provided on the control participants of this study. Gold et al. (2004) demonstrated that thermography was able to detect post-typing skin temperature differences in response to a 9-min typing challenge followed by a 10 min-rest period. Temperatures for non-symptomatic participants were found to increase 0.1°C from baseline temperatures directly following the typing before decreasing by 0.3°C. Further research on forearm activity during and after various tasks can give helpful information as to how the forearm responds to different stresses.

2.2.3 Thermographic Reliability

Reliability of thermographic readings is an issue that requires continued exploration. Gold et al. (2004) state, "the reliability of infrared thermography is unknown" and it would be useful to evaluate reproducibility of results through repetitions of the study over an extended time-period. Few studies have been performed assessing the repeatability of thermal readings on various body parts. Sharma et al. (1997) reported that thermal readings are reproducible based upon the results which showing four of the five patients who returned nine months after the initial study, again exhibited cooling after a typing induced stress. Orelemans et al. (1999) showed test-retest reliability correlation was high ($r = 0.94$ for Tester A and 0.96 for Tester B; $p<0.001$) in a study where 13 asymptomatic participants had multiple measurements taken on dorsal and palmar aspects of the hand by two different testers. Interobserver correlation was also shown to be high across measurements (r = 0.97 and 0.96 for the observations at measurements 1 and 2, respectively; $p<0.001$). Varjú et al. (2004) evaluated twelve subjects who received two thermographic studies of the hands three hours apart on the same day . Although the aim of this study was not to assess thermal images of a task, Varjú et al. demonstrate reliability of thermographic measures over a brief period, as the calculated test-retest coefficients were high. This study also states, "it will be necessary to establish the long term stability of these measures in order for longitudinal assessments to be reliable", supporting the continued need for repeatability studies using various time intervals. Reliability has yet to be thoroughly established in assessing repeatability of thermal readings during and post-job tasks.

2.2.4 Benefits and Limitations

There are several benefits to using thermography as a tool. The use of thermography offers a non-invasive method to assess a person with or without pain. Thermography shows high correlation with other tests such as electromyography (EMG) and computed tomographic (CT) scan (Hubbard & Hoyt, 1985). Thermography has uses for evaluation of neuromuscular function, athletic injuries, peripheral nerve injuries, and chronic pain syndromes. In evaluation of treatment conflicts between other tests, thermography can also serve as a second opinion. Neuro-thermography may serve as an assessment tool before invasive diagnostic or therapeutic procedures. In comparison to other methods, thermography offers an understandable visual representation of what may or not be felt, allowing patients to further understand any diagnoses made and increase willingness to participate in suggested remedies (Hubbard & Hoyt, 1985). Thermography has potential for evaluating job tasks, assisting in ergonomic evaluation, and producing data that can be used to proactively prevent injuries.

As with any tool, limitations do exist with thermography. Thermal readings can be affected by smoking as this results in vasoconstriction with concomitant, limiting thermographic sensitivity (Pochacz'Aevsky, 1986; Taylor & Warfield, 1985). Subcutaneous fat can also alter thermal readings. For this study, participants classified as falling within the 'normal' range for their respective height and weight groups will be permitted to take part in the study. In addition to subcutaneous fat, females have an added possible limitation as menstrual cycles may also affect temperature readings. Factors affecting blood flow, such as cancer, age and surgery, can also affect thermal pattern symmetry (Tsuchida, 1990).

2.3 Reliability (repeatability)

Reliability is the “consistency” or “repeatability” of measures or a test (Trochim, 2006). Reliability assesses a measure or test’s ability to reproduce the same result multiple times, also described as consistency and dependability. There are multiple types of reliability. Generally these include, Inter-Rater or Inter-Observer, Test-Retest, parallel-forms, split-halves, and internal consistency reliability. This research will only discuss test-retest reliability as this study will focus on the consistency of thermal readings taken at two different points in time. Test-retest reliability is affected by the amount of time elapsed between the occasions of measurement. An increase or decrease in time interval can affect the correlation between the observations. This study uses a shorter time intervals to minimize data loss. Although a measure will never be absolutely reliable, the goal is to reduce the measurement error and variability as much as possible to increase reliability.

2.3.1 Reliability Indexes

Disagreement among clinicians and researchers exist about which reliability index is appropriate to use and in what situation. There is no set index which has been labeled the “best”. For the purposes of this study, we will classify reliability indexes in two categories, interclass and intraclass reliability indexes. Interclass reliability indexes (e.g. Pearson Product Moment Correlation Coefficient) are those indexes used to estimate the correlation between two different variables. Intraclass reliability indexes (e.g. intraclass correlation coefficient (ICC)) are used to estimate correlations between the same variable measured under different conditions. These conditions include different times, different raters, or different instruments. Despite the popularity of using Person correlation coefficient to estimate reliability, it is not without its problems. Several researchers agree that one of the biggest problems is that reliability will be overestimated as a result of systematic bias going undetected (Bland & Altman, 1986; Denegar & Ball, 1993; Larsson, Karlsson, Eriksson, & Gerdle, 2003). This is a result of the fact that correlation is a measure of association and not agreement (Aspden, 2005; Bland & Altman, 1986). An additional problem with using the correlation as a reliability measure is that a correlation is dependent upon the range of the variables being compared. Higher ranges will appear to produce higher correlations than more restricted ranges despite possibly containing extreme values (Aspden, 2005). However, range of variables also affects ICC values as well. The present research will use ICC and correlations to determine repeatability.

Intraclass correlation coefficient (ICC) is a relative measure of reliability (Larsson et al., 2003). ICC is a ratio of between-subject variance divided by total variance (Denegar & Ball, 1993). Shrout and Fleiss (1979) have determined six version of the intraclass correlation coefficient and discuss how to use them and the appropriate situation in which to use the different equations. The six equations are labeled (1,1), (2,1), (3,1), (1,k), (2,k), and (3,k). The first digit denotes the appropriate analysis of variance (ANOVA) model that should be used. The second digit represents whether there is one or k raters or a mean of k ratings (Shrout & Fleiss, 1979). The value of the ICC generally ranges from 0 to 1, where 0 represents no reproducibility and 1 for perfect reliability. Occasionally ICC may be negative when the within-subject variance exceeds the between-subjects variance. This will indicate no reproducibility and will be equivalent to ICC = 0 (Larsson et al., 2003). The current study will use ICC (2,1) as the appropriate model for this research (Equation 1).

$$ICC(2,1) = \frac{BMS - EMS}{BMS + (k-1)EMS + k(TMS - EMS)/n}$$

BMS = Between-subjects mean square

EMS = Error mean square

TMS = Trial mean square

k = Number of trials, judges, or evaluators

n = Number of subjects

Equation 1: Calculation for Intraclass Correlation Coefficient

ICC (2,1) is chosen because the number of measures is considered a random sample from a population and the number representing the measurement is not a composite (i.e. a mean of k numbers) but represents a single value. The model ICC (2,1) will be calculated using a repeated measures analysis of variance (Denegar & Ball, 1993).

Alternate methods have been suggested to test reliability so a researcher is not simply relying on a categorical label or ‘global terms’ (Lexell & Downham, 2005). Assessing changes in the mean values between two test occasions has been identified as an additional method to determine agreement. Changes can be attributed to two differences: random change and systematic change. Random change is that which arises purely from random error of measurement resulting in making the mean for trial different. Systematic change is the non-random change in the values between the trials that applies to all study participants (Hopkins, 2000). Graphically representing the differences between the two occasions against their means can give a better indication of the actual differences of the test occasions versus a plot of one test occasion against the other (Bland & Altman, 1986). Using this plot, a researcher can also easily determine if the change is due to systematic error or random error. 95 % confidence intervals for the mean difference are calculated using the standard error of the mean differences (Equation 2), and are plotted with the difference-mean plot. “SE represents the precision of the mean difference as an estimate of the underlying change in the mean (Lexell & Downham, 2005)” (pg. 723). When graphing a 95% confidence interval for the mean difference between the occasions (Equation 3), if zero is not included within the interval, this is an indication of systematic changes in the mean.

$$SE = SD_{diff} \big/ \sqrt{n}$$

SE = Standard error of the mean

SD_{Diff} = Standard deviation of the differences

n = number of participants

Equation 2: Calculation for standard error of the mean for confidence intervals

$$95\%\ CI = \overline{d} \pm t_{0.95,\nu} \times SE$$

$\overline{d}$ = Mean difference

$t_{0.95,\nu}$ = t statistic with cumulative probability 0.975 and ν degrees of freedom

SE = Standard Error of mean

Equation 3: Calculation for 95% confidence intervals for the mean difference

2.3.2 Reliability Index Interpretation

There are several methods for classifying ICC values. Researchers have yet to agree on which method is optimal. Several classification categories from psychology, medical and ergonomic related research are listed in Table 1.

Table 1: Classifications for ICC reliability values

Source	Interpretation
Bartko et al. (1966)	Poor: 0 - 0.6, Good: 0.8 – 1.0, Excellent: 0.8 – 1.0
Landis et al. (1977)	Slight: 0 – 0.2, Fair: 0.21 – 0.4, Moderate 0.41 – 0.60, Substantial 0.61 – 0.80, Almost perfect 0.81 – 1.0
Fleiss (1986)	Poor: 0 – 0.2, Fair to Good: 0.40 -0.75, Excellent 0.75 – 1.0
Sleivert et al. (1994)	Poor: 0 – 0.59, Fair: 0.60 – 0.79, Good: 0.8 – 1.0
Shrout (1998)	Virtually none: 0 – 0.1, Slight: 0.11 – 0.40, fair:0.41 – 0.60, Moderate: 0.61 – 0.80, Substantial: 0.81 – 1.0
Stokdijk et al. (2000)	Poor: 0 – 0.39, Fair: 0.40 – 0.59, Good: 0.60 – 0.74, Excellent: 0.75 – 1.0
Koumantakis et al. (2002)	Poor: 0 – 0.69, Fair: 0.70 – 0.79, Good: 0.80 – 0.89, High: 0.90 – 0.99

The present research will use the classification scheme as follows: Poor: 0 – 0.39, Fair: 0.40 – 0.59, Good: 0.60 – 0.79, Excellent 0.80 – 1.0. This scheme is a combination of the classification categories as used by Bartko et al. (1976) and Stokdijk et al, (2000). The above classification levels were also used in a previous study performed by Hager (2003) in assessing the reliability of fatigue measures in an overhead work task. As established by Hager, the classification incorporates a more stringent "Excellent" reliability category as well as the use of the "Poor" and "Fair" classifications. This scheme will allow for consistency in reporting reliability values.

2.3.3 Reliability Application to Thermography

Determining the reliability of thermal readings across days can help establish thermography as a future investigatory and diagnostic tool. Currently there exists a lack of studies assessing the test-retest reliability of thermal readings; in particular, the upper extremity. Performing studies which demonstrate high repeatability can increase the validity of thermography.

2.4 Summary

Work-related musculoskeletal disorders of the upper-extremity are a concern with the increased use of computers and data entry tasks. Upper-extremity postures are implicated as a contributing factor for incidence of WMSDs during data entry tasks. Current research uses methods such as EMG and MRI scans to investigate muscle activity and upper extremity postures during various work task demands. These methods can be invasive procedures with regard to the need for either attaching equipment or having to stop activities in order to collect necessary data. Further, there is limited evidence that these methods are reliable. The use of thermography is an additional resource that may be used to study the physiological responses of the upper extremities during data entry and typing tasks. Thermography is a non-invasive tool used to evaluate the surface skin temperature. Despite gaining acceptance as a diagnostic aid, there are minimal studies using thermography as a prognostic or evaluative aid, specifically assessing physiological responses during job tasks. This study specifically focuses on evaluating the dorsal forearm during and post data entry task, and quantifying the resulting thermal readings. Understanding the physiological response of the forearm during data entry may give additional information on the upper extremity during evaluation, and aid in establishing how to prevent unnecessary loadings or postures which may increase the risk of upper extremity WMSDs.

In order for any tool to be widely accepted, it must be proven to be both valid and reliable. Lack of literature addressing the reliability of thermography in evaluating the physiological responses during job tasks provides opportunities to confirm the reliability of thermography in evaluating physiological responses during various job task demands. Establishing test-retest reliability will help thermography gain acceptance as a prognostic and evaluative tool. Thermal images are hypothesized to be repeatable across testing days for both during and post-task images regardless of gender.

CHAPTER III
METHODOLOGY

3.1 Experimental Design

A mixed factor design was used to study the effects of data entry tasks on thermal images of the forearm and perceived discomfort of the forearm. Thermal images were taken of the participant's dorsal forearms while sitting at a computer workstation in a temperature- and light-controlled environment. Dorsal forearms were used as clear images could easily be obtained of active muscles used during typing without task interruption. Perceived forearm discomfort was recorded in parallel to the recording of thermal images. Factors included task phase, gender, and day. Effects of task phase (data entry, recovery), forearm region (upper left, lower left, right), day (1, 2) and gender (male, female) on the surface skin temperature of the forearm were quantified. The effects of task phase, day, and gender on perceived forearm discomfort were also determined. A 35-minute data entry task followed by a 30 minute recovery period was employed in this study. Data entry duration was set to allow sufficient data collection to determine trends while also simulating a realistic time for a continuous data entry task. Testing procedures on day one were repeated when participants returned for a second scheduled day. Each participant had 44 total (including two baseline images) thermal images obtained over a two-day period (21 collected images per day).

3.2 Independent Variables

Independent variables that were manipulated include: task phase (within subjects factor), day (within subjects factor), region (within subjects factor) and gender (between subjects factor). Details for each independent variable are provided below.

3.2.1 Task Phase

Task phase consisted of two levels: data entry (a 35 minute data entry task) and recovery (30 minutes immediately following the data entry activity). Phase was considered as a variable as there might have been interesting trends in thermal images following task activity showing muscular response to task demands.

3.2.2 Day and Gender

Participants completed two days of testing using the same protocols to assess repeatability. Participants completed a second day of testing no closer than 24 hours and no later than 48 hours from the initial testing day. Returning within this time frame served a two-fold purpose:

1. Participants would not be working at full maximum capacity. Therefore, a longer time interval was not necessary to allow full recovery from fatigue effects due to the typing task.
2. Markings used for thermal marker placement on the skin would fade over time due to washing, lotions, oils, or anything done to the skin on the forearm. To aid in consistency with marker placement across testing days, participants would need to return within a reasonable amount of time in which markings are still visible.

Testing was completed at approximately the same time of day for both day one and two to minimize the effects of circadian rhythms.

3.2.3 Forearm Regions

The left and right forearms were divided into 12 regions; regions 1 – 6 representing the left arm and regions 7 – 12 representing the right arm (Figure 2). Following statistical analysis, regions were re-grouped into Upper Left, Lower Left, and Right regions. Further forearm region details can be found the ‘forearm analysis regions’ sub-section pg. 23.

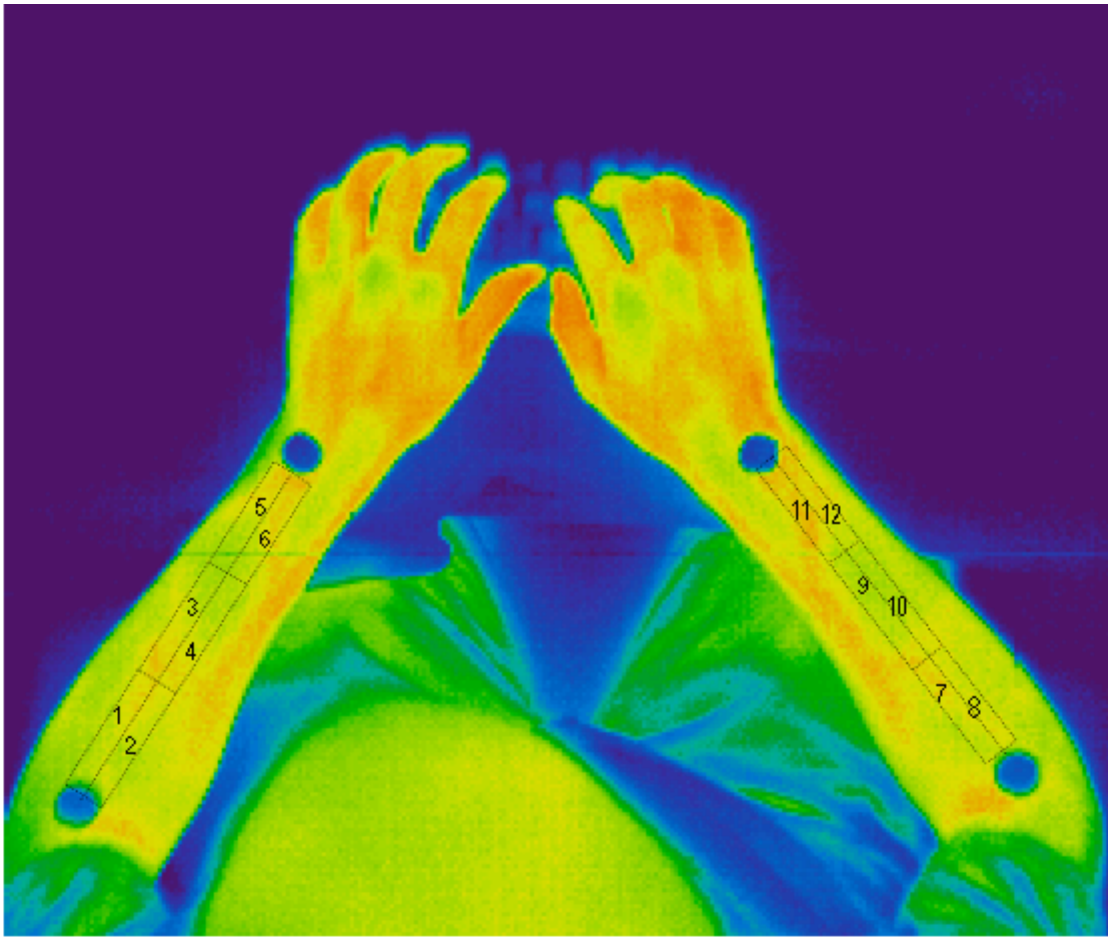


Figure 1: Forearm analysis regions

3.3 Dependent Variables

Skin surface temperature of the forearms (both left and right) and perceived forearm discomfort were the dependent variables considered. Rates of change (i.e. slopes) and means for thermal images were also analyzed.

3.3.1 Forearm Skin Surface Temperature

Skin Surface temperature of the forearms was measured using a Mikron 7200V infrared camera (Mikron Infrared, Inc., Oakland, NJ). The infrared camera has an internal temperature conversion feature with measurement accuracy at 2% of the reading. To facilitate data collection, two markers (Styrofoam discs) were used to standardize the area of assessment across participations. The first marker was located two fingerbreadths lateral to the styloid process of the ulna (Marieb, 2001). This location was chosen as the insertion point of several muscles that are primarily used in data entry and would be visible during the data entry activity (Marieb, 2001). The second marker was placed two finger breadths lateral to the bicep tendon (Perotto, 1994) (Figure 3). This location was chosen because it is medial to the origin of primary muscles used in data entry activities. The actual origin points could not be used as they lay on the lateral edge of the forearm when the forearm is pronated, making imaging of these points difficult. The markers, Styrofoam disks, were taped to the participant's forearm in their respective places using double-sided tape for the duration of the study. The Styrofoam material did not absorb body heat allowing for easy detection by the computer software; yet was still flexible and minimally obtrusive for the participant during data entry. The Styrofoam markers were 17.9 millimeters in diameter, the size of a dime. The locations of these markers were marked with a permanent marker to facilitate consistent marker location across testing days.

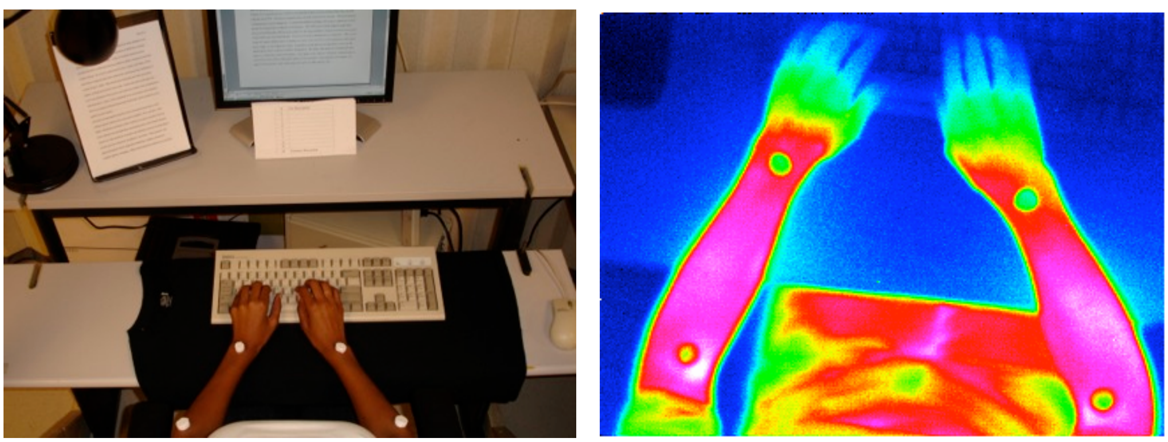


Figure 2: Marker placement on forearms

Several thermal images were collected: screening image, and a baseline and testing images (21 total) for both test sessions. All images were collected for 10 seconds, sampled at 1 Hz. This sampling strategy was selected due to file size and memory capacity limitations that prohibit continuous data collection. The camera was positioned 1.5 meters from the forearms throughout all procedures, allowing for full visualization of both forearms (Figure 4).

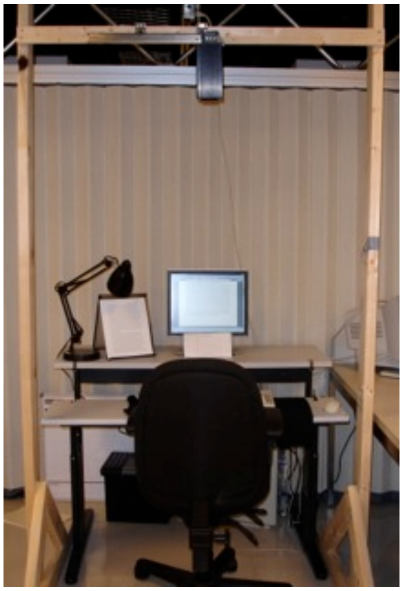


Figure 3: Experimental setup

The screening image was used to detect temperature abnormalities within the forearms prior to participating. Participants were seated in a chair, with arms resting on the arm rests. The screening image was collected following a 15 minute rest period during which participants sat quietly in the chair. Rectangular regions of interest (ROI) were superimposed over both forearms from the elbow crease to styloid process of the ulna. Participants with thermal images differing by greater than 0.9°C were excluded from participation, as this is indicative of an abnormality (see 'Thermography' section, pg. 6).

Baseline images were used to normalize the thermal images. Baseline images were taken prior to commencement of the data entry task on both testing days, after the acclimation period. Using a custom Matlab program, a rectangular analysis grid was superimposed over both forearms, dividing each forearm into six regions. Average forearm baseline temperatures were determined for each region. Details of forearm analysis regions can be found in the 'Statistical Analysis' section on page 23.

Twenty-one images were taking over an approximate one hour testing session, 11 during typing and 10 during recovery. The first and last five images were sampled at roughly one minute intervals, while the remaining images were sampled at roughly five minute intervals. To ensure that data collection did not coincide with the cessation of the task phases (data entry and recovery), images were obtained at the 0:45 second mark within each one minute interval for the first and last five images, and at the 4:45 second mark within each five minute interval for the remaining images (Figure 5).

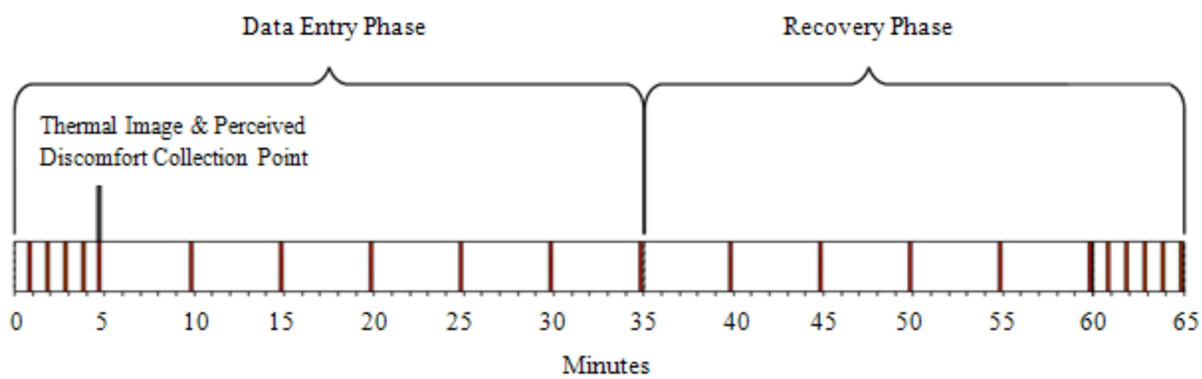


Figure 4: Graphical representation of the data collection points during and following data entry task

3.3.2 Perceived forearm discomfort

Perceived forearm discomfort was quantified using a modified Borg CR-10 scale (Borg, 1982) (Appendix C). The Borg CR-10 scale was chosen because it is a well known and extensively used tool that can be used to obtain subjective feelings of perceived discomfort (Borg, 1982; Kumar, Narayan, & Bjornsdottir, 1999). The Borg scale was taped under the computer monitor for easy visibility. During data entry and recovery phases, participants were asked to verbally report their perceived forearm discomfort by giving a number which corresponded to the level of discomfort they were feeling at that moment. Perceived discomfort levels were recorded following the previously discussed thermal image schedule for typing and recovery phases of the task (Figure 4).

3.4 Testing Environment

The experiment took place in a draft free room. Ambient room temperature was controlled between 22-24°C. Room temperature was recorded prior to and following each day using a Digital Thermometer clock (General Electric, Billerica, MA). Indirect lighting was measured using a DLM2 Light Meter (UEi, Beaverton, OR) and set to be no more than 75 lux, preventing errors in thermal images but still allowing participants to read the data entry material. The light setting is equivalent to an indirect light in a dark room in conjunction with the light emitted from the computer monitor.

Participants used a standard Dell Quite Key keyboard and 17" computer monitor on a height adjustable workstation (Generation IV, SIS Human Factor Technologies, Londonderry, NH). The workstation was adjusted according to ergonomic guidelines (Eastman Kodak Company, 2004), and participant preferences. Workstation set up and keyboard location was recorded for standardization across testing days. A height adjustable chair equipped with arm rests (OM96601, OMX, Inc., Naperville, IL) was provided and adjusted according to participant preferences. Participants were permitted to adjust the height of the chair so that the elbows were bent at approximately 90° and the forearms were parallel to the floor. If needed, a foot-rest was provided to allow the knees to be bent at approximately 90°. A document holder was used to present the information for the data entry task and was located based upon participant preferences.

3.5 Task

A standard data entry task was completed by all participants. Text passages were copied from a human resources book (Bolman & Deal, 1997) and presented to participants using a document reader. Participants recreated these documents using Microsoft Word (2003, Microsoft Corporation, Redmond, WA). Following the data entry task, participants completed the recovery phase where they rested with arms on the desk with forearms facing upwards while remaining still. The text passages for the two to days were different, though the reading level and word counts, measured using the Flesch-Kincaid and word count features within Microsoft Word, were approximately equal.

3.6 Participants

Twelve participants participated in the study, six males and six females. Participant ages ranged from 19 to 26, with a mean age of 22.5 yrs (Table 2).

Table 2: Participant demographics

	Female (n = 6)		Male (n = 6)		Total (n = 12)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Age (yrs)	20.5	0.8	24.5	3.6	22.5	3.3
Weight (lbs)	146.8	29.3	191.5	52.2	169.1	46.6
Height (in)	64.5	3.2	71.3	2.8	67.9	4.6
Dominant Left Hand (count)	1	--	0	--	1	--
Dominant Right Hand (count)	5	--	6	--	11	--

--Denotes standard deviations were not calculated

Participants were professional typists by trade or held a job that required equivalent typing or data entry demands, as reported in a demographic questionnaire (Appendix B).
Data entry equivalency requirements maintained that the vocation must involve a minimum of four hours of typing per workday. The specified data entry range was used to help ensure that the participants' muscles were conditioned to minimize confounding effect on the thermal readings. Participants were required to use ten-finger touch-typing. Prospective participants showing signs of current or previous musculoskeletal pain or discomfort in the upper extremity were excluded as their conditions may have affected thermal images (Appendix B).

3.6.1 Participant Screening Procedure

In addition to data entry duration and injury requirements, potential participants also received a visual inspection of the forearms to identify any marks, scars, or dark blemishes that could interfere with thermal images. As stated earlier, eligible participants whose forearm thermal images were within 0.9°C were allowed to continue with experimental protocols. Female participants menstruating during their scheduled testing days were asked to reschedule. If rescheduling is not possible, they were removed from the study. Participant's height and body weight were determined using a standard physician's balance scale (Detecto, Webb City, MO).

3.7 Procedure

Participants were asked to wear either a dark color sleeveless or short sleeve shirt with loose fitting sleeves to the screening as well as for all testing days. Initially, participants received a verbal and written description of the project, its objectives and procedures, and completed informed consent documents. Participants were screened for confounding medical conditions, completed a demographic questionnaire to determine eligibility, and completed the screening procedures. On testing days, participants entered the testing room, adjusted the workstation to their preferences (or on day two, had the station adjusted to their day one setting prior to their arrival), and rested for a 15 minute acclimation period. The baseline image was collected, the camera adjusted, and testing begun. At the end of the 35-minute data entry phase, participants assumed the baseline image posture (hands flat on the work surface to allow for forearm visualization) and recovery phase images collected for an additional 30 minutes. During the data entry and recovery phases, participants verbally reported their perceived discomfort rating, using the provided modified Borg CR-10 Scale, when prompted. At the end of each day, participants were monetarily compensated for their time.

3.8 Statistical Analysis

3.8.1 Forearm Analysis Regions

A rectangular analysis grid was superimposed on the thermal images between the markers fixed at the participant's wrists and approximately the bed of the elbows. The grid divided each forearm into 6 equal regions. Regions 1-6 represented the left arm, while regions 7-12 represented the right arm (Figure 5). ANOVA results showed that the regions were significantly different with respect to mean temperatures ($p < 0.0001$). Twelve forearm regions were combined and re-organized into three regions for data analysis: 'Upper Left (UL)' (formerly regions 1-2) representing the upper left arm, 'Lower Left (LL)' (formerly regions 3-6) representing the lower left arm, and 'Right (R)' (formerly regions 7-12) representing the right arm.

Using a custom MatLab program, average temperatures were found for each frame for reach region. Change in temperatures, referred to as ‘delta mean’, was calculated for each thermal image by subtracting the baseline temperatures from the temperature values for each participant during the respective day. Temperature trends were determined by calculating the slope of the change in temperature values as time progressed during each phase using simple linear regression. Slope values, referred to as ‘delta mean slope’, were included in the ANOVA analysis. Rates of change were determined for perceived discomfort data, again using simple linear regression, and were referred to as ‘perceived discomfort slope’ during data entry and recovery separately. Perceived discomfort slopes were also included in the ANOVA analysis.

Appropriate descriptive statistics (i.e. mean, standard deviations, etc.) were obtained for the independent variables. A Shapiro-Wilk’s test was completed prior to data analysis to test for normality. The effects of day (1, 2), gender (male, female), region (UL, LL, and R), phase (typing, recovery), and their interactions on delta mean temperatures, delta mean slope, and perceived discomfort slope were determined using a mixed factor ANOVA. A 0.05 significance level was used in the analysis of the results. Any significant differences found were further analyzed using a post-hoc analysis, Tukey HSD Test, where appropriate.

3.8.1 Test Re-test Reliability

Intraclass Correlation (ICC) was calculated using ICC (2, 1) equation. ICC values were classified using the following categories: Poor: 0 – 0.39, Fair: 0.40 – 0.59, Good: 0.60 – 0.79, Excellent 0.80 – 1.0 as described in Chapter 2. Correlations were classified using the following scheme: Low: 0 – 0.3, Moderate: 0.4 – 0.5, Good: 0.6 – 0.7, Excellent: 0.8-1.0. Widely used standard correlation categories for human subjects data are unavailable. As a result, correlations were classified based on the above arbitrary scheme.

Systematic sampling error was tested using changes in mean values. Differences and means of differences were calculated between day one and day two thermal readings for each participant (72 data points each for both mean and difference values). Differences were plotted against the mean values for day one and day two. Limits of agreement (+/- 2 standard deviations) and 95% confidence intervals for the mean difference between day one and day two were formed and added to the plot. This procedure was completed for both phases (data entry and recovery) of the task. This analysis also gave a visual indication of how much the thermal readings actually vary across the two testing periods.

CHAPTER IV
RESULTS

Descriptive statistics were determined and are presented in Table 3. Several general trends can be noted. Temperatures for day two were higher than day one, recovery temperatures were lower than data entry temperatures, and perceived discomfort trends increased during data entry but decreased during recovery.

Table 3: Descriptive statistics

Day	1		2	
	Mean	Std. Dev.	Mean	Std. Dev.
Delta Mean (Δ°C)	0.231	0.590	0.381	0.818
Delta Mean Slope (Δ°C/sec)	0.003	0.111	0.0154	0.109
Perceived Discomfort Slope (Δdiscomfort/sec)	0.566	0.197	0.0362	0.146

Gender	Female		Male	
	Mean	Std. Dev.	Mean	Std. Dev.
Delta Mean (Δ°C)	0.311	0.516	0.302	0.877
Delta Mean Slope (Δ°C/sec)	0.002	0.109	0.017	0.110
Perceived Discomfort Slope (Δdiscomfort/sec)	0.063	0.210	0.030	0.126

Phase	Data Entry		Recovery	
	Mean	Std. Dev.	Mean	Std. Dev.
Delta Mean (Δ°C)	0.446	0.540	0.156	0.844
Delta Mean Slope (Δ°C/sec)	0.100	0.062	-0.081	0.061
Perceived Discomfort Slope (Δdiscomfort/sec)	0.147	0.185	-0.055	0.071

Region	Upper Left		Lower Left		Right	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Delta Mean (Δ°C)	0.426	0.595	0.267	0.784	0.227	0.745
Delta Mean Slope (Δ°C/sec)	0.018	0.112	0.004	0.115	0.007	0.103
Perceived Discomfort Slope (Δdiscomfort/sec)	--	--	--	--	--	--

-- Indicates values were not determined for these effects

ANOVA P-values for independent variables and interactions are listed in Table 4, with significant values in bold. Means and standard deviations for all significant effects can be found in Appendix E.

Table 4: Mixed factor ANOVA

Effect	Delta Mean	Delta Mean Slope	Perceived Discomfort Slope
Gender	0.9432	0.4375	0.4231
Phase	**< 0.0001**	**< 0.0001**	**< 0.0001**
Region	**< 0.0001**	0.4708	--
Day	**< 0.0001**	0.2092	0.6367
Gender*Phase	0.5276	0.6542	0.3288
Gender*Region	0.6357	0.7403	--
Gender*Day	0.0951	0.6532	0.7489
Region*Phase	**0.0150**	0.3131	--
Day*Phase	0.4132	0.2811	0.2959
Day*Region	0.0862	0.9542	--
Gender*Region*Phase	0.0920	0.4416	--
Gender*Day*Phase	0.8623	0.4566	0.7847
Gender*Day*Region	0.1311	0.8884	--
Day*Region*Phase	0.7672	0.9817	--

Bolded values indicate significant effects; -- indicates values were not determined for these effects

4.1 Thermography

4.1.1 Delta Mean Temperature

Several effects were found to impact delta mean temperatures. These effects include phase, region, day, and the region by phase interaction. Temperatures during the Data entry phase (*mean* = 0.446 Δ°C, *sd* = 0.540) were significantly higher than during the Recovery phase (*mean* = 0.156 Δ°C, *sd* = 0.844). The Upper Left (UL) region produced higher average temperature values than both the Lower Left (LL) and Right (R) arm regions (Figure 6) (Tukey groupings in Appendix D).

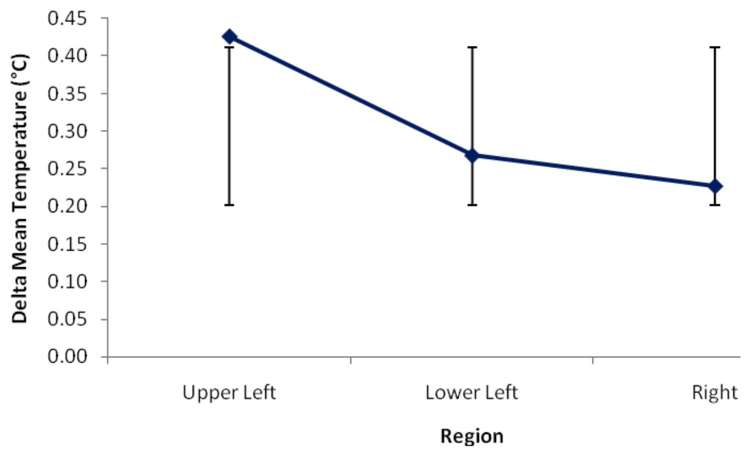


Figure 5: Regional Temperatures

4.1.2 Delta Mean Slope

Delta Mean slope values were only affected by task phase, where delta mean slope increased during data entry (*mean* = 0.100 (Δ°C/sec), *sd* = 0.0618) and decreased during recovery (*mean* = -0.081 (Δ°C/sec), *sd* = 0.061) (Figure 7).

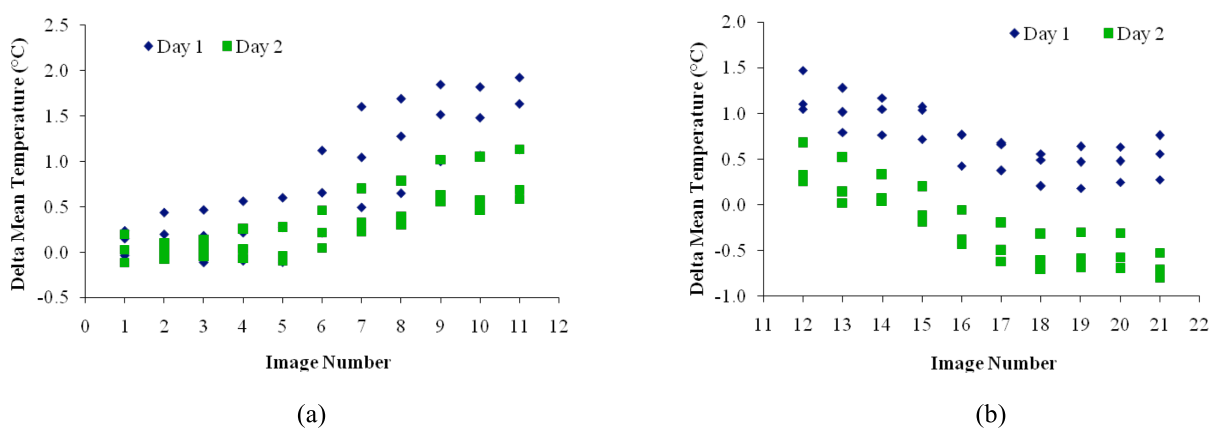
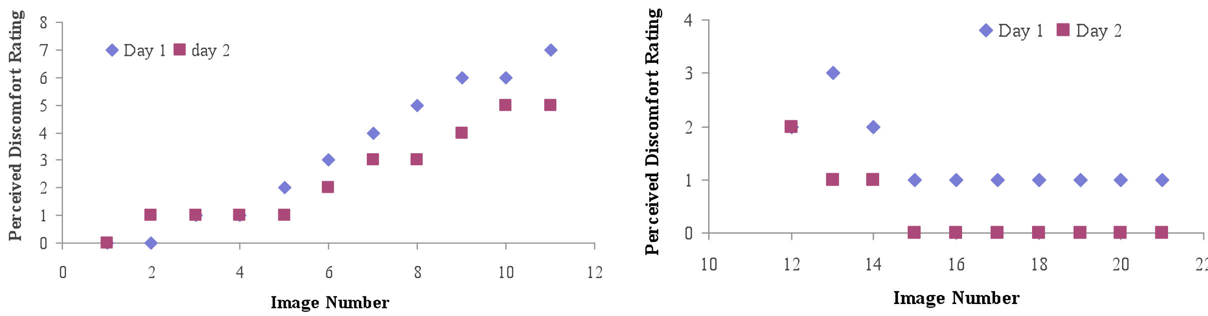


Figure 6: Data entry phase (a) and recovery phase (b) trends for days 1 and 2

4.2 Perceived Discomfort Slopes

There were significant task phase differences in perceived discomfort slopes. Perceived discomfort had an increasing trend (Figure 8a) during the data entry phase (*mean* = 0.147 (Δdiscomfort/sec), *sd* = 0.185) and a decreasing trend (Figure 8b) during the recovery task phase (*mean* = -0.055 (Δdiscomfort/sec), *sd* = 0.071).



(a) (b)

Figure 7: Perceived discomfort trends for data entry (a) and recovery (b) phases across days

4.3 Reliability

Several correlations were calculated including: (1) temperature values between days, (2) temperature trends between days, (3) subjective discomfort rating trends between days, and (4) subjective discomfort rating trends versus temperature trends. Spearman correlation coefficients are shown in Table 5. All correlations were significant. Moderate correlations (r = 0.477) exist between temperature magnitudes on Day 1 and Day 2; whereas, excellent correlations (r = 0.817) were found between temperature trends on Day 1 and Day 2. Self-reported forearm discomfort rating trends for Day 1 had good correlation with rating trends for Day 2 (r = 0.783). Subjective discomfort ratings trends also showed good positive correlations with delta mean trends for Day 1 and Day 2 (r = 0.643 and 0.687 respectively), where discomfort-rating trends and temperature trends increased and decreased simultaneously. The Spearman Correlation matrix can be found in Appendix F.

Table 5: Spearman correlation and p-values

	Correlation (*r*)	*p*-value	Correlation Category
Delta Mean Between Days*	0.477	< 0.0001	Moderate
Delta Mean Slope Between Days*	0.817	< 0.0001	Excellent
Perceived Discomfort Slope Between Days*	0.783	< 0.0001	Good
Delta Mean Slope Day 1 vs. Perceived Discomfort Slope Day 1*	0.643	0.0007	Good
Delta Mean Slope Day 2 vs. Perceived Discomfort Slope Day 2*	0.687	0.0002	Good

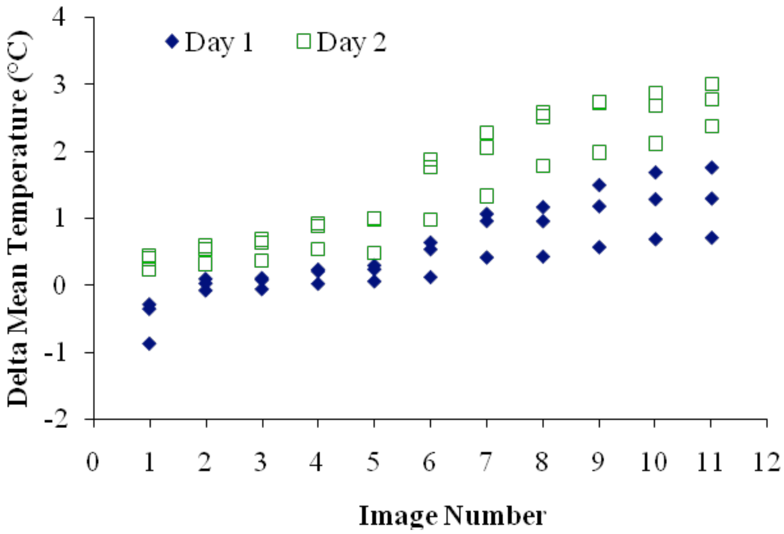
*Includes data entry and recovery phase values

Intra-class Correlation Coefficient (ICC) values were determined for reliability of temperature magnitudes and trends between days for both data entry and recovery phases. Temperature magnitudes and trends produced during data entry show fair reliability, producing consistent values across days (Figure 8). Day 1 values were consistently lower than day 2 values. In contrast to the data entry phase, ICC values for temperature magnitudes and trends produced during the recovery phase show poor reliability across testing days. Inconsistencies in recovery values and trends between days are shown in Figure 9. Recovery for perceived discomfort slope showed fair reliability, whereas data entry perceived discomfort slope showed excellent reliability.

Table 6: ICC values and categories*

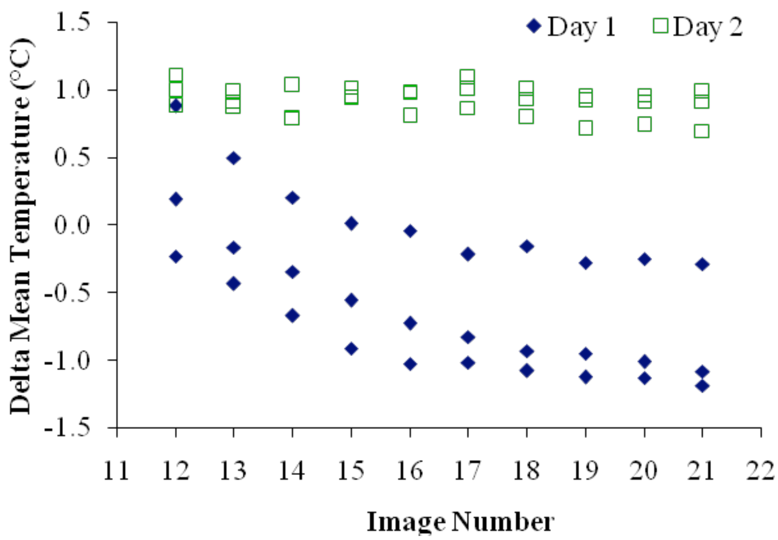
Variable	ICC Value	ICC Category
Data Entry	0.46	Fair
Recovery	0.39	Poor
Data Entry Slope	0.44	Fair
Recovery Slope	0.19	Poor
Perceived Discomfort Slope Data Entry	0.85	Excellent
Perceived Discomfort Slope Recovery	0.53	Fair

*All values are between day comparisons



*Each image number has a data point for each forearm region

Figure 8: Graphical representation of data entry phase reliability



*Each image number has a data point for each forearm region

Figure 9: Graphical representation of recovery reliability

In conjunction with ICC values, difference-mean plots were constructing by graphing the difference between day 1 and day 2 temperature values against the average of temperature values between days. 95% confidence intervals (CI) were determined for the mean difference between days. Difference-mean plots were produced for both data entry (Figure 10) and recovery phases

(Figures 11). The figures indicate that systematic error may be present, as zero is not contained within the 95% confidence interval of the mean difference.

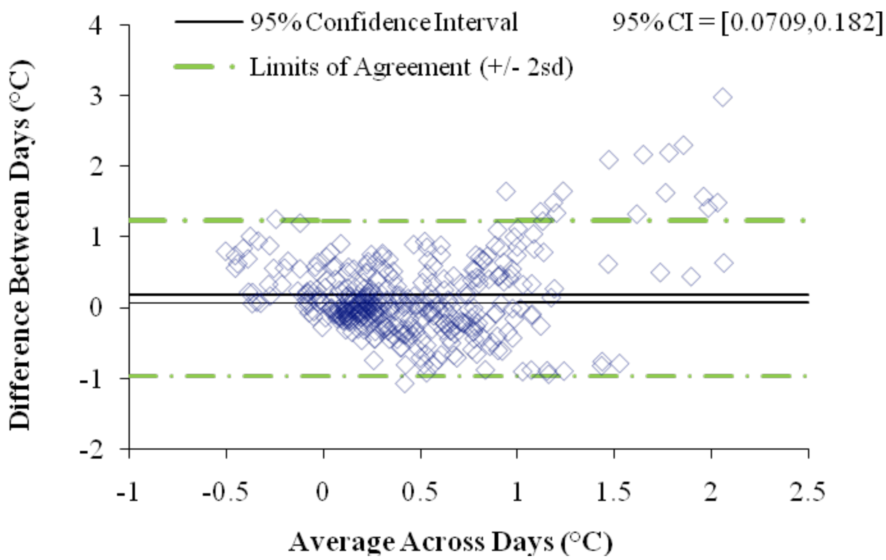


Figure 10: Data entry phase Bland-Altman plot

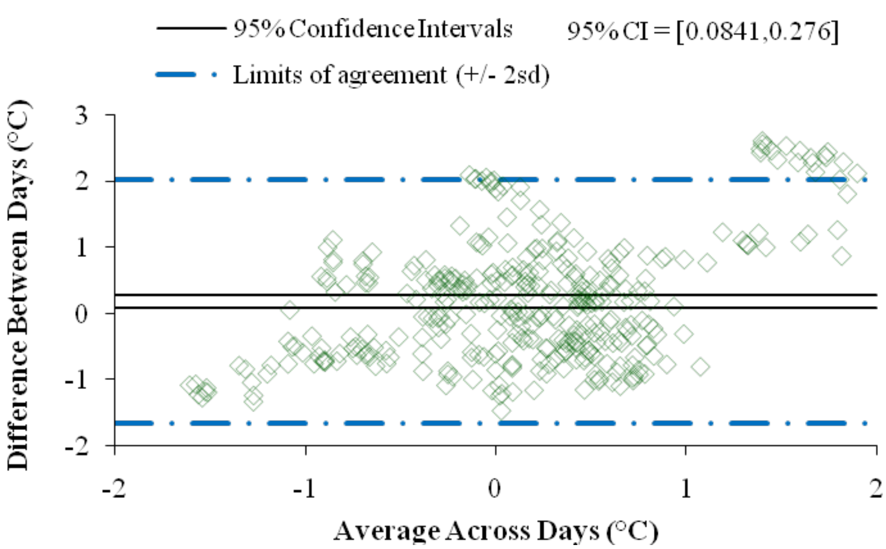


Figure 11: Recovery phase Bland-Altman plot

CHAPTER V
DISCUSSION

The objectives of this study were to (1) evaluate the feasibility of using thermography to quantify differences in thermal readings of participants during and following data entry tasks, and (2) to assess the repeatability of thermal readings. The hypotheses for this study were mostly supported (Table 7).

Table 7: Results of hypotheses

Hypothesis	Supported
Thermal readings of the forearm will increase during the data entry task for all participants, though not at the same rate	Yes
Thermal readings will remain elevated following task performance and decrease with times.	Yes
Thermographic readings will be repeatable and consistent both during and post task for all participants	Yes/No
There will be no significant difference in the thermographic readings of men and women	Yes

Mean temperature increases of 0.446 °C during typing and mean decreases of 0.381 °C during recovery in this study are comparable to results found by Gold et al. (2004) who assessed temperatures of the dorsal aspect of the hand following a 9 minute typing task. Gold et al. (2004) found a mean temperature increase of 0.7°C from baseline temperatures in the control population. Temperatures showed an overall average decrease of 0.3°C during the post-typing task phase.

Although not included in the hypotheses, regional differences within the forearm with respect to temperature were found, and are reasonable. Increased muscle activity results in increased blood flow, supplying oxygen needed by the muscles to carry out activity demands leading to more heat being released from the muscle through the skin surface. The forearm analysis regions used were mainly atop the body of the extensor carpi ulnaris (ECU), an active muscle during a typing and data entry (Hughes, 2004; Martin et al., 1998; Simoneau, Marklin, & Berman, 2003). The origin of the ECU is the lateral epicondyle of the humerus and the posterior border of the ulna

(Marieb, 2001), the approximate location of the upper left forearm region. Warmer temperature readings of the upper left region may be accounted for as the body of the ECU muscle is captured in the upper left forearm region producing more heat during the typing task. As the muscle extends into the insertion points around the base of the hand (captured in the lower left region), the tendons becomes long and lean, producing less heat in comparison to the upper left region.

The left wrist has shown greater ulnar deviations and wrist extension in comparison to the right wrist (Honan et al., 1996; Honan et al., 1995). The left hand is used at greater frequency than the right during typing because of the "distribution and frequency of use of alphabetic, numeric or special function keys (Simoneau et al., 1999)" (pg. 8). "Approximately 58% of letters typed in English text are typed with the left hand (Simoneau et al., 1999)" (pg. 9). Because of differences in muscle demand requirements of the left and right forearms during data entry tasks, the upper left region of the forearm can also be expected produce warmer thermal readings than the right forearm region.

As seen in the study results, the upper left region produced warmer temperatures than the other regions during the data entry phase. As more active muscles are warmer and will take longer to cool toward baseline values, warmer temperatures in the upper left region were also seen in the recovery phase. Because of activity demands, the lower left region would be expected to produce warmer temperatures in comparison to the right region during data entry; however, during recovery the right region was shown to produce warmer temperatures in comparison to the lower left region. This may be a result of the right region being comprised of both the body of the ECU and the tendons, leading to longer cool down periods following the data entry task compared to the lower left region which is manly comprised of tendons.

Repeatability of thermal readings was poor despite higher correlations of thermal readings between testing days. The magnitudes of thermal temperatures across days were notably different; however, temperature trends across days were fairly consistent when inspected visually despite poor reliability reported through Intra-class correlation values. Poor reliability for trends may be a result of changes in the pitch of the trends across days, or the potential of non-linear trends. Although not reported in this study, it must be noted that most trends determined for individual participants were significantly linear.

Data entry magnitudes and trends showed higher repeatability than temperature readings and trends occurring during the recovery phase. Thermal images were characterized by high intra-person variability for both task phases. Some participants exhibited all around repeatable thermal images, where thermal magnitudes and trends on day 1 and 2 were consistent (Figure 13). Other participants showed either inconsistency in thermal readings during both phases (Figure 14) or inconsistent thermal readings or trends during either the data entry phase (Figure 15) or the recovery phase (Figure 16).

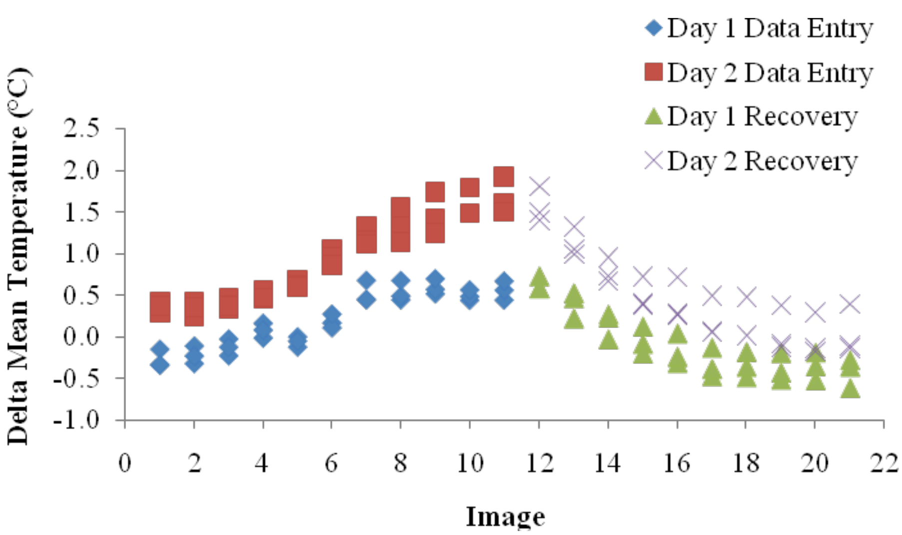


Figure 12: Good thermal image consistency

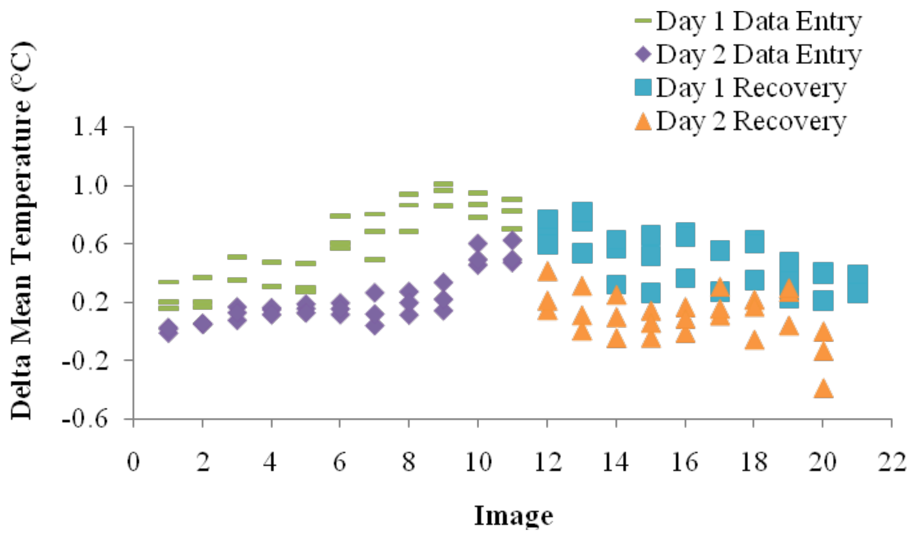


Figure 13: Poor thermal image consistency

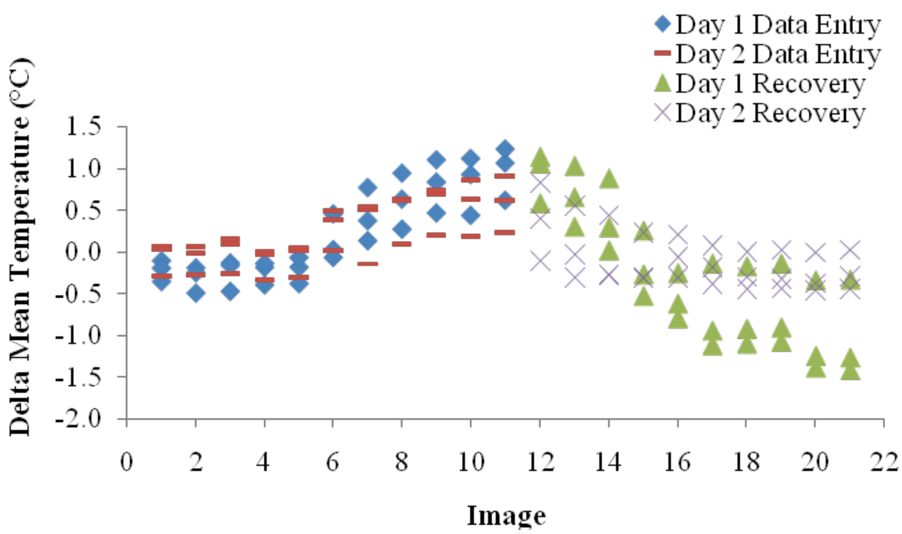


Figure 14: Consistent data entry phase temperatures

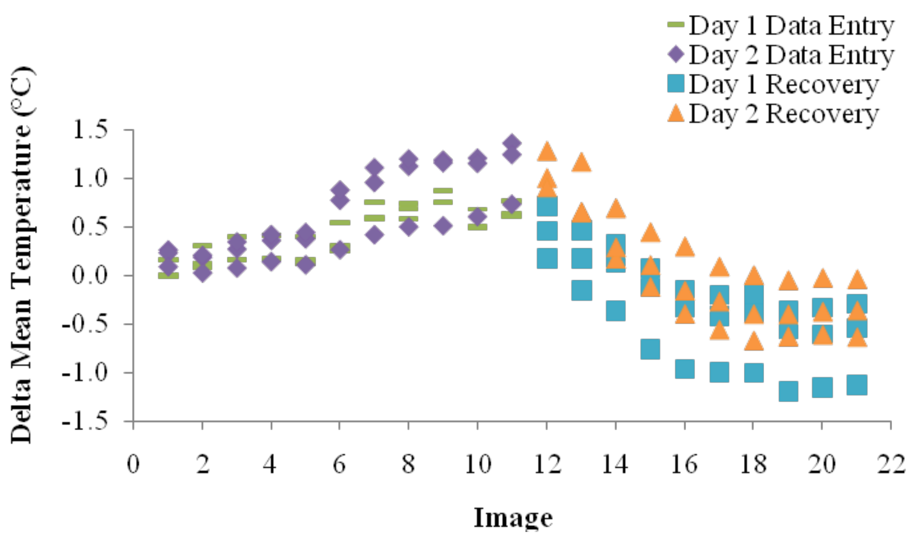


Figure 15: Consistent recovery phase temperatures

Intra-personal differences can result from various environmental and physiological factors. These factors can include, but are not limited to variable day-to-day activities unaccounted for or unreported prior to testing. These activities can affect muscular response to the stimulus, health conditions, and physical conditions, for example. These factors, not only differ on an individual basis, but can change for one individual on a daily basis.

As previously mentioned, the recovery phase thermal images have poorer reliability for both thermal image magnitudes and trends in comparison to the reliability of the thermal images taken during the typing task. The muscular response to the applied stress is more predictable during the data entry task. The longer the stress is applied, the harder the muscles work until they reach capacity, and the more heat will be produced as a bi-product of the work. Therefore, thermal temperatures and trends should increase with time as shown within the results. However, because of the previously discussed inter- and intra-personal variability, muscular behavior during the recovery phase is less predictable resulting in lower reliability. Thermal readings magnitudes and trends from day to day for the recovery phase can be expected to be more variable in comparison to those during the data entry task.

In comparison to thermography, electromyography (EMG), a tool widely used for muscle activation detection and assessment of muscular response due to fatigue, has also shown inconsistency in reliability in test-retest scenarios. In looking at overhead tasks, Sood et al. (2007) found that EMG measures showed inconsistency for various muscles in the shoulder in a low exertion level environment; ICC values ranged from 0 to 0.97 across different muscles. Elfving et al. (1999) also produced similar results, where ICC values for median frequency and slope of median frequency for EMG data at various location of the back showed a high degree of variability, ranging from 0.04 to 0.70. Thermal ICC values for this study range from 0.19 to 0.85 across phases. Although reliability will vary with the evaluation of different body areas under different scenarios, the high degree of variation found in the reliability of EMG suggests that a method should not be deemed un-useful.

When asked to report perceived forearm discomfort, participant discomfort levels increased with time during data entry and decreased during recovery. Interestingly, participants appeared to have consistency in reported discomfort levels between days despite the findings of increased thermal readings on day 2 of the study. Regardless of not feeling a noticeable difference in physical discomfort, physiological differences were present. This evidence supports the theory that thermography is sensitive to detecting physiological changes not perceived by the participant.

Although the 95% confidence intervals were non-inclusive of zero, suggesting possible systematic error, no obvious outliers were determined upon visual inspection of the data. Skewness may be attributed to the normal variability within the temperature magnitudes across testing days.

Several limitations were realized following the completion of the study. The forearm analysis grid used in the study lies directly above the ECU muscles. Despite being an important muscle used during data entry, other active forearm muscles neighboring the ECU, such as the flexor carpi ulnaris (FCU), were not analyzed although possibly having an effect on the thermal temperature results. Two additional markers should be placed on each forearm, forming a larger rectangular region allowing for analysis of neighboring forearm muscles that may affect thermal results.

With the overhead camera positioning used in the study, often the participant's trunk or head movement would interfere with the visibility of the upper forearm markers. Thermal image frames where all markers were not visible (approximately 1% of the thermal images) were discarded, possibly affecting the accuracy of the results. Using a thermal camera with increased zoom capabilities would allow for a wider range of possible camera positions allowing the capture of only the forearms and analysis markers, reducing the possible interference of the head or trunk.

Due to time and resource constraints, task procedures could not extend beyond two days. Increasing the amount of days for which data was collected could allow for further assessment possibly increasing repeatability of thermal images.

Although unable to completely control a participant's daily activities prior to participation, restrictions were placed on involvement in activities that overly stress the forearms two hours prior to completing the study. However, further documentation should be collected about activities participants engaged in as this can give further insight into reasoning behind intrapersonal differences occurring within thermal readings across testing days.

Participants were allowed to adjust their seating and document stand location to their preferences in accordance with the standard guidelines as discussed in the 'Methodology section' (pg. 21). However, this standard typing position was uncomfortable for some participants as it was not their preferred typing position. This may have caused some additional stress on their forearms, possibly affecting thermal temperature readings.

Confounding effects such as room temperature, lighting conditions, and heat produced by the available light source were controlled to the best of the researcher's abilities. However, these factors are still likely to impact temperature readings.

CHAPTER VI
CONCLUSION

The results of this study show that thermography can be used to quantify differences in thermal readings of participants during and following data entry tasks. Thermography is sensitive to physiological changes during and following a work task, specifically data entry activities. Future studies should be conducted which apply the use of thermography to occupational tasks incorporating other body segments.

Thermography is a tool that can be used to evaluate the physiological responses of muscles during a work-applied stress. Providing real time data, this type of evaluation gives information on how muscles respond under stress and can help identify important response patterns that can be used to determine the risk of injury (e.g. development work-related musculoskeletal disorders). Despite poor repeatability of thermal readings in this study, additional research should be completed with multiple sessions over an extended period time as this could increase the repeatability of the thermal readings or give further indications as to the sources of variability affecting the repeatability of thermal images.

The specific results of this study contribute to the understanding of forearm muscular response to during and following a standard data entry activity. The discussed forearm patterns found in healthy individuals may serve as information for developing standards used for evaluation for potential risk of injury. Temperatures deviating from results under normal conditions can be flagged as problematic and tracked for progression of deviations, aiding in catching early indications of potential problems and proactively responding prior to development of noticeable symptoms of injury.

6.1 Future Directions

As this study was an evaluative study, there are opportunities for expansion into different directions for future studies. Under the same conditions, repeatability of thermal readings should be assessed using different thermal equipment. This will aid in establishing the reliability of thermography. Other measures of central tendency should also be evaluated. This study primarily focused on the use of averages, but determining if similar results can be found using minimum or maximum temperatures may be of added interest.

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APPENDIX A: INFORMED CONSENT

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants in Research Projects

Title of Project: Thermographic Assessment of the Forearm During Data Entry Tasks: A Reliability Study

Investigator(s): Maury Nussbaum, Ph.D., and Robin Littlejohn

Purpose
This study was designed to determine if thermography can be used as a tool to evaluate the forearm response during and post typing task through quantifying differences in thermal readings of participants. In addition to providing additional literature on the physiological response of the forearm during and post data entry tasks using thermography, this study will have implications for verifying the reliability of thermography as a reliable evaluative tool for job task demands that can increase the risk of development of work-related musculoskeletal disorders of the upper extremities.

Procedures
This study has a total of 2 sessions. Each session will last approximately 1 hour and 25 minutes. This will result in a total time commitment of approximately 2 hours and 45 minutes. You will be asked to not smoke or complete any physical activities that overly stress the forearms 2 hours prior to each session. You will also be instructed to wear a loose fitting short-sleeve or sleeveless shirt (with loose fitting sleeves) of a dark color to each session. In order to participate, you must use 10-digit touch method typing, as well as type a minimum of 4 hours per day. Initially, you will be given a verbal description of the study and its objectives, and you will be asked to read and complete informed consent documents approved through the Institutional Review Board for research involving human participants. You will then be asked to take a seated position with your arms resting on the arm rests of the chair. You will be seated in this position for 15 minutes while your body adjusts to the temperature of the room. During this time period you will verbally fill out a demographics questionnaire read by the experimenter who will write down your responses. The demographic questionnaire includes items on previous history or current presence of hand, wrist, or forearm injuries or illnesses. If you have any condition, past or present, that may affect hand, wrist, or forearm mobility, you will be excused from the study. Also during this 15-minute period, the experimenter will complete a visual inspection of your forearms, looking for any scars, dark marks or blemishes which may compromise the thermal images. The experimenter will determine marker place for the Styrofoam discs, cleanse the area with alcohol, and mark these areas using a permanent marker. The location of the discs is marked to insure consistent placement of the Styrofoam markers for all testing days. The first disc will be located 2 finger breadths lateral of the bicep tendon (approximately at the crease of the elbow). The second disc will be located two fingerbreadths lateral of the styloid process of the ulna (the bone located on the outer side of the wrist). The 2 discs will be secured to each forearm over the markings using double-sided tape. A 10 second thermal image will then be taken of your forearms to verify thermal symmetry of your forearms. If there is forearm thermal asymmetry or you have any visible marks which could affect the results of the study, you will be excused from the study.

VT IRB – This document is valid from 5 July 2007 – 4 July 2008.

If you meet all inclusion criteria, the experimental computer workstation will be adjusted so that the forearms are parallel to the floor, and elbows are at roughly 90°. Chair height will be adjusted so that the knees form a 90° angle and the feet are flat on the floor (when necessary, a foot rest will be used). You will be allowed to adjust the location of the keyboard and document holder to fit your needs.

A 10-second baseline image will be taken of your forearms while in the typing position prior to beginning the 35- minute typing task.

The main task consists of recreating text presented on the document holder. You will type the passages into Microsoft word document for a total of 35 minutes. During the typing task, thermal images will be taken of your forearms. You will also be asked to verbally report your discomfort rating using a perceived discomfort scale posted on top of the computer monitor at specific times during the typing task. The experimenter will record your responses on a data sheet. After the 35-minute typing task, you will be asked to resume the position used for the screening image (forearms resting on the arm rests of the chair). You will be seated in this position for a 30-minute period during which thermal images will be taken and you will again be asked to report your discomfort rating when prompted by the experimenter. At the end of the 30-minute recovery period, the Styrofoam discs will be removed. You will then be debriefed and scheduled for the second day of testing.

All thermal images will be taken using an Electrophysics PV320T2 infrared camera. The infrared camera will cause you no harm.

Risks and Benefits
There is not more than minimal risk associated with this study that would not be found in daily office activities. Temporary discomfort or fatigue in the hands, wrists, and/or forearms may result from typing continuously for a 35-minute period; however, you are encouraged to discontinue usage of the equipment if you experience extreme discomfort. By participating in the study, you will be assisting the investigators in possibly further establishing the capabilities of thermography as an evaluative tool as well as gain information about the response of the forearms during and following keyboard usage.

Extent of Anonymity and Confidentiality
Your anonymity will be kept in the strictest of confidence. NO names will appear on questionnaires or surveys, and a coding system will be used to associate your identity with questionnaire answers and data. All information will be collected in a file and locked when not being used. No videotaping or audiotaping will occur during the experiment.

Informed Consent
You will receive two informed consent forms to be singed before beginning the experiment; one copy will be for you records and the other copy will be obtained for the investigator's records

Compensation
You will be compensated at a rate of $8 per hour for your participation.

VT IRB – This document is valid from 5 July 2007 – 4 July 2008.

Freedom to Withdraw
You are free to withdraw from this study at any time without penalty or reason state, and no penalty or withholding of compensation will occur for doing so.

Approval of Research
The Department of Industrial and Systems Engineering has approved this research, as required by the Industrial Review Board (IRB) for Research Involving Human Participants at Virginia Polytechnic Institute and State University.

Participant's Responsibilities
I voluntarily agree to participate in this study. I have the following responsibilities:

1. To read and understand all instructions
2. To answer questions, survey, etc. honestly and to do the best of my ability
3. To type at the speed defined by the investigator to the best of my ability
4. To inform the investigator of any discomforts I experience immediately
5. Be aware that I am free to ask questions at any point

Participant's Permission
I have read and understand the Informed consent and conditions of this research project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project

If I participate, I reserve the right to withdraw at any time without penalty. I agree to abide by the rules of the project.

____

Participant's Signature   Date

____

Printed Name

____

Experimenter's Signature   Date

VT IRB – This document is valid from 5 July 2007 – 4 July 2008.

Signature Page

I have read the description of this study and understand the nature of the research and my rights as a participant. I hereby consent to participate with the understanding that I may discontinue participation at any time if I choose to do so.

Participant's Signature Date

Printed Name

Experimenter's Signature Date

The research team for this experiment includes Dr. Kari Babski-Reeves, Dr. Maury Nussbaum, and Robin Littlejohn. Team members may be contacted at the following address and phone number:

Dr. Maury Nussbaum
Grado Department of Industrial and Systems Engineering
549 Whittemore Hall
Blacksburg, VA 24061
540.231.6053

Robin Littlejohn
Grado Department of Industrial and Systems Engineering
536DWhittemore Hall
540.951.3009 (h)

In addition, if you have any detailed questions regarding your rights as a participant in University Research, you may contact the following individual:

Dr. David Moore
IRB Chair
Assistant Vice Provost Research Compliance
Director, Animal Resources
2000 Kraft Drive, Suite 2000
Virginia Tech (0497)
Blacksburg, VA 24061
540.231.4991

VT IRB – This document is valid from 5 July 2007 – 4 July 2008.

APPENDIX B: PARTICIPANT DATA FORM

Participant Number _______

Demographics

Instructions: Please answer the following questions. You may skip any questions you do not wish to answer.

1. Age: _____
2. Gender: _____Male _____Female
3. Dominant Hand: _____ Right _____ Left
4. Ethnicity: _____ Caucasian (European-American)
   _____ African-American (Black)
   _____ Hispanic/Latino
   _____ Asian-American/Pacific Islander
   _____ Native American
   _____ Other (Please specify: ___________________________)

5. Present Occupation (Title, Part/Full time, Starting Date) ________________________________
   ____

6. Description of Occupation ____
   ____

7. Previous Occupation (Title, Part/Full time, Starting Date) ________________________________
   ____

6. How hours per week do you work? ____

7. How many hours per day do you spend using a computer? _____ hours
   Of this time, please give an estimate of the percentage of time spent typing (rather than using the mouse or reading the screen). Mark on the scale with a vertical line.

0%　　　　25%　　　　50%　　　　75%　　　　100%

|--------------------|--------------------|--------------------|--------------------|

8. What type of typing style do you use most often?

____ touch-type with 10 fingers ____ do not touch type/do not type with all 10 fingers

9. How many hours a day do you type? ______ hours

10. Are you a native English speaker? (Is English your first language?) _____ Yes _____ No

11. Have you ever been diagnosed by a physician with any of the following conditions:

_____ Diabetes _____ Arthritis of the hand or wrist _____ Hypothyroidism

12. Do you have any condition that limits the mobility of your wrist, hand, or fingers? (Note: if you are currently pregnant or have recently experienced rapid weight gain, please mark "yes")

_____ Yes _____ No

If yes, please specify: ____

13. Have you ever broken your hand or wrist? _____ Yes _____ No

14. Have you, in the past 12 months, ever experienced any pain, numbness, or tingling in your wrists, hands, or fingers?

_____ Yes _____ No

15. Are you experiencing any pain, numbness, or tingling in your wrist, hand, or fingers TODAY?

_____ Yes _____ No

Have you had Pain, Ache, Discomfort, Injuries in :	In the past 12 month		In the last 7 days	
	When did it occur	Duration it lasted	When did it occur	Duration it lasted
Neck				
Shoulder				
Arms/ Elbows/ Wrist/ Hands				

Any other comments: ____

____

Anthropometrics

Weight ____________ lbs Stature _____________ in

Visible Marks on Forearms ____

Workstation Placement

Table Level 2 height from floor: _____

Seat distance from floor: _________

Arm Rest Level: ______

Keyboard location:

Distance from right side of table surface edge: ______

Distance from bottom edge of table surface: ________

Document Holder location

Distance from right side of table surface edge: ______

Distance from bottom edge of table surface: ________

Participant Perceived Discomfort

Phase	Image #	Discomfort Rating
Typing	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
	10	
	11	
Recovery	12	
	13	
	14	
	15	
	16	
	17	
	18	
	19	
	20	
	21	

APPENDIX C: MODIFIED BORG CR-10 SCALE

0	No Discomfort
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	Extreme Discomfort

APPENDIX D: TUKEY – KRAMER GROUPINGS

Table D.1: Delta mean region

Tukey Grouping	Mean (Δ°C)	Region
A	0.426	Upper Left
B	0.267	Lower Left
B	0.227	Right

Table D.2: Region*Phase interaction

Tukey Grouping	Region	Phase	Mean (Δ°C)
A	Upper Left	Data Entry	0.528
A B	Lower Left	Data Entry	0.469
B	Right	Data Entry	0.342
C	Upper Left	Recovery	0.316
D	Right	Recovery	0.101
D	Lower Left	Recovery	0.052

APPENDIX E: SIGNIFICANT EFFECTS' MEANS AND STANDARD DEVIATIONS

Table E.1: Delta Mean phase temperatures

Phase	Mean (Δ°C)	Standard Deviation
Data Entry	0.446	0.540
Recovery	0.156	0.844

Table E.2: Delta Mean region temperatures

Region	Mean (Δ°C)	Standard Deviation
Upper Left	0.426	0.595
Lower Left	0.267	0.784
Right	0.227	0.745

Table E.3: Delta Mean Day temperatures

Day	Mean (Δ°C)	Standard Deviation
1	0.231	0.590
2	0.381	0.818

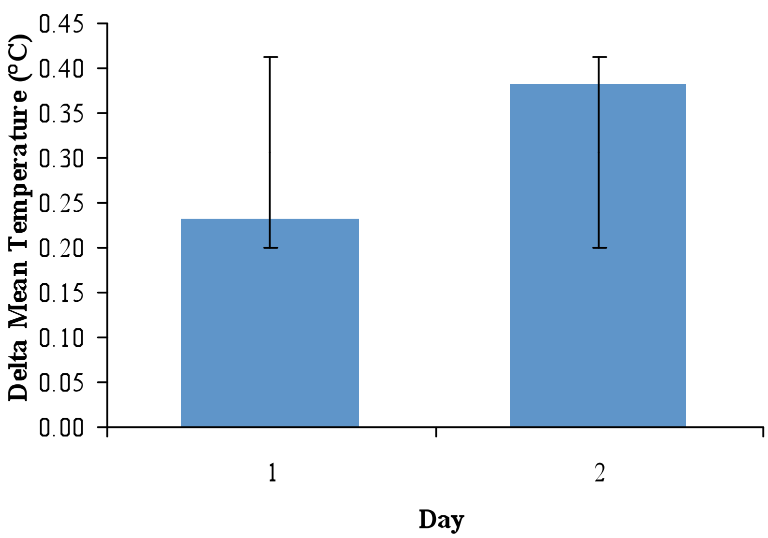

Figure E.1: Delta mean day values

Table E.4: Delta mean temperatures for region*phase interaction

	Data Entry		Recovery	
Region	Mean (Δ°C)	Std. Dev.	Mean (Δ°C)	Std. Dev.
Upper Left	0.528	0.500	0.316	0.666
Lower Left	0.469	0.528	0.052	0.942
Right	0.342	0.574	0.101	0.878

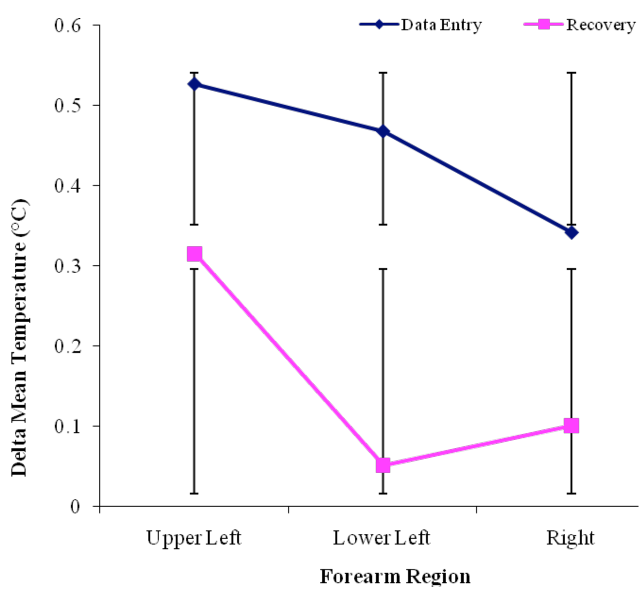

Figure E.2: Region*Phase Interaction for Delta Mean

Table E.5: Delta mean slope phase temperatures

Phase	Mean (Δ°C/ sec)	Standard Deviation
Data Entry	0.100	0.062
Recovery	-0.081	0.062

Table E.6: Perceived discomfort slope day temperatures

Day	Mean (Δ discomfort/ sec)	Standard Deviation
1	0.057	0.197
2	0.036	0.146

APPENDIX F: SPEARMAN'S CORRELATION MATRIX

Table F.1: Correlations and P-values for between day dependent variable comparisons

	Delta Mean Day 1	**Delta Mean Day 2**	**Delta Mean Slope Day 1**	**Delta Mean Slope Day 2**	**Perceived Discomfort Slope Day 1**	**Perceived Discomfort Slope Day 2**
Delta Mean Day 1	1.00000					
Delta Mean Day 2	0.47711 < 0.0001	1.00000				
Delta Mean Slope Day 1	--	--	1.00000			
Delta Mean Slope Day 2	--	--	0.81655 < 0.0001	1.00000		
Perceived Discomfort Slope Day 1	--	--	0.64323 0.0007	--	1.00000	
Perceived Discomfort Slope Day 2	--	--	--	0.68715 0.0002	0.78321 < 0.0001	1.00000

--Indicates that correlations were not determined for these pairs

VITA

Robin Littlejohn graduated from Virginia Polytechnic Institute and State University with a Bachelor's of Science in Industrial and Systems Engineering, with minors in Business and Mathematics in July 2005. She directly continued her education in the Industrial and Systems Engineering Department in the Human Factors and Ergonomics Option. While pursuing her Master's of Science degree, Robin served as a treasurer for the Human Factors and Ergonomics Society (HFES) in 2006. She is an active member of HFES, Alpha Pi Mu, and Institute of Industrial Engineers (IIE). Robin plans to pursue a Ph.D. in the same area upon completion of her degree.