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Table of Contents

List of terms and abbreviations....3
Abstract....4
Highlights/Significant findings....6
Translation of findings....7
Outcomes/Relevance/Impact....8
Scientific Report....9
Publications....21
Inclusion Enrollment Report....23

List of terms and abbreviations

ANOVA – analysis of variance
CTS – carpal tunnel syndrome
DMMT - dorsum mean temperature thermography
ICC – intraclass correlation coefficient
MDT – mean dorsal temperature
MSD – musculoskeletal disorder
NIRS – near infrared spectroscopy
PCC – Pearson correlation coefficient
RBV – relative blood volume
RMDT – relative mean dorsal temperature
SA – specific aim
SNS – sympathetic nervous system
T1 - 0-2 minutes post-typing
T2 - 3–5 min post-typing
T3 - 8–10 min post-typing
UEMSD – upper extremity musculoskeletal disorder

Abstract

Musculoskeletal disorders, including those localized to the upper extremity such as carpal tunnel syndrome (CTS) and forearm tendinitis, comprised 30 percent of the approximately 1.2 million total workplace illnesses and injuries reported in 2006 in the United States according to the Bureau of Labor Statistics. While UEMSDs occur in many types of exposed jobs, a major source of concern is computer keyboard work where associations between UEMSDs and keyboard usage have been reported in epidemiological studies. The U.S. Census Bureau has estimated that half of employed adults used a computer on the job in 1997. In 2003, 73.5% of those in office and administrative support positions reported using a computer at work. Although highly prevalent, objective options for surveillance, screening and diagnosis of upper extremity musculoskeletal disorders (UEMSDs) are few. Additionally, with the exception of CTS, pathophysiology in UEMSDs is little understood. Several investigators have theorized a role for blood flow abnormalities. Subcutaneous perfusion is a major determinant of skin temperature, which in turn, is detectable through infrared thermography (far-infrared imaging). The overall aim of the study was to determine the utility of infrared thermography for evaluation of UEMSDs and for improved understanding of UEMSD pathophysiology.

The dorsal mean temperature in the hands of office workers (n = 45) was measured before and after a 9-minute typing task under controlled ambient temperature conditions. Ten asymptomatic controls and 35 subjects with symptoms in the right distal arm (elbow, wrist, or hand) were imaged for one minute prior to typing and at three 2-minute imaging periods during the 10 minutes following the typing task. Also, a near infrared spectroscopy (NIRS) probe measured relative blood volume (RBV) in the first dorsal interosseous muscle (FDI) during the experiment. The objective of Aim 1 was to evaluate the reproducibility and reliability of dorsum mean temperature thermography (DMTT). Mean temperature of the dorsal hand as ascertained through infrared thermography proved to be reliable before and after a 9-minute typing task under controlled ambient temperature conditions. Good to excellent reproducibility was obtained for controls at room temperature (22° C). The objective of Aim 2 was to use DMTT to investigate differences between symptomatic and asymptomatic office workers. Mean temperature in the dorsal hand was associated with severity of musculoskeletal disorders in office workers. Specifically, as compared with asymptomatic controls, we measured colder pre-typing hand temperatures in cases a) with more anatomically widespread symptoms, and b) meeting more case definitions of upper extremity musculoskeletal disorders as ascertained through a physical examination and symptom reports. The objective of Aim 3 was to estimate the correlation between skin temperature (DMTT) and subcutaneous blood volume as measured by near-infrared spectroscopy. Post-typing mean dorsal hand temperature and muscle blood volume in the FDI as determined through NIRS were moderately correlated during a 10 minute recovery period post-typing. Hence, skin temperature in response to a typing challenge does appear to reflect underlying muscle perfusion in the hand.

The reliability of thermography under controlled ambient temperature and the decreased mean dorsal hand temperature found in those with more severe UEMSDs bodes well for the consideration of the method for screening or surveillance in the workplace and diagnosis in the clinic. We found that a short typing task (possibly generalizable to other low-level manual activity) in asymptomatic subjects resulted in reduced skin temperature to the hands and likely reduced perfusion to the underlying muscles under ambient temperature conditions (18° C) frequently encountered in cooler workplaces (such as in an office during the summer with air conditioning or in industrial environments during the winter). Ambient temperature should be measured in epidemiological studies of manual workers to further explore the association of this risk factor with UEMSDs. As a precautionary measure, workplaces warmer than 18° C are suggested.

Altered blood flow and sympathetic nervous system dysfunction are likely involved in the pathophysiology of UEMSDs. Further research, including longitudinal studies, is recommended to further elucidate this relationship.

Highlights/Significant findings

Mean temperature in the dorsal hand was associated with severity of musculoskeletal disorders in office workers after acclimation to a controlled ambient temperature (18° C and 22° C). Specifically, as compared with asymptomatic controls, we measured colder pre-typing hand temperatures in cases a) with more anatomically widespread symptoms, and b) meeting more case definitions of upper extremity musculoskeletal disorders as ascertained through a physical examination and symptom reports.

Mean temperature of the dorsal hand as ascertained through infrared thermography proved to be reliable before and after a 9-minute typing task under controlled ambient temperature conditions. Good to excellent reproducibility was obtained for controls at room temperature (22° C).

Post-typing mean dorsal hand temperature and muscle blood volume in the first dorsal interosseous as determined through near infrared spectroscopy were moderately correlated during a 10 minute recovery period post-typing (Pearson correlation coefficient [PCC] = 0.75, $p = 0.01$ at 0-2 minutes after typing; PCC = 0.52, $p = 0.12$ at 3-5 minutes after typing; PCC = 0.77, $p = 0.01$ at 8-10 minutes after typing). Skin temperature in response to a typing challenge does appear to reflect underlying muscle perfusion in the hand.

Translation of findings

This study has demonstrated an objective and reliable method of determining UEMSD severity in manual workers through the measurement of hand temperature under controlled ambient conditions. Most current diagnostic practices for UEMSDs rely on a patient's self-report rather than physiological measures. There is potential for dorsal mean temperature as determined through infrared thermography to serve diagnostic tool in the clinic. Further research is necessary to determine the feasibility and validity of this technique. Additionally, it is possible that eventually skin temperature could be used as a surveillance method to identify groups of employees with severe UEMSDs. Jobs of such employees could be modified to reduce ergonomic exposures for prevention of further injury and reduction in injury rates in general.

We found that a short typing task (possibly generalizable to other low-level manual activity) in asymptomatic subjects resulted in reduced skin temperature to the hands and likely reduced perfusion to the underlying muscles under an ambient temperature of 18° C (~65° F). Skin temperature response to a longer duration of hand activity is unknown. The ambient temperature identified above is frequently encountered in cooler workplaces, such as in offices during the summer with air conditioning or in industrial environments during the winter. As a precautionary measure, it is suggested that workplace ambient temperature should be greater than 18° C.

Outcomes/Relevance/Impact

This study has demonstrated an objective and reliable method of determining UEMSD severity in office workers through the measurement of dorsal hand temperature using infrared thermography under a controlled ambient environment (18-22° C recommended). Future epidemiology studies should assess skin temperature in sizable cohorts of employees in hand-intensive jobs (such as manufacturing workers) in order to test the generalizability and applicability of this physiological measurement in the workplace for severity of UEMSD signs and symptoms. Additionally, there is potential for dorsal mean temperature as determined through infrared thermography to serve diagnostic tool in the clinic. Further research is necessary to determine the feasibility and validity of this technique. The most symptomatically severe UEMSD cases were excluded from this study because they were unable to type for the nine minutes required by the experimental design. Since it was discovered that no typing was required for the detection of UEMSD severity, the present technique could be used for anyone regardless of their ability to perform low-level exercise. It is possible that the current study underestimated the differences in skin temperature between cases and controls due to this selection bias.

We found that a short typing task (possibly generalizable to other low-level manual activity) in asymptomatic subjects resulted in reduced skin temperature to the hands and likely reduced perfusion to the underlying muscles under an ambient temperature of 18° C (~65° F). Skin temperature response to a longer duration of hand activity is unknown. The ambient temperature identified above is frequently encountered in cooler workplaces, such as in offices during the summer with air conditioning or in industrial environments during the winter. Ambient temperature should be measured in epidemiological studies of manual workers to further explore the association of this risk factor with UEMSDs. As a precautionary measure, it is suggested that workplace ambient temperature should be greater than 18° C.

Reduced hand skin temperature with accompanying reduced underlying muscle perfusion in those with more severe signs and symptoms suggests that alterations in blood flow and sympathetic nervous system dysfunction have a role in the pathophysiology of UEMSDs. Longitudinal studies are recommended to further elucidate these relationships.

Scientific Report

Background

Musculoskeletal disorders, including those localized to the upper extremity such as carpal tunnel syndrome (CTS) and forearm tendinitis, comprised 30 percent of the approximately 1.2 million total workplace illnesses and injuries reported in 2006 in the United States according to the Bureau of Labor Statistics (BLS 2007). While UEMSDs occur in many types of exposed jobs, a major source of concern is computer keyboard work. The U.S. Census Bureau has estimated that half of employed adults used a computer on the job in 1997 (Newberger 1999). Associations between UEMSDs and keyboard usage and other aspects of these manually-intensive clerical jobs have been reported (Gerr et al. 2002, 2006; Juul-Kristensen et al. 2006; Lassen et al. 2004; Punnett and Bergqvist 1997). In 2003, 73.5% of those in office and administrative support positions reported using a computer at work (BLS 2005).

Options for screening, surveillance, and diagnosis of UEMSDs are limited. The pathology in carpal tunnel syndrome is likely better understood than in other upper extremity disorders. Although imperfect, electrodiagnostic studies serve as a valid and reliable method for differentiating CTS from other conditions associated with upper extremity pain (Herbert et al 2000). This method serves to some extent as a model for what is desired to diagnose other conditions, but its public health utility is greatly limited by the fact that CTS accounts for only a small proportion of all UEMSDs (Herbert et al 2000). A need for improved diagnostic and screening methods, especially objective techniques, has been identified (Viikari-Juntura 1999; Punnett and Gold, 2003).

Altered blood flow may play a role in the pathophysiology of upper extremity musculoskeletal disorders (Larsson et al. 1998; Larsson et al. 1999; Pritchard et al. 1999; Brunnekreef et al. 2006; Zeisig et al. 2006). Proposed mechanisms include compression of the brachial artery, increased intramuscular pressure and inadequate blood flow regulation (see Visser and van Dieen 2006 for review).

Subcutaneous perfusion is a major determinant of skin temperature, which in turn, is detectable through infrared thermography. The overall goal of this study was to determine the suitability of thermography for evaluation of UEMSDs and for improved understanding of UEMSD pathophysiology.

Specific aims

1. Evaluate the reproducibility and reliability of dorsum mean temperature thermography (DMTT).

    a. Test the null hypothesis there is no change in DMTT response to the typing challenge among controls in three trials carried out at room temperature (22° C).

b. Test the null hypothesis that ambient temperature (at 18° C, 22° C, and 26° C) has no effect on the change in DMTT in controls following a typing challenge.

2. Use DMTT to investigate differences between symptomatic and asymptomatic office workers.

a. Seek to replicate our pilot findings of three distinct thermographic responses to the typing challenge in controls and in cases with and without cold hands, and to determine whether ambient temperature modifies these responses.

b. Extract features from the hand image to determine whether symptomatic regions of the hand as marked on a hand diagram show temperature differences from asymptomatic regions.

3. Estimate the correlation between skin temperature (DMTT) and subcutaneous blood volume as measured by near-infrared spectroscopy.

Methods and study subject characteristics

A total of 45 office workers who had used a keyboard for four or more hours/day at least five days/week for five or more years participated in the study. Subjects included ten asymptomatic controls and 35 cases defined by recurrent symptoms in the right distal arm (forearm and/or wrist and/or hand) attributable to keyboard usage. Twenty cases were those with MSDs not reporting cold hands with keyboard usage (type I cases), and 12 were those with MSDs reporting cold hands exacerbated by keyboard usage (type II cases). Controls were recruited simultaneously and matched to cases (equal numbers matched to warm cases and to cold cases) by age (± 5 years) and gender. Most subjects were female (87%), with a mean age of 40 (range: 23-61) years.

Skin temperature measurements (i.e., far infrared images) of the hands were captured with the ThermaCAM AM40 thermographic camera (FLIR Systems, Wilsonville, OR). ThermaCAM Researcher Pro 2.8 (FLIR Systems, Wilsonville, OR) was used in thermal image capture and preliminary data analysis. The mean temperature in the dorsal right hand (MDT) was defined as an area bounded by the heads of the ulna and radius and the metacarpal joints. The mean temperature of this delineated area in each image was imported into Excel (Microsoft Corporation, Redmond, WA) for further data processing.

A custom near infrared spectroscopy (NIRS) probe with optodes at 11 mm apart (depth ~5.5 mm) measured relative absorbancy of oxy- and deoxyhemoglobin in the first dorsal interosseous (FDI) of the right hand. A near infrared spectrometer (USB4000-VIS-NIR, OceanOptics Inc., Dunedin, FL) was used in conjunction with OOIBase32 Spectrometer Operating Software (OceanOptics Inc., Dunedin, FL) to capture the absorbance measurements. The probe was adhered to the FDI with double-sided electrode washers (E432 In Vivo Metric, Healdsburg, CA). Total hemoglobin, represented as the sum of absorbency of de-oxygenated and oxygenated hemoglobin, is proportional to muscle blood volume. Relative blood volume (RBV) from baseline was determined through the UCL6 algorithm (Matcher et al. 1995) encoded into software.

At the initial visit, a questionnaire characterized the quality and duration of subjects' symptoms. On average, cases had experienced symptoms for 48 months (SD = 44 months) with their usual duration of discomfort lasting between "less than one week" and "less than one month". The questionnaire also included a hand/arm diagram (adapted from a carpal tunnel self-administered diagnostic tool for carpal tunnel syndrome, Katz and Stirrat 1990) where participants noted the location of symptoms including: pain, numbness, tingling, coldness, and burning. Number of anatomical symptom sites marked in the hand/arm diagram was coded. Possibilities included: hand/wrist, lower arm/elbow, and upper arm/shoulder. Additionally, a physical therapist examined all subjects for upper extremity musculoskeletal disorders (UEMSDs) before proceeding to the temperature controlled room. Each subject performed the typing experiment in a simulated office environment in a temperature controlled room at each of three ambient temperatures: 18° C, 22° C, and 26° C. Temperature resolution was ± 1° C. The order of ambient temperature was randomly assigned. Each control had two additional visits at 22° C to assess thermography reproducibility.

Participants were seated at a desk with an adjustable chair and keyboard tray, situated at or below seated elbow height. After a brief demonstration on how to adjust both chair and keyboard tray, subjects were invited to adjust their workstation for maximum comfort prior to the experiment. All subjects' elbows were situated below desk height. The infrared camera was focused from a height of approximately 1 m above the desk. Adhesive markers were placed on a 1 inch thick acrylic slab underneath each subject's fingertips. In this way, their fingers would be placed in the same location before and after typing, and temperature of the desk was isolated from the participant's hands. Subjects were acclimatized to the room for 20 min prior to measurement. During this acclimatization period, all subjects were seated and given a magazine to read. Baseline thermographic data was captured for 1 min prior to 9 min of typing of a standard non-technical text. During a 10-min post-typing period, three image sequences were obtained. These sequences will be referred to as: T1 (0-2 min post-typing), T2 (3–5 min post-typing), and T3: (8–10 min post-typing). NIRS data was captured throughout the experiment, although due to motion artifact only baseline and post-typing data was analyzed. All visits were completed within two weeks and each visit was scheduled at the same time of day on a per subject basis.

For methods specific to aim 2b, please see below.

Results

Specific Aim (SA) 1. Evaluate the reproducibility and reliability of dorsum mean temperature thermography (DMTT).

a. Test the null hypothesis there is no change in DMTT response to the typing challenge among controls in three trials carried out at room temperature (22° C).

In controls, baseline mean dorsum temperature (MDT) demonstrated good reproducibility, with intraclass correlation coefficient (ICC) = 0.46, p = 0.14. Post-typing mean dorsum temperatures relative to baseline (post-typing RMDTs) at each of the three imaging periods showed good to excellent agreement (Table 1).

Table 1. Intraclass correlation coefficients of RMDTs for controls (n = 10) at 22° C (3 trials)

Analysis	**ICC**	***p* value**	**Fleiss agreement rating**
RMDT at T1	.85	.001	Excellent
RMDT at T2	.68	.025	Good
RMDT at T3	.64	.04	Good

b. Test the null hypothesis that ambient temperature (at 18° C, 22° C, and 26° C) has no effect on the change in DMTT in controls following a typing challenge.

Ambient temperature did have an effect on controls. In particular, as could be expected, baseline MDT at colder ambient temperatures resulted in reduced skin temperature ($p < 0.001$, repeated measures ANOVA). No difference was observed at T1 (p = 0.28), with increasing differentiation in RMDT (T2: p = 0.04; T3: p = 0.005) through the 10 minute post-tying period (Figure 1).

SA2. Use DMTT to investigate differences between symptomatic and asymptomatic office workers.

a. Seek to replicate our pilot findings of three distinct thermographic responses to the typing challenge in controls and in cases with and without cold hands, and to determine whether ambient temperature modifies these responses.

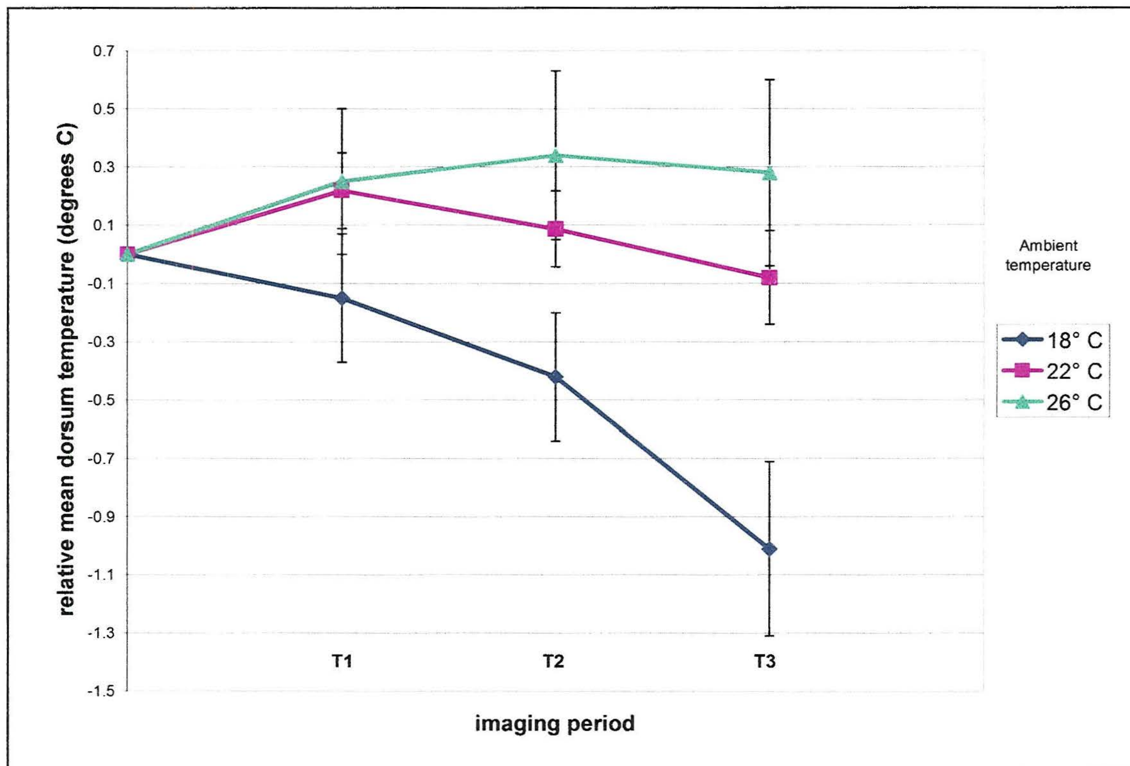

Figure 1. Relative mean dorsum temperature after typing in control subjects, by ambient temperature (degrees C), n = 10. Repeated measures ANOVA: at T1, $p = 0.28$; at T2, $p = 0.04$; at T3, $p = 0.0005$. Error bars = standard error.

In the pilot study, although median ambient temperature did not differ by case type, we did not have adequate ambient temperature control. Our expectation that ambient temperature control in the present study would confirm the relationships that were observed in the pilot was only partially met. That is, at 18° C ambient temperature, we observed differences in response to the typing challenge in controls and the two case types (ANOVA, $p \leq 0.05$ at each post-typing imaging periods, Figure 2). A post-hoc Tukey test demonstrated a difference in RMDT between UEMSD cases not experiencing cold hands upon keyboard usage (type I cases) and those with cold hands (type II cases), at all three imaging periods after typing; colder RMDTs were observed in type II cases. This result is similar to our qualitative assessment of the 10 minute post-typing response between the two case types in the pilot. Additionally, in both studies, type I cases had an increase in RMDT without returning to baseline levels post-typing. Differences in post-typing RMDTs between case types were not apparent at 22° C or at 26° C.

The distinction between type I and type II case types was not thought to be particularly germane for application in the clinic or in epidemiological studies. Additionally, our goal of enrolling 20 type II cases were not met (given the relatively rare prevalence of this condition), thus limiting the power of these comparisons. A more useful distinction among persons with UEMSDs is the severity of symptoms and physical examination findings.

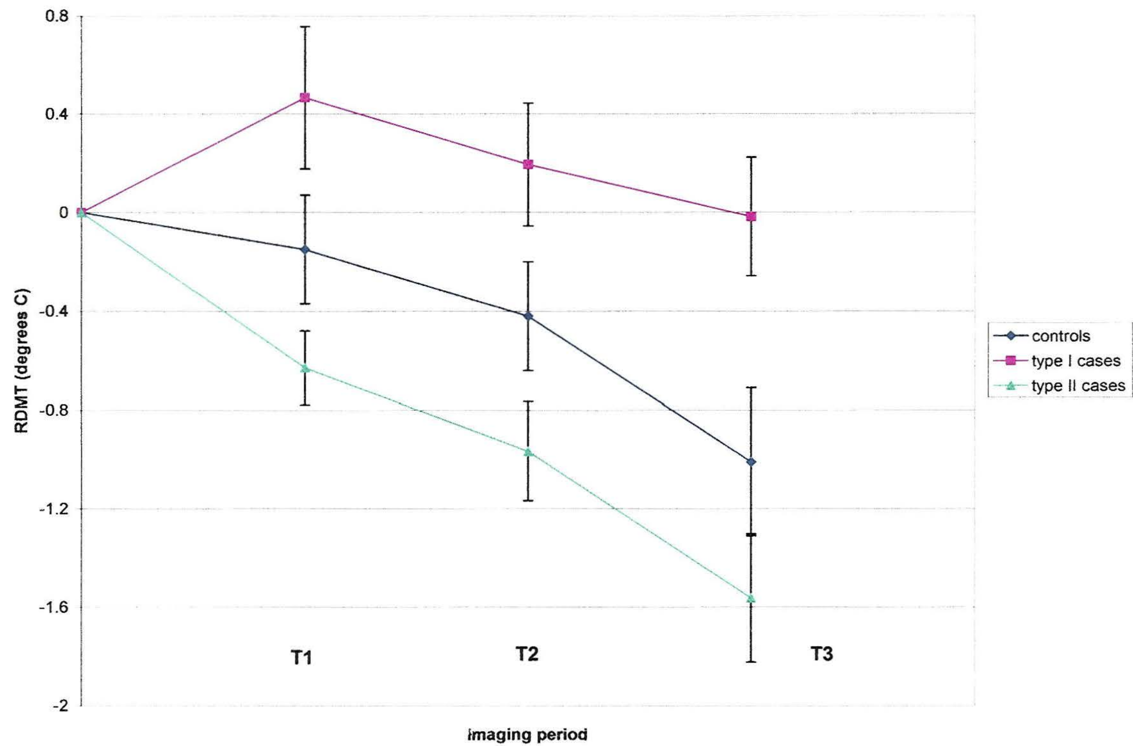

Figure 2. Post-typing RMDT (degrees C) by imaging period, stratified by case type at 18° C ambient temperature. ANOVA, $p \leq 0.05$, at T1, T2 and T3. Error bars = standard error.

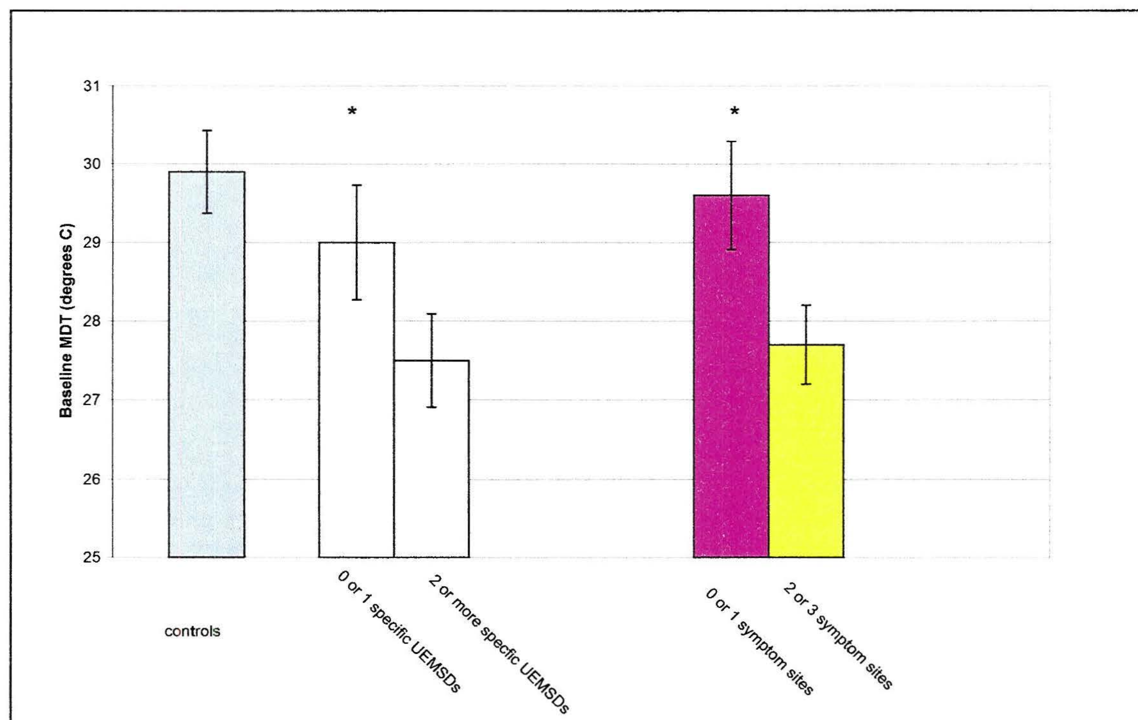

Figure 3. Baseline MDT (degrees C) by selected case definitions and symptom characteristics at 18° C ambient temperature. * ANOVA, $p \leq 0.05$

Baseline MDT (at both 18° C and 22° C) differed according to UEMSD severity as determined by number of symptom sites as marked on a hand/arm diagram and by number of UEMSDs (ANOVA, $p \leq 0.05$ both metrics, shown for 18° C in Figure 3). The latter were ascertained through case definitions based on symptoms and physical examination findings for specific UEMSDs (CTS, lateral epicondylitis, etc.) as detailed in publication 2. Tukey post-hoc comparisons revealed a difference between baseline MDT in controls vs. those with 2 or 3 symptom sites. Similarly, a difference between controls and those with 2 or more specific UEMSDs was also observed. An analogous pattern of colder pre-typing hand temperature in those with more severe symptoms as compared with controls was found at 26° C. However, differences at the higher ambient temperature were not statistically significant.

b. Extract features from the hand image to determine whether symptomatic regions of the hand as marked on a hand diagram show temperature differences from asymptomatic regions.

Two approaches were taken for specific aim 2b, in which the question of identifying anatomically localized symptoms in accordance with regions of non-uniform skin temperature was raised.

I. The mean dorsal hand temperature and standard deviation was determined from a single image extracted from the dynamic thermal image stream immediately after typing for cases at 22° C. All images were standardized to display a specific color palette (rain palette) with a linear temperature scale ranging from 20° C - 35° C in ThermaCAM Researcher Pro. The isotherm tool in the software package in was used to highlight regions plus or minus either one or two standard deviations from the mean dorsal temperature in this image. Initially, these hot or cold regions (of 4x4 pixels or greater) were coded according to their location based on a demarcation of the hand in the hand/arm diagram. The front and back of each hand in the hand/arm diagram was sub-divided into eight regions for analysis. On the palmar side, regions roughly corresponded to each of the five digits from the distal interphalangeal joint through the palmar digital crease, wrist (below the level of the styloid processes), and palm divided into two regions with a line running through the center of the 4th digit at the palmar digital crease to the wrist. Regions were similarly defined on the dorsal side. Because hot or cold spots in the thermal image were located in nearly every region, we decided to further sub-divide the hand for increased specificity. Fingers were divided into distal, middle, and proximal phalanges, and the palm and the dorsum were divided into lateral, middle, and medial areas. For regions of the thermal image ± 1 SD from the MDT, statistically significant Spearman correlation coefficients of 50% or less were found for five regions. No correlations were observed between regions of the thermal image ± 2 SD from the MDT and symptom sites as marked on the hand diagram.

II. The second approach was based on the hypothesis that dissimilar patterns of skin temperature between two fingers within either the ulnar or median nerve distribution would be correlated with being a UEMSD case, whereas controls would show similar

patterns between the two digits. Images extracted from the dynamic thermal image stream immediately after typing for controls at 22° C were randomly ordered with the analogous images for cases as described above. Three researchers blinded to image case status judged if the skin temperature in the fingers within each of the median (2nd and 3rd digits) and ulnar (4th and 5th) nerve distributions (on a per hand basis) in the thermal image were qualitatively different or not. Differences in coding were resolved by consensus. Sensitivity measures were higher for the left hand than for the right, and specificity was uniformly low (Table 2).

Table 2. Sensitivity and specificity of qualitative difference in skin temperature pattern between digits for UEMSDs (median – comparison of digits 2 and 3, ulnar – comparison of digits 4 and 5)

Hand Region	Sensitivity	Specificity
Right median	54%	33%
Right ulnar	68%	56%
Left median	70%	0%
Left ulnar	80%	11%

SA3. Estimate the correlation between skin temperature (DMTT) and subcutaneous blood volume as measured by near-infrared spectroscopy.

RMDT and RBV were moderately correlated during 10 minutes post-typing (Pearson correlation coefficient [PCC] = 0.75, p = 0.01 at 0-2 minutes after typing; PCC = 0.52, p = 0.12 at 3-5 minutes after typing; PCC = 0.77, p = 0.01 at 8-10 minutes after typing).

Discussion

The aim of this study was to evaluate the suitability of infrared thermography for evaluation of UEMSDs and for improved understanding of UEMSD pathophysiology. Mean dorsal temperature demonstrated reproducibility within a non-symptomatic group before and after a short typing task under controlled ambient temperature. MDT differences before typing were observed when UEMSD signs and symptoms were more severe. At ambient temperatures of both 18° C and 22° C, lower baseline MDTs were found in those with two or three symptom sites marked on a hand-arm diagram, and in those with two or more specific UEMSDs as determined by physical examination signs and symptoms, as compared with control subjects. These reduced hand temperatures observed after acclimation to ambient temperature in the absence of even a low level of exercise (i.e., typing) may indicate disturbed cutaneous temperature regulation in subjects with numerous or widespread UEMSDs.

Subcutaneous perfusion is a major determinant of skin temperature. Perfusion is, in turn influenced by both the sympathetic nervous system (SNS) and the larger arterial flow where hormonal effects predominate. The median and ulnar nerves provide the cutaneous SNS innervation of the dorsal hand. Hence, it is possible that we are observing autonomic dysfunction in these nerve distributions in the more symptomatic study subjects. Abnormal skin sympathetic response has been discerned in patients with carpal tunnel syndrome (Caccia et al 1993; Reddeppa et al 2000) and in lateral epicondylitis (Smith et al 1994). Greening et al (2003) observed sensory, but not autonomic neural deficits in asymptomatic office workers working at least 40% of their jobs at video display terminals. Yet they observed dysfunction in both nerve classes in patients with non-specific arm pain. This is consistent with our finding that severe cases appeared more vasoconstricted, i.e. cooler, than the less affected.

Models of UEMSD pathology involving both neurological and musculoskeletal causation have been proposed, and the current study's finding of likely SNS involvement in subjects with severe UEMSDs does not contradict their conclusions. Compression of sympathetic nerve fibers is not incompatible with our findings. Prolonged static postures in office workers are hypothesized to result in direct nerve compression through mechanical pressure at entrapment sites or due to muscle use imbalance as nerve trunks course through shortened, tight muscles (Mackinnon and Novak 1994; Novak and Mackinnon 2002). The sympathetic nerves anatomically track with sensory nerves from spinal cord through the skin (Sparks 1978). SNS fiber compression could result in a change in vasomotor activity, which in turn would cause altered skin temperature (Ming et al 2005). The Brussels Model describes a positive feedback mechanism for SNS excitation in work-related disorders of muscle origin in conjunction with low force repetitive work (Johansson et al. 1999, 2003). Briefly, the SNS is activated via exercise. Under low force work where metabolites, inflammatory mediators and other substances are not rapidly removed from the muscle, local neurotransmitters released by muscle afferents result in further activation of the centrally mediated SNS with concomitant reduction in muscle and skin blood flow. Our findings of reduced baseline MDT in

subjects with severe UEMSDs appear consistent with this model and are suggestive of SNS involvement.

Exposure to cold ambient temperature has been identified as a risk factor for UEMSDs (see Pienimäki 2000 for review; Piedrahíta et al 2004). However, the temperatures identified in these studies are typically 10° C and below. Reduced mean dorsal hand temperature was induced by a short typing task in asymptomatic subjects in an ambient temperature environment of 18° C. This temperature is equivalent to a cool office environment (~65° F). The moderate correlation between RMDT and relative blood volume in the first dorsal interosseous that we observed in controls suggests that skin temperature at least partially reflects underlying muscle perfusion in the hand. As this lowered cutaneous temperature likely represents a reduction in both skin and muscle perfusion, ambient temperature in office workers should be further investigated in epidemiology studies for its association with UEMSDs.

Conclusions

Studies of reliability for physical examination maneuvers for UEMSDs have found moderate to low reliability (Bertilson et al. 2003) With refinement, there is a possibility that thermography could be used in diagnosing or characterizing UEMSDs in the clinic or in the workplace.

Results are suggestive of a sympathetic nervous system effect in UEMSDs. Further research should be conducted to explore this possibility.

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Publications

1. Gold JE, Cherniack M, Hanlon A, Soller B: [2009] Skin temperature and muscle relative blood volume in the hand. International Journal of Industrial Ergonomics, Special Issue NIRS and Ergonomics, in press.

This article describes the post-typing correlation between dorsal hand skin temperature and blood volume in the first dorsal interosseous muscle. It is related to Aim 3.

2. Gold JE, Cherniack M, Hanlon A, Dennerlein JT, Dropkin J: [2009] Skin temperature in the dorsal hand of office workers and severity of upper extremity musculoskeletal disorders. International Archives of Occupational and Environmental Health, under revision for re-submission.

This article details the association between various metrics of UEMSD severity and pre-typing dorsal hand temperature. Reproducibility of infrared thermography in controls is also discussed. Aims 1 and 2 are relevant here.

Published Abstract

3. Gold JE, Hanlon A, Soller B, Cherniack M: [2007] Skin temperature and muscle relative blood volume in the hand: are they correlated? International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders (PREMUS), Boston, MA, 277, August 27-30.

This conference abstract describes the post-typing correlation between dorsal hand skin temperature and blood volume in the first dorsal interosseous muscle. It is related to Aim 3.

Inclusion of gender and minority study subjects

See next page

Inclusion of Children

This section is not applicable. Study subjects were 18 years of age and older.

Inclusion Enrollment Report

This report format should NOT be used for data collection from study participants.

Study Title: Skin Temperature in the Hands of Office Workers

Total Enrollment: 51 **Protocol Number:**

Grant Number: 5 K01 OH228134

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race

Ethnic Category	Sex/Gender			
	Females	Males	Unknown or Not Reported	Total
Hispanic or Latino	5	0		5 **
Not Hispanic or Latino	40	6		46
Unknown (individuals not reporting ethnicity)				
Ethnic Category: Total of All Subjects*	45	6		51 *
Racial Categories				
American Indian/Alaska Native				
Asian	1	1		2
Native Hawaiian or Other Pacific Islander				
Black or African American	7	0		7
White	36	5		41
More Than One Race				
Unknown or Not Reported	1	0		1
Racial Categories: Total of All Subjects*	45	6		51 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)

Racial Categories	Females	Males	Unknown or Not Reported	Total
American Indian or Alaska Native				
Asian				
Native Hawaiian or Other Pacific Islander				
Black or African American	1			1
White	4			4
More Than One Race				
Unknown or Not Reported				
Racial Categories: Total of Hispanics or Latinos**	5			5 **

* These totals must agree.
** These totals must agree.