2000

The effect of heat on fingertip sensitivity of meat processing workers

Brian James Finder

University of Northern Iowa

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THE EFFECT OF HEAT ON FINGERTIP SENSITIVITY
OF MEAT PROCESSING WORKERS

An Abstract of a Dissertation
Submitted
In Partial Fulfillment
of the Requirements for the Degree
Doctor of Industrial Technology

Approved:

Dr. Ali E. Kashef, Committee Chair
Dr. John W. Somervill
Dean of the Graduate College

Brian James Finder
University of Northern Iowa
July, 2000
DEDICATION

This doctoral dissertation is dedicated to
my devoted and highly talented wife, Kathleen,
and to our splendid daughter, Emily Catherine.

For the numerous lifestyle sacrifices they individually made
so as to permit this degree to become a reality,
my deepest gratitude is extended.

It is also dedicated to my parents, Lyle and Jackie Finder,
and to the loving memory of Melvin R. Stevens.
ACKNOWLEDGMENTS

It is said that one typically is not alone during the process that a new level of knowledge is gained, but rather, that a village of highly dedicated individuals are at work to inspire as well as facilitate his/her learning process. Such a philosophy could be nothing less than the truth as it pertains to my educational endeavors these past five years. Through countless hours of study as well as research, numerous individuals have stood beside me to provide an unbiased opinion, patiently explain a certain concept, cover a given responsibility, provide a warm hug of affection, or simply lend an ear to understand the trials and tribulations associated with enduring such a process. With this selfless giving from so many, the impossible dream becomes one that is ultimately within reach.

The dedication bestowed by my committee members for the out-of-hide support they repeatedly provided was nothing short of impressive. I shall never forget the ceaseless support given by Dr. Kashef for his road-clearing skills during the dissertation development process, by Dr. Lerner for his tactful urging to ensure that the bases were adequately covered in the literature review, by Dr. Betts for his detailed-oriented eye in identifying possible threats to the study's internal validity, by Dr. Dolgener for his insight into human performance-related issues, and by Dr. Rogers for his wisdom in statistical analysis methodologies. To have such a highly dedicated team of professionals unquestioningly support my hunch with regard to the effect of repeated cold exposure was a supreme gift in itself. For allowing me the opportunity to stand on your shoulders and look beyond the walls of our current body of knowledge, I sincerely thank you.

I cannot end the praise and thanks to those beloved members of my immediate family; Kathleen and Emily, for tolerating my absence during the days, weeks, and...
sometimes months that were required to accomplish this dream. I pray that in the years to come you will be rewarded many times over for the sacrifices that you made on my behalf. Your faith in my ability to reach this goal was undoubtedly tested and as a result of that test, you hopefully have developed a greater level of strength and determination to seek out and achieve goals of your own choosing.

I sincerely thank many of my ex-teammates; namely Chris Henderson, Cindy Cernohous, and Randy Albrecht, for their advisement as well as uncompromising belief that the execution of this research study held significant potential to promote the continuous process improvement culture that is ingrained in their meat processing organization. While the level of detail required to successfully complete the study was at times overwhelming, their sheer presence as well as frequent words of encouragement were often enough to keep me focussed and thus accomplish the task at hand.

Last but not least, a sincere and heartwarming level of appreciation goes out to the numerous other relatives, friends, and colleagues who were continuously around to smoothen out many of the bumps in the road. I can only hope that in the near future, there is an opportunity to reciprocate the gifts that this portion of the village provided.
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THE EFFECT OF HEAT ON FINGERTIP SENSITIVITY
OF MEAT PROCESSING WORKERS

A Dissertation
Submitted
In Partial Fulfillment
of the Requirements for the Degree
Doctor of Industrial Technology

Approved:

Dr. Ali E. Kashef, Committee Chair
Dr. Yury S. Lerner, Co-advisor
Dr. M. Roger Betts, Committee Member
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Brian James Finder
University of Northern Iowa
July, 2000
ABSTRACT

Current research indicates that acute non-freezing cold exposure elicits short-term performance problems; namely reduced upper extremity temperature, blood flow, tactile sensitivity, and dexterity. However, various animal-related studies indicate that humans are at increased risk of incurring semi-permanent upper extremity nervous system dysfunction as a result of repeated cold exposure.

The purpose of this research was to examine various factors that may contribute to hand/arm nervous system impairment of individuals who work in a refrigerated meat-processing environment. The methodology used was primarily the Experimental Method and from studies conducted by other researchers, was driven by the following questions:

1. How would heat applied to the hands of meat processing workers who work in a refrigerated environment affect their level of fingertip sensitivity?

2. To what extent does smoking negatively contribute to the development of a semi-permanent nervous system impairment in the hands of meat processing workers?

3. To what extent does the time that an individual works in a refrigerated meat-processing environment significantly correlate to his/her level of fingertip sensitivity?

4. To what extent does the skin thickness on the dorsal side of a meat processing worker's hand significantly correlate to his/her level of fingertip sensitivity?

The study was conducted by initially testing the subjects' index fingertip sensitivity with a Bruel and Kjare vibrometer. For the next 8 weeks, the treatment subjects wore a glove equipped with a functional heat pack on the dorsal side of their left (non-dominant) hand during the normal work routine while the control subjects' glove...
contained a non-functional heat pack. Two additional vibrometry tests were performed during the study; one after 4 weeks and the other after 8 weeks.

Through the use of t-tests and Pearson correlation coefficient statistical analysis techniques, it was found that subjects who received the heated glove experienced a significant improvement in left as well as right-hand fingertip sensitivity. Thus, this study indicates that individuals are at increased risk of incurring semi-permanent upper hand/arm nervous system impairment as a result of repeated cold exposure.
CHAPTER I
INTRODUCTION

The human body is a complex system of components which work in concert to perform a variety of functions. Communication within this system is supported by a network of nerves that transmit electrochemical-based messages to and from the body's primary control center; the brain (Lewin, 1974). The nervous system may carry brain-generated involuntary messages which instruct a person's heart to beat or eye to blink. Voluntary messages which also originate from the brain but stem from deliberate thought processes may facilitate the graceful movements of a figure skater or the explosive exertions of a weight-lifter. Whether voluntary or involuntary-related, disruption of the nervous system can result in reduced bodily function to the point of complete paralysis or even death (Wyburn, 1960).

Maurice Raynaud was a French physician who may have been the first person to identify the nervous system's role in controlling blood circulation. It was during the late 1860s when he observed that hands exposed to cold caused pallor of the skin, numbness, and discomfort in the fingers. By late 1889, significant research by Raynaud led him to hypothesize that such reactions were principally due to irritation of the nervous system (Raynaud's phenomenon, 1995). Theories based on recent medical research still align with the disrupting effect that cold has on the nervous system as well as blood circulation, although the exact physiological cause remains an enigma (Cleophas & Niemeyer, 1993).

The immediate cause of peripheral nervous system dysfunction had led to the use of terminology that recognizes the individual who spent a significant part of his life
studying the phenomena. Professionals in the medical as well as occupational health fields currently use the term “primary Raynaud’s syndrome” to identify decreased blood circulation in the hands and feet as a result of cold exposure (Raynaud’s syndrome, 1983). With this decrease in blood circulation, a variety of disruptions in the associated peripheral nervous system have also been identified. Acute localized cooling of the human hand has been found to reduce tactile discrimination of the index finger (Provins & Morton, 1959). Nelms and Soper (1961) discovered that the fingers of workers routinely exposed to frigid conditions were much colder than what such individuals thought; thus indicating the development of diminished sensitivity to the onset of hypothermia. In addition, it was Abramson et al. (1966) who identified a significant reduction in forearm nerve conduction rates during the time that a hand was cooled below 68°F. Given the variety of negative effects that cold exposure has been found to cause from a circulation as well as nervous system standpoint, it would seem plausible that more chronic forms of injury to the nervous system could occur to an individual routinely working in such an environment.

In addition to the primary effect that cold has on the body from a circulatory as well as nervous system standpoint, research within the last 40 years indicates that secondary causes of Raynaud’s syndrome also exist. Various secondary causes that disrupt circulatory and nervous system operation, particularly in the hands, are most likely due to certain personal (e.g., tobacco, stimulants, disease, psychiatric disturbances, etc.) as well as various occupational-related factors (Cleophas & Niemeyer, 1993). An occupational-based study conducted by Birkbeck and Beer (1975) revealed that
employment in light but highly repetitive jobs caused at least three out of four individuals to suffer from a nerve compression disorder of the wrist known as carpal tunnel syndrome. From a more occupation-specific standpoint, Armstrong, Foulke, Joseph, and Goldstein (1982) identified jobs in the poultry processing industry as requiring workers to perform highly repetitive hand/arm movements. Given the repetitive nature of work in a poultry processing plant, it may be reasonable to conclude that the risk of incurring some type of nervous system disorder would be heightened if associated individuals were exposed to more than one primary and/or secondary cause of Raynaud's syndrome at a given time.

In most highly developed countries, it is likely that one would routinely observe various food-handling and/or storage-related activities being performed in refrigerated conditions. U.S. Department of Agriculture (1987) requirements specify that the air temperature in raw product handling areas of meat processing facilities must be maintained at or below 50° F to limit bacterial growth. In an attempt to improve the shelf life of their products, some companies within the meat industry may maintain their work environment temperatures as low as 39° F. Not only can the overall body temperature be cooled by long-term exposure to such refrigerated work environments, but excessive conductive-based cooling of the hands and arms tends to occur due to contact with cold equipment, materials, and tools (Havenith, van de Linde, & Heus, 1992). It is therefore conceivable that performing light but repetitive activities with cold hands/arms in a meat processing environment could place a person at greater risk of experiencing nerve-related
disorders (e.g., primary Raynaud's or carpal tunnel syndrome) than if the same type of work was performed with normal temperature hands.

Purpose

The purpose of the study was to examine various factors that may contribute to hand/arm nervous system impairment of individuals who work long-term in a refrigerated meat processing environment. Specific objectives of the research project included:

1. Identify the preferred methodology to reasonably quantify fingertip sensitivity.
2. Develop a means by which auxiliary heat could be applied to the hands of individuals who work long-term in a refrigerated meat processing environment.
3. Verify the effect that auxiliary heat applied to the hands of meat processing workers has on their level of fingertip sensitivity.

Problem

Current research indicates that acute non-freezing cold exposure elicits various short-term performance problems with the human extremities; namely a reduction in hand/foot temperature, blood flow, sensitivity, and level of dexterity. The present body of scientific knowledge has yet to confirm that repeated/chronic cold exposure causes a more long-term or semi-permanent form of nervous system impairment. However, the synthesis of various animal-related studies does give credence to the inclination that meatpacking workers are at increased risk of incurring impaired upper hand/arm nervous system function as a result of repeated/chronic exposure to cold working conditions.
Research Questions

As a result of the conclusions derived from other researchers as well as the author's observations during his tenure in the meat processing industry, following are four questions which served as the basis for the study:

1. How would heat applied to the non-dominant hand of meat processing workers who work in a refrigerated environment affect their level of fingertip sensitivity?

2. To what extent does smoking negatively contribute to the development of a long-term or semi-permanent form of nervous system impairment in the hands of meat processing workers?

3. To what extent does the length of time that an individual is employed in a refrigerated meat processing environment significantly correlate to his/her level of fingertip sensitivity?

4. To what extent does the skin thickness on the back of a meat processing worker's hand significantly correlate to his/her level of fingertip sensitivity?

Significance of the Research

The treatment of injuries and illnesses sustained by American workers in 1992 cost business and industry $55 billion in worker compensation premiums alone (U.S. Chamber of Commerce, 1995). For every worker compensation-related dollar spent by an organization, Bird and Germain (1985) predict that an additional 6 to 53 dollars in accident-related losses are also incurred. This additional loss might result from process/facility damage, production disruption, product downgrading, excessive overtime, recruiting replacement employees, new employee training, and decreased
productivity of new employees. Consequently, the work of Bird and Germain indicates that annual losses sustained by American business and industry as a result of on-the-job injuries/illnesses could potentially run in the trillions of dollars. In addition to the above financial-related losses, the humanitarian side of pain, suffering, and decreased quality of life for those who are injured could also be viewed as a serious loss.

The term "cumulative trauma disorder" is often used to describe certain types of musculoskeletal illnesses which develop over a period of weeks or months as a result of repetitive bodily movements (Putz-Anderson, 1988). Specific nerve-related cumulative trauma disorders of the upper extremities (e.g., hands and arms) which result in decreased finger sensitivity or hand paralysis include neuritis and carpal tunnel syndrome (Armstrong et al., 1982). Since the early 1980s, these and other types of upper extremity cumulative trauma disorders have been publicly recognized by various safety/health professionals and government agencies as being highly prevalent in the meat processing industry. Investigations performed by Jensen, Klein, and Sanderson (1983) identified meat processing industries as accounting for up to 8% of all wrist disorders in the U.S.; nearly four times greater than the next highest occupation. Of 457,000 occupational illnesses reported by private industry to the U.S. Department of Labor in 1992, greater than 61% involved some type of cumulative trauma disorder. During this same year, meat processing firms led all other industries with an incidence rate of nearly 14 cumulative trauma disorders per 100 full-time employees per year (U.S. Dept. of Labor, 1995). Considering that National Institute for Occupational Safety and Health (NIOSH; 1989) found that the average worker compensation claim cost for a
cumulative trauma disorder in 1989 was $2,640 and that 365,000 of such cases were reported by the meat industry in 1992 (U.S. Department of Labor, 1995), then approximately $963 million in losses were incurred by meat processing firms for that year alone. This means that at least 1.7% of the $55 billion spent in 1992 on worker compensation premiums was disproportionately borne by an industry which employs approximately 279,000 people (U.S. Department of Labor, 1994), or only 0.22% of the U.S. workforce. From an injury incidence standpoint, the magnitude of this problem has been pointed out by Armstrong et al. (1982) and the National Institute for Occupational Safety and Health (NIOSH; 1990) where 17.4 to 19.5 cumulative trauma disorders occur per 200,000 person-hours worked in meat processing firms. Given the above loss-based statistics, it is reasonably apparent that this industry requires assistance in identifying and controlling risk factors which contribute to the occurrence of human suffering and financial loss.

**Delimitation of the Study**

The study is limited to employees who worked full-time in environments ranging from 39°-45° F. in the boning departments of a mid-western meat processing firm from 11/1/99 to 12/31/99.

**Limitation of the Study**

The study is limited to the extent that data collected only identified whether or not the subjects smoked tobacco, and not on the frequency or the number of years tobacco was smoked.
Assumptions of the Study

1. It was assumed that activities performed by the subjects outside of the environment of the study as well as any interaction that occurred between the treatment and control group subjects would not significantly affect the results of the study.

2. It was assumed that the Bruel and Kjare vibrometer is a valid and reliable instrument in which to assess an individual's fingertip sensory threshold level (Grunert, Wertsch, Matloub, & McCallum-Burke, 1990).

Operational Definitions

In light of the reasonably technical nature associated with the study, following are a variety of terms and their associated definitions:

Cumulative trauma disorder: Musculoskeletal impairments that result from over-use of certain body parts over an extended period of time (Putz-Anderson, 1988).

Carpal tunnel syndrome: A decrease in the median nerve's transmission abilities within the hand as a result of tendon-related swelling in the wrist (Putz-Anderson, 1988).

Musculoskeletal: Parts of the human anatomy that involve the combination of muscles, nerves, and bones (e.g., arms, legs, back) that facilitate the performance of various task-related movements (Putz-Anderson, 1988).

Neuritis: A decrease in a nerve's ability to transmit necessary electrochemical information as a result of physical injury or disease (Putz-Anderson, 1988).

Non-dominant hand: The upper extremity of a subject which typically was equipped with a steel-mesh protective glove and was not associated with continuous gripping of a knife or other meat processing-related tool.
Non-freezing cold exposure: Environmentally-induced cooling which does not permit the body temperature to drop below 32° F (Nukada, Pollock, & Allpress, 1981).

Peripheral nervous system: The branching of nerves that extend to the outermost areas of the body which facilitate the transmission of electrochemical messages to and from the brain (Partridge & Partridge, 1993).

Primary Raynaud's syndrome: A vasoconstrictive occurrence in the hands which is primarily the result of exposure to a cold environment (Raynaud's syndrome, 1983).

Repetitive motion: A high rate of similar movements for a given set of body parts (Putz-Anderson, 1988).

Secondary Raynaud's syndrome: A vasoconstrictive occurrence in the hands which is primarily the result of certain personal (e.g., smoking, stimulants, disease, psychiatric disturbances, etc.) as well as occupational factors (Cleophas & Niemeyer, 1993).

Upper extremity: Major musculoskeletal structures of the working arm which include the shoulder, upper/lower arm, wrist, hand, and fingers (Putz-Anderson, 1988).

Vasoconstriction: The process by which blood vessels decrease in diameter and thus reduce the volume of blood they can carry (Reed, Pepper, Armstrong, Von Tersch, & Lewis, 1989).

Vibrometer: An electronic-based instrument which measures fingertip tactile sensitivity at vibration frequencies ranging from 8 to 500 Hz (Lundborg, Lie-Stenstrom, Sollerman, Stromberg, & Pykko, 1986).
CHAPTER II
REVIEW OF LITERATURE

Given the varied climates that the human race has been known to inhabit, it seems likely that our ancestors recognized the effects of abnormal body cooling (e.g., hypothermia) for thousands of years prior to current times. Early recognition that cold exposure is not conducive to proper functioning of the body is evidenced in the writings of Hippocrates in 460 BC where travelers exposed to inclement weather conditions incurred cold-related injury to the extremities (Hippocrates, 1588). In more current times, the type of hypothermic-related situation that appears to be more publicized is of the acute type where an individual falls through the ice and is miraculously resuscitated from a non-breathing unconscious or comatose state. While there is little doubt that acute exposure to the cold can be a life-threatening situation, the potential for one who continuously lives or works in such an environment to experience some degradation in their quality of life can also be significant.

Effects of Cold on the Mammalian Body

Various experts currently acknowledge that exposure to cold adversely influences the operational ability of the peripheral nervous system. According to Partridge and Partridge (1993), abnormal cooling of the hands disrupts the firing rate of peripheral nervous system cold receptors, thus minimizing one’s perception of the severity of cold he/she is being exposed to. It is likely that this desensitization-effect was first established by Nelms and Soper (1961) when British fish filleters were found to reasonably withstand hand immersion in ice-water while other subjects unaccustomed to work in
cold environments experienced severe distress from such an activity to the point of fainting. This finding aligns with the results of observations reported by Henderson (personal communication, March 25, 1998) which indicate that individuals working long-term in a cold meatpacking environment typically believe their hands are warmer than is actually the case. In addition to this desensitization-effect which occurs during the cooling phase of a body limb, Dembert (1982) found that the associated individual is likely to experience moderate pain, swelling, muscular weakness, and even heightened cold sensitivity during the period that a chilled limb is re-warmed. While one's ability to withstand the distress of initial cold exposure could be beneficial from a short-term performance standpoint, the reduced level of motivation to seek a warm environment to regain body heat after an extended exposure would most likely interfere with long-term safe and efficient bodily operation.

In addition to disrupting operation of nervous system cold receptors, Abramson et al. (1966) as well as Reed et al. (1989) established that localized cooling of the hands reduced circulation of blood through the arterial system. Referred to by the medical field as vasoconstriction, this condition is thought to be the body's attempt to conserve core heat by shutting down blood flow to the extremities (Reed et al., 1989). It was through short-term cooling of the hands to a temperature of 60° F that Abramson, Zazela, and Marrus (1939) identified an average 60% decrease in blood flow when compared to a hand temperature of 90° F. Brown and Page (1952) studied long-term blood flow in cooled forearms and found that circulation experienced a reasonably continuous decrease for at least two hours during the time that test subjects' hand temperatures were
maintained at 68° F. While numerous theories on the peripheral nervous system have attempted to pinpoint the exact physiological mechanism for the above blood-flow phenomena, a major consensus for this occurrence has yet to be reached (Cleophas & Niemeyer, 1993).

It is reasonably accepted that among other functions, blood transports oxygen and nutrients throughout the body. Another role that blood flow has been also found to play is in the transporting of heat to the extremities of the body. Through an experimental study in which semi-nude men were exposed to temperatures as low as 11° F, Reed et al. (1989) strongly correlated reduced fingertip temperature with a decrease in blood flow and blood oxygen saturation to the upper extremities. A lowered forearm muscle temperature was found by Barnes and Larson (1985) to reduce an individual's maximal grip strength. One of the reasons for cold's effect on reduced grip strength relates to the work by LeBlanc (1956) who determined that a decrease in finger joint temperature causes an increase in its synovial fluid viscosity, thus requiring greater forearm muscle output to perform a given finger movement task. Given the performance-related deficits that cold elicits on upper extremity vascular, muscular, and skeletal systems, an individual performing a certain manual task with cold hands/arms may place such body parts under greater stress than if they were of normal body temperature, thus resulting in long-term impairment.

The ability of the human body to sustain a given level of performance during various levels of acute cold exposure is a topic that displays a reasonable depth of research. Regardless of whether the cold-related stress is induced through the whole body or just through the arms, Giesbrecht, Wu, White, Johnston, and Bristow (1995) concluded
that decreased performance of the finger, hand, or arm is likely to occur. LeBlanc (1956) established that a person with cold hands is less productive at performing manual tasks and exhibits reduced coordination, thus placing himself/herself as well as others at risk of accidental injury. This finding also aligns with work by Lockhart, Kiess, and Clegg (1975) which established that below 60° F, fingers significantly lose their fine dexterity but still possess the ability to manipulate large objects. From a tactile discrimination standpoint, Provins and Morton (1959) established that the fingertip was unlikely to distinguish between a single and dual edge when the digit was cooled to a temperature below 50° F. Through the short-term immersion of unprotected hands and forearms in 44° F water, Vincent and Tipton (1988) found that grip strength was significantly decreased during the first two minutes of the cold exposure test. Vincent and Tipton eventually concluded that some form of hand and forearm protection is essential for maintaining hand grip-strength prior to the occurrence of cold water immersion. Given the various adverse effects that acute cold exposure has been found to elicit on at least the upper extremities of the mammalian body, one may wonder why more emphasis isn’t placed upon preventing or at least minimizing such from a personal, occupational, and recreational standpoint.

An experimental study aimed at identifying hand operating temperature threshold through dexterity-based testing was performed by Clark (1961) in which enlisted men were required to perform manual tasks with their hands positioned inside a refrigerated box. Prior to the dexterity testing process, the subjects’ hands were placed in an electrically heated muff until their hands reached a reasonably normal temperature of 90°
At this point, the subjects inserted their hands into a refrigerated box and were timed with regard to how long it took for them to tie five series of knots when their hands reached various temperatures. The results of this study indicated that at hand temperatures of 55° F and lower, the time required to tie a given number of knots was significantly greater than with a normal hand temperature at the beginning of the test (Clark, 1961). Given the fact that only the hands of these test subjects were placed within the refrigerated environment, it would seem likely that decreased manual dexterity of the hands would be more profound if the entire body was working in the cold. Clark's method of heating the hand in an electric-powered muff is especially noteworthy to this proposed study as it ensured that all subject's hands were of reasonably equal temperature prior to the testing process.

Regenerative Capabilities of the Peripheral Nervous System

The regenerative capability of the mammalian peripheral nervous system appears to be a topic that has and continues to receive a significant amount of attention, particularly as it applies to the nerve's ability to recover from amputation or surgery-related severing. A Russian study involving recovering amputees identified a significant correlation between an early increase in blood supply to a repaired nerve and its eventual rate of regeneration (Krupatkin, 1992). As it relates to a peripheral nerve's response to cold exposure, a New Zealand-based experimental study by Nukada et al. (1981) was conducted by cooling the sciatic nerve of a rat to a temperature of 40° F for a period of two hours. For three days after this treatment, all of the rats displayed a progressive decrease in sciatic nerve function on the cold-treated side of their lower body. From
three to seven days after the treatment, the same rats showed evidence of severe sciatic nerve paralysis on the cold-treated side. Observable clinical recovery began shortly thereafter and progressed so that after four weeks, only minimal weakness and gait disturbance was present (Nukada et al., 1981). Other studies involving cooling of the ulnar nerve of dogs (Large & Heinbecker, 1944), sciatic nerves of cats (Schaumburg, Byck, Herman, & Rosengart, 1967), and the ventro-caudal nerve of rat tails (Peyronnard, Pedneault, & Aguayo, 1978) also found similar degradation and recovery-based results. From these four animal-based studies, it can be surmised that non-freezing long-term cold exposure not only degrades human peripheral nervous system function, but that a recovery to this degradation can occur in a reasonable period of time as long as the affected body part is not subjected to further cold stress.

The Effects of Smoking on the Cardiovascular System

Although the earliest writings of smoking tobacco date back to when foreign explorers found Native Americans partaking in this practice nearly five centuries ago (Stewart, 1967), it seems likely that North and South America were home to the consumption of this plant for hundreds of years prior to the early 16th century. Up until the middle 20th century, smoking tobacco was probably regarded as a reasonably harmless activity until Hammond and Horn (1958) published the first major study which identified a high degree of association between cigarette smoking and mortality. Their 44-month study involved the tracking of 187,783 men aged 50 through 69 to identify their primary causes of mortality as well as smoking habits. Analysis of the collected data revealed that of 11,870 deaths which occurred among this group during the 44-
month period of time, 7,316 were regular cigarette smokers who primarily died from coronary artery disease, lung cancer, and other cancerous-related abnormalities of the larynx and esophagus. In addition, the study also associated cigarette smoking with increased susceptibility to pneumonia, influenza, and aortic aneurysm (Hammond & Horn, 1958). Given the results of this as well as subsequent studies by Longo (1977), Shepard (1980), and Benowitz (1988) that also correlated smoking with human disease and mortality, a seemingly growing emphasis on minimizing its use through various legislative, medical, and privately supported endeavors have made smoking illegal for some and relatively unfashionable for many.

Of at least 250 individual compounds which have been found to exist within tobacco smoke (Westfall & Brase, 1971), nicotine is one that appears to receive the most negative public attention. Such notoriety should not be surprising since nicotine has been found to possess a toxicity similar to cyanide (Rose, 1991) and be nearly as addictive as cocaine or heroin (U.S. Department of Health and Human Services, 1987). The almost exclusive occurrence of nicotine in the tobacco plant makes exposure to this substance primarily confined to activities associated with smoking (Maisto, Galizio, & Connors, 1995) as well as harvesting of the uncured leaves (Gehlbach, Williams, & Perry, 1974). Nicotine's unique chemical nature makes it soluble in both water and oil-based compounds, thus facilitating reasonably efficient entry into the body through the mucous membranes of the mouth/gastrointestinal tract, active diffusion into the blood during respiration, and by skin absorption (ACGIH, 1991).
The physiological action of nicotine on the human body is one which is predominantly stimulating in nature (Maisto et al., 1995). Lower-level doses ranging from 1 to 4.5 mg are typically absorbed by adults as a result of smoking one cigarette (ACGIH, 1991) and cause an increase in heart rate, elevated blood pressure (Herxheimer, Griffiths, Hamilton, & Wakefield, 1967), and a decrease in skin temperature due to constriction of peripheral blood vessels (Schievelbein & Eberhardt, 1972). Of these known physiological reactions to nicotine, constriction of the peripheral blood vessels and the subsequent occurrence of skin cooling would most likely exacerbate the body’s natural vasoconstrictive response to cold exposure. Thus, the negative effect of nicotine in itself would mean that a person who smokes and works long-term in a refrigerated environment would probably have more severe impairment in his/her hand nervous system than a co-worker who does not smoke.

While nicotine limits the amount of blood that flows to the peripheral circulatory system, there is strong evidence that the carbon monoxide normally found within tobacco smoke negatively impacts the overall concentration of oxygen in the blood itself (Westfall & Brase, 1971). Aside from various environmental-related sources of carbon monoxide exposure including automobile exhaust, petroleum-based industrial processes, and blast furnace operations (ACGIH, 1991), tobacco smokers comprise the most heavily exposed non-industrial segment of the population (Stewart, Baretta, & Platte, 1974). It is likely that the physiological effect of carbon monoxide was probably first discovered more than a century ago by Haldane (1895) when he proved that it binds more readily with hemoglobin than oxygen does, thus reducing the blood’s oxygen-carrying capacity.
and subsequently causing depressed cardiac as well as cellular function. While it would take until the mid-1900s for research to discover that the mammalian body naturally contains trace but non-hazardous amounts of carbon monoxide (Sjostrand, 1951), Haldane's work has been repeatedly supported by the work of other researchers including Astrup and Kjedlsen (1974) and Tirlarpur, Gicheru, Charlambous, Evans, and Mir (1983). In an experimental study involving the assessment of subcutaneous oxygen levels, Jensen, Goodson, Williams, and Hunt (1991) found that baseline blood-oxygen levels decreased anywhere from 22% to 48% within 20 minutes of smoking one cigarette. Although Jensen et al. concede that various smoke-related compounds other than carbon monoxide may be at work to cause such significant blood-oxygen reductions to occur, their results do help broaden the picture as to the negative blood circulation as well as oxygen deficiency effects that smoking has on the body.

There is evidence which indicates that both the vasoconstrictive effect of nicotine and the oxygen starvation aspect of carbon monoxide derived from smoking tobacco impede the body's ability to repair itself after physical injury/trauma. Armed with insight on the decreased circulatory effects of cigarette smoking, Mosely and Finseth (1977) are likely to have been the first to chronicle the strife of a smoker from Denmark who began to experience chronic coolness, finger blanching, and painful ulcers on the middle and ring fingers of his right hand during the month of December. The symptoms persisted for at least six months until the man had ceased his smoking habit for a 12-week period of time (Mosely & Finseth, 1977). Although it is interesting to note that Mosely and Finseth did not correlate the subject's circulation-related symptoms with the low-temperature
time of year, their study does shed some light on the body's regenerative capabilities when it is eventually freed from contaminants derived from smoking cigarettes.

The issue of cigarette smoking and its adverse effect on the body's ability to make a reasonably efficient recovery from surgical-related trauma appears to be one which should not be taken lightly. In two case studies presented by Wilson and Jones (1984), male subjects who underwent finger reattachment surgeries showed positive circulation and temperature-related signs of recuperation during the first four days following their surgeries. On the fifth day of recuperation, each subject happened to resume his smoking habit since the surgery and promptly experienced pain as well as a decrease in circulation and temperature in the reattached finger. Immediate medical treatment with various prescriptive drugs did little to resume circulation in the affected areas and both subjects ended up losing their reattached fingers within a short period of time (Wilson & Jones, 1984). These situations correspond to a survey performed by Lind, Kramhoft, and Bodtker (1991) on 137 lower extremity amputees where the occurrence of reamputation as well as infection for individuals who smoked post-operatively was found to be 2.5 times greater than those who did not smoke. The fact that the mean age for the smoking group was 6.4 years younger than the non-smoking group could be interpreted as an indication of how much more detrimental cigarette smoking is to the degeneration of bodily functions than the natural aging process itself. In addition, the study found a lack of correlation between the frequency at which the smoking group post-operatively consumed tobacco and their overall healing rate (Lind et al., 1991). Such a finding indicates that the sheer number of cigarettes smoked by an individual does not influence
the overall healing rate as much as simply whether or not he/she actually smokes tobacco. Thus, the Wilson and Jones (1984) as well as Lind et al. (1991) case studies indicate that reasonably efficient healing of surgically injured/traumatized body tissue is highly dependent upon the subject's ability to avoid the smoking of tobacco during the time of recuperation.

Given the previously mentioned studies related to tobacco and its negative impact on the body's healing process, one could hypothesize that employees who smoke tobacco and work long-term in refrigerated environments are at higher risk of experiencing peripheral nervous system degeneration than their counterparts who did not smoke. Such a hypothesis is based on the premise that the vasoconstrictive-effect of nicotine coupled with the oxygen starvation aspect of carbon monoxide serves to intensify the vasoconstrictive response associated with cold exposure. Hence, the individual who smokes and works long-term in a refrigerated environment would receive at least a double dose of risk factors that would impede operation of their circulation and subsequent nervous system. In addition, it is probable that smoking individuals would be at increased risk of developing more serious and possibly permanent musculoskeletal injuries due to their body's inability to completely heal itself as a result of continued exposure to the various components of the cigarette smoke.

**Body Fat Content in Relation to Cold Stress**

The insulating property that body fat possesses from a heat transfer standpoint appears to be a phenomena that has long been regarded by the scientific as well as medical communities. By comparing skin-fold thickness and the level of shivering
observed during cold exposure, Swift (1932) may have been one of the first to conclude that the wide variation in cold response from one subject to another was principally due to the insulating properties provided by the subcutaneous fat layer. This concept was later supported by Daniels and Baker (1961) who also found that individuals with significantly greater amounts of subcutaneous fat possessed a higher body core temperature, cooler skin temperatures, and lower levels of oxygen consumption than persons with minimal amounts of subcutaneous fat. Their analysis of the body core and skin temperature-related findings appear to be consistent with the insulation-based properties that fat could provide. While Daniels and Baker only looked at core temperature of the torso through rectal-based monitoring, it would seem conceivable that a person with greater amounts of subcutaneous body fat may possess warmer extremities due to higher temperature blood being transported from the greater temperature core to the hands or feet. Given this premise, it could be concluded that individuals who possess a greater amount of body fat and therefore have warmer upper extremities would not experience the potential neural, muscular, and skeletal problems associated with long-term abnormal cooling of the hands and arms.

**Auxiliary Heating of the Body**

Numerous strategies have been employed in an attempt to prevent or at least minimize the negative effects associated with cold exposure. A study performed by Mackiewicz and Piskorz (1977) in a fish processing plant is renown for its analysis on the effect of periodic auxiliary hand heating on the prevention of blood circulation disturbances (e.g., primary Raynaud’s syndrome) in the hands. The population studied
involved subjects who filleted ice-frozen fish and then periodically re-warmed their bare hands (e.g., 3-15 times/hour) in hot water. Measurement techniques with this study involved visual inspections of subjects' hands and monitoring of corresponding skin surface temperatures. Within this group of subjects, it was determined that the onset of localized hand discoloration, numbness, moderate pain, and cold sensitivity associated with primary Raynaud's syndrome was first observed within 2-3 years of initial employment. Of the subjects with greater than 10 years employment, nearly 90% were diagnosed with moderate to severe symptoms of the syndrome. Hand temperature monitoring indicated that periodic re-warming of the hands in hot water had little effect in long-term raising of finger temperatures to normal levels (Mackiewicz & Piskorz, 1977). This finding also aligns with more recent experimental research conducted by Ceron, Radwin, and Henderson (1995) within the cold environments of a turkey processing facility. The results of both studies provided evidence that intermittent heating of the hands is not sufficient in raising finger temperature back to normal levels. In the case of the Mackiewicz and Piskorz study, it was also determined that periodic application of heat to the bare hands during cold exposure was not sufficient at preventing moderate to serious symptoms of primary Raynaud's syndrome from occurring (1977).

The use of devices that continuously promote warmth of the hand in frigid conditions has been explored with mixed success. One of the first of such studies was conducted by Rapaport, Fetcher, Shaub, and Hall (1949) in which bare-handed subjects wore a full-body air-heated suit in a -29°F environment. While the air-heated full-body
suit proved to be effective at keeping bare hands comfortable for up to one hour in such ultra-frigid condition (Rappaport et al., 1949), the cumbersome nature of this device would probably restrict its use to the laboratory setting. The effectiveness of a similar device which circulated heated air around the upper torso of a subject was tested approximately 15 years later by Goldman (1964). Of particular interest in this study was the fact that even though the subjects were wearing arctic mitts as well as other sub-zero turnout gear, the air-heated vest was not sufficient at maintaining reasonable extremity comfort to the test subjects. Given the results of these two studies, it may be that the determining factor for hand comfort and performance in sub-zero conditions is more related to the location that the continuous heat source is placed on the body.

In an attempt to develop effective forms of continuous auxiliary heating from more of a localized placement standpoint, Newton and Peacock (1957) devised a test where electric heating pads were strapped to the forearms of their subjects. The methodology of this experiment required barehanded subjects to perform simple manual dexterity tests while wearing heavy parkas and rubber arctic boots within an environment of 0°F. Although the heating pads were so hot that first-degree burns occurred on some of the subjects' forearms, significant reductions in hand comfort, temperature, and finger dexterity were observed during the test. The final conclusion of the experiment was that even when fitted with appropriate thermal insulation, continuous heating of the forearms alone is not sufficient to maintain adequate temperature of a bare hand in frigid conditions (Newton & Peacock, 1957). Given the results of the Rappaport et al. (1949), Goldman (1964), and the Newton and Peacock (1957) tests, the amount of body surface
area covered by the heat source appears to positively influence hand temperature and dexterity more than localized heat application to areas other than the hand.

The application of continuous heat directly to the hands as a means of improving manual performance has been tested with relative success. Gaydos (1958) studied the effect of heat applied continuously to the hands of minimally-clothed subjects (e.g., shorts, T-shirts, socks, and shoes) while they were exposed to temperatures of 45° F. While the subjects were probably in a state of negative-heat-balance during the time that only the hands were kept inside of a heated box, their knot-tying abilities indicated that short-term cooling of the body has no effect upon complex manual performance so long as the hands are kept warm (Gaydos, 1958). These results closely align with an experimental study performed later by Lockhart and Kiess (1971) involving the use of infra-red radiant heaters which were pointed towards the backs of unprotected hands in environments ranging from 60° F. to -20° F. The principal dependent variables in this study were skin temperature of the hands as well as the time required to complete simple assembly and knot-tying activities. The results indicated that the continuous use of heaters positively affected hand temperature and manual performance when compared to the control group that did not receive auxiliary heat (Lockhart & Kiess, 1971).

Consequently, of all places on the human body, the use of localized continuous auxiliary heat to maintain normal hand temperature and reasonable manual dexterity within a cold environment may be best if it is directly applied to the hands.
Research and Literature-Related Inconsistencies

Carpal tunnel syndrome and neuritis of the hands are considered to be nerve-related upper extremity problems which are a type of cumulative trauma disorder (Putz-Anderson, 1988). The occurrence of carpal tunnel syndrome was found by Reinstien (1981) to exist more often in the dominant hand of individuals diagnosed with the disorder. In a guide which outlines conservative approaches to preventing carpal tunnel syndrome, Armstrong (1983) stressed minimizing the individual's work rate, level of exertion (e.g., force), postural extremes of the wrist, and the presence of mechanical stresses that may occur when hand tool handles are not properly padded. He also advocated maintaining the hands at temperatures that feel warm to the touch of protected areas of the body (Armstrong, 1983). This stance appears to indicate his belief that upper extremity cold exposure should be avoided, but with little reasoning as to why.

Three years after publishing his carpal tunnel syndrome prevention guide, Armstrong (1986) published a document on cumulative trauma disorders which again stressed minimizing work rates, physical exertion, postural, and mechanical-related risk factors. Also included in this document is a section which recognizes that cooling of the upper extremities to a level above the freezing point may impede coordination and tactile discrimination (p. 563), although Armstrong makes no reference that cold exposure may cause direct soft-tissue injury. This statement appears to neglect the muscular weakness and heightened cold sensitivity effects that Dembert (1982) found as well as the moderate to severe primary Raynaud's syndrome observations that Mackiewicz and Piskorz (1977) made in the fish processing facility. Armstrong (1986) provides recommendations for
maintaining reasonable finger temperature by using gloves, providing handles with insulating properties, wearing additional clothing, and diverting the chilled exhaust of air-powered tools, but fails to mention the positive effects of using auxiliary heat to the hands as found by Lockhart and Kiess (1971). While it is unclear why Armstrong does not highlight the negative physiological effects of cold exposure as well as advocate the use of auxiliary heat to improve hand dexterity and temperature, it may simply be the result of not having reviewed some of the previously presented research.

It appears that governmental-based entities fail to recognize the potentially adverse effects of long-term exposure to the cold. An ergonomic program guide for meatpacking plants developed by the U.S. Department of Labor (1990) recommends the use of hand protection from temperatures below 40°F, but only as a means of minimizing stress on body joints. In addition, descriptive studies performed by Armstrong et al. (1982) and NIOSH (1990) do provide work rate, exertion, postural, and mechanical stress-related recommendations for reducing cumulative trauma disorder-related risk factors in poultry processing plants, but fail to address the issue of minimizing exposure to cold conditions. A more recent NIOSH (1997) publication on the occurrence of musculoskeletal disorders in general industry makes no reference to cold exposure as being a potential causal factor. Conversely, a working draft of the U.S. Department of Labor's (1999) Proposed Ergonomics Program Standard states that cold and heat stress can result in the occurrence of workplace musculoskeletal disorders, but with no indication of how or even what to do if such environmental conditions are identified. The reason for inconsistencies regarding whether or not cold is a contributing
factor in the occurrence of upper extremity nervous system disorders is difficult to ascertain. However, it may be due to the fact that limited research has been undertaken to actually quantify the effect that long-term cold exposure has on promoting the occurrence of upper extremity nervous system dysfunction.

Nervous System Measurement Methodologies

There exists a variety of means by which to non-invasively measure the functional capability of the hand/arm nervous system. One of the more simple methodologies utilized since the early 1960s involves the use of two-point discrimination calipers that are fitted with a pair of semi-sharp points. The protocol for this process requires a technician to place the two caliper points upon the subject's skin to test the distance required for the subject to sense the existence of both points (Von Prince & Butler, 1967). Another tactile measurement technique similar to the two-point discrimination caliper employs the use of synthetic monofilament fishline-like material which is mounted on a handle, similar to the appearance of a toothbrush with a single strand. The end of the monofilament is pushed perpendicular into the subject's skin by the associated technician and feedback is provided as to whether or not the subject can sense its presence upon the skin. The subject's ability to sense a fine gauge of monofilament that possesses a significant amount of flex would indicate high fingertip sensitivity while the ability to only feel a more coarse gauge of monofilament would indicate reduced fingertip sensitivity (Werner & Omer, 1970).

The results associated with manually administering the two-point discrimination as well as the monofilament tactile testing techniques appear to possess limitations from...
a consistency standpoint. Repeated side-by-side testing of these tactile quantitative methodologies found that the results were highly contingent on the method of technician administration (Dellon, Mackinnon, & Crosby, 1987). In a study that correlated decreased tactile sensitivity with a reduction in skin temperature, Stevens, Green, and Krimsley (1977) found that the velocity at which the monofilament fiber is applied to the skin surface can affect the subject's ability to sense the particular gauge being tested. Consequently, the two-point discrimination and monofilament tactile sensitivity testing methodologies are likely to be questionable in their ability to add internal validity to a study in which the dependent variable is hand sensitivity.

A testing methodology known as vibrometry has been employed since the mid-1980s as a means of identifying dysfunction in the nerve of the hand. Manufactured by Brue and Kjaer until the mid-1990s, a vibrometer consists of a vertical vibrating stylus on which the subject's index finger is placed. During a time that seven frequencies ranging from 8 to 500 Hz. are automatically presented through the stylus, the subject presses an electrical button to indicate the minimum amplitude at which the particular frequency is detected. This testing methodology is based on the premise that an object vibrating at frequencies greater than 125 Hz possesses a limited amount of displacement and therefore would be more difficult to sense, especially by individuals with impaired nerve operation (Lundborg et al., 1986). The testing of hand nervous system sensitivity on this limited-displacement premise appears to be reasonably founded and could be reasonably precise, especially when it can be performed in an automated manner to help eliminate the potential for errors introduced by variations in technician administration.
In a manufacturing-based study, Neese and Konz (1993) utilized vibrometry to determine the level of hand sensitivity for healthy workers with high job demands (e.g., repetition, force requirements, and wrist posture) as well as those who were already experiencing the pain and numbness-related symptoms associated with carpal tunnel syndrome. The results of this study indicated that the presence of pain and numbness in the hands was a significant predictor of a worker having a marked reduction in sensitivity to vibration frequencies at or above 125 Hz. In contrast, workers that did not possess significant physical discomfort in their hands but performed tasks involving repetitive, forceful, and extreme wrist angle movements did not exhibit significant difficulties in sensing higher frequencies (1993). A study by Grunert et al. (1990) examined average sensitivity thresholds on subjects who were given the opportunity to experience an initial practice trial to the vibrometry test. A correlation-based statistical analysis on the results of this study indicated that vibrometry can be a reliable assessment tool for determining the threshold of vibratory sensation provided that an initial practice trial is included in the methodology (1990). While studies involving the validation and reliability of this instrument as well as its use in testing subjects exposed to long-term cold could not be located, it appears that this device would serve as a reasonable tool to identify the extent of nerve impairment in the hand.

Availability of External Heating Sources

From an external heating standpoint for an experimental study, it is anticipated that the use of radiant heaters similar to those used by Lockhart and Kiess (1971) may not be a feasible means of raising meat processing workers' hand temperatures due to the
wide range of movements that they generally make. The use of such heaters may also heighten the possibility of increasing the temperature of chilled product, thus jeopardizing its quality. Another option would lie in the use of electric resistance-type coils that are either battery operated or run off an AC power source. One drawback of such a methodology is that the mass of D-cell batteries may place significant musculoskeletal stress on the arms and shoulders of the subject. The wiring associated with an AC-powered system would likely interfere with the subject's ability to perform his/her job and even pose an electrocution hazard in the wet environment of a meat processing facility. Thus, the issues associated with electric-based heating systems indicates that a more practical means of warming worker hands needs to be investigated.

The existence of scientific-based studies that have employed the use of commercially available heat packs was researched without any success. Such auxiliary heating devices that provide continuous heat when exposed to air appear to have become somewhat popular among outdoor enthusiasts, especially during the winter months. Marketed under the brand names of Thermacare®, Hot Rods®, and Grabber Mycoal®, these heat packs operate on a chemical-based exothermic reaction and are manufactured in relatively small sizes (e.g., 2” x 2” x 1/4”). Such a size could reasonably fit within the back of a person's glove. The retail cost for these heat packets range from 25 to 40 cents each and their ability to provide heat for up to 10 hours is supported by literature published by the associated manufacturers. While the means of attaching a packet to a subject's hands was not found to be commercially available, it is very likely that a technique utilizing double-stick adhesive tape or employing a Velcro®-type pocket could
be used. The simplicity as well as uninterrupted supply of heat that is provided by this product appears to make it more preferred than any other available heat source.

**Summary**

Based on the above literature review, the development of nervous system impairment in the human hand as a result of chronic/repeated exposure to cold conditions is plausible. The development of this impairment may be due to disruptions in the fingertip cold receptors or possible nerve impairment as a result of oxygen and nutrient starvation from decreased blood flow. Animal-based studies strongly suggest that not only does peripheral nerve impairment result from situations involving extended cooling, but that the nervous system can regenerate itself from such degeneration within a reasonable period of time provided that further cold stress is avoided. Reductions in hand temperature, blood flow, manual dexterity, and fingertip sensitivity have been well documented as it relates to short-term exposure to cold and attempts have been made to identify means of minimizing associated exposures. Cigarette smoking has been found to impede the peripheral circulation as well as the oxygenation of blood and is likely to accentuate the vasoconstrictive effect that cold exposure elicits. While the length of employment may also produce a cumulative effect on decreasing hand sensitivity, it appears that the thickness of the lipid layer below the skin may actually serve to increase hand warmth due to its insulating properties.

The application of auxiliary heat to various body parts as well as intermittently to the hands has been tried with little or no success. However, experimentation involving continuous application of heat to the hands to improve dexterity and temperature has
been performed with reasonably successful results. Research aimed at studying if an improvement in fingertip sensitivity may occur as a result of applying heat to the hands of individuals during their work in cold environments could not be located. From a fingertip sensitivity testing standpoint, the frequency-displacement measuring technique associated with the automatic Bruel and Kjaer vibrometer appears to be the most promising means of identifying if an improvement in fingertip sensitivity could result from the long-term application of heat to the hands of workers employed in cold environments. The potential product quality as well as worker health and safety issues associated with the use of radiant heaters or electrical resistance coils would likely override the benefits which such heating techniques could provide. Consequently, the use of commercially available exothermic heat packs would be the preferred method of providing auxiliary heat to the hands of workers in a meat processing setting. Given the technology-based resources available to reliably test fingertip sensitivity as well as provide continuous heat to the hand, it appears that an opportunity exists to test the effect that repeated/chronic cold exposure has on the development of hand/arm nervous system impairment in meat processing workers.
CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

The purpose of the study was to examine various factors that may contribute to fingertip nervous system impairment of individuals who work long-term in a refrigerated meat processing environment. Specific objectives of the study included:

1. Identify the preferred methodology to reasonably quantify fingertip sensitivity.
2. Develop a means by which auxiliary heat could be applied to the left hand of individuals who work long-term in a refrigerated meat processing environment.
3. Verify the effect that auxiliary heat applied to the left hand of meat processing workers has on their level of fingertip sensitivity.

Research Questions

As a result of the conclusions derived from other researchers as well as the author's observations during his tenure in the meat processing industry, following are four questions which served as the basis for the study:

1. How would heat applied to the non-dominant hand of meat processing workers who work in a refrigerated environment affect their level of fingertip sensitivity?
2. To what extent does smoking negatively contribute to the development of a long-term or semi-permanent form of nervous system impairment in the hands of meat processing workers?
3. To what extent does the length of time that an individual is employed in a refrigerated meat processing environment significantly correlate to his/her level of fingertip sensitivity?
4. To what extent does the skin thickness on the dorsal side of a meat processing worker's hand significantly correlate to his/her level of fingertip sensitivity?

**Hypotheses**

The literature search and the corresponding documented literature review provided the researcher with a reasonable feel of the scientific and technical-based knowledge which currently exists. Given the preceding research questions and logical conclusions that were drawn from the literature review as presented in Chapter 2 of this study, four hypothesis and their corresponding null-hypothesis were developed.

**H₁.** Meat processing workers who have heat applied to the dorsal side of their left hand will experience a significantly greater improvement in fingertip sensitivity than those who do not receive heat.

**H₀.** Meat processing workers who have heat applied to the dorsal side of their left hand will not experience a significantly greater improvement in fingertip sensitivity than those who do not receive heat.

**H₂.** Meat processing workers who smoke will experience less fingertip sensitivity than those who do not smoke.

**H₀.** There would be no difference in fingertip sensitivity between meat processing workers who smoke and those who do not smoke.

**H₃.** There will be a significant correlation between the fingertip sensitivity of meat processing workers and the number of months that they have worked in a refrigerated environment.
H₀. There will be a non-significant correlation between the fingertip sensitivity of meat processing workers and the number of months that they have worked in a refrigerated environment.

H₄. There will be a significant correlation between the fingertip sensitivity of meat processing workers and their dorsal-hand skin thickness.

H₀. There will be a non-significant correlation between the fingertip sensitivity of meat processing workers and their dorsal-hand skin thickness.

Research Design

This study was an experimental pretest-posttest control group design which consisted of a treatment group who received supplementary heat to the non-dominant hand and a control group that did not receive heat. The treatment and control groups were made up of subjects from the boning departments of a mid-western meat processing firm. Subjects working within both of these departments performed similar activities associated with manually dismembering carcasses in a refrigerated (e.g., 39°-45° F) environment for an 8-hour work-shift. The experiment required eight weeks to complete, starting on 11/1/99 and concluding on 12/30/99.

Population

In order to assess the fingertip sensitivity-related effects of repeated/chronic cold exposure, the population in this study consisted of individuals who were able to work for extended periods of time in a refrigerated meat processing environment. The job description specifies that such individuals must possess physical mobility in the hands and arms to continuously handle meat processing tools, equipment, and chilled meat.
product. They must also be able to work for extended periods of time in a refrigerated environment. During the first shift, at least 106 people were employed in both departments when the meat processing plant was running at full capacity. Every reasonable attempt was be made to get all employees from each department to participate in the study. This helped minimize the effect that any voluntary subject dropout and/or employment-related turnover may have had on the statistical power of the study.

**Heating Device Selection/Use**

The use of various electrically-operated heating devices was not revered as being realistic for this study due to the presence of wires which could break or otherwise pose a safety hazard to the associated subjects. Consequently, a more practical source was the use of commercially available heat packs which operate on a chemical-based exothermic reaction when exposed to air. This packet is manufactured in small sizes (e.g., 2” x 2” x 1/4”) which could reasonably fit on the back of an adult’s hand. The study used these types of packets after testing confirmed their ability to provide a reasonably constant amount of heat for an 8-hour period of time.

Confirmation of the level and duration of heat provided by the heat packets was achieved by constructing a wooden box-shaped testing apparatus which was fitted with a Precision 0.01° electronic thermometer manufactured by Control Company (see Figure 1). The testing apparatus was located in a 70°-72° F. environment where the presence of other heat-emitting appliances, direct ventilation, drafts, exposure to sunlight, and tampering could be controlled. After hourly readings throughout normal work-times confirmed the ability of this location to maintain the above temperature range for five
consecutive days, a randomly selected heat packet was removed from its sealing wrapper, placed upon a porous mat, and then concealed within the inner hollow area of the testing device. Hourly readings were subsequently performed and recorded with the assistance of a timer to identify the heat emission values. At the conclusion of the eight-hour test, the exhausted heat packet was removed from the apparatus and the process was repeated at the beginning of the next day until 10 of the packets had been tested. From a minimum heat output standpoint, at least nine of the tested packets had to provide heat which did not vary by greater than plus or minus 10°F of the mean peak value throughout the eight-hour test. Table 1 below provides the results of testing which identified the G28 Mini-Mini Hand Warmer® manufactured by Grabber Performance Group as the heat pack which ultimately met the established heat output requirements for the study.
Table 1

<table>
<thead>
<tr>
<th>Day</th>
<th>Hr. 1</th>
<th>Hr. 2</th>
<th>Hr. 3</th>
<th>Hr. 4</th>
<th>Hr. 5</th>
<th>Hr. 6</th>
<th>Hr. 7</th>
<th>Hr. 8</th>
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<td>115.3</td>
<td>115.0</td>
<td>114.5</td>
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<td>112.7</td>
<td>111.2</td>
<td>108.9</td>
<td>115.5</td>
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<td>114.4</td>
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<td>111.3</td>
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<td>112.6</td>
<td>111.1</td>
<td>109.3</td>
<td>115.1</td>
</tr>
</tbody>
</table>

Note. Mean Peak Value = 114.9

Placement of the heat packet so that the subjects’ fingers and hands could receive maximum benefit from its exothermic properties was a major consideration in this study. Since feedback from various production employees indicated that locating the packet on the palm of the hand would interfere with various required manual tasks, the next most likely place to locate the packet was on the back of the subjects’ hand. The packet was secured within a Velcro®-sealed pouch which was hand-sewn on the back of a nylon
glove that was identical to the type of liners being used by all of the employees within the respective boning departments (see Figure 2). The only difference between the treatment and control group gloves was that the treatment group received a fresh and therefore functional heat pack at the beginning of each day while the control group received a previously-used heat packet that no longer possessed any exothermic capabilities. Since all 65 of the subjects who participated in the study were right-handed, both the treatment and control groups wore a modified glove liner on only their non-dominant (i.e., left) hand. This was due to the belief that the stainless steel mesh outer glove which was worn on the non-dominant hand placed the associated extremity at increased risk of incurring conductive-based cold stress from continuous contact with chilled turkey product. Placement of the heat pack on the subjects' dominant hand was not viewed as practical since this extremity typically holds a knife and performs high-acceleration types of movements. With the addition of the hand-sewn Velcro®-sealed pouch as well as the heat pack to the back of the nylon glove, the overall weight of the glove was raised from 8.9 grams to approximately 30 grams.

Subject Selection

Approximately one month prior to the main study, all first-shift boning department employees attended department-specific informational meetings on paid-time during their normal work-shift. At least 106 boning-related employees were employed during the first shift when the meat processing plant was running at full capacity. During each department meeting, a generic review of information was performed regarding the study as well as steps that would be taken to ensure subject safety and privacy. At the
conclusion of each meeting, the associated University of Northern Iowa-approved authorization forms were distributed for review and a request was made for the employees to participate in the study. Ten-dollar gift certificates for a local food establishment were purchased and offered as an incentive by the meat processing firm for those who participated in the study through its completion. After the authorization forms were signed, the participants received a letter thanking them for their involvement in the study and a coin toss was performed on each one to determine who would be randomly assigned to the treatment group and to the control group. During the entire 8-week study which started with 33 subjects in the control group and 32 subjects in the treatment group, two individuals were dropped from the treatment group on account of absenteeism as well as work-related injury problems that were not the result the study's methodology.
Appendix A contains a copy of the authorization form that the potential subjects volunteering for this study were allowed to review and sign. A copy of the thank you letter that each participant eventually received can be found in Appendix B.

**Subject Pre-testing**

All subjects participated in a finger sensitivity pre-test one week prior to the distribution and initial use of the heated/non-heated glove liners. This testing established a baseline of the subjects' fingertip sensitivity and was performed during the first shift on the Tuesday, Wednesday, and Thursday of this week in order to minimize interference with the chaotic production schedule that tends to exist on Mondays and Fridays. As agreed upon by the respective department supervisors, at least two extra employees were available to cover for processing-related responsibilities of subjects who were pulled away from their normal line jobs to perform the pre-test. Prior to performing the test, each subject was required to sit in a room-temperature environment (68°-72° F.) with their upper torso and hands/arms wrapped in an electric blanket until the temperature of the outermost index finger joint for both hands reached a minimum of 90° F. This re-warming process helped to restore circulation and feeling to the hand and thus promote the collection of the subjects' normal fingertip sensitivity. A Digi-Sense Model 8525 Thermistor electronic thermometer (Cole-Parmer Instrument Company) was used to determine the outermost index finger joint temperature.

The testing station was located in a private area and designed so that the warmed subject could sit comfortably at a table and face in the direction of the examiner. Each subject was asked to first place the index finger of his/her non-dominant hand on the
vertical vibrometer stylus which was under a two-inch high by four-inch square cover of clear acrylic plastic (see Figure 3) that had been brushed with light abrasive paper to make it semi-translucent. The translucent nature of the plastic allowed the subject to vaguely see the vertical vibrometer stylus for fingertip positioning purposes, but prevented him/her to identify actual movement of the stylus during the testing process. This helped ensure that the subjects' responses to the vibrating stylus were prompted by tactile sensory rather than visual stimuli. A solid screen with a small viewing slot was placed between the subject and the examiner to eliminate the opportunity for the subject to observe operation of the equipment or recording of the testing results.

A Brüel and Kjær Model 9627 Vibrometer was the device used to assess hand sensitivity for this study. The main components of this system included a sensory stylus mechanism that was connected to the automatic frequency generator and recorder. For
each frequency that the sensory stylus was able to assume, the intensities of such could be varied from 5 to 160 decibels (dB). A saw-tooth exposure pattern was employed where the stylus vibration intensity for a given frequency began low and gradually increased until the subject indicated that he/she could sense it by pressing and holding a button down with the other hand. With the button held down, the intensity was automatically reduced until the subject indicated that the vibration could no longer be felt by releasing the button. The sequence of exposure progressed from the lowest to the highest of seven frequencies so as to quantify the subjects' overall level of nervous system function in the hand (Neese & Konz, 1993). It was felt that the simplistic operation of the vibrometer coupled with the process by which it automatically progressed a subject through the respective frequencies promoted the collection of reliable data. The vibrometer was calibrated by its manufacturer prior to the study and stored in a secure location throughout the study to ensure that it was not damaged or tampered with.

In a methodology similar to studies performed by Grunert et al. (1990) as well as Neese and Konz (1993), vibrometry evaluations were conducted in a quiet room with the seated subject wearing ear-muffs to minimize distraction by extraneous noises. The index finger of the subject's non-dominant (i.e., left) hand was first placed on the vibrometer stylus and the other hand on a pushbutton electrical switch that was mounted to a flexible cord. The subject was then instructed to press the electrical switch when he/she first sensed vibration at the fingertip and to release the switch after the sensation of vibration was no longer felt. Prior to the formal test, the subject was acquainted with three of the seven tested vibration frequencies (e.g., 8 Hz, 63 Hz, and 500 Hz) at reasonably obvious
intensities. After a practice session had been completed for the index finger of both hands, the examiner then had the subject place the non-dominant index finger on the stylus and initiate the testing program which automatically progressed the subject through the seven tested frequencies. The index finger of the dominant hand was always tested after the subject's non-dominant hand index finger had completed the test to make certain that every subject was treated the same.

At the conclusion of the initial vibrometry test, a measurement of the subject's skin-fold thickness was taken from the central dorsal side of each hand with a Lang skin-fold caliper (Cambridge Scientific Industries). Through questioning, information was also gathered from the subject with regard to his/her continuous time of employment in a refrigerated environment as well as smoking status. A vibrometry testing protocol/script that the examiner followed is listed in Appendix C. Appendix D contains the testing results form which was used to record the pre and post-test vibrometry and other pertinent data collected for each subject.

Subject Assignment

All recorded testing data was stored at an off-site location to maintain subject confidentiality. After all of the subjects had received the pre-test, the researcher performed a coin toss on each one to determine who was assigned to the treatment group and to the control group. This subject assignment process needed to be performed twice before a difference in the number of subjects assigned to the treatment group versus the control group was no greater than one.
Subject Training

During the week prior to the beginning of the study, a training session for each department was conducted on paid time during their regular work shift. Issues addressed during this training included time and location of glove distribution, proper wearing of the liner glove, the importance of wearing the glove provided to each subject during work-related activities throughout the study, and the need to return the glove at the completion of the shift. The subjects were also informed of routine follow-up which was performed during the study to ensure that they were wearing the appropriate glove. Appendix E contains an outline of the information that was reviewed with the subjects during the training session.

Glove Distribution and Use

The individual performing this study assumed the responsibility of preparing the treatment and control group gloves just prior to the beginning of each work shift in an area which ensured privacy from other hourly employees or management personnel. For the treatment gloves, a heat packet was removed from its sealed package, placed in the pouch, and then secured in place with the Velcro®-type flap. The prepared treatment glove liners were then stored in an air-tight bag in order to minimize their exposure to oxygen and therefore reduce the amount of heat that they would generate prior to use. Within the pouches of glove liners to be used by the control group contained a used and therefore thermally dead heat pack that had been exposed to the air for a minimum of 36 hours. The control glove liners were also stored in a separate plastic bag which, aside from a small and reasonably inconspicuous permanent black mark, was identical to the
one used for storing the treatment gloves. The treatment and control group glove liners were distributed to the subjects immediately outside of the production area from the Glove Room window.

Every reasonable attempt was made to control the process of distributing glove liners to the subjects. Using a discreetly displayed list of alphabetized subject names with their corresponding assigned glove type, the individual performing the study distributed the gloves to the appropriate employees by referencing the names on their company-provided bump-caps. The subjects were not allowed to see which bag their glove was removed from and no commentary was provided by the person distributing the glove liners during this process other than to thank each subject for picking up the glove. Subjects in both the treatment and control groups then wore the same type of protective rubber glove and stainless steel chain-mesh glove over the glove liner as was used by all employees within the two boning departments. The researcher was present at the window of the Glove Room at the conclusion of the shift to receive the glove liners from subjects as they exited the production area. The master listing of subjects was used as a means of tracking individuals who received a glove at the beginning of the shift and whether or not a glove was turned back in. Immediate follow-up was performed with the appropriate supervisor whenever a subject failed to turn a treatment or control glove liner back in at the end of the work-shift.

**Primary Study Activities/Controls**

On the first Monday morning of the study and for the next 8 weeks, the treatment and control glove liners were distributed to the subjects from the Glove Room. During
every day of the study, the researcher randomly selected three subjects to interview as they were working in the processing area. The purpose of this interview was to determine if the assigned glove liner was being correctly worn. The researcher clarified the purpose of the interview and politely asked the subject to remove his/her rubber gloves to examine the glove liner. Any identified deviations from the established testing protocol and/or requirements were politely discussed with the subject and immediately reported to the corresponding supervisor.

Daily contact was made with the boning department supervisors to identify mortality in the study due to attendance, work-related injury, or dropout (e.g., voluntary withdrawal or employment-related turnover). Any subject who was absent from performing his/her normal work routine for more than three consecutive working days and/or missed a total of five days during the eight-week period was eliminated from the study. A subject who incurred some type of hand/arm injury and was restricted from performing less than 75% of his/her normal job duties for more than five full days during the study was also eliminated. During the entire 8-week study which started with 33 subjects in the control group and 32 subjects in the treatment group, 2 individuals were dropped from the treatment group on account of absenteeism as well as injury-related problems that were not related to the research methodology.

**Pilot Study**

A pilot study utilizing five randomly selected subjects from the second shift boning departments was conducted one month prior to the beginning of the main study. Subjects involved with the pilot study received the same human subjects clearance.
presentation, vibrometry pre-test, regular training, and heat/no heat glove liners planned for the main study. The only major problem that was identified in the methodology as a result of performing the pilot study involved switching to the use of a more comfortable chair for the subjects to sit in during the time when they were being warmed.

**Data Collection**

On the Tuesday, Wednesday, and Thursday during the fourth and eighth weeks of the main study, posttest vibrometry testing was conducted on all remaining subjects to reestablish their fingertip sensitivity levels. The reason for performing the two posttests on a 4-week frequency was primarily based on the nerve regeneration rates that Nukada et al. (1981) as well as Schaumburg et al. (1967) found in their studies on small mammals. Another reason for performing the posttests on a 4-week basis (rather than every 2 or 3) was to limit the disruptive effect of pulling subjects away from the production area. The examiner followed the testing protocol/script and recording of testing results as found in Appendices C and D respectively. Extra employees were available to cover for processing-related activities of subjects who were pulled away from their regular jobs to perform the posttests. Each of the subjects completing the vibrometry test at the end of the eighth week were presented with the promised ten-dollar gift certificate as well as verbal appreciation.

**Data Analysis**

Analysis of the data was performed by first establishing a ratio-type numerical value that represents each subject's hand sensitivity to the seven frequency and intensity-based components of the vibrometry test. This was accomplished by calculating what
Neese and Konz (1993) refer to as a "Jetzer" index for each subject. The process of establishing this numerical value first involved averaging the four highest decibel response values for each of the frequencies tested. Take for example the 8 Hz portion of the vibrometry test for a subject's left hand that yielded an average response value of 105 dB (e.g., an average response to a moderately intense vibration). This value would then be subtracted from 160 dB (e.g., no response to an intense vibration). The difference of 55 dB would be divided by a factor of 10 to yield a sensitivity score of 5.5 for the 8 Hz frequency. The sensitivity scores for all seven frequencies tested on a given hand would then be added to yield a total score (or Jetzer index). An index value of below 20 indicates vibration insensitivity (e.g., probable neural transmission deficiency of the median nerve) while a value above 30 indicates more normal sensitivity. It should be noted that although Bruel and Kjaer claim the vibrometer as being a stable and reproducible means of identifying an individual's fingertip sensitivity, that no validity and reliability-related studies could not be located for this instrument. Figure 4 below contains an example of the mathematical process used to determine a subject's Jetzer index as found on the Subject Testing Results Form in Appendix D.

The statistical analysis techniques employed in this study included equal variance independent t-tests to help identify the significance that the application of heat to the left hand as well as the subjects' smoking status had on fingertip sensitivity. The Pearson correlation coefficient analysis technique was used to analyze how the subjects' continuous time of employment in a refrigerated environment as well as the thickness of their dorsal-hand skin layer was related to the level of hand sensitivity. A criterion for
Pre-Test Results—Right Hand

160 - ____ dB (8 Hz) = __________ ÷ 10 = __________
160 - ____ dB (16 Hz) = __________ ÷ 10 = __________
160 - ____ dB (31.5 Hz) = __________ ÷ 10 = __________
160 - ____ dB (63 Hz) = __________ ÷ 10 = __________
160 - ____ dB (125 Hz) = __________ ÷ 10 = __________
160 - ____ dB (250 Hz) = __________ ÷ 10 = __________
160 - ____ dB (500 Hz) = __________ ÷ 10 = __________

Jetzer Index = __________

Figure 4. Means of calculating the subject's fingertip sensitivity or "Jetzer" index.

rejecting the null hypotheses was established at the 0.05 significance level and the
subjects' hand sensitivity, smoking status, time worked in a cold environment, and dorsal
hand skin thickness data were processed by a p.c. version of SPSS 9.0. Chapter 4
contains the data collected throughout the study as well as its statistical analysis to
determine the extent to which various factors may contribute to fingertip nervous system
impairment of individuals who work long-term in a refrigerated meat processing
environment.

Summary

While the process associated with preparing for as well as conducting the research
required literally hundreds of hours on the researcher's part, it would never have been
possible without the help/consent of various management-based individuals at the meat
processing firm, as well as the assistance of numerous hourly personnel who graciously
volunteered to be the study subjects. Careful consideration was continuously paid to the
various processes associated with instrument calibration and security, glove design and maintenance, glove distribution, as well as subject-related communications in order to ensure that the study possessed the highest possible degree of internal validity. The ultimate goal was to execute a study which yielded data that could be consistently duplicated if it was performed in exactly the same manner with subjects in similar working conditions.
CHAPTER IV
PRESENTATION, ANALYSIS OF DATA, AND DISCUSSION

As a result of utilizing the research questions to drive the overall direction of the literature review, a total of four hypotheses and their associated null-hypothesis were formulated. This process then paved the way to develop a scientific testing methodology which promoted reasonably smooth execution of the study and subsequently permit the analysis of collected data. This chapter will serve to present, objectively analyze, and discuss the data collected by the researcher.

Presentation of Collected Data

After the subjects received the third and final vibrometry test, the top of the Subject Testing Results Form (see Appendix D) was cut off to ensure that the subjects' names were not associated with the data upon removal from the test site. At this point the researcher individually numbered the results forms, regardless of whether the subject was assigned to the treatment or control group. All of the subjects' skinfold thickness, period of employment, smoking status, and raw fingertip sensitivity data (the highest response for each frequency tested) were then entered into a spreadsheet program. After the spreadsheet program calculated the subjects' Jetzer index for their hands at each of the three major test times, the raw fingertip data was cut out to leave only the data essential for future analysis. Appendix F contains the subject and hand sensitivity data collected for the control and treatment groups respectively, from 11/1/99 through 12/30/99.
Analysis of Data for the Research Questions

The collection of data for this study spanned a period of 9 weeks with the first week involving the activity of establishing subjects' baseline fingertip sensitivity as well as identifying their smoking status, hand skin-layer thickness, and length of continuous employment in a refrigerated environment. For the following 8 weeks, the assigned heat or no-heat glove was worn by each subject on his/her left hand whenever work was being performed in the refrigerated production area.

Analysis of Research Question 1

Of the four research questions that served as the basis for this study, the one which required the most time to answer from a planning and execution standpoint dealt with the use of specially modified gloves which were worn on the subjects' non-dominant hand. This first research question was stated as follows: How would heat applied to the dorsal side on the non-dominant hand of meat processing employees who work in a refrigerated environment affect their level of fingertip sensitivity? A corresponding null hypothesis was then developed as follows: Meat processing workers who have heat applied to the dorsal side of their non-dominant hand will not experience a significantly greater improvement in fingertip sensitivity than those who do not receive heat. This null hypothesis eventually served as a basis for the statistical analysis portion of the study.

A basic analysis of the control and treatment groups' fingertip sensitivity (e.g., Jetzer index value) for the pretest, 4-week, and 8-week vibrometry tests was performed. Tables 2 and 3 provide this information in which the mean Jetzer index values as well as
other significant statistics for the control and treatment groups can be compared for both hands at the pretest, 4-week, and the 8-week vibrometry tests.

Table 2

**Summary of the Control Group's Fingertip Sensitivity (Jetzer Index)**

<table>
<thead>
<tr>
<th>N</th>
<th>Time</th>
<th>M Jetzer Index</th>
<th>SD</th>
<th>Std. Error of M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>33</td>
<td>Pre-test</td>
<td>36.04</td>
<td>36.88</td>
<td>3.84</td>
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<td>33</td>
<td>4 week</td>
<td>35.32</td>
<td>36.86</td>
<td>4.99</td>
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<tr>
<td>33</td>
<td>8 week</td>
<td>35.13</td>
<td>35.96</td>
<td>4.42</td>
</tr>
</tbody>
</table>

Table 3

**Summary of the Treatment Group's Fingertip Sensitivity (Jetzer Index)**

<table>
<thead>
<tr>
<th>N</th>
<th>Time</th>
<th>M Jetzer Index</th>
<th>SD</th>
<th>Std. Error of M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>30</td>
<td>Pre-test</td>
<td>32.52</td>
<td>34.05</td>
<td>5.96</td>
</tr>
<tr>
<td>30</td>
<td>4 week</td>
<td>35.63</td>
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</tr>
<tr>
<td>30</td>
<td>8 week</td>
<td>36.55</td>
<td>35.43</td>
<td>4.60</td>
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</table>
Of primary interest with regard to the heat-related question was the amount of change that occurred between the first and second as well as the first and third vibrometry tests for the hands of the control and treatment groups. A statistical analysis of this difference would then serve as the basis for determining whether or not to accept the associated null hypothesis. Tables 4 and 5 provide a summary with regard to the amount of change in the mean values that occurred between the first and second as well as the first and third vibrometry tests for the hands of the control and treatment groups.

Table 4

Summary of Control Group's Change in Fingertip Sensitivity

<table>
<thead>
<tr>
<th>N</th>
<th>Time Span</th>
<th>Change in M</th>
<th>SD</th>
<th>Std. Error of M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>33</td>
<td>0-4 weeks</td>
<td>-.72</td>
<td>-.02</td>
<td>4.14</td>
</tr>
<tr>
<td>33</td>
<td>0-8 weeks</td>
<td>-.91</td>
<td>-.92</td>
<td>2.87</td>
</tr>
</tbody>
</table>

Table 5

Summary of Treatment Group's Change in Fingertip Sensitivity

<table>
<thead>
<tr>
<th>N</th>
<th>Time Span</th>
<th>Change in M</th>
<th>SD</th>
<th>Std. Error of M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>30</td>
<td>0-4 weeks</td>
<td>3.11</td>
<td>1.41</td>
<td>5.00</td>
</tr>
<tr>
<td>30</td>
<td>0-8 weeks</td>
<td>4.03</td>
<td>1.38</td>
<td>3.81</td>
</tr>
</tbody>
</table>
In order to determine if the changes in hand sensitivity that occurred between the control and treatment groups were statistically significant, a two-tailed independent samples t-test was performed on a p.c. version of SPSS 9.0. The amount of fingertip sensitivity change experienced between the treatment and control group's first and second as well as first and third vibrometry tests for both hands served as a basis for the t-test. Table 6 contains the results of the calculated t-values as well as the level of significance for the two-tailed independent samples t-test. Note that the positive calculated t-values in Table 6 represent a positive change in fingertip sensitivity, due to the fact that the mean level of change in fingertip sensitivity measured in the control group was subtracted from the mean level of change measured in the treatment group.

Table 6

Results of Independent Samples t-test

<table>
<thead>
<tr>
<th>Hand</th>
<th>Time Period</th>
<th>Calculated t-value</th>
<th>df</th>
<th>Significance (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>0-4 week</td>
<td>3.315</td>
<td>61</td>
<td>0.01</td>
</tr>
<tr>
<td>Right</td>
<td>0-4 week</td>
<td>1.629</td>
<td>61</td>
<td>0.10</td>
</tr>
<tr>
<td>Left</td>
<td>0-8 week</td>
<td>5.829</td>
<td>61</td>
<td>0.001</td>
</tr>
<tr>
<td>Right</td>
<td>0-8 week</td>
<td>3.286</td>
<td>61</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The above statistical analysis indicates that the following null hypothesis: "Meat processing workers who have heat applied to the back of their non-dominant hand will
not experience a significantly greater improvement in fingertip sensitivity than those who do not receive heat," can be rejected at the 0.05 level. Thus, the following statements can be made with regard to this portion of the study:

1. With a 99% level of confidence, it can be said that the treatment group's level of left-hand sensitivity after the first 4 weeks of the study was significantly better than the control group's level of left-hand sensitivity.

2. With a 99.9% level of confidence, it can be said that the treatment group's level of left-hand sensitivity after the entire 8 weeks of the study was significantly better than the control group's level of left-hand sensitivity.

3. With a 99% level of confidence, it can be said that the treatment group's level of right-hand sensitivity after the entire 8 weeks of the study was significantly better than the control group's level of right-hand sensitivity.

Analysis of Research Question 2

While the second research question was also dependent on the vibrometry testing-related portion of the study, it focussed more on the difference in hand sensitivity that existed between the non-smokers and the smokers. This second research question was stated as follows: To what extent does smoking negatively contribute to the development of a long-term or semi-permanent form of nervous system impairment in the hands of meat processing workers? A corresponding null hypothesis was then developed as follows: There would be no difference in fingertip sensitivity between meat processing workers who smoke and those who do not smoke. This null hypothesis eventually served as the basis for the statistical analysis portion of the study.
A basic analysis of the non-smoking and smoking groups' fingertip sensitivity (e.g., Jetzer index value) for the pretest was performed. Tables 7 and 8 provide this information in which the mean Jetzer index values as well as other significant statistics for the non-smoking and smoking groups can be compared for both hands at the time of the vibrometry pretest.

Table 7

**Summary of the Non-Smoking Group's Fingertip Sensitivity (Jetzer Index)**

<table>
<thead>
<tr>
<th>N</th>
<th>Time</th>
<th>M Jetzer Index</th>
<th>SD</th>
<th>Std. Error of M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>39</td>
<td>Pretest</td>
<td>34.83</td>
<td>36.03</td>
<td>5.25</td>
</tr>
</tbody>
</table>

Table 8

**Summary of the Smoking Group's Fingertip Sensitivity (Jetzer Index)**

<table>
<thead>
<tr>
<th>N</th>
<th>Time</th>
<th>M Jetzer Index</th>
<th>SD</th>
<th>Std. Error of M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>24</td>
<td>Pretest</td>
<td>33.60</td>
<td>34.71</td>
<td>5.22</td>
</tr>
</tbody>
</table>
Question Number 2 focused primarily on the amount of change in hand sensitivity that occurred between the non-smoking and smoking groups at the time of the initial vibrometry test. A statistical analysis of the difference between the non-smoking and smoking groups would then serve as the basis for determining whether or not to accept the associated null hypothesis. A basic analysis of the data found that 23 of the subjects who completed the study were smokers and the remaining 40 subjects were non-smokers. Since it was anticipated that the smoking group would possess less fingertip sensitivity than the non-smoking group, the mean pretest fingertip sensitivity (i.e., Jetzer index) values for both hands of the smoking group were subtracted from those of the non-smoking group. This process yielded a difference of 1.23 for the left hand and 1.32 for the right hand.

In order to determine if the differences in hand sensitivity that existed between the non-smoking and smoking groups were statistically significant, a two-tailed independent samples t-test was performed on a p.c. version of SPSS 9.0. The amount of fingertip sensitivity that existed between the non-smoking and smoking groups at the time of the pretest for both hands served as a basis for the t-test. Table 9 contains the results of the calculated t-values as well as the level of significance for the two-tailed independent samples t-test.
Table 9

Results of Independent Samples t-test

<table>
<thead>
<tr>
<th>Hand</th>
<th>Time Period</th>
<th>Calculated t-value</th>
<th>df</th>
<th>Significance (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>Pretest</td>
<td>0.904</td>
<td>61</td>
<td>0.369</td>
</tr>
<tr>
<td>Right</td>
<td>Pretest</td>
<td>1.000</td>
<td>61</td>
<td>0.321</td>
</tr>
</tbody>
</table>

Based on the established critical t-values, the calculated t-values, and the associated level of significance, the following null hypothesis: "There would be no difference in fingertip sensitivity between meat processing workers who smoke and those who do not smoke." was not rejected.

Analysis of Research Question 3

The third research question was dependent on the vibrometry testing-related portion of the study, but it focussed on correlating the difference in hand sensitivity that may exist between subjects who had worked for a shorter period of time (in months) and those who had worked for a longer period of time. This third research question was stated as follows: To what extent does the length of time that an individual is employed to work in a refrigerated meat processing environment significantly correlate to his/her level of fingertip sensitivity? A corresponding null hypothesis was then developed as follows: There will be a non-significant correlation between the fingertip sensitivity of meat processing workers and the number of months that they have worked in a refrigerated environment.
environment. This null hypothesis eventually served as the basis for the statistical analysis portion of the study.

From the raw data collected and presented in Appendix F, a basic analysis was performed with regard to the amount of time (in months) that the subjects have been continuously working in a refrigerated meat processing environment. Table 10 provides a summary of this information in which the range, mean, and standard deviation values are calculated for all of the subjects involved in the study.

Table 10

<table>
<thead>
<tr>
<th>N</th>
<th>Range</th>
<th>M</th>
<th>Median</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>11 - 295 months</td>
<td>98.19 months</td>
<td>69 months</td>
<td>81.91 months</td>
</tr>
</tbody>
</table>

A Pearson correlation coefficient analysis was performed on a p.c. version of SPSS 9.0 to determine if a relationship existed between the subjects' pretest fingertip sensitivity value (e.g., Jetzer index) and the total number of continuous months that were worked in a refrigerated environment. Based on this statistical analysis between fingertip sensitivity and length of continuous exposure for the 63 subjects that completed the study, it was found that the correlation coefficient for the left hand was 0.04 (significance of 0.77) and the right hand was -0.15 (significance of 0.23).
Based on the calculated Pearson Correlation coefficient values and the fact that their corresponding levels of significance were nowhere near the established 0.05 level, the null hypothesis; "There will be a non-significant correlation between the fingertip sensitivity of meat processing workers and the number of months that they have worked in a refrigerated environment," was not rejected.

**Analysis of Research Question 4**

The fourth research question focussed on correlating measured hand sensitivity with the thickness of the skin on the dorsal side of the hand. This fourth and final research question was stated as follows: To what extent does skin thickness on the dorsal side of a meat processing worker's hand significantly correlate to his/her level of fingertip sensitivity? A corresponding null hypothesis was then developed as follows: There will be a non-significant correlation between the fingertip sensitivity of meat processing workers and their dorsal-hand skin thickness. This null hypothesis eventually served as the basis for the statistical analysis portion of the study.

From the raw data collected and presented in Appendix F, a basic analysis was performed with regard to the subjects' dorsal-hand skin thickness. Table 11 provides a summary of this information in which the range, mean, and standard deviation values are calculated for all of the subjects involved in the study.
Table 11

Summary of Subjects' Dorsal-Hand Skin Layer Thickness (in mm)

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Left</td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>1.5 - 5.0</td>
<td>1.5 - 5.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.46</td>
<td>2.33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.78</td>
<td>0.66</td>
<td></td>
</tr>
</tbody>
</table>

A Pearson correlation coefficient analysis was performed on a p.c. version of SPSS 9.0 to determine if a relationship existed between the subjects' pretest fingertip sensitivity value (e.g., Jetzer index) and the thickness of his/her dorsal hand skin layer. Based on this statistical analysis between fingertip sensitivity and dorsal hand skin thickness for the 63 subjects that completed the study, it was found that the correlation coefficient for the left hand was 0.17 (significance of 0.18) and the right hand was 0.18 (significance of 0.15).

Based on the calculated Pearson Correlation coefficient values and the fact that their corresponding levels of significance were nowhere near the established 0.05 level, the following null hypothesis: "There will be a non-significant correlation between the fingertip sensitivity of meat processing workers and their dorsal-hand skin thickness." was not rejected.
Discussion

The results of data collected to answer the four research questions need to be reviewed with regard to the literature as presented in Chapter II of this study. Following is a discussion of the data for each research question and the corresponding literature:

Research Question 1

A statistically significant increase in fingertip sensitivity for the treatment group's left hand as indicated by the 4 and 8-week vibrometry tests corresponds to two major findings of the animal-based nervous system experimental studies conducted by Nukada et al. (1981), Large and Heinbecker (1944), Schaumberg et al. (1967), and Peyronnard et al. (1978); non-freezing nerve cold exposure not only degrades mammalian peripheral nervous system function, but that a recovery to this degradation can occur in a reasonable period of time as long as the affected body part is not subjected to further cold stress. While the treatment group's fingertip/hand temperatures were not monitored before or during the study, it would seem likely that locating the heat packs on the hands caused an increase in upper extremity temperature as found by auxiliary heating-related experiments conducted by Gaydos (1958) and Lockhart and Kiess (1971). Such an increase in hand warmth would then promote blood flow similar to the findings of Reed et al. (1989) and result in neural health-related benefits as found by Krupatkin (1992). A deficiency of literature which could explain why the treatment group's right hand fingertip sensitivity experienced a significant level of improvement at the 8-week vibrometry test indicates that such a subject should receive additional research-based attention.
Research Question 2

The data which indicates that the non-smokers didn't possess a significantly greater level of fingertip sensitivity than the smokers appear to be contrary to literature presented in Chapter II of this study. These results are contrary to the prediction of reduced skin temperature due to nicotine found by Schievelbein and Eberhardt (1972) as well as Jensen's et al. (1991) discovery that diminished blood-oxygen levels from carbon monoxide accentuated the level of cold-stress experienced by an individual exposed to frigid conditions. While the work of Lind et al. (1991) did not identify a correlation between the amount that amputees smoked and the occurrence of infection/reamputation in the affected lower extremity, it should be stressed that their study did not involve repeated/chronic exposure to cold environments. Consequently, it is possible that fingertip sensitivity may more strongly correlate to the level as well as length of tobacco consumption for individuals exposed to cold environments than simply whether or not such persons smoke. Even though the results of this study indicate that the absolute smoking status (e.g., whether or not a person smokes) may not be as detrimental to fingertip sensitivity as repeated long-term cold exposure, there may be a relationship between smoking and the occurrence/severity of various upper extremity disorders.

Research Question 3

While a lack of significant correlation existed between the pretest level of fingertip sensitivity and the time in months that the subjects worked continuously in a cold environment, this finding may still align with the immediate nervous system degeneration that occurred when Nukada et al. (1981) cooled the sciatic nerves of rats.
Since 11 months was the minimum time that any of the subjects were continuously employed in a refrigerated environment, it is conceivable that a bulk of upper extremity nervous system degeneration for such individuals occurs during the first year of cold exposure.

Research Question 4

The work of Daniels and Baker (1961) demonstrated a significant relationship between greater amounts of subcutaneous fat and higher body core temperatures. However, a lack of studies which found significant relationships between higher body core temperature and increased upper extremity temperature (and consequently better nervous system function) led the researcher to only speculate that a greater amount of subcutaneous fat would ultimately result in improved nervous system function of the hands.

Summary

The quantification of hand sensitivity data through the use of the Bruel and Kjaer vibrometer served as one of the primary means for data collection in this study. Meticulous attention was paid to the care and use of this instrument so as not to compromise the study's internal validity and thus ensure the collection of quality data. Relatively simple statistical analysis techniques were employed to determine if a significant amount of change and/or the difference in fingertip sensitivities existed as it pertained to four null hypotheses. Of these null hypotheses, the one which stated that no difference in left hand sensitivity would exist between subjects who received heat and those who did not receive heat was rejected through statistical analysis. Thus, it can be
concluded from this study that meat processing workers who have heat applied to the dorsal side of their non-dominant hand will experience a significantly greater improvement in fingertip sensitivity than those who do not receive heat.
CHAPTER V  
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The effect that cooling of the body has in causing a certain level of discomfort as well as a decrease in performance has likely been regarded for hundreds if not thousands of years. Various attempts have been made since the mid-1950s to provide auxiliary heat to the body, especially the hands, with varying degrees of success. Certain occupations like meat processing still require employees to work their entire shift in a refrigerated environment and thus be subjected to the rigors of cold stress of the hands. Such abnormal cold exposures may not only cause the development of certain physiological-related problems, but could place the employee at risk of injury to themselves as well as their co-workers. Consequently, the primary focus of this research was to determine how the application of auxiliary heat to the hand affected fingertip sensitivity for meat processing workers.

Summary of the Research

The ability to maintain the human body temperature within a reasonably narrow thermal range is necessary to ensure maximum operational efficiency. Current research indicates that acute non-freezing cold exposure elicits various short-term performance problems with the human extremities; namely a reduction in hand/foot temperature, blood flow, tactile sensitivity, and the level of dexterity. The present body of scientific knowledge has yet to confirm that repeated/chronic cold exposure causes a more long-term or semi-permanent form of nervous system impairment. However, a synthesis of animal-related studies does give credence to the inclination that meatpacking workers are
at increased risk of incurring impaired upper hand/arm nervous system function as a result of repeated/chronic exposure to cold working conditions. The purpose of this research was to examine various factors that may contribute to hand/arm nervous system impairment of individuals who work long-term in a refrigerated meat processing environment.

The means by which to conduct this research was based largely on the experimental techniques as well as results of scientific-based studies conducted by other researchers. From a comprehensive review of applicable literature, the following four research questions were formulated and thus served to drive the remaining research process:

1. How would heat applied to the hands of meat processing workers who work in a refrigerated environment affect their level of fingertip sensitivity?

2. To what extent does the use of tobacco negatively contribute to the development of a long-term or semi-permanent form of nervous system impairment in the hands of meat processing workers?

3. To what extent does the length of time that an individual is employed in a refrigerated meat processing environment significantly correlate to his/her level of fingertip sensitivity?

4. To what extent does the skin thickness on the dorsal side of a meat processing worker's hand significantly correlate to his/her level of fingertip sensitivity?

In practically all of the previously performed studies that were reviewed, only the continuous application of auxiliary heat to the hands was found to promote a reasonable
degree of hand/finger warmth for individuals who were exposed to nonfreezing as well as subfreezing environments. Since using warmed glove-boxes as employed by Gaydos (1958) or Lockhart and Kiess's (1971) application of infrared heat to the hands were not deemed suitable for a meat processing environment, the most logical and practical heat source for the hands appeared to be the use of commercially available heat packets. An extensive amount of time was invested to determine not only the most appropriate area in which to locate the heat packet, but also how to secure it so as to limit possible contamination of the food product. This problem was eventually solved by devising a Velcro®-sealed pouch which was hand-sewn on the back of a nylon glove that was identical to the type of liners being used by all of the subjects within the study (see Figure 2, p. 40). The level as well as duration that the packets provided auxiliary heat was tested to ensure that they could maintain reasonable exothermic qualities throughout a typical eight-hour work-shift. After the subjects' hands achieved a more normal temperature as verified by an electronic thermometer, their fingertip sensitivity was initially tested with a Bruel and Kjare vibrometer.

For a total of 8 weeks immediately following the initial vibrometry test, the randomly-assigned treatment group subjects wore a modified glove equipped with a functional heat pack on their left (i.e., non-dominant) hand during their normal daily work routine within a refrigerated environment. The randomly-assigned control group of subjects used the same type of glove that contained a non-functional heat pack. Morning distribution and afternoon collection of the modified gloves was performed in a manner which was careful not to indicate that there was any difference between the heating
potential of the treatment and control groups' gloves. All subjects received a second and third vibrometry test during the course of the study. The second test was performed after they had worn the modified gloves for 4 weeks and the third after they had worn the modified gloves for 8 weeks. In addition to collecting the pretest, 4-week, and 8-week fingertip sensitivity-related data, information collected on the subjects included their smoking status, time of continuous employment in a refrigerated environment, and the thickness of the dorsal-hand skin layer. Upon the completion of the third and final vibrometry test, each subject was presented with a company sponsored ten-dollar gift certificate for a local food processing establishment.

Conclusions Based Upon the Collected Data

Research Question 1

The process of analyzing how the heated and non-heated gloves affected hand sensitivity of the respective treatment and control groups revealed the most conclusive results of the study. In response to Research Question 1, it can be concluded that the treatment group experienced a statistically greater level of left-hand fingertip sensitivity over the control group's left-hand sensitivity after the 4 and 8-week vibrometry tests. Furthermore, the treatment group's level of right-hand fingertip sensitivity was statistically better than the control group's right-hand sensitivity after the 8 week test. Given the reasonable conclusion that fingertip sensitivity improvements were principally due to the heated glove causing an increase in hand temperature as well as blood flow, several viable conclusions can be drawn from this portion of the study.
The effect of repeated long-term cold exposure. A statistically significant improvement in fingertip sensitivity for the subjects who wore the heated glove indicates that repeated long-term exposure of meat processing workers to a refrigerated environment may contribute to a semi-permanent form of nervous system impairment in the affected extremities. Since a reduction in fingertip as well as forearm temperature was found by Reed et al. (1989) to decrease upper extremity blood flow and blood-oxygen saturation, it is plausible to conclude that degeneration will occur to the associated neural as well as muscular tissues as a result of repeated long-term cold exposure. This cold-induced neural degeneration would most likely exacerbate the decreased hand sensitivity-related symptoms that are commonly associated with other upper extremity nervous system-based ailments such as neuritis and carpal tunnel syndrome.

The neural transfer-effect of heating one upper extremity. Of particular interest to the results of this portion of the study was the statistically significant improvement in fingertip sensitivity that occurred between the right-hand of the treatment group over the right hand of the control group. Even though the subjects of the treatment group did not receive heat to their right hands, their level of fingertip sensitivity was improved over the control group's level of right-hand fingertip sensitivity. While the literature provides no indication as to why this may occur, it is possible that in sensing the heat to the back of the left hand, the body's central nervous system actually reduces its seemingly natural response to minimize blood flow to the unheated right hand.
Research Question 2

In response to an analysis of data that corresponded to Research Question 2, the potentially adverse effects of smoking was not found to cause the non-smokers to possess a statistically greater level of fingertip sensitivity than the smokers. While the issue of smoking was not the primary focus of the research, it is acknowledged that this study was limited by the fact that data regarding the amount of tobacco consumed by the smoking subjects was not collected.

Research Question 3

An analysis of the data applicable to Research Question 3 indicates that the amount of time (in months) than an individual is continuously employed in a refrigerated environment did not significantly correlate to his/her level of fingertip sensitivity. Of particular interest to this finding is the fact that none of the subjects had been working in either of the refrigerated departments for less than 11 months. Given the data and the fact that the treatment group did respond favorably to the heated glove, it is possible that the greatest amount of nervous system degeneration occurs during the first year that an individual continuously works in a refrigerated environment.

Research Question 4

In response to Research Question 4, the data indicated that skin-fold thickness on the dorsal side of the hands did not significantly correlate to the subject's level of fingertip sensitivity. Such being the case, a thicker skin layer on the dorsal side of the hand is not a reasonable indicator of susceptibility to repeated/chronic cold-induced upper extremity nerve degeneration.
Recommendations to Improve Data Collection

During the process of setting up as well as performing the study, a few issues were identified in which the efficiency associated with various procedures/activities could have been improved. Such improvements could ultimately minimize the disruptive nature that the study had on production within the associated departments.

**Have More Substitute Employees Available**

It is highly likely that having more substitute employees available in the respective departments to take the place of the subjects undergoing the fingertip sensitivity testing would ease the researcher's feeling a certain amount of pressure by the supervisors to rush the testing process. This would then lend to ensuring that a more methodical and thus consistent data collection process could be performed.

**Improve Subject Re-Warming Methodologies**

The fact that the researcher sometimes had to wait a substantial amount of time in order to allow certain subjects to re-warm under the heated blanket (just prior to receiving their fingertip sensitivity test) indicates that a more rapid means of warming the subjects should be investigated. It is possible that the use of heated air and/or direct contact with warm water would facilitate the re-warming process better than what the electrically-powered radiant heat blanket was able to provide.

**Improve the Method of Securing the Heat Packs**

Since numerous gloves needed to be repaired throughout the study, the method of hand-stitching them should be replaced with a machine stitch or else some type of
adhesive that is able to withstand the daily high-temperature washing and drying processes used in the glove room.

**Utilize Alternative Fingertip Sensitivity Measurement Methodologies**

While the fingertip sensitivity as well as skin-fold thickness measurement processes employed in this study are believed to have facilitated the collection of reasonably accurate as well as consistent data, the availability of other devices and/or use of different collection methodologies should be researched. It is likely that other alternative devices and/or methodologies are more conducive to determining how tobacco use, length of exposure time, and skin-fold thickness relate to potential degeneration of soft-body tissue.

**Enlist More Subjects in Similar Studies**

It is possible that the limited number of subjects involved with the study caused lack of statistical power as it relates to the issue of smoking, length of exposure time, and skin-fold thickness-based research questions and their associated hypothesis. Consequently, the researcher should be vigilant for opportunities to perform similar studies that can recruit significantly greater numbers of subjects.

**Recommendations for Future Research**

While the results of the study permitted only one of the four null hypothesis to be rejected, significant opportunities for additional research are reasonably apparent. Given the results, following are opportunities for additional research as it relates to repeated/chronic exposure to refrigerated environments:
1. Since the use of a heated glove on the non-dominant hand was found to elicit a statistically significant improvement in dominant hand (unheated glove) fingertip sensitivity, it may be of great interest to provide workers with heated gloves on both hands to identify if foot sensitivity as well as temperature is improved. Such a study could also be performed by providing auxiliary heat to only the feet or the head in order to identify a possible improvement in fingertip sensitivity and temperature.

2. The lack of statistically significant correlation between the length of continuous employment in a refrigerated environment and measured fingertip sensitivity indicates that weekly or monthly vibrometry testing of new workers should be performed to identify the rate at which hand sensitivity decreases as a result of repeated/chronic exposure to cold. Such testing for new employees could also be performed with the heat packs attached to the dorsal side of the hands in order to determine if the degenerative effect of the cold can be minimized or even prevented.

3. For some jobs/activities within the refrigerated meat processing environment, it may be prudent to test how fingertip sensitivity, hand temperature, and/or dexterity is affected when the heat packet is placed on the palm of the hand. Such data may indicate that product quality as well as safety is ultimately improved as a result of using the heat packs on the hands.

4. Further testing should be performed to identify the extent that the heat packets warm the fingertips as well as other application methods that may be used in order to maximize fingertip warmth.
5. Further testing should be performed on a more long-term basis (e.g., 3 to 6 months) to determine if the incidence of reported repetitive motion injuries decreases as a result of using the heated gloves.

6. Since an improvement in fingertip sensitivity was achieved with the auxiliary heat pack applied to the backs of the hand, further research should be performed to assess the effect of limiting exposure to chronic/repeated cold through various administrative means like periodic job rotation (e.g., every 2 hours) to a warmer environment within the processing facility.

7. While a person's smoking status (on a yes/no basis) was not found to correlate with fingertip sensitivity, further research should be performed to identify if the frequency and/or length of time that a subject consumes tobacco significantly correlates to his/her level of fingertip sensitivity.

8. Additional research should be performed as it relates to age and gender-related susceptibility to the degenerative effects of repeated/chronic cold exposure.

9. Further statistical analysis should be performed to identify if the difference in improvement between the right and left hands of the control group after the 8-week test was as significant as the difference in improvement between the right and left hands of the treatment group.

10. Additional research should be performed to assess the validity and reliability of utilizing the Bruel and Kjare vibrometer as a means of determining an individual's fingertip sensory threshold level (Grunert et al., 1990).
REFERENCES


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APPENDIXES
APPENDIX A

HUMAN SUBJECT CONSENT FORM
Informed Consent Statement to the Human Subjects Review Form

This study is being performed as part of my doctoral degree program in Industrial Technology at the University of Northern Iowa. The purpose of this study is to see the effect of wearing a small pad on the back of your hand. The first part of this test will have you take part in a fingertip feeling test. For up to eight weeks following this test, you will be asked to wear a modified liner glove that has a small pad on the back whenever you are in the processing area. During the following fourth and eighth weeks of the study, you will again take part in a fingertip feeling test. You will not be subject to any foreseeable type of personal risk during the fingertip feeling test or during the time that the modified glove is being worn. The benefit of participating in this study is that we may find ways of making your job less demanding.

Results of fingertip feeling tests that are collected in this study will not be made available to your management or your co-workers. These records will be stored off the premises of the company in a secure manner. Your participation in this study is completely voluntary and you may choose to quit it at any time with no risk to employment benefits that you are entitled. Your refusal to take part in this study will not place you at risk of losing employment benefits that you are entitled. You will receive a $10.00 gift certificate for participating in the study through its completion. The following persons may be contacted if you have any questions about this research as well as your rights:

Dr. Ali Kashef  
136 Industrial Technology Center  
University of Northern Iowa  
(319) 273-2596

Human Subjects Coordinator  
1 Seerley Hall  
University of Northern Iowa  
(319) 273-2748

Your support in this matter is sincerely appreciated.

Brian J. Finder  
(715) 874-5760

I am fully aware of the nature and extent of my participation in this project as stated above and hereby agree to participate in this project. I acknowledge that I have received a copy of this consent statement.

(Signature of subject)  
Date

(Printed name of subject)

(Signature of investigator)
APPENDIX B

PARTICIPANT THANK YOU LETTER
October 25, 1999

John Doe
c/o Meat Processing Firm
34 North 7th Street
Midwest, USA 00000

Hello John,

Thank you for volunteering to participate in the upcoming glove test within your department. As stated in the recent meeting with you and your co-workers, it is hoped that this testing will help us learn more about the design of gloves that you wear.

It is anticipated that during the week of November 1, 1999, you will take part in the fingertip sensitivity testing. This testing will take place on the third floor of the office complex and should take about 10 to 12 minutes to complete. Beginning on November 8, 1999, you will start wearing the assigned glove on your non-dominant hand. You will then be involved in two additional fingertip sensitivity tests which will then take place every four weeks until late December.

Please do not hesitate to call me at (715) 232-1422 if you should have any further questions about this process. Again, I thank you for volunteering.

Sincerely,

Brian Finder
APPENDIX C

EXAMINER TESTING PROTOCOL AND SCRIPT
Testing Protocol & Script

Following is the Examiner's testing protocol & script:

1. Greet subject and direct him/her with the following:

   "Good day, my name is _____ and I'm the person who will be performing the test today. Could you please sit over here in this chair and I'll wrap your upper body in this electric blanket to help you warm up for the next five or so minutes? I'll let you know as soon as we're ready for you to perform the test. Thanks."

2. In a non-threatening and inconspicuous manner, watch the subject to ensure that he/she stays wrapped in the electric blanket.

3. When the test of an electronic thermometer indicates that last joint of the subject's index fingers reach at least 90° F, the examiner will then provide the following directive:

   "Please remove the blanket from yourself, come over to this station, and make yourself comfortable in this chair."

4. Ask the subject his/her full name and the department he/she is currently working in. Record this information in the appropriate spaces on the Subject Testing Results Form.

5. Instruct the subject with the following directive:

   "You will need to wear these ear muffs throughout the entire test. I'll first give you an idea of the vibration that you'll most likely feel throughout the test". What I'd like you to do is to place the bare index finger of your non-dominant or steel mesh glove hand on the small circular surface in front of you. Place the index finger of your other hand on the black button and press and hold it down as soon as you can feel the vibration. You will release the button only when you can no longer feel the vibration. Would you like me to repeat those directions?

6. With the subject's index finger of his/her non-dominant hand on the sensory stylus and ear muffs donned, activate the vibrometer to run the practice session.

7. At the conclusion of this practice session, instruct the subject with the following:

   "Now I'd like you to switch hands and allow the index finger of your dominant hand to practice feeling the vibration"
8. At the conclusion of the second practice session, instruct the subject with the following:

"Now I'd like you to place the index finger of your non-dominant hand back on the circular surface and we will begin the test."

9. When the employee appears ready, activate the vibrometer to test the subject's non-dominant hand.

10. After the non-dominant hand has been tested, instruct the subject with the following:

"Now I'd like you to place the index finger of your dominant hand on the circular surface."

11. At the completion of the vibrometry test, ask the employee his/her age, smoking status, and years of continuous employment in the boning area. Record these results on the Subject Testing Results Form.

12. With the employee's permission, measure the thickness of the dorsal side of the hand with the Lang skin-fold thickness caliper. Record this data on the Subject Testing Results Form.

13. At the completion of the test, say to the employee:

"Thank you for performing the test. You may now return back to your job."

14. After the subject has left the testing station, manually record the appropriate date and fingertip sensitivity-related data on the Subject Testing Results Form.

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APPENDIX D

SUBJECT TESTING RESULTS FORM
Subject Name: ___________________________ Department: ___________________________
-------------------------------------------------- detach here at conclusion of study ---------------------------------------

Subject Age: __ Subject Hand Dominance: R L (circle one) Subject Smokes Tobacco Y N (circle one)
Subject Back-Hand Skin Fold Thickness: R _____ mm L _____ mm Time Subject Worked in Cold ______ months

Pre-Test Date: __________

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Pre-Test Results - Left Hand:

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Week 4 Test Date: __________

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Week 4 Test Results - Left Hand:

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Subject Testing Results Form - Side 2

Subject Name: ______________________  Department: ____________

Week 8 Test Date: ______

Week 8 Test Results - Right Hand:

160 - _____ dB (8 Hz) = _______ + 10 = _______
160 - _____ dB (16 Hz) = _______ + 10 = _______
160 - _____ dB (31.5 Hz) = _______ + 10 = _______
160 - _____ dB (63 Hz) = _______ + 10 = _______
160 - _____ dB (125 Hz) = _______ + 10 = _______
160 - _____ dB (250 Hz) = _______ + 10 = _______
160 - _____ dB (500 Hz) = _______ + 10 = _______

Jetzer Index = _______

Week 8 Test Results - Left Hand:

160 - _____ dB (8 Hz) = _______ + 10 = _______
160 - _____ dB (16 Hz) = _______ + 10 = _______
160 - _____ dB (31.5 Hz) = _______ + 10 = _______
160 - _____ dB (63 Hz) = _______ + 10 = _______
160 - _____ dB (125 Hz) = _______ + 10 = _______
160 - _____ dB (250 Hz) = _______ + 10 = _______
160 - _____ dB (500 Hz) = _______ + 10 = _______

Jetzer Index = _______
APPENDIX E

SUBJECT INFORMATION/TRAINING OUTLINE
Subject Information/Training Outline

1. Introduce self.

2. Explain basic purpose of proposed study (i.e., to test the result of employees wearing a small pad on the back of their hands while performing their production-related activities).

3. Briefly review the following:
   A. The appearance of the modified glove liner that the subjects will wear.
   B. How the modified glove liner is to be worn on the subject's non-dominant hand (e.g., with the pad on the back of the hand).
   C. The need for the subjects to use the same modified glove liner that is provided to them at the beginning of the shift for the remainder of the day.
   D. The time during the work-shift that the modified glove liner must be worn (e.g., anytime the subject is working in the refrigerated production area).
   E. The time period that the modified glove liners will be distributed to the subjects (e.g., every working day for an eight-week period of time).
   F. The location from which the gloves will be distributed every morning.
   G. The specific day which the study will begin (e.g., when the subjects will begin to pick up the modified glove liners).

4. Attempt to answer any questions the subjects may have without providing too much detail regarding the exact nature of the modified glove liners.

5. Thank the subjects for their participation.
APPENDIX F

RAW SUBJECT-RELATED DATA
### Raw Data Collected from the Control Group

#### Basic Subject Data

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#### Corresponding Jetzer Index Values

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