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ACUTE EFFECTS OF HAND ELEVATION AND WRIST POSITION ON MEAN ARTERIAL PRESSURE AND PULSE RATE MEASURED IN THE HAND

by

Lee Dearborn Shibley

A thesis submitted in partial fulfillment
of the requirements for the Master of Arts
degree in Physical Therapy
in the Graduate College of
The University of Iowa

July 2000

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To my father, always a teacher, and to my mother, a perfect student, who each instilled in me the meaning and the importance of both.

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I love you very much.

ABSTRACT

Musculoskeletal disorders (MSD) to the wrist and hand are common among workers, and are associated with working conditions that use forceful, repetitive and extreme wrist joint postures that including end range flexion. Construction workers that report performing overhead work for more than two hours per day are found to be three times more susceptible to carpal tunnel syndrome (CTS) symptoms and six times more susceptible to electrophysiological CTS changes. Blood pressure to the wrist and hand generally decreases with overhead hand positions, and decreased blood pressure to the hand is associated with decreased tissue perfusion and nerve conduction velocity at the wrist. Thus, overhead hand positions and some end range wrist positions are associated with decreased tissue perfusion to the hand in addition to increased risk of carpal tunnel syndrome and MSD.

The purpose of this study is to test the effect of five different vertical hand locations relative to heart level (0, -20, -40, 20, 40 cm) and two different wrist positions (neutral and flexed) on the acute long finger digital artery blood pressure and pulse rate of the dominant right hand of healthy individuals. These data should provide an improved understanding of the acute response to elevating the human hand overhead and achieving end range wrist postures, its

associated risk for decreased blood perfusion and nutrition to the tissues of the wrist and hand, and thus its associated risk for position-induced ischemia.

These results show that digital artery blood pressure changes significantly with hand position across an 80 cm range of elevation regardless of wrist position. Pulse rate does not change with hand position or wrist position. These findings indicate that hand elevation is associated with acute changes in finger blood pressure and thus tissue perfusion that occur with overhead hand placement. These changes occur whether the wrist is neutral or flexed to end range, during common wrist postures. Implications exist for position-induced hand ischemia as a risk factor for workplace MSD.

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CHAPTER 1
INTRODUCTION

Background for the Study

Musculoskeletal disorders (MSDs) to the wrist and hand are common among workers, and are associated with working conditions that use forceful, repetitive and extreme joint postures (NIOSH, 1997). Workers in the construction trades are among those exposed to these working conditions, which frequently includes construction work done with hand overhead postures and extreme postures (Verdon 1996, Ferry et al 1998). Construction workers that reported performing overhead work for more than two hours per day are found to be three times more susceptible to carpal tunnel syndrome symptoms and six times more susceptible to electrophysiological CTS changes (Farrell 1998). Extreme wrist positions include end range flexion, extension and ulnar deviation and are commonly used by construction workers during routine task performance (Verdon 1996). Wrist extension is associated with increased pressures within the carpal tunnel (Keir et al 1997). Blood flow to the wrist and hand decreases with overhead hand positions (Wright 1945), and decreased blood flow to the hand is associated with decreased nerve conduction velocity at the wrist (Fullerton 1963). Thus, overhead hand positions and some end range wrist positions are associated with increased risk of carpal tunnel syndrome and may be associated with other musculoskeletal disorders as well.

In the lower extremities of healthy persons, blood flow and tissue perfusion is directly proportional to blood pressures (normal blood pressures associated with normal blood flow and tissue perfusion, low blood pressures associated with below-normal blood flow and tissue perfusion) (Ashton 1975). Blood flow and tissue perfusion is then in turn dependent upon the effect of gravity on the hydrostatic column of blood (Ashton 1975), with direct application to upper limb blood flow and resultant tissue perfusion of blood-borne nutrition as well. The ability of active muscle contractions to impede or assist blood flow in the arm and hand depends upon strength of contraction and autonomic input, and is difficult to control (Kagaya and Homma 1997, Ferguson and Brown 1997, Jaspers et al 1994). Long-term muscle training in males results in training effects on vascular parameters including decreased blood pressure and increased blood pooling in extremities during maximum forearm contractions (Ferguson and Brown 1997). Thus, blood flow to the hand and its resulting tissue perfusion is dependent upon many factors, including muscle contractions, blood pressures, autonomic factors, training effects and the effect of gravity on the hydrostatic column of blood. The effect of hand elevation on the hydrostatic column of blood, and thus on measured hand blood flow and tissue perfusion, has not been directly addressed in the previous literature and may be an important factor in determining risk for carpal tunnel syndrome and related overuse injuries of the overhead wrist and hand.

Investigators have found good agreement between fingertip blood pressure monitors and invasive radial artery monitoring (Lingqvist 1995). Pulse oximetry, Doppler ultrasound and blood pressure cuff were found to correlate well with invasive radial artery monitoring and thus be reliable measuring devices of finger blood flow (Talke et al 1989). A spectrum of acute decreased blood flow to the hand resulting from overhead placement and awkward wrist position has not been identified previously. Mean long finger systolic and blood pressure decreases at least 50% upon overhead arm positions of 120 degrees shoulder abduction with a neutral wrist position and the shoulder in a position of scaption (Cook et al 2000). Thus, measuring acute digital artery blood pressure changes at the long finger during changes in overhead hand positions may depict a spectrum of hand and wrist blood flow and perfusion, as measured in the long finger. Common non-neutral wrist positions may add further variability to blood flow and perfusion to the wrist and hand.

Statement of Purpose

The purpose of this study is to test the effect of five different vertical hand locations relative to heart level and two different wrist positions on the acute long finger digital artery mean arterial pressure and pulse rate of the dominant right hand of healthy individuals. These data should provide an improved understanding of the acute response to elevating the human hand overhead and achieving end range wrist postures, its associated risk for decreased blood perfusion and nutrition to the tissues of the wrist and hand, and thus its associated risk for position-induced ischemia. An additional benefit would be a better understanding of the possible interaction for digital artery blood pressure (and thus perfusion) of the long finger observed between end-range wrist flexion and neutral wrist during hand-overhead positions. Finally, these data should provide an improved understanding of the human response to hand-overhead positions and a better basis for decreasing its likely detrimental effects.

Statement of Hypotheses

This study addresses the question: does raising the hand overhead decrease blood pressure in the long finger, and if so, is there any difference in the effect when the wrist is flexed? The first null hypothesis of this study is that no effect exists on long finger digital artery blood pressure and pulse rate when the hand is moved actively to five different vertical hand locations relative to the heart. The second null hypothesis is that there is no effect on long finger digital blood pressure and pulse rate when the hand is moved from neutral wrist position to the non-neutral wrist position of end range wrist flexion. Hand locations are defined as -40 cm, -20 cm, 0 cm, +20 cm, and +40 cm vertical distance from heart level. Heart level is defined as the anatomic location of the aorta, previously described as the location of the 4^{th} intercostal space (Webster et al 1984, Mitchell et al 1964). Neutral wrist position is defined as neutral wrist flexion-extension-radioulnar deviation (Magee 1992). End-range actively flexed wrist is defined as actively flexed to end of range while in neutral radioulnar deviation (Magee 1992). The position of the test arm during data collection is one of neutral pronosupination (Magee 1992) at the forearm, and of scaption (Magee 1992) at the shoulder. The position of the control arm during data collection is one of rest at the location of heart level. Systolic and diastolic blood pressures of the digital artery of the index finger for each subject will be compared to ipsilateral brachial artery pressures to establish validity of digital artery blood pressure measurement as compared to brachial artery blood pressures. Automatic oscillometric techniques will be used to measure all brachial and digital artery blood pressures. Pulse rates will be measured by chest-strap-to-wrist-monitor telemetry. This pulse rate value from a chest belt telemetry transmission unit and wristwatch monitor-receiving unit has the ability to measure pulse rates during submaximal activities such as hand placement overhead, and has a much lower measurement error ($\pm$1% compared to $\pm$5%) compared to oscillometric pulse rate values. All data values will be recorded manually on a data collection sheet. The two-tailed alpha level for all statistical tests will be predetermined at the 0.05 level of significance.

Significance of the Study

Musculoskeletal disorders (MSDs) of the wrist and hand are a frequent, disabling and expensive workplace injury with a need to better understand and prevent these disorders (NIOSH 1997). Epidemiological evidence exists that identifies the length of time spent working in hand-overhead positions as a significant predictor of carpal tunnel syndrome, an MSD, among construction workers (Farrell, 1998). Extreme wrist positions place increased loads on bony (Hara et al 1992) and soft tissue structures (Armstrong and Chaffin 1979, Szabo et al 1994) of the wrist which are translated to the hand, are believed to be associated with musculoskeletal disorders (Younghusband and Black 1963, Herberts et al 1981), and are often used to perform work in hand-overhead and below-head level positions (Armstrong 1983). The results of this study may lead to suggestions regarding the selection of optimum hand and wrist work positions as well as tool design, which would be directed at reducing the negative effects of performing tasks while assuming these overhead and end-range wrist work postures. This study may lead to additional research aimed at identifying exposure levels to these individual work postures. Establishing an acute blood pressure decrement spectrum during these wrist and hand positions would link ischemic conditions to MSDs and form the basis of a hand blood flow model. In addition, deriving an acute blood pressure spectrum and a hand blood pressure model may provide an important step toward identifying overhead work postures coupled with extreme wrist positions as combined risk factors for decreased tissue perfusion of the wrist and hand and resulting position-induced hand/wrist ischemia, and thus identified overhead and extreme joint posture as combined risk factors for MSDs of the wrist and hand.

Definition of Terms

Fourth intercostal space: Used to determine the level of the heart at its aorta, upon palpation of the center of the 4th space between the anterior ribs where the ribs lie lateral and adjacent to the sterno-costal junctions bilaterally at the anterior chest wall. Intercostal spaces are identified and assigned names based upon the rib number in the position just superior to the intercostal space, thus the 4th intercostal space is just below the 4th rib anteriorly.

Neutral wrist position: Defined as neutral wrist flexion-extension-radioulnar deviation during neutral forearm pronosupination (Magee 1992).

Mean blood pressure: Used to determine the average of all systolic or diastolic blood pressures of the artery of interest, at a given hand location or wrist position, taken across all subjects.

Subject blood pressure: Used to determine the average of all systolic or diastolic blood pressures of the artery of interest, at a given hand location, for that subject. Used to determine inter- and intra-subject variability and related intraclass correlation coefficients.

Mean pulse rate: Used to determine the average of all pulse rates at a given hand location or wrist position, taken across all subjects.

Mean Time in Position: Used to determine the average of all position times at a given hand location or wrist position, taken across all subjects.

Systolic blood pressure: The minimum pressure applied to the artery of interest that is required to stop blood flow. This represents an estimate of the strain against the arterial walls and the work of the heart as blood is ejected from the ventricles, at its highest force, during systole.

Systole: Period of time when the left ventricle contracts and ejects blood to the aorta, the contraction phase.

Diastolic blood pressure: The minimum pressure applied to the artery of interest, which provides resistance to blood flow. This represents an estimate of the peripheral resistance to blood flow, or the ease to which blood flows through the artery of interest, at its lowest force, during diastole.

Diastole: The relaxation phase of the cardiac cycle, between left ventricle contractions.

Mean Arterial Pressure: (MAP) the average pressure in the artery of interest during one complete cardiac cycle. MAP = 1/3(systolic - diastolic) + diastolic pressure, or the equivalent expression, MAP = 1/3(systolic + 2Xdiastolic) (Burton 1968, McArdle et al 1991). MAP is a measure of average blood pressure that contributes to blood flow from artery to arterioles into capillaries, as well as a direct measure of perfusion through semi-permeable membranes for oxygen and nutrient delivery to adjacent tissues.

CHAPTER 2
REVIEW OF LITERATURE

Introduction

The cost of health care is the topic of much focus and debate, with a general agreement that reducing costs while improving health is the ultimate goal. Toward this end, the traditional medical model of treating illness and injury after it occurs is now allowing room for the disablement model, which demands intervention to prevent injury and illness before it occurs (Anonymous, 1997). As a result, an emphasis on primary care and injury prevention has grown, with injury prevention efforts aimed at reducing financial costs and the costs of human suffering. Once risk factors for a specific injury are identified and quantified, prevention efforts can be put into practice with best chances for success. Prevention efforts focused at the workplace to improve health and safety may have application to tasks that are performed at home or other non-work settings as well.

Injuries to the wrist and hand among workers are common and difficult to diagnose and treat (Verdon 1996, Ferry et al 1998). Work-related musculoskeletal disorders (MSDs) of the upper extremity are associated with exposure to physical factors while performing work tasks on-the-job (NIOSH 1997). These MSDs include carpal tunnel syndrome (CTS) and hand-wrist tendonitis. For 1994, the U.S. Bureau of Labor Statistics reported the number of MSDs involving upper extremity repeated trauma exceeded 300,000 which represents a 14-fold increase from 1972 to 1994 and the highest level of any year prior to 1994 (NIOSH 1997). Annual cost estimates vary, between $13 billion from NIOSH data to $20 billion from American Federation of Labor-Congress of Industrial Organizations data (NIOSH 1997). More than 55,000 injuries to the wrist were reported for 1994 that were associated with repetitive motion, with a median time away from work of 18 days (NIOSH 1997). Estimated cost of compensable upper extremity MSDs for 1993 was $563 million or an average of $8,070 per case (Webster and Snook, 1994). Carpal tunnel syndrome (CTS) and overuse syndromes are included in MSDs and are among the most common work-related pathologies and are associated with extreme joint posture, repetition, prolonged constrained posture and mechanical vibration (Verdon 1996). Repetitive motion and force are shown to be risk factors common to both CTS and wrist tendonitis, with extreme wrist posture shown to be an additional risk factor for wrist tendonitis (NIOSH 1997). Extreme wrist posture is defined as the time spent in deviated wrist postures per work cycle (Kuorinka and Koskinen, 1979). Strong evidence exists to suggest a positive association between work requiring extreme wrist postures and wrist tendonitis when the risk factors of repetitive motion and force are combined with extreme wrist postures (NIOSH 1997). Workers commonly perform tasks in a variety of settings and upper extremity positions. These work settings include construction (carpenters, plumbers, electricians, sheet metal workers, painters) and agricultural workers (landscapers, farmers and lumberjacks) (Stromberg et al 1996, NIOSH 1997). Overhead hand positions and extreme joint postures are commonly used during task performance in these groups of workers (Stromberg et al 1996). In addition to MSDs, secondary Raynaud's phenomenon (associated with hand ischemia) is also among hand disorders most frequently seen in these groups (Verdon 1996). Interventions aimed at reducing the number of wrist and hand injuries provide a better understanding of how to prevent their occurrence (Cook et al 1999, Schneider et al 1995), and reveal some initial success at injury prevention (Schneider et al 1995). Identifying and verifying risk factors is an ongoing process, as the associations between risk factors and injury occurrence are studied.

In a study examining construction workers, workers with CTS symptoms and diagnostic electrophysiologic changes spent more time working with hands overhead than workers without CTS evidence (Farrell 1998). Subjects reporting overhead work exceeding two hours per day were three times more likely to have CTS symptoms and six times more likely to have electrophysiological changes than construction workers with less than two hours spent in overhead tasks (Farrell 1998). Construction workers likely assume extreme joint postures while performing overhead work. The effect of raising the human limb above the level of the heart has been shown to decrease blood pressure in that limb, and believed to decrease blood flow and tissue oxygenation to the elevated tissues

(Hill 1909, Kahn 1919, Wright 1945, Mitchell et al 1964, Ashton 1975, Webster et al 1984, Cook et al 2000). Time spent performing overhead tasks has not been reported in other epidemiological studies of MSDs and is not included in Bureau of Labor Statistics reports (NIOSH 1997). At present, the effect of overhead task performance combined with known risk factors for CTS and wrist tendonitis (NIOSH 1997) is unknown. Thus, overhead hand position as a risk factor, alone or combined with other risk factors, warrants further study.

Handgrip forces during chainsaw operation and incidence of vibration white finger in Finnish lumberjacks was investigated; chainsaw grip forces 12 % of maximum grip force were associated with the ischemic vascular component of this pathology (Farkkila et al 1979). Fatigue was excluded as a contributing factor due to the relatively low fractions of maximal grip forces used during chainsaw operation (Farkkila et al 1979). Prolonged static extreme positions were attributed to the ischemic vascular component (Farkkila et al 1979), with work performed above and below head level depending upon the specific task.

Anecdotal reports exist of numbness in the wrist and hand upon prolonged static arm elevation and extended or flexed wrists. Human subjects involved in overhead hand position for extended time periods (3-15 minutes) report numbness, tingling and pain in hands and fingers (Wright 1945). These symptoms have been reproduced artificially by shoulder placement in frontal and horizontal plane abduction with elbow flexion resulting in hand placement above heart level, producing radial pulse absence with presence of hand numbness and tingling (Wright 1945). These symptoms resolved upon returning the shoulders and arms to anatomic (neutral) position; ischemia of peripheral neurovascular structures was thought to cause these symptoms (Wright 1945). Inflating a blood pressure cuff placed around the brachium to obliterate blood flow from distal brachial artery for 18 minutes produced decreased nerve conduction velocities and action potentials in median nerve at the wrist (Fullerton 1963). Median nerve conduction velocities and action potentials were restored upon restoring tested-arm brachial artery blood flow, concluding neurological changes were caused by ischemic conditions (Fullerton 1963). Thus, hand ischemic components are suggested for overhead (Wright 1945), below head level (Farkkila et al 1979) and tourniquet-occluded hand conditions (Fullerton 1963).

Prolonged overhead arm positioning appears to be one condition associated with ischemic changes to the wrist and hand. Overhead hand positioning could then be associated with blood pressure drops, resulting decreased blood perfusion and blood volume, lack of blood-borne oxygen, tissue perfusion and tissue nutrition and resulting ischemic damage to wrist and hand tissues when demands for oxygen and nutrition increase during the performance of workplace tasks. Thus, overhead hand position during workplace task performance could predispose wrist and hand tissue to injury and increased risk for MSDs. Extreme wrist positions combined with overhead placement may further affect, or interact with, overhead position-induced ischemia to the wrist and hand.

Biomechanical Factors and Risk of MSDs

Extreme joint angles are recognized by investigators as associated with MSDs of the upper extremity, particularly at the wrist (Younghusband and Black 1963, Herberts et al 1981). In a study of industrial workers using descriptive analysis, investigators found that high-risk workers performed tasks with a generally higher mean magnitude of wrist motion parameters (wrist flexion-extension-radioulnar deviation-pronosupination) than did the low-risk group (Marras et al 1993). Velocity and acceleration parameters for the wrist exhibited significantly greater values for the high-risk group than the low-risk group (Marras et al 1993). Each group had equal numbers of men and women (50% each), and measured parameters consisted of wrist angle and its mean, maximum, minimum and range, as well as angular velocity and acceleration (Marras et al 1993). Risk was defined as high if data from Occupational Safety and Health Administration (OSHA) Form 200 logs showed an incident rate of greater than or equal to 18.4 reported claims and resulting 111.5 lost workdays, per 200,000 worker-hours of exposure. Low risk was defined as zero for both incident rate and lost workdays due to injury (Marras et al 1993). The authors concluded that wrist position and forces present during dynamic position changes are associated with the increased injury rate and severity (Marras et al 1993). A previous study showed wrist acceleration significantly increases the resultant reaction force on the tendons as they glide through the carpal tunnel (Schoenmarklin and Marras 1990). Mechanical modeling from excessive tendon forces could then result in tendon degeneration, inflammation (Armstrong 1983) and compression of the median nerve by these tendons (Marras et al 1993). Thus, a case can be made for reducing extremes of wrist posture and the forces present at the wrist tendons during workplace task performance.

Other investigators examined wrist motion of supermarket cashiers as they bagged groceries, and found larger items (10 cm hand couplings) required more extreme wrist flexion and greater range of radioulnar deviation and pronosupination than when handling smaller (5 cm hand couplings) (Estill and Kroemer 1998). Supermarkets rank among the industries with the highest number of MSDs (NIOSH 1997), with cashiers bagging groceries performing significantly more repetitive movements (mean difference = 62%) than in cashiers that did not bag groceries (Estill and Kroemer 1998). Finger-thumb grasp and 10 cm hand couplings require larger wrist deviations and greater velocities than 5 cm hand couplings, and thus pose a greater risk for MSDs of the wrist for the grocery bagger (Estill and Kroemer 1998). Thus, the risk factors of wrist extreme postures and high joint velocities are associated with the high number of wrist MSDs in this group of workers.

When comparing repetitive wrist flexion at three wrist flexion angles (10°, 28°, 45°) and three force levels (5N, 25N, 50N), subjective ratings of discomfort were positively correlated to force and wrist flexion angle (Lin and Radwin 1998). The validation of these subjective ratings to wrist flexion angle and force was consistent with findings from previous investigations of drilling tasks at specific wrist flexion angles (Kim and Fernandez 1993) and with grip postures (Snook et al 1995). These findings were confirmed by other investigators (Harber et al 1994, Franzblau et al 1997) using wrist flexion-extension, pinch grip versus power grip and task frequency with subjective measures of wrist stressors by questionnaire. The subjective questionnaire was found to have good test-retest reliability for subject self-rating discomfort and effort (Franzblau et al 1997), and appears to be a valid and useful tool in assessing job tasks at high risk for MSDs.

In a study comparing wrist posture to maximum acceptable frequencies of a drilling task, wrist postures of flexion, extension and radial deviation had a significant effect on drilling task frequency (Davis and Fernandez 1994). Maximum acceptable frequency of the drilling task was given for the neutral wrist position, with minimal acceptable frequency given for the wrist flexion position (Davis and Fernandez 1994). These findings are consistent with previous findings that extreme wrist postures are associated with discomfort and higher risk for MSDs.

In a survey of workers using visual display unit (VDU) for job tasks in a Hong Kong bank, investigators found 15% of workers reported hand and wrist discomfort with a significant association with repetitive movements (Yu and Wong 1996). The authors speculate that modification of workstation design may reduce the prevalence of hand and wrist discomfort and improve the health of these workers. No report of missed time from work or other indicators of impact on the worker or the workplace was mentioned.

In a study of wrist position to grip strength, investigators found a self-selected mean position of 35° extension and 7° of ulnar deviation for optimal strength without difference due to gender in 20 healthy subjects (O'Driscoll et al 1992). Moving out of this position significantly reduced grip strength, as measured by Jamar grip dynamometer, when controlling for fatigue by monitoring force decrement (O'Driscoll et al 1992). Thus, extreme wrist postures are associated with increased grip strength within this test group.

Investigators compared continuous handgrip to intermittent handgrip (10-second rest every three minutes) at 25% MVC (Byrstom et al 1981). Subjects performed intermittent gripping and constant hand gripping. Intermittent gripping showed a significantly longer mean endurance time, faster mean recovery time and with less subjective fatigue than the continuous gripping subjects (Bystrom et al 1991). Thus, initial findings suggested that micropauses were an effective means of avoiding overexertion. However, the mean frequency content of the EMG signal was reduced for a significantly longer time period for the intermittent grip compared to the continuous grip. Thus, the authors concluded a delayed recovery and a false sense of rest for the intermittent grip may predispose subjects to injury and MSDs (Bystrom et al 1991). When examining mean EMG frequency, intermittent repetitive gripping appears to be more strenuous than continuous gripping, with the authors conclusion that interventions are needed to decrease fatigue and excessive tissue loads with means other than micropauses. Test positions of the wrist were not described by Bystrom et al.

Investigators measured joint contact pressure with pressure sensors within the radio-ulnar-carpal joints of fresh frozen cadaver limbs and placed incremental loads up to 12 Kg, finding increased mean scapho-lunate forces by 75% and decreased by 50% when moving from radial deviation to ulnar deviation, respectively (Hara et al 1992). Lowest joint forces were present with neutral wrist positions (Hara et al 1992), consistent with previous findings of neutral wrist positions associated with lower forces at the wrist in live subjects (Lin and Radwin 1998, Harber et al 1994, Franzblau et al 1997, O'Driscoll et al 1992).

In the study of flexor tendon gliding through the carpal tunnel in the live human wrist, flexor digitorum superficialis (FDS), profundus (FDP) and flexor pollicus longus (FPL) excursion varied by wrist position (Wehbe and Hunter 1985). When combining wrist flexion–extension with finger flexion, amplitude of FPL increases by 30%, FDP by 56%, and FDS by 104% (Wehbe and Hunter 1985). During wrist flexion the excursion of the flexor tendons decreases, and increases with wrist extension (Wehbe and Hunter 1985). Thus, wrist position affects tendon gliding while the tendon is loaded.

In a study of cadaver carpal tunnel pressures during tendon loading, wrist position changes and tendon loading was shown to increase carpal tunnel pressure (CTP) and cause increased pressure on median nerve with potential for harm (Keir et al 1997). CTP increased to its highest level in wrist extension when no tendon load existed, and CTP was highest during wrist flexion greater than

20° and ulnar deviation greater than 20° under 1-Kg loaded tendon conditions (Keir et al 1997). To apply these findings to live human wrists will further support the avoidance of extreme wrist postures, as a means of protection of tendon and nerve tissue that is susceptible to damage during forceful exertions such as those performed in the workplace. Other investigators (O'Driscoll et al 1992) found optimum grip strength at a self-selected position of 35° wrist extension, which is a wrist position directly associated with increased CTP as found by Keir et al.

In another cadaver study, investigators identified a direct linear relationship ($r^2 = 0.992$) between flexor tendon displacement and median nerve displacement in the carpal tunnel during "active" wrist extension greater than 60° provided by a stepper motor and a 75-gram counter weight attached to the flexor tendons (Szabo et al 1994). This relationship was not affected by changes in wrist position between 0°-60° extension nor by transecting or ignoring the transverse carpal ligament (Szabo et al 1994). These findings suggest that median nerve excursion occurs normally in live human subjects, and that further irritation of the median nerve may occur with non-forceful finger flexion, even in an environment where the transverse carpal ligament has been surgically released.

In a biomechanical analysis of the wrist and flexor tendons, Armstrong and Chaffin (1979) reveal that, for a given hand force, greater tendon forces per unit length are produced in thumb-index finger grip than in gripping with the entire hand. In addition, extreme wrist postures during exertions of the hand would place greater force on the tendons and adjacent carpal bones than a neutral wrist position. Again, these results may be interpreted as a recommendation to avoid extreme wrist postures under a load, to reduce forces upon the tendons and the median nerve at the wrist.

Changes in Limb Position and Associated Changes in Systolic and Diastolic Pressure

Subject positioning and test arm location significantly affects the blood pressure readings taken at the brachial artery using indirect measurement techniques with sphygmomanometer and auscultation (Cushman et al 1990, Webster et al 1984, Mitchell et al 1964, Kahn 1919, Hill 1909). In an early study comparing arm (radial artery) and leg (posterior tibial artery) systolic blood pressures in supine and standing, arm pressures varied little while leg pressures increased in standing (Hill 1909). The change in systolic leg pressures while standing versus supine differed by a factor equal to the hydrostatic effect on a column of blood (Hill 1909). In a study comparing brachial blood pressures measured while seated in a chair to pressures taken while seated on an examination table without back support, the unsupported sitting showed no difference in systolic blood pressures (Cushman et al 1990). However, the diastolic pressures were significantly higher (6.5 mm Hg) in unsupported sitting than in supported sitting, regardless of whether the subjects were African-

American or white, or placed on hypertension medication or did not require medication (Cushman et al 1990). The authors did not state the position of the test arm. In another study, blood pressures measured at the brachial artery from 90 hypertensive patients with test arm at heart level while seated. These values were shown to be lower than values from measurements that were repeated with the subjects standing and arms placed in a (below heart level) dependent position along their sides (Webster et al 1984). These authors conclude that sitting blood pressure measurement positions are more amenable to their tested arm supported at heart level (such as a desk top), more accurately reflecting the true brachial artery blood pressure and not affected by hydrostatic pressure, and thus are an accurate indicator of disease (Webster et al 1984). Investigators have demonstrated a significant difference in brachial blood pressure when comparing measurements by sphygmomanometer and auscultation techniques that are dependent upon the position of the subject's measurement arm relative to their heart (Mitchell et al 1964). These investigators used three arm positions relative to each subject's heart (from superior to inferior along the body); (Cushman 1990) the sternomanubrial junction (above heart level), (Webster et al 1984) the 4th intercostal space at the sternum (heart level), and (Mitchell et al 1964) the xiphosternal junction (below heart level). These investigators found a significant mean difference between systolic values at these three arm levels and diastolic values at these three arm levels, across normotensive (<140/90), borderline (140/90 to 150/100) and hypertensive (>150/100) individuals in the sample group (Mitchell et al 1964). In the study of brachial blood pressures measured by sphygmomanometer and auscultation techniques at 0°, 45°, 90°, 135° and 180° frontal plane abduction while standing, results reveal that a steady blood pressure decline proportional to arm elevation which they attributed to combined hydrostatic and vasomotor effects (Kahn 1919). This blood pressure decline is more marked in subjects with disease states than in healthy subjects (Kahn 1919). Thus, limb position relative to the heart directly affects both systolic and diastolic blood pressure values as measured indirectly using sphygmomanometer and auscultation techniques. In addition, these observed blood pressure values are not statistically different from those predicted from the standard formula for calculating hydrostatic pressure in a column of blood (*vertical distance of limb above heart, in cm*) X (*one mm Hg per 1.3 cm of blood*) (Matsen et al 1979) (Webster et al 1984, Mitchell et al 1964, Kahn 1919, Hill 1909). Arm position may predispose false-negative (arm placement too high and thus blood pressure readings artificially low) or false-positive diagnosis (arm placement too low and thus blood pressure readings artificially too high) and thus adversely affect the diagnosis and treatment of hypertension states. In the early study of systolic pressures in supine and standing radial and posterior tibial artery (Hill 1909), the author did not state the specific placement of the measured arm. Positioning of the tested arm at the level of the subject's heart in both standing and supine would be consistent with an absence of change in systolic readings at the arm between standing and supine. Of the three test positions described (Mitchell et al 1964), the heart position was found to be the optimum position for brachial artery blood pressure measurement, and was defined as the position of the 4^{th} intercostal space at the sternum (Webster et al 1984, Mitchell et al 1964). Other human studies of blood pressure characteristics specifically state this definition of heart location as well (Kirchoff et al 1984, Winsor and Burch 1945).

Ischemia and Muscle Performance

Several authors report a decrease in human muscle performance during various artificially induced ischemic conditions of muscle contraction (Babcock et al 1995, Bendahan et al 1998, Fulco et al 1996, Pitcher and Miles 1997). In study of human diaphragm muscle fatigue, both hypoxic (15% oxygen) and normoxic (21%) environments were introduced by breathing hypoxic gas during intense aerobic treadmill or stationary bicycle exercise (Babcock et al 1995). Specifically, decreased peak tension, increased contraction time, and increased one-half relaxation time were found upon analysis of electromyographic (EMG) activity. These findings persisted much longer in subjects in hypoxic conditions (90 minutes) than in subjects in normoxic conditions (60 minutes).

Muscle functions less efficiently when using insufficient oxygen. Investigators used simultaneous radioisotope phosphorus labeling with surface EMG recordings to monitor EMG frequency and metabolic activity during submaximal (60% of maximal) voluntary contraction of flexor forearm muscle

(Bendahan et al 1998). Myoelectric and metabolic activity were compared during normal aerobic (21%) and hypoxic (12%) conditions, with less high frequency EMG activity in hypoxic muscle than in aerobic upper extremity muscle (Bendahan et al 1998). Radioisotope phosphorous labeling showed metabolic activity to be greater under hypoxic conditions for a given change in EMG signal. Hypoxic conditions greatly slowed the rate of change in integrated surface EMG activity. Myoelectric activity shifted from high frequency to low frequency towards the end of each bout of sustained isometric contractions, consistent with the presence of a high frequency fatigue characteristic. Their findings suggest during periods of hypoxia that adaptive mechanisms exist to improve excitation-contraction coupling, increase energy consumption for a given amount of electrical activity and shift from activation of fast anaerobic muscle fibers toward slow aerobic muscle fibers (Bendahan et al 1997). Thus, energy consumption increases and slow muscle activity predominates for hypoxic muscle.

Tourniquet-induced muscle ischemia recovers more slowly from fatigue than normoxic muscle. The ratio of interpolated muscle twitch to gastrocnemius muscle force has been shown to remain unchanged after normoxic evoked and voluntary muscle contractions to fatigue; this ratio increased for ischemic muscle during comparison of normoxic and ischemic leg recovery from fatigue using inflated tourniquet (Behm and St-Pierre 1997). This translates into greater inactivation of ischemic post-fatigue gastrocnemius muscle compared to non-ischemic post-fatigue gastrocnemius (Behm and St- Pierre 1997), which demonstrates the impairment of lower extremity muscle recovery in a normoxic exercise-ischemic recovery environment.

When exercising by isometric hand-grip with and without occluded blood flow by sphygmomanometer cuff to induce ischemia, peak force was similar in both groups but fell rapidly with minimal recovery delay in the ischemic group (Pitcher and Miles 1997). Investigators concluded the fall in muscle force output was due less to fast muscle depleting energy stores and due more to slow muscle depleting oxygen supplies. In their view, hypoxia is less likely to occur during intermittent than during sustained muscle contraction. Thus, sustained maximum voluntary contractions are hypoxic events and are unsuitable for submaximal fatigue study (Pitcher and Miles 1997). Ischemia due to intermittent muscle contractions during arm elevation, as in overhead work, was not included in this study. Thus, oxygen-starved muscle performance is diminished but overhead work positions are not considered.

In contrast, one author reports an isometric strength increase under ischemic tourniquet conditions, suggesting benefit from exercise in an ischemic environment (Short Communication, Shinohara et al 1998). These findings contradict the above observed decreased muscle performance associated with ischemic human muscle (Bendahan et al 1998, Behm and St-Pierre 1997, Fulco et al 1996). While the results are noteworthy, the observed isometric leg strength increases may be explained by the phenomenon of contralateral limb cross-training rather than induced ischemia. Cross-training effects (Mathews et al

1956, Komi et al 1978, Moritani and de Vries 1979) from non-ischemic to ischemic leg would likely predominate over any cross-training effects from reverse direction. Venous pooling in ischemic leg during tourniquet use may act as a sensory stimulant during isometric contractions, further enhancing strength testing and isometric force production in the ischemic leg.

With one exception in citations listed above, ischemia from various sources contributes to muscle function impairment. The limb studied was placed in a below-the-heart or in a level-with-the heart position in all cases. If investigated, overhead arm positions may reveal previously unknown ischemic conditions that are associated with impaired muscle performance as well as MSDs for the wrist and hand.

Mechanics of Distal Limb Tissue Perfusion As It Relates To Blood Pressure and Muscle Performance

Successful blood flow and tissue perfusion to the tissues of the hand requires greater inside-vessel pressure than surrounding tissue. The difference between intravascular pressure and adjacent tissue pressure is defined as transmural pressure and is a key factor in maintaining patent human finger and toe capillaries (Ashton 1975). The relationship between blood flow and transmural pressure is positive and linear at moderate and high transmural pressures, allowing blood flow from proximal to distal-most tissues. When intravascular pressure drops too low (or tissue pressure increases, as in edema), a point is reached where vessel wall collapses and vessel blood flow ceases (Ashton 1975). In 1952, Gaskell and Burton demonstrated that raising a limb above heart level would lower transmural pressure (by decreasing hydrostatic pressure of the blood) until blood flow to fingers and toes ceased; these findings were similar to results obtained by raising tissue pressures, and were confirmed by other investigators (Ashton 1975). Anterior compartment pressures were studied to assess the risk of decreased tissue oxygenation while an Air-splint-type external leg compression device was applied, in both supine and leg-elevated positions (Matsen et al 1979). The leg-elevated group showed less tibialis anterior oxygenation than supine group, tolerating less external compression to maintain the same tissue oxygenation. The difference in external compression was considered analogous to difference in blood pressure due to this increased external compression, and was almost entirely explained by the calculated drop in hydrostatic pressure of the blood upon raising the leg above heart level (Matsen 1979). The conversion factor for hydrostatic column is (*vertical distance of limb above heart, in cm*) X (*one mm Hg per 1.3 cm of blood*) (Matsen et al 1979). Measuring vertical limb height above heart level can predict that limb's blood pressure, in the absence of confounding variables (Matsen et al 1979). The risk of decreased oxygenation was then compounded by limb elevation with external compression applied. These findings from the leg can be applied to the arm, and studies of the arm and hand logically follow these for the leg. Thus, investigating this topic for arm and hand would quantify decreased blood pressure and thus blood flow and the resulting lack of tissue oxygenation due to overhead positioning.

Optimal muscle performance can be measured by endurance and strength and is dependent upon sufficient muscle blood flow in an aerobic environment. Comparing repetitive and sustained grasp performance in elite male rock climbers and in sedentary individuals, rock climbers showed greater endurance, equal peak grip strength, lower peak blood pressures and greater forearm pooling effect than sedentary subjects, suggesting an adaptive response to training in males (Ferguson and Brown 1997). Another study of rock climbers found both handgrip strength and endurance decreases with sustained difficult rock climbing, strength recovering more quickly than endurance (Watts et al 1996), both remaining depressed after a 20-minute rest recovery time. During isometric muscle contraction, mechanical compression of the vessels can impede blood flow despite metabolite-induced vasodilatation (Kagaya and Homma, 1997). In comparing forearm blood flow at differing isometric exercise intensities in females (10, 30, 50, 70 % of maximum voluntary contraction), brachial artery flow was measured using Doppler techniques and found to be maintained by increased heart rate and blood pressure during exercise (Kagaya and Homma 1997). These subjects were tested in supine position and arm position was not described. In the study of handgrip force and forearm blood flow as related to age, investigators found no significant difference in peak handgrip workload and forearm blood flow with well-preserved vasodilatation responses when comparing ages of males 19-74 years (Jasperse et al 1994). Tested arm placement was described as slightly above heart level, to allow for venous return and avoid ameliorating the pooling of blood in the test arm during measurement of forearm vascular conductance (Jasperse et al 1994). Gravitational effects on elevated limb likely impaired arterial blood flow in the tested arm and may have aided pooling in the opposite limb. In addition, resting arm and leg vascular response during supine sustained three-minute isometric handgrip at 30% of maximum was studied; arm vasodilatation and leg vasoconstriction were found with increased EMG activity in the resting arm attributed to both vasomotor and contralateral effects (Jacobsen et al 1994). Blood flow to the forearm was measured in a dependent position using venous occlusion plethysmography at the wrist using six minutes of sustained isometric handgrip at 10% maximum voluntary contraction (MVC) and found to increase blood flow two-fold (Williams and Lind, 1979) even in the absence of occlusion. These investigators found no change in forearm blood flow during intermittent isometric handgrip regardless of occlusion plethysmography or non-occlusive plethysmography at the wrist (four subjects using 20% and two subjects using 60% MVC, 2-seconds contracted 10-seconds relaxed) (Williams and Lind, 1979). Conversely, other investigators have found local vessels had occluded blood flow at 60% MVC (Humphreys and Lind 1963, Lind and Williams 1979). Thus, vasomotor changes and resulting blood flow increases and decreases can occur during sustained muscle contractions without accounting for gravitational effects on the limb. Intermittent or low-intensity static muscle contractions may contribute to both arm blood pooling and restricted blood flow to the arm in certain conditions. Overhead arm positions could then compound vasomotor decreases during arm blood flow and magnify overhead hand ischemic conditions.

Common Indirect Blood Pressure Measurement—The Riva Rocci Method

Accurate and reliable indirect measurement of human blood pressure is dependent on many factors, including properly functioning equipment, appropriate-sized air bladders and cuffs, adequate deflation rate, adequate pressure on the stethoscope, avoiding terminal digit bias and resulting inappropriate round off (Padfield et al 1990), and hearing impairments (Ellestad 1989). The most common method of indirect blood pressure measurement is the Riva Rocci technique (Hill 1909, Kahn 1919, Mitchell et al 1964, Curb et al 1983, Webster et al 1984, Ellestad 1989, Padfield et al 1990, Cushman et al 1990, Perloff et al 1993, Nolan and Nolan 1993, Dieterle et al 1998,). However, this method has opportunity for error due to reliance on interpretation of arterial refilling sounds and on the quality of hearing of the tester as well as the factors mentioned above. In this method, the brachial artery is occluded with an air bladder, the pressure inside the bladder is measured with a mercury manometer, the bladder slowly deflates and auscultation of the artery is performed as blood flow returns (Ellestad 1989). The first and fifth Korotkoff sounds define the frequency and intensity changes that occur during arterial refilling, and represent systolic and diastolic pressure, respectively (Ellestad 1989). The majority of the first Korotkoff sound occurs below a frequency of 20 Hertz and the fifth Korotkoff sound at 5-50 Hertz range, can be difficult to distinguish audibly from second and third Korotkoff sounds, and depends upon amplification from a stethoscope that can be variable (Ellestad 1989). The lowest frequency an ideal human ear can distinguish is approximately 16 Hertz, with optimum hearing occurring between 200 and 4,000Hertz, thus introducing a potential source of error in establishing systolic and diastolic pressure (Wickens et al 1997) unless clinically well-trained in the auscultation technique (Curb et al 1983, Nolan and Nolan 1993, McKay et al, 1992).

Various factors associated with variability in using the Riva Rocci blood pressure method involve the status of the patient that is monitored. Ingested caffeine (Myers and Reeves 1991, Campbell 1990), eating food, using tobacco, exposure to cold and strenuous exercise within 30 minutes of measurement will increase systolic and diastolic values (Campbell et al 1990). Voiding bowel and bladder prior to measurement, wearing loose clothing or absent sleeves and resting at least five minutes in a quiet room also reduce variability in systolic and diastolic blood pressure measurement, as these factors tend to elevate blood pressure levels as well (Campbell et al 1990). Supporting the tested arm to avoid isometric contraction is also recommended, since isometrics may increase systolic pressures as much as 10% (Campbell et al 1990). Investigators assessed home blood pressure readings and found them to be stable over a 4-week period and significantly lower than readings taken in a hospital clinic, in subjects with mild hypertension (Padfield et al 1990). Their findings included the identification of diurnal variation and the periods of greatest variability in blood pressure; greatest variability was found between midnight and noon, with the least variability during the afternoon and evening hours, from 1 pm to 11 pm (Padfield et al 1990).

Significant increases in systolic and diastolic pressures were shown in both normotensive and hypertensive subjects during periods when the subjects were talking, and reduced to baseline when the subject ceased talking (Lynch et al 1981). Increases were significantly larger for hypertensive subjects when compared to normotensive subjects (Lynch et al 1981). Other investigators confirm these findings (Thomas et al 1984, Hellmen and Grim, 1984) and include significant elevation in heart rate as well.

Thus, adequate training in auscultation and sphygmomanometry as well as strict attention to detail renders the Riva Rocci a reliable method for clinical measurement of brachial artery blood pressure, and comparison with other blood pressure measurement techniques.

Comparison of Direct Arterial Blood Pressure Measurement to Direct Aortic Measurement

When comparing direct blood pressure measurements from the aorta to direct measurements at the brachial and radial artery with test limb placed at heart level, the brachial artery registered 109% (systolic) and 96% (diastolic) of the aorta, while the radial artery registered 112% (systolic) and 93% (diastolic) with no significant difference in all mean values when subjects were tilted to 70° (Kroeker and Wood, 1955). Similar findings were achieved in comparisons of aortic and radial pressures at rest, with differences between aortic and radial artery pressures during strenuous treadmill exercise only (Rowell et al 1968). Thus, direct brachial and radial artery measurement of blood pressure correlates with measurements taken directly by cannula at the aorta, with limb placement at heart level and in the absence of confounding variables and exercise.

Comparison of Indirect (Riva Rocci) Arterial Blood Pressure Measurement to Direct Arterial Values

In comparison of indirect laser technique to direct cannula arterial measurement of blood pressure in the central ear artery of rabbit, no significant difference was found between methods (Herrold et al 1992). Indirect human blood pressure measurement values are validated by direct blood pressure measurement, comparing brachial artery pressures by Riva Rocci to radial artery pressures with intr-artertial catheter in 355 observations from 30 post-operative patients (Asiain et al 1990). Simultaneous brachial artery measurements were taken, one using cannula in the left brachial artery and the other using indirect auscultation (Riva Rocci) methods over the right brachial artery. Results showed a mean difference in indirect systolic pressures of 5.65 mm Hg if direct pressures ranged from 75-100 mm Hg, and 9.76 mm Hg if direct pressures ranged from 101-135 mm Hg. A mean difference in indirect systolic pressures of 18.27 mm Hg was found if direct pressures ranged from 136-200 mm Hg; mean direct measurements were higher than mean indirect measurements in all cases (Asiain et all 1990). The authors concluded that sufficient agreement existed between the two methods for appropriate clinical decision-making; clinicians would be required to use direct intra-arterial methods of blood pressure measurement if patient status became critical (Asiain et all 1990).

When compared to brachial arterial pressures, fingertip blood pressure monitors correlated well during aerobic cycle ergometry until end-stage exercise, upon finger vasodilatation response to overheating and at exercise levels >40 % of maximum exertion when low systolic readings occurred (Nijboer et al 1988). Another investigator found fingertip blood pressure monitors to correlate well with invasive brachial artery monitoring during cycle ergometry, until maximum exercise intensity was reached (Idema et al 1989). When compared to American Heart Association guidelines for diagnosis of hypertension, fingertip blood pressure monitors were found to give false positives (Iyriboz 1990) and were not recommended in diagnosis. Limb position was not reported. Strict attention to hand positioning at the subject's heart level during data collection was not discussed, and may be a source of variability in values recorded from a fingertip blood pressure monitor. Another investigator found good agreement between fingertip blood pressure monitors and invasive radial artery blood pressure monitoring (Lingqvist 1995). Pulse oximetry at the index fingertip was compared with invasive radial artery blood pressure monitoring, Doppler ultrasound and brachial artery blood pressure cuff, with pulse rates and blood pressure values found to correlate well with all (r=0.88, 0.996, 0.958 respectively) (Talke et al 1989). Comparison of direct radial artery blood pressure values by cannula with indirect blood pressure values at the index finger using photoplethysmography was conducted (Van Egmond et al 1985). This comparison revealed strong correlation between methods for systolic (r=0.99 to r=0.89), diastolic (r=0.99 to r=0.70) and mean arterial pressure (r=0.99 to r=0.86) (Van Egmond et al 1985). Other investigators using the same method of indirect measurement achieved similar findings (Parati et al 1989, Imholz et al 1990).

Comparison of Oscillometric Blood Pressure Devices With Intra-Arterial and Riva Rocci Methods

Oscillometric blood pressure methods use a measurement technique that differs from Riva Rocci (auscultation) or direct arterial (intra-arterial pressure transducer) methods. The oscillometric technique uses a semi-conductor pressure transducer, which detects the pulsations upon arterial filling, and uses an average of the beat-to-beat difference of two successive beats (Bridges and Middleton 1997, Henneman and Henneman 1987). The point at which pulsations are first detected and averaged is designated as systolic pressure, and where pulsations cease is designated as diastolic pressure, with digital representation of the signal (Bridges and Middleton 1997, Henneman and Henneman 1987). Limitations in the use of oscillometric devices include external shock or vibration, rapidly changing pressure (10-50 mm Hg within 4-5 seconds) or extremely low flow rates (shock or low pulse pressure) (Bridges and Middleton 1997). Sources of variability for oscillometric methods are otherwise similar to Riva Rocci techniques (Bridges and Middleton 1997, Henneman and Henneman 1987), with limb placement at heart level appearing to be a critical element in reducing variability.

In a comparison of direct brachial artery measurement with two different oscillometric devices and Riva Rocci methods at the opposite arm brachial artery, investigators found no significant differences between intra-arterial and

Riva Rocci nor between intra-arterial and oscillometric methods with 58 hypertensive subjects at rest (White et al 1990). Five measurements were taken with each device with subjects in seated position and five taken while in supine, group means were used, with stated emphasis in the text by the authors that "...great care..." was taken to ensure both arms were positioned at heart level throughout the test (White et al 1990). Systolic values (mm Hg) for Riva Rocci and oscillometric methods (intra-arterial in parentheses) were 142 +12 (146+14) and 142+12 (144+12), respectfully (White et al 1990). Similar agreement was found for diastolic values as well, with no significant additional variability added when introducing isometric or stationary cycle exercise compared to intra-arterial measurement (White et al 1990). In a comparison of Riva Rocci and oscillometric methods at the brachial artery of 52 adult subjects with non-insulin dependent diabetes mellitus, investigators found a close correlation between these two methods (r=0.94 systolic, r=0.84 diastolic) (Raptis et al 1997). These findings of agreement between Riva Rocci and oscillometric blood pressure measurement methods are consistent with the results of other investigators (Rutten et al 1986, Johnson et al 1985, Venus et al 1985, Nystrom et al 1985, Loubster 1985).

Oscillometric techniques are accurate and reliable in clinical situations measuring blood pressure including ectopy, respiration-induced variations in blood pressure, severe vasoconstriction and shock (Bridges and Middleton 1997, Henneman and Henneman 1987). In a comparison of supine long finger digital artery blood pressure in construction workers, Intraclass Correlation Coefficients

(ICC) for long finger digital artery oscillometric measurements range from 0.73-0.89 (Farrell 1998). Good reliability is defined as ICC values between 0.75 and 0.90, depending upon the variable of interest and criticality of measurement (Portney and Watkins, 1993). The two monitors used were the Marshall F-89 Automatic Electronic Digital Blood Pressure and Pulse Monitor, and the Omron HEM-705CP Automatic Blood Pressure Monitor (Farrell 1998), and these same monitors will be used in this proposed study as well.

Thus, indirect (photoplethysmography) blood pressure measurement at the index finger correlates well with direct (invasive) techniques at the nearby radial artery. Direct arterial pressure measurements at the radial artery correlate well with values obtained by direct measurement. Fingertip digital artery blood pressure monitors correlate well with both invasive and non-invasive brachial and radial artery devices at submaximal exercise levels. Oscillometric brachial artery devices compare well with brachial artery Riva Rocci methods, and compare well with oscillometric digital artery measurements at the finger. Fingertip oscillometric monitors would then be expected to appropriately measure blood pressure during hand elevation and wrist flexion at low levels of physical exertion in healthy adult subjects, with increased variability likely in the presence of hypertension.

Risk Factors Associated with Radial Artery Catheterization

While direct intra-arterial blood pressure measurement is considered the most accurate measure of blood pressure in the artery of interest, this method requires invasive catheterization. Catheterization of the radial artery during direct arterial blood pressure measurement is associated with risks to the subject, such as radial artery thrombus, arterial occlusion, emboli and ischemia (Larson 1973, Bedford and Wollman 1973, Sanchez-Garcia et al 1997). The most commonly reported complication of long-term arterial catheterization is ischemia (Samaan 1971). The additional risk factor of infection was not addressed in these studies. Thus, indirect blood pressure measurement avoids complications associated with arterial catheterization and correlated well with invasive measurement.

A single citation in the literature directly associates ischemia with CTS. Sanchez-Garcia (1997) observed a patient who had undergone radial artery cannalization while hospitalized for coronary bypass surgery; radial artery thrombus and resulting hand ischemia developed and electrophysiological signs indicative of CTS followed. Thrombolysis treatment ensued, radial artery blood flow to the hand was restored at the wrist, and both subjective and objective CTS symptoms resolved afterward. Further evidence of ischemic events near the wrist may provide a link between ischemia and CTS, to warrant further study of this ischemia-CTS phenomenon and a possible link with workplace MSDs.

Summary

MSDs of the wrist and hand include CTS and wrist tendonitis with associated inflammation to nearby structures. Ischemic hand trauma is shown for both overhead and below head level positions. Two or more hours per day of overhead construction work is associated with subjective and objective CTS evidence. Prolonged leg elevation is associated with blood pressure drops, lack of blood-borne oxygenation and imminent muscle ischemic damage with direct application to upper limb elevation as well. Oxygen-starved muscle performance is diminished but common overhead arm work positions were not considered. Digital artery finger blood pressure monitors correlate well with standard measurement methods and allow such study of hand blood flow during overhead activities. Extreme wrist postures place excessive loads on the bony and soft tissues of the wrist and hand, which may interact with diminished blood flow to the hand during overhead tasks. This study investigated overhead hand positions and wrist positions to reveal and quantify previously unknown ischemic conditions that may contribute to MSDs. Future investigators will then be prepared to study overhead hand position as a risk factor for MSDs.

CHAPTER 3
METHODS

Introduction

This chapter describes the subject population sampled and the instrumentation used in this study. In addition, an outline of the method of testing, test protocol, data collection and statistical procedures are included.

Subjects

Twenty subjects volunteered for sampling, according to statistical power of 0.90 calculated from pilot data. The formula $\phi = z_{\alpha/2} + (\mu_1 - \mu_2)\,(n)^{1/2}/\sigma$ was used, with:

$$\phi(x) = -1.96 + 6(20)^{1/2}/(37.4458)^{1/2} = \phi(2.42) = 0.90 \text{ (Rosner 1995).}$$

Subjects consisted of healthy volunteers. Each subject had no previous occupational experience or hobbies performing overhead tasks. A previous investigator cited greater than two hours per day of overhead tasks performance is associated with significant increases in prevalence of CTS (Farrell 1998). In addition, previous authors have found a muscle training effect on blood pressure to the upper extremity (Ferguson and Brown 1997). Thus, subjects having previous or current experience performing overhead tasks may be predisposed to changes in blood pressure that would introduce unwanted variability, and were excluded from study. No such subjects were identified, so none were excluded from participation.

Only right-hand dominant subjects were used, with the dominant limb as the test limb, and the non-dominant limb as the control limb. Tobacco and blood pressure medication users were excluded from participation. No such subjects were identified, so none were excluded. To avoid increasing blood pressure variability prior to testing, each subject restricted food and caffeine intake to at least thirty minutes prior to data collection (Myers and Reeves 1991, Campbell 1990), and emptied their bowel and bladder at least 15 minutes prior to testing (Campbell et al 1990). Testing of each subject required approximately 100-120 minutes. Before initiating this study, the human subjects review committee approved all procedures and informed consent was obtained from each subject. All subjects were free to discontinue participation at any time. Remuneration of $5.00 was provided to each subject upon test completion. Test subjects' group anthropometric data of age, height, and weight is included and listed with mean, maximum and minimum values (Table 4.0.1).

Instrumentation and Equipment

The following is a description of the instrumentation used in the testing procedure. Systolic and diastolic brachial artery and digital artery blood pressures were measured using an automatic oscillometric device that displays units of millimeters of mercury (mm Hg) in digital form (Figure 3.2). Specifically, the brachial pressures were measured at each upper arm by using automatic blood pressure monitor Omron® model HEM-705CP, manufactured by Omron Healthcare Incorporated, Vernon Hills, IL. Specifications: measurement range systolic and diastolic pressure 0-280 mm Hg, measured accuracy-pressure $\pm$3 mm Hg or 2% of reading. Digital artery pressures were measured at the long finger of each hand, using Omron Marshall® F-89 automatic digital blood pressure and pulse monitor. Specifications: measurement range systolic and diastolic pressure 0-280 mm Hg; measured accuracy-pressure $\pm$3 mm Hg or 2% of reading (also manufactured by Omron Healthcare Incorporated), resolution 1 mm Hg. Mean arterial pressure (MAP) was calculated from systolic and diastolic pressure values using the following formula: MAP = 1/3(systolic - diastolic) + diastolic pressure, or the equivalent expression, MAP = 1/3(systolic + 2Xdiastolic) (Burton 1968, McArdle et al 1991). A spring scale (Pelouze® Postal Scale, Healthometer, Inc., Bridgeview, IL) maintained a consistent force target for the wrist, upon end range wrist flexion. Pelouze® Postal Scale has a measured accuracy and linearity of 2.1% full scale (0-454 grams range), with repeatability and hysteresis of 1.7% full scale, and resolution of 7.0 grams. A radiotelemetry heart rate monitor with wristwatch digital display (Polar® Electro Inc., Woodbury, NY) displayed heart rate data and allowed comparison of blood pressure data to this pulse rate reference standard. This Polar® radiotelemetry monitor has a measured accuracy of 2% full scale (1-200 bpm range) and resolution of 1 bpm. A standard wrist-hand goniometer manufactured by Sammons Incorporated

(Chicago, IL) was used to measure end range wrist flexion, with a measured accuracy of 3% full scale (0-180°), repeatability of 3% and resolution of 2.5°. A standard cloth measuring tape manufactured by Sammons Inc. (Chicago, IL) was used for limb length and vertical distance measurements with a resolution of 1 mm. Limb lengths were defined by previous authors (Winter 1990) as upper arm measured from lateral acromion process to lateral epicondyle; lower arm measured from lateral epicondyle to ulnar styloid process; hand from wrist joint center at ulnar styloid to distal tip of 3rd metacarpophalangeal joint. Black electrician's tape was placed on the skin overlying medial ulnar border and ulnar hand surface. In addition to electrician's tape, goniometer placement upon a rectangular mirror provided a consistent wrist-positioning target for the subject and investigator to visualize, upon achieving end range wrist flexion test positions. An adjustable chair manufactured by Dauphin North America (Seacaucus, NJ) maintained consistent subject positioning with limbs at heart level during base line readings of brachial and finger blood pressures. An adjustable over-bed hospital table manufactured by Borg-Warner (Chicago, IL) maintained resting left arm and hand position at the subject's heart level. I used a self-made vertical 80-centimeter adjustable height measuring rod and marked 20-centimeter increments, to identify hand position relative to heart level (Figure 3.3). A digital stopwatch manufactured by Casio, Ltd (Tokyo, Japan) was used for measuring time of hand position at each location. Measurement range: 0.00 seconds to 24 hours; accuracy $\pm$0.01 seconds, $\pm$3 seconds protocol

Research Design

This study used a 2 x 5 two-factor fixed effects repeated measures design, with random effects assigned to between-subject variation. In addition, baseline sampling was performed during pretest and posttest periods, to examine measurement repeatability. Correlation between same-limb brachial artery and digital artery pressures was examined while the subject was resting and seated with their upper limbs resting at heart level, during pre-test and post-test sampling. Five values each of sequential brachial artery and digital artery blood pressure values for each upper limb were recorded. The high and low values were discarded to reduce variation in the sample due to sampling frequency, and the middle three values retained and studied. The two independent variables (wrist position, hand position) have ten combinations, with two different wrist positions (neutral wrist and flexed wrist) and five different hand positions relative to the vertical level of the subject's heart: (-40 cm, -20 cm, 0 cm, +20 cm, +40 cm) (Figure 3.1). The dependent variables of finger systolic and diastolic blood pressure, heart rate and time elapsed in each hand position were measured at each of the different combinations of independent variables. Mean arterial pressure values were calculated from these systolic and diastolic values for each subject. All measurements were repeated for each subject, for two measurements at each test position. Each subject completed a total of 10 test positions with two repetitions at each test position (20 data points). A calibrated spring scale recorded the force that the subject produced at end range wrist flexion. Force recordings provided a force target of 0.98 N. This target force is of sufficiently low proportion of maximum voluntary contraction of the wrist flexors as to avoid any measurable affect upon upper limb blood flow (Williams and Lind 1979, Humphreys and Lind 1963).

Procedure and Test Protocol

Each subject's name, age, height, weight, and right upper limb segment lengths were recorded prior to testing. Subjects were screened for present tobacco history as well as history of upper extremity pathology and blood pathology prior to scheduling. No subjects met the exclusion criteria, thus none were excluded from participation. Each subject refrained from exercising aerobically at least 24 hours prior to testing, at least 30 minutes prior to testing refrained from eating food, from ingesting caffeine, and emptied their bowel and bladder at least once at least 15 minutes before testing begins (Myers and Reeves 1991, Campbell 1990). If a subject suffered from an illness or menses, the potential effects of their condition on blood pressure would have been discussed with them, and they would have been rescheduled for a day after which the condition has subsided. No subjects fit this category during data collection. Each subject wore a sleeveless or loose-fitting shirt and removed any wristwatches, rings on the long finger, and other jewelry or articles of clothing that could possibly restrict blood flow to the hand during testing. All testing occurred in a restful private setting without visual or auditory distractions

(Campbell et al 1990), in the afternoon hours (Padfield et al 1990). Talking of the subject and investigator were kept to a minimum once data collection began (Lynch et al 1981). Periodic and barely audible white noise from heating/ventilation fans were the only audible background sound during testing. A comfortable and consistent range of room temperature of 68-78 °F and one atmosphere pressure was maintained throughout testing, and a combination of natural and fluorescent lighting was used. Subjects remained seated during pre-test and post-test baseline sampling as well as when performing dominant hand/wrist test positions.

The Pretest and Post-test Protocol

The pre-test and post-test portion of subject sampling involved bilateral brachial and digital artery systolic and diastolic oscillometric blood pressure measurement (in units of millimeters of mercury, mmHg) and pulse measurement (beats per minute, bpm). This seated portion occurred prior to testing and after test completion, and consisted of three seated resting blood pressure measurements taken alternately from each upper limb, as described above. All values were recorded, the highest and lowest pressure values ignored and the middle three values retained and studied. The limbs were positioned at the level of the aorta with the elbows comfortably flexed, upper limbs relaxed and resting on an adjustable-height table (Figure 3.4). For all aspects of subject testing, aorta position was defined as the position of the 4th intercostal space and was determined by the investigator upon palpation along the subject's bilateral sterno-costal borders. Resting the subject's arms and hands on the adjustable table while seated provided limb support at a level consistent with the position of the aorta while seated during this baseline portion of testing. The distance of the chair seat-to-floor and tabletop-to-floor was measured while the arms are supported at aorta level during initial subject sitting and was recorded (centimeters, cm). This tabletop and chair seat position was then maintained when performing all subject measurements.

The Test Protocol

The test portion involved repeating the blood pressure and pulse measurements that were sampled during the seated position but will exclude the brachial arterial pressures, and thus consisted of sampling only the bilateral digital arteries of each long finger. The tabletop height remained unchanged, and was adjusted to the level of the subject's heart as above. The tabletop remained at this level during the remainder of the standing portion of the test. The left hand rested on the tabletop at this height while the right hand is sampled. The left arm/hand served as the resting control hand, and rested at heart level during all tests, and its position did not change relative to the subject's heart throughout the test. The right hand served as the test hand throughout this portion of data collection, and its position will change relative to the subject's heart level and relative to the subject's neutral wrist position (Figure 3.5). The test hand rested at heart level between right hand testing periods. Both hands thus rested on the tabletop at this position, while the subject took approximately a one-minute pause to allow blood flow to reach steady state in the test limb upon completing each test position and upon recording the data. During this seated rest, both arms/hands rested on the tabletop at the original heart-level height when testing began. Skin appearance, skin color, tissue turgor and capillary refill time of the right long finger nailbed and hand were examined at the end of each one-minute pause and compared to the left long finger/hand. To confirm the return of normal blood flow and tissue perfusion after deflation of the pressure bladder of the long finger cuff, these characteristics of the right hand were given the appropriate time to be made distinguishable as normal (pink color, soft tissue turgor, capillary refill time less than five seconds) (McArdle et al 1991) and equal between hands. Once tissue perfusion (and thus hand blood flow) was determined as returned to normal, the subject assumed the next test position and data collection continued. Each test position was repeated twice and its data recorded. For consistency of end range wrist flexion within each subject over repeated trials, each subject performed and had recorded their active wrist flexion to end of range, which was measured by standard goniometry (Magee 1992). Upon performing wrist flexion test positions, the subject repeated and sustained their end range wrist flexion and then received black electrician's tape along their lateral forearm and hand (one piece of tape from lateral epicondyle to ulnar styloid, then a second piece of tape from ulnar styloid to the lateral portion of the head of metacarpal V). A mirror was then positioned horizontally under the subject's test hand (Figure 3.6). The subject performed consistent active wrist flexion to end range and this position was measured using a standard hand goniometer. Without changing goniometer position after the wrist flexion measurement, this same goniometer was then placed upon the mirror such that the goniometer was adjacent to the subject's wrist during the test position and data collection. This allowed the subject and investigator to easily visualize and create a wrist flexion "target" angle during these test positions, for consistent wrist flexion positioning during each test position (Figure 3.6). To provide consistent force of wrist flexion, a spring scale was secured to a brace near the 80-cm rule, at each wrist flexion test position. The test hand was positioned such that achieving end range wrist flexion produced a force equivalent to 0.98N at the spring scale (Figures 3.7, 3.8). The investigator coached the subject to ensure that this force resulted from wrist flexors alone.

Finger Pressure Monitor Position and Hand Placement

Once the digital artery oscillometric cuff was placed on the long finger of each of the subject's hands, the cuff remained in place throughout the testing procedure. The bladder in the finger cuff was oriented in such a way that the tubing connection to the bladder was always oriented toward the volar side of each long finger during testing, to sample both the radial-side and the ulnar-side digital artery of the long finger. Measurements from the long finger were selected to represent blood flow to the anatomic center of the palmar arch (Hollinshead and Rosse 1985) and thus represent blood pressure and perfusion to the entire wrist and hand. A previous investigator has demonstrated this finger cuff orientation is associated with repeatable measurements and intraclass correlation coefficient (ICC) values interpreted as good (Farrell 1998). I determined test positions that achieved consistent right arm and hand placement relative to the subject's heart. To accomplish this, I adjusted the middle marker of the 80-cm dowel (the 'zero-point") to the pre-determined level of the subject's aorta, at the top level of the table which was previously adjusted to heart level. The table was then rotated toward the subject's left to allow the right arm to move through the range of test positions unhindered, while allowing the resting hand to lie upon the table at heart level. Then, the test arm was positioned with the elbow fully extended and the wrist in neutral with the subject's long finger at the level of the above-determined zero-point. The investigator then determined that the test arm and the rest arm are both at the same level and at the subject's heart level. Now any final adjustments to the 80-cm vertical measuring rod will be made to ensure the zero-point (midpoint) of the measuring rod is aligned with the subject's heart level. To confirm this, the zero-point height from floor was measured and compared to the table height measurement. The vertical nature of the measuring rod was confirmed by use of a carpenter's level. Each 20-centimeter increment on the 80-cm vertical measuring rod now corresponds with that vertical distance from the long finger of the dominant right hand to a point 20 and 40 cm above and below the level of that subject's heart.

Test Procedure

The test procedure began by the subject assuming the test position. To achieve test position, the subject sat supported and erect and positioned their right arm such that the long finger of the right hand is at the 0-cm mark, as described in the above paragraph. Next, the right wrist assumed neutral flexion-extension-prono-supination and radio-ulnar deviation, the right shoulder was in a position of scaption and the scapula is in neutral protraction-retraction. Scaption was defined as 90° shoulder flexion and 55° shoulder horizontal abduction (McGee 1992). The left hand was positioned at heart level throughout testing, and sustained there by resting upon the adjustable tabletop. The only position changes from this initial position were the right hand vertical position from the heart, and the position of the right wrist. During testing, the right hand assumed positions of –40,-20, 0, +20 and +40 cm vertical distance relative to heart level, and wrist positions of neutral and end range flexion. By design, positive numbers represented vertical distances of the hand above the heart and negative numbers those vertical distances below the heart. These test positions were randomized by vertical distance from heart level and by wrist position, to minimize a test ordering effect and to make each test position order available to each subject in the subject pool. Systolic and diastolic index finger blood pressure and pulse rate measured from the digital artery were recorded at each hand position and wrist position from the digital display of the finger blood pressure monitors. During each long finger pressure reading, the subject's heart rate was recorded from the radiotelemetry unit. Finger blood pressure and corresponding pulse rate measurements were repeated two times for each position for each subject on one day. Subjects received $5.00 remuneration upon completion of their data collection.

Data Collection and Statistical Analysis

Blood pressure and pulse rate data were collected directly from the digital displays onto a datasheet and later were entered directly into a Microsoft Excel® spreadsheet for database creation and analysis (Microsoft Systems, Los Angeles, CA). The chest monitor heart rates were considered the "gold standard" pulse rates for each test subject, due to decreased pulse rate measurement error ($\pm$1%) compared to pulse rate measurement error of oscillometric units ($\pm$5%). Individual mean and variance finger blood pressure values were determined for each subject, and neutral wrist data compared to flexed wrist data. Then, average values of the dependent variables of systolic blood pressure, diastolic blood pressure, pulse rate and time at position were studied, consistent with previous investigators (Raptis et al 1997, Cushman et al 1990, Mitchell et al 1964, de Faire et al 1993, Mengden et al 1992, Widgren et al 1992, Sakuma et al 1997), according to each hand position and wrist position. Group mean values and their standard error values for systolic, diastolic and mean arterial pressures were derived from these mean data compiled from each subject. Mean values for these dependent variables were then compared to independent variables of hand position relative to the heart, wrist position and time at each position. Neutral wrist dependent variable data were compared to neutral wrist independent variable data, and flexed wrist dependent variable data were compared to flexed wrist independent variable data. These comparisons were made using regression analysis and analysis of variance, accounting for fixed effects of the independent variables and the random effects of between-subject variation. Coefficients of determination and regression equations were determined. Slopes of neutral and flexed wrist linear regressions were analyzed for statistical differences. Covariance and interaction were studied, and upon the presence of interaction, simple effects were studied. Variance due to subjects was included in each model. Statistical analysis was performed using SigmaPlot (Jandel Scientific, San Rafael, CA) and Statistical Analysis Systems (Raleigh, NC). Statistical significance was predetermined at $\alpha = 0.05$ for all tests. Intraclass correlation coefficients (ICC) were determined from baseline data for test-retest reliability for each hand. A specific finger pressure monitor was dedicated to each hand for the entire study, with all finger measurements taken simultaneously from each hand. One brachial monitor was used for this study, with brachial measurements taken sequentially from right arm then left arm.

Figure 3.1. Test conditions for all subjects. Systolic and diastolic blood pressure, pulse rate and time in position were measured for each condition.

	HAND POSITION RELATIVE TO HEART LEVEL (cm)				
	-40	-20	0	+20	+40
NEUTRAL WRIST	subject1-subject20	subject1-subject20	subject1-subject20	subject1-subject20	subject1-subject20
FLEXED WRIST	subject1-subject20	subject1-subject20	subject1-subject20	subject1-subject20	subject1-subject20

Figure 3.2. Omron Marshall® F-89 automatic digital blood pressure monitors.

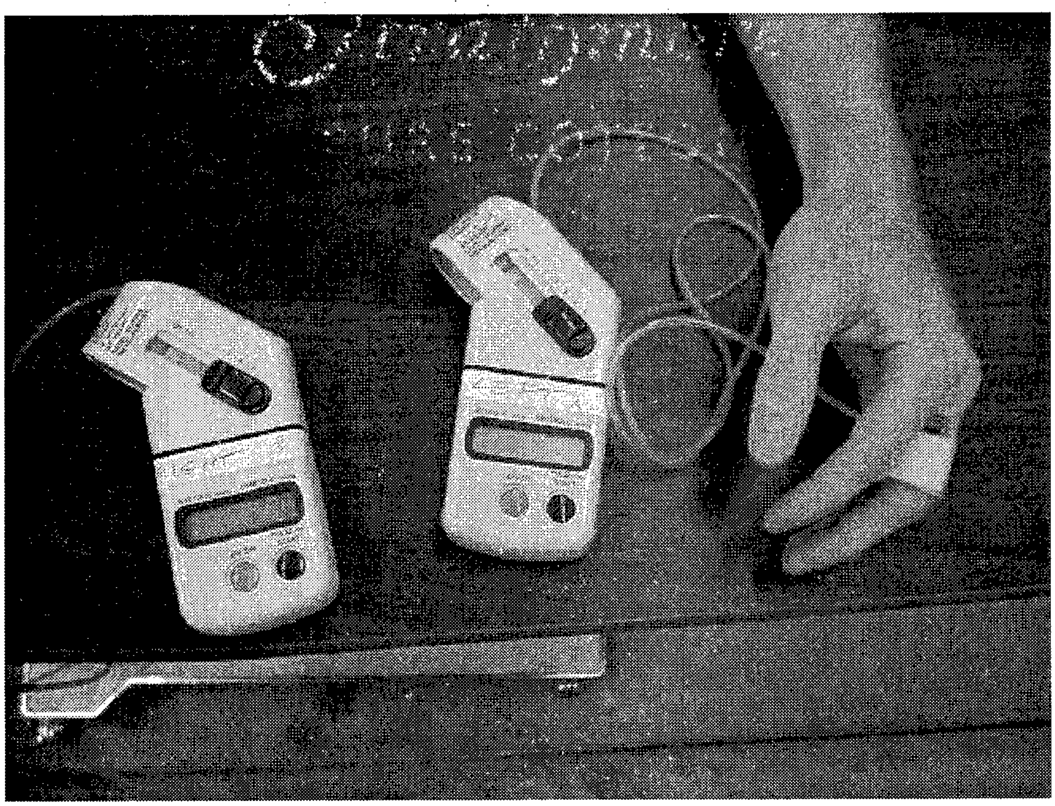


Figure 3.3. Subject positioning of test hand to +40 cm above heart level.

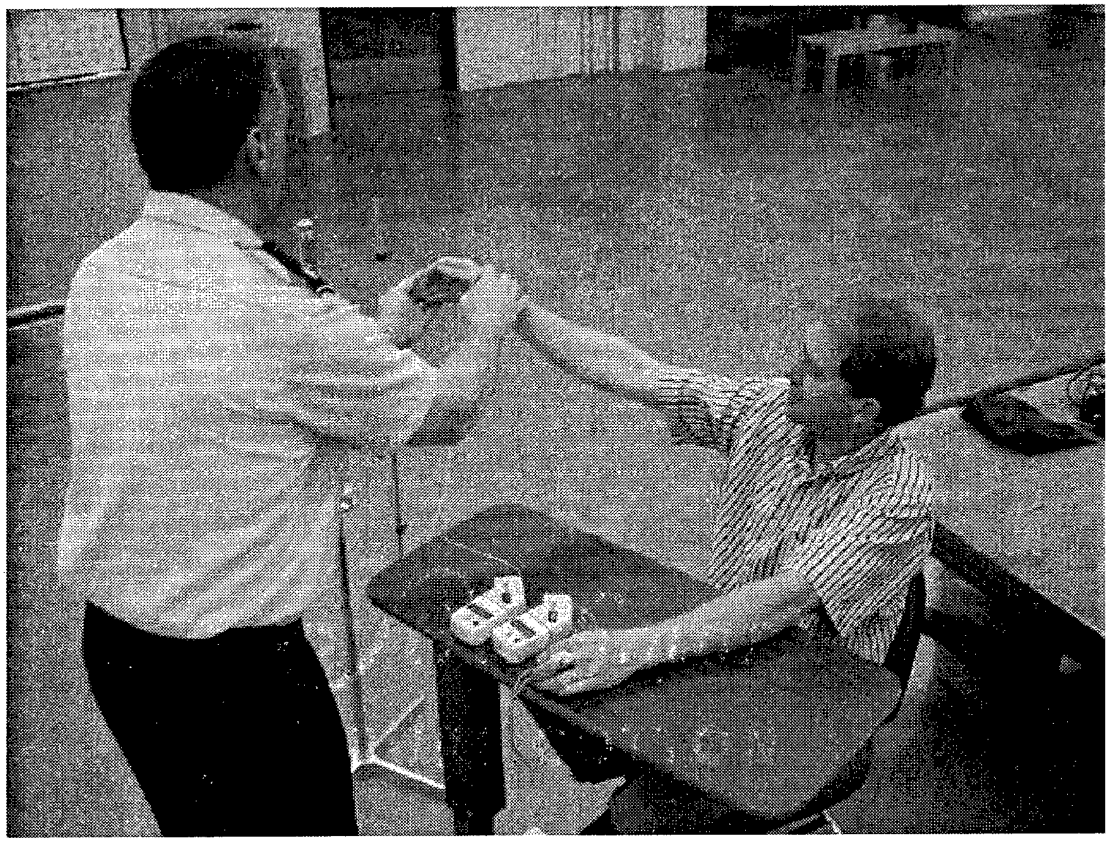


Figure 3.4. Bilateral upper limbs resting at heart level during baseline sampling.

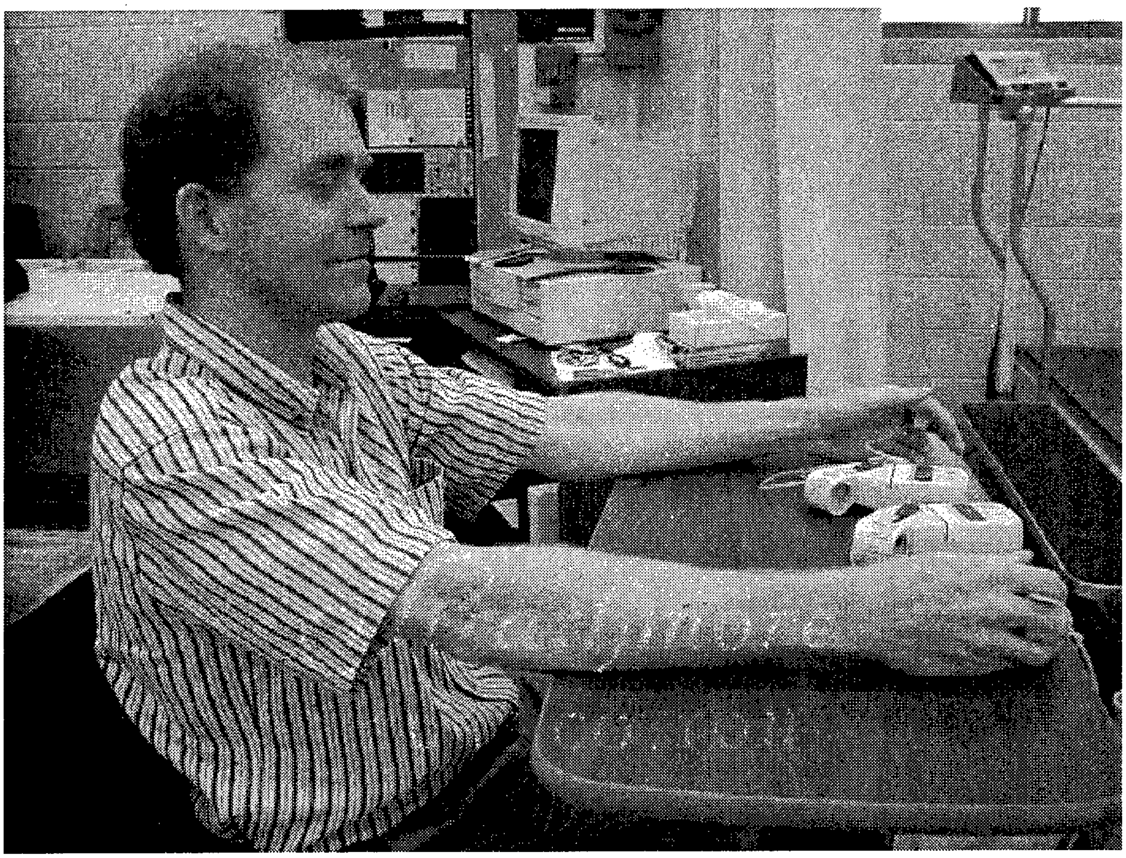
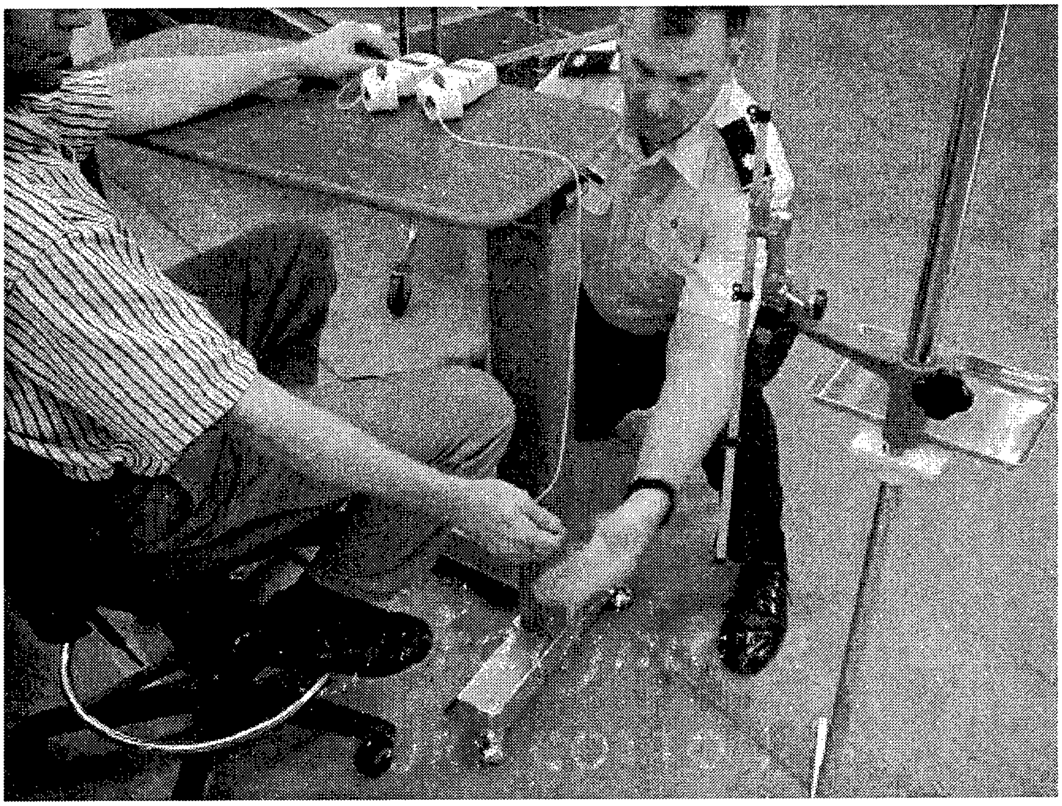


Figure 3.5. Subject's control hand resting at heart level while the test hand assumes –40 cm position for finger blood pressure measurement.



3.6. Subject performed active wrist flexion to end range at target force of 0.98N. Investigator places goniometer on mirror to provide target wrist flexion.

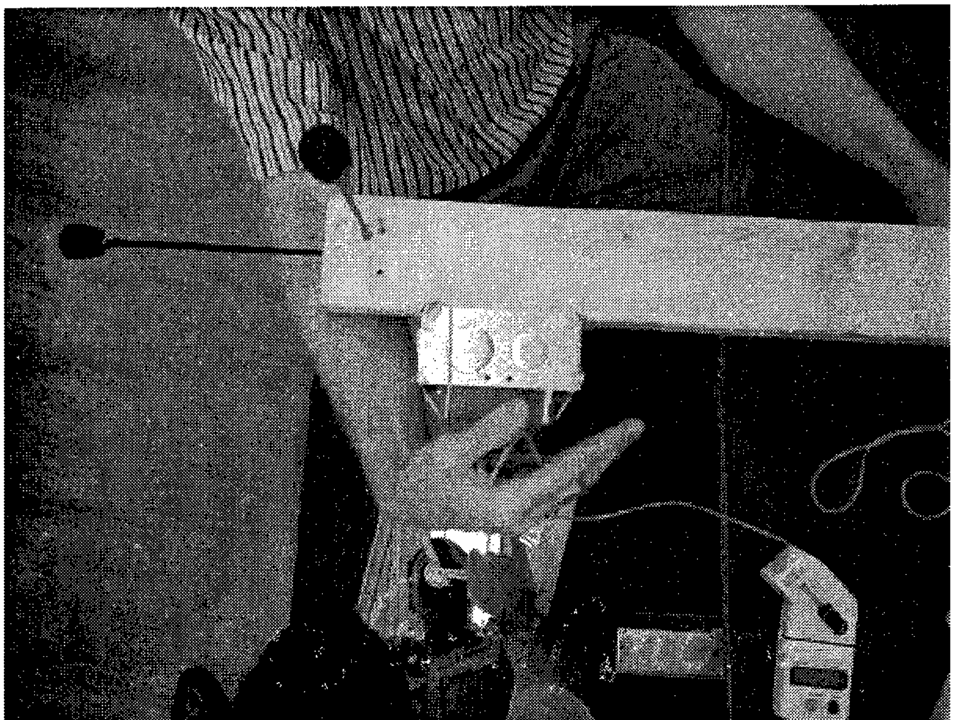


Figure 3.7. Wrist flexion achieving target force of 0.98N and target position at end range.

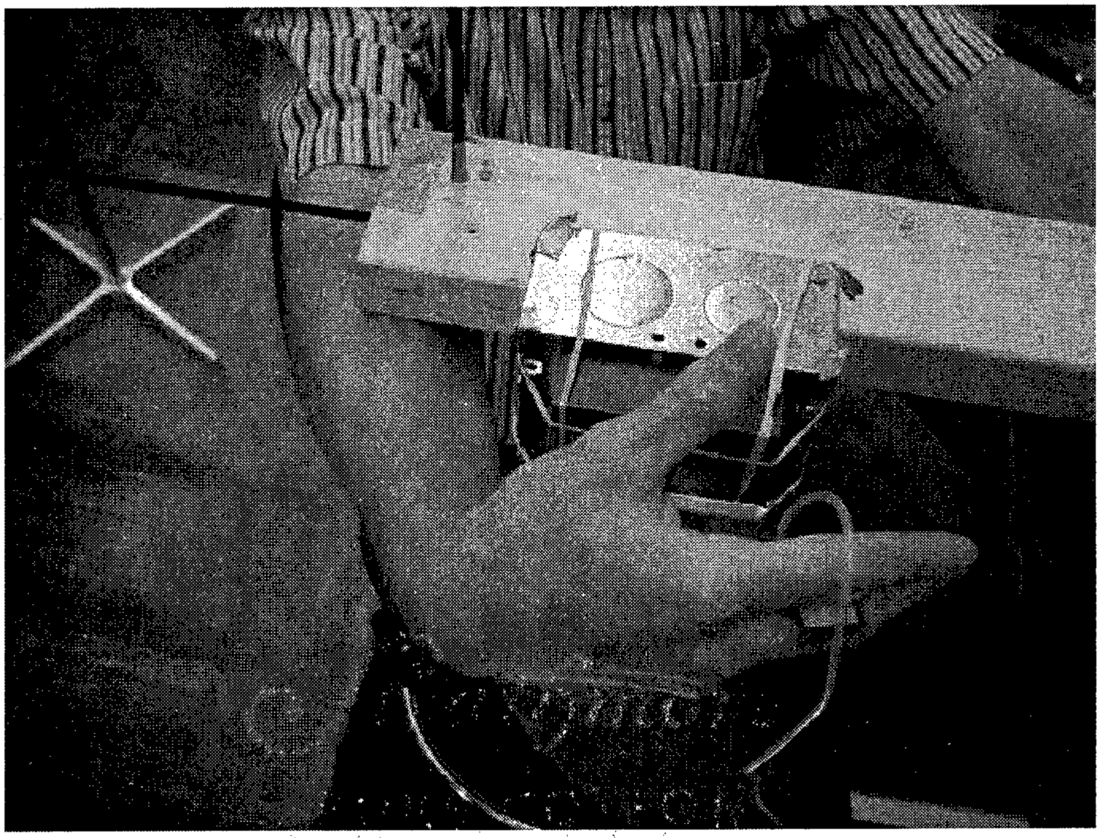
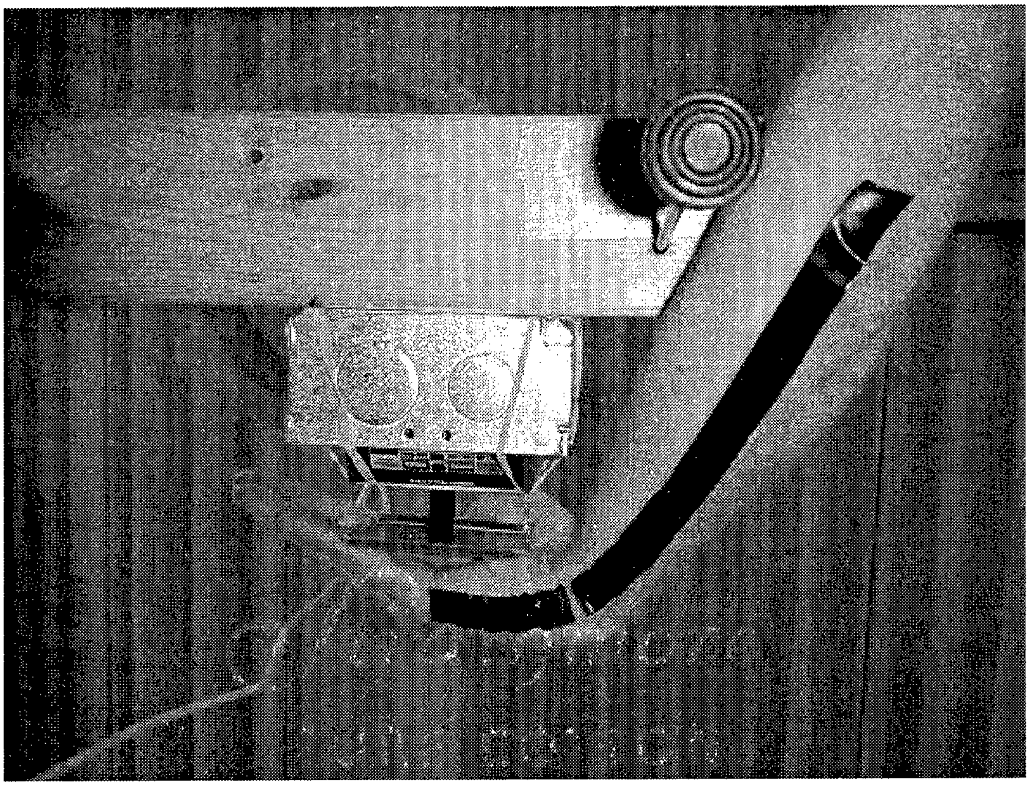


Figure 3.8. Wrist flexion target force of 0.98N was achieved by subject and monitored by investigator. Electrician's tape provided contrast of test limb.



CHAPTER 4
RESULTS

Introduction

A description of the data analysis and anthropometric data are given below, and are followed by a description of the results of the experiment and the statistical procedures that were performed. The α=0.05 level of significance was used for all statistical procedures. Statistical analysis was performed to identify how well wrist and hand position explain the variation in long finger systolic, diastolic and mean arterial blood pressure values, pulse rate and time in test position. Systolic, diastolic and mean arterial pressure were analyzed by wrist position to identify possible covariance and interaction associated with wrist position. Twenty subjects volunteered, consisting of undergraduate and graduate university students. Anthropometric data was collected and described below (Table 4.1). Fifteen males and five females volunteered, with age range 21 to 47 years and mean age of 31 years. Subject height ranged from 160.0-193.0 cm (mean=178.12 cm) and weight ranged from 55.9-100.9 Kg (mean=79.0 Kg). Wrist angle at end range flexion ranged from 45-90° (mean=70.99°). Upper limb segment lengths were as follows: upper arm length ranged from 25.0-34.0 cm (mean=70.99 cm); lower arm length ranged from 21.3-32.0 cm (mean=26.38 cm); hand length ranged from 7.0-12.5 cm (mean=9.07 cm) (Table 4.1).

Pre-test and post-test baseline values for pulse rate and blood pressure were used for test-retest reliability comparisons and to generate intraclass correlation coefficients, and not included in the above-mentioned statistical comparisons. Sums of squares and mean square values from raw data were used for all statistical comparisons.

Intraclass Correlation Coefficients

Measurement reliability of brachial and finger blood pressure measurement was assessed using raw data from sampling on same-day, same-investigator, across subjects, using three trials for each subject. Intraclass correlation coefficient (ICC) values were generated and listed below in Table 4.2. ICC values from this study agree with values previously published (Farrell 1998) and are considered good to excellent reproducibility (Portney and Watkins 1993, Fleiss 1986).

Baseline Blood Pressure From Brachium and Long Finger, Measured at Right and Left Side and Pre- and Post-Test

Each subject's blood pressure was sampled at each upper arm and long finger and three values were recorded. Independent variables of right or left side, brachium or finger, and pretest or posttest were recorded for each sampling. The dependent variables consisted of systolic and diastolic pressures, with a third dependent variable mean arterial pressure calculated from systolic and diastolic values. Three models were then created, with one dependent variable in each model as a function of all independent variables listed above. Three-way analysis of variance (ANOVA) was then performed, with subjects included in the model, examining systolic, diastolic and mean arterial pressures classified by the baseline independent variables of right/left hand, brachium/finger blood pressure and pretest/posttest. Post hoc Tukey's Studentized Range Test and adjusted Bonferroni tests were performed to determine pairwise differences between systolic, diastolic and mean arterial pressure values. Coefficients of determination, F-values, probabilities and adjusted mean values are given for each model in the tables below. Bonferroni-adjusted means and significance levels were identical to those for Tukey's Tests. Tukey's comparisons were selected, since all pairwise comparisons were made (Kleinbaum et al 1998).

Baseline Systolic Blood Pressure Data

Baseline systolic blood pressure model consists of right/left side sampling, arm/hand sampling, pretest/posttest sampling, subject variability, and interaction terms. In the model for baseline systolic pressure, the model explained greater than 97% of the variance present with R^2=0.977 for this model. The presence of right and left side and arm and hand classifications improved significantly the model's ability to predict systolic pressure (Table 4.3). The addition of pretest and posttest classifications to the model did not significantly improve the model's ability to predict systolic pressure. Differences in systolic blood pressure were statistically significant between side of the body, between arm and hand and between pre and posttest by Tukey's pairwise comparisons.

No interaction was found between left/right side and arm/hand conditions. Thus, systolic pressure remains unchanged when classified by right/left and pre/post conditions. Interaction was found between arm/hand and pre/post classifications of systolic pressure (Table 4.4). Thus, systolic values must be examined by arm and hand separately, and by pretest and posttest separately. No three-way interaction was found between right/left, arm/hand and pre/posttest conditions (Table 4.4). The ANOVA results, Tukey's means and differences are listed below (Table 4.3). Interaction terms and probabilities are listed below (Table 4.4).

Differences between Tukey's mean values are small, and range between 1.6 and 5.9 mm Hg (Table 4.7, Figure 4.3). Measurement error of blood pressure devices (6 mm Hg full scale) exceeds differences between means of all independent variables. Thus, no differences exist between right and left hands, between arm values and hand values, and between pretest and posttest conditions for systolic pressure.

Baseline Diastolic Blood Pressure Data

Baseline diastolic blood pressure model consists of right/left side sampling, arm/hand sampling, pretest/posttest sampling, subject variability, and interaction terms. In the model for baseline diastolic pressure, $R^2=0.902$, thus the model explained greater than 90% of the variance present. The addition of right/left side, arm/hand and pretest and posttest classifications to the model all significantly improved the model's ability to predict diastolic pressure.

Differences in diastolic pressure were statistically significant between right/left side of the body, between arm/hand and between pre/posttest conditions. Interaction exists between right/left side and arm/hand, and between arm/hand and pre/posttest classifications of diastolic pressure. No interaction exists between left/right side and pre/posttest conditions. No three-way interaction was found between right/left, arm/hand and pre/posttest diastolic values. ANOVA results, Tukey's means and differences are listed below in Table 4.5. Interaction significance is listed below in Table 4.6.

Interaction exists between right/left side and arm/hand, and between arm/hand and pre/posttest classifications of diastolic pressure. Thus, baseline diastolic pressure for arm/hand must be examined at each level of right/left side and pre/posttest classification. No interaction exists between left/right side and pre/posttest conditions. Thus, diastolic pressure values are unchanged when classified by right/left side and pre/post test, and may be grouped together when examining left/right side and pre/posttest conditions. No three-way interaction was found between right/left, arm/hand and pre/posttest diastolic values. Interaction terms and probabilities are listed below (Table 4.6).

Differences between Tukey's mean values are small, and range between 2.3 and 6.8 mm Hg (Table 4.5, Figure 4.2). Measurement error of blood pressure devices (6 mm Hg full scale) exceeds differences between means of right/left side, and is equal to differences between pre/post test. However, differences between means for arm/hand exceed pressure measurement error. Thus, significant differences between baseline arm and hand diastolic pressure values were identified. No differences exist between right and left hands and between pretest and posttest conditions for diastolic pressure.

Mean Arterial Pressure Baseline Data

Mean arterial blood pressure model consists of right/left side sampling, arm/hand sampling, pretest/posttest sampling, subject variability, and interaction terms. In the model for baseline mean arterial pressure (MAP), R^2=0.948, thus the model explained greater than 94% of the variance present. The presence of right/left side, arm/hand and pre/posttest classifications to the model all significantly improved the model's ability to predict MAP.

Differences in mean arterial pressure were statistically significant between side of the body, arm/hand and pre/posttest conditions (Table 4.7). Interaction was found between right/left side and arm/hand, and between arm/hand and pre/posttest MAP classifications (Table 4.8). Thus, baseline MAP for arm/hand classification must be examined at each level of right/left side and pre/posttest. No interaction exists between left/right side and pre/posttest MAP classifications.

Thus, MAP values remain unchanged when classified by right/left side or pre/posttest, and may be grouped together when examining left/right side and pre/posttest conditions. No three-way interaction was found between right/left, arm/hand and pre/posttest MAP values. No interaction exists between left/right side and pre/posttest conditions (Table 4.8). Thus, MAP values do not change for all levels of right/left side and pre/posttest conditions. Interaction terms and probabilities are listed below (Table 4.8).

Differences between Tukey's mean values are small, and range between 2.1 and 6.5 mm Hg (Table 4.5, Figure 4.2). Measurement error of blood pressure devices (6 mm Hg full scale) exceeds differences between means of MAP classified by right/left side, and exceeds differences between means of MAP classified by pre/post test. However, differences between means for arm/hand MAP exceed pressure measurement error. Thus, significant differences between baseline arm and hand MAP values were identified. Further, no differences exist between mean MAP values classified by right and left hands and between mean MAP values classified by pretest and posttest conditions. The ANOVA results and Tukey's means are listed in Table 4.7.

Systolic, Diastolic and Mean Arterial Blood Pressure by Hand Position and Wrist Position

Repeated measures ANOVA procedures were performed on each of three models (systolic, diastolic and mean arterial pressure) of finger blood pressure as a function of neutral wrist position, hand position and subject variation. Hand position and subject variance both contribute significantly to all three neutral-wrist models (Tables 4.9, 4.11, 4.13). For the model of systolic long finger blood pressure as a function of hand position, neutral wrist position and subject variation, R^2=0.986 (Table 4.9). Thus, this model accounts for greater than 98% of the variance present. For the model of diastolic pressure as a function of hand position, neutral wrist position and subject variance, R^2=0.968 (Table 4.11). Thus, this model for diastolic pressure accounts for greater than 96% of the variance present. For the model of MAP as a function of hand position, neutral wrist position and subject variance, R^2=0.979 (Table 4.13). Thus, the model for mean arterial pressure at the long finger accounts for greater than 97% of the variance present.

Post-hoc Bonferroni-adjusted comparisons were performed to examine significant differences between hand positions while in neutral wrist position (Tables 4.10, 4.12, 4.14). Long finger systolic pressure values differ significantly by each pairwise comparison across the range of hand positions (Table 4.9). In addition, diastolic pressure values differ significantly by each pairwise comparison across the range of hand positions tested (Table 4.11). To follow, mean arterial pressure values differ significantly from one another at each hand position (Table 4.13). Summaries of ANOVA and Bonferroni-adjusted pairwise comparisons are listed in Tables 4.9-4.13 below.

Differences between Bonferroni-adjusted mean values are large, and range between 16.3 and 18.1 mm Hg for neutral wrist systolic pressure (Table 4.10, Figure 4.4). Differences between Bonferroni-adjusted mean values (minimum 16.3 and maximum 18.1 mm Hg) exceed measurement error of Omron blood pressure devices (6 mm Hg full scale). Thus, significant differences between finger systolic pressure values were found for neutral wrist conditions associated with changes in hand position, that exceeded measurement error (Table 4.10). Changes of 71.5 mm Hg systolic pressure were identified across a range of 80 cm hand distances, for a conversion factor of 71.5 mm Hg/80 cm = 0.89 mm Hg/cm (Table 4.10).

Differences between Bonferroni-adjusted mean values range between 12.7 and 14.6 mm Hg for neutral wrist diastolic pressure (Table 4.12, Figure 4.5). Differences between Bonferroni-adjusted mean values (minimum 12.7 and maximum 14.6 mm Hg) exceed measurement error of Omron blood pressure devices (6 mm Hg full scale). Thus, significant differences between finger diastolic pressure values were found for neutral wrist conditions associated with changes in hand position, that exceeded measurement error (Table 4.12). Changes of 53.6 mm Hg systolic pressure were identified across a range of 80 cm hand distances, for a conversion factor of 53.6 mm Hg/80 cm = 0.67 mm Hg/cm (Table 4.12).

Differences between Bonferroni-adjusted mean values range between 14.2 and 15.1 mm Hg for neutral wrist mean arterial pressure (Table 4.14, Figure 4.6). Differences between Bonferroni-adjusted mean values (minimum 14.2 and maximum 15.1 mm Hg) exceed measurement error of Omron blood pressure devices (6 mm Hg full scale). Thus, significant differences between finger diastolic pressure values were found for neutral wrist conditions associated with changes in hand position, that exceeded measurement error (Table 4.14). Changes of 58.5 mm Hg systolic pressure were identified across a range of 80 cm hand distances, for a conversion factor of 58.5 mm Hg/80 cm = 0.73 mm Hg/cm (Table 4.14).

Pulse Rate vs. Hand Position

A model was created with pulse rate as a function of wrist position, hand position, subject variation and interaction terms. This model was created to identify changes in pulse rate associated with hand position changes. Pulse rate associated with measurement of the test hand was recorded at each hand position and wrist position. For this model, R^2=0.9534, thus this model accounting for greater than 95% of the variance. Hand position and subject variation both contributed significantly to the model (Table 4.15). Wrist position and interaction did not contribute significantly to the model (Table 4.15). Thus, in the absence of wrist*hand interaction, pulse rate values classified by hand position remain unchanged for all values of wrist position, and may be grouped together by wrist position when examining hand position conditions. Mean pulse rate did not change significantly when classified by wrist position (Table 4.17). No significant pairwise comparisons for pulse rate Bonferroni-adjusted means were found, with 1.3 bpm change across 80 cm hand position change identified from the data analysis (Table 4.19).

Measurement error for pulse rate is 2% full scale or 4 bpm, with resolution 1 bpm. Pulse rate error of 4 bpm is the measurement limit of the pulse rate monitor. The range of pulse rate changes that were measured was 1.3 bpm by hand position (Table 4.19) and 0.3 bpm by wrist position (Table 4.17). Measurement error exceeds the range of pulse rate changes measured for both wrist position and hand position. Thus, no change in pulse rate could be detected for wrist or hand position changes. In addition, no significant statistical differences were found for pulse rate across the range of hand positions tested (Table 4.19).

Time in Position vs. Hand Position

A model was created with time in test position as a function of wrist position, hand position, subject variation and interaction terms. This model was created to identify changes in time in position associated with hand position and wrist position changes. Time in position associated with measurement of test hand blood pressure was recorded at each hand and wrist position. For this model, R^2=0.5980, thus this model accounting for approximately 59% of the variance. Hand position contributed significantly to the model (Table 4.16). However, wrist position, subject variation and interaction terms did not contribute significantly to the model (Table 4.16). In the absence of wrist*hand interaction, time in position values classified by hand position remain unchanged for all values of wrist position. Classified by wrist position, mean time in position did not change significantly (Table 4.18). Classified by hand position, mean time in position changed significantly between –40 position and all other positions (Table 4.20). No other pairwise comparisons differed significantly (Table 4.20). Minimum significant difference=6.67 seconds, with significant pairwise comparisons involving –40 cm position (Table 4.20).

Total measurement error for time in position is 5 seconds, with resolution 0.01 seconds. Thus, time in position error of 5.01 seconds is the measurement limit for this variable. The range of time in position changes that were recorded was 0.6 seconds by wrist position (Table 4. 18), and 10.1 seconds (Table 4.20). Measurement error exceeds the range of time in position changes measured for wrist position. Thus, no change in time in position by wrist position could be detected. In addition, significant statistical differences were found for time in position across the range of hand positions tested (Table 4.16). However, mean time in position for –40 differs from all other positions by a range of 10.1 seconds, with no difference between the remaining four positions (Table 4.20).

Thus, change in mean time in position exceeds measurement error across the range of hand positions tested and a difference in mean time in position was detected. Time in position then differs significantly between –40 cm and the grouping of all other hand positions (Table 4.20).

Long Finger Systolic Blood Pressure By Wrist and Hand Position

After establishing a model for neutral wrist finger blood pressure, a model for flexed wrist finger blood pressure was created and compared against the neutral wrist model. Thus, long finger blood pressure was classified by wrist and hand position, and flexed wrist values compared to neutral wrist values. In the comparison of flexed wrist values to neutral wrist values, regression analysis was performed. To account for subject variation in the model and to compare regression line slope and intercept from each subject, regression analysis was performed using a mixed-effects random coefficients model. This analysis was performed for systolic, diastolic and mean arterial pressure. Slopes and intercepts were determined for each classification and level. These slopes and intercepts were then compared to zero, and then compared to one another for interaction effects. In addition, test hand pressure values were compared to control hand pressure values.

Systolic blood pressure slopes and intercepts differ significantly from zero when classified by wrist position and hand position, at all levels, for the test hand

(Table 4.21). No significant difference was found when comparing the systolic blood pressure slopes across flexed and neutral wrist positions, and when comparing the intercepts across flexed and neutral wrist positions (Table 4.22). Thus, at α=0.05, the systolic blood pressure regression lines for the test hand across flexed and neutral wrist positions are coincident.

For comparisons involving the control hand, systolic pressure slopes and intercepts differ significantly from zero when classified by wrist position and hand position, at all levels (Table 4.23). Significant differences were found when comparing the systolic pressure slopes for neutral wrist across test and control hands (Table 4.24). In addition, significant differences were found when comparing flexed wrist slopes across test and control hands (Table 4.24). Thus, slopes differ significantly between test hand and control hand regardless of wrist position (Table 4.24). Further, when comparing the intercepts for flexed wrist position for test and control hands, a significant difference was found (Table 4.24). However, when comparing the intercepts for neutral wrist positions across test and control hands, no significant difference was achieved (Table 4.24). Thus, at α=0.05, the systolic pressure regression lines differ significantly between test and control hands regardless of wrist position, exhibit interaction and have significantly different slopes (Table 4.24).

Finger blood pressure measurement error is 6 mm Hg with resolution of 1 mm Hg. Thus, a change of 7 mm Hg is the minimum change detectable with the above equipment. To achieve this minimum change across the range of hand positions, the minimum difference in pressure measurement from one hand position to the next must be 7 mm Hg/20 cm = 0.35mm/cm difference in slope. The minimum pressure difference between minimum and maximum hand positions across the range (-40 cm to +40 cm) must be 7 mm Hg/80 cm = 0.0875 mm/cm difference in slope. Thus, the minimum detectable difference between slopes is 0.0875mm/cm, and the minimum detectable difference between intercepts is 7 mm.

The slopes of finger systolic pressure comparing neutral and flexed wrists differ by 0.0482, are not statistically different (Table 4.22), and measurement error (0.0875) exceeds these differences in slopes (0.0482). In addition, intercepts do not statistically differ, with difference of 0.9910 exceeded by minimum detection of 7 mm (Table 4.22). Thus, the regression lines for systolic finger pressure do not differ by wrist position and exhibit coincident lines.

Control hand systolic blood pressure behaves differently than the test hand with a smaller slope compared to test hand (Tables 4.21, 4.23). For neutral wrist, no differences were found between control and test hand intercepts for long finger systolic pressure, with the difference of 0.8300 mm exceeded by minimum detection of 7mm (Table 4.24), with significant differences found between slopes (Table 4.24). This difference in slopes between test and control hand with neutral wrist is 0.8936, which does exceed the minimum detectable slope difference of 0.0875mm/cm. Thus, the difference in systolic slopes for test and control hand is both significant (Table 4.24) and greater than measurement error. For flexed wrist, the intercepts and the slopes differ significantly between test and control hands (Table 4.24), with a difference in slopes of 0.9513 which exceeds measurement error. Differences in intercepts between flexed and control hands are exceeded by measurement error, 6.0187mm intercept <7mm detection (Table 4.24) with the range of intercepts for test and control hands across wrist positions 118.36-124.38mm or 6.02mm difference, which is also exceeded by measurement error. Thus, control and test regression lines exhibit interaction and share common intercepts, regardless of wrist position. For systolic pressure, the control hand behaves differently than the test hand regardless of wrist position.

Long Finger Diastolic Blood Pressure
By Wrist and Hand Position

Diastolic blood pressure slopes and intercepts differ significantly from zero when classified by wrist position and hand position (Table 4.25). Significant differences were found when comparing diastolic blood pressure slopes for flexed wrist positions, and when comparing the intercepts, across flexed and neutral wrist positions (Table 4.26). Thus, at $\alpha=0.05$, the diastolic blood pressure regression lines for the test hand across flexed and neutral wrist positions exhibit interaction.

For comparisons involving the control hand, diastolic blood pressure slope for flexed wrist and intercepts for both flexed and neutral wrist positions differs significantly from zero (Table 4.27). Neutral wrist slope does not differ significantly from zero (Table 4.27). Significant differences were found when comparing the diastolic blood pressure slopes for neutral wrist positions across test and control hands (Table 4.28) and when comparing flexed wrists across test and control hands (Table 4.28). Significant differences were found when comparing the diastolic blood pressure intercepts, for neutral wrist positions across test and control hands (Table 4.28), and when comparing flexed wrists across test and control hands (Table 4.28).

However, differences between diastolic pressure slopes for flexed and neutral wrist are -0.06238mm/cm (Table 4.26) and are exceeded by measurement error (0.0875). Intercept differences by wrist are 2.6353mm, and are exceeded by minimum detectable difference (7mm). Thus, the differences in diastolic pressure regression lines by wrist fall within measurement error and these lines are then coincident.

For comparisons of control hand to test hand, slopes (flexed slope=0.7517mm/cm, neutral slope=0.6814mm/cm) differ greater than measurement error (0.0875) regardless of wrist position (Table 4.28). Intercept differences between test and control hands range from –2.8220 to –5.6700mm (Table 4.28) and are exceeded by the minimum detectable difference (7mm). Thus, diastolic pressure regression lines across control and test hands exhibit interaction and share common intercepts, within measurement error. Control hand has a smaller slope than test hand.

Long Finger Mean Arterial Pressure

By Wrist and Hand Position

Mean arterial pressure (MAP) slopes and intercepts differ significantly from zero when classified by wrist position and hand position, at all levels, for the test hand (Table 4.29). Significant differences were found when comparing MAP slopes, across flexed and neutral wrist positions (Table 4.30). However, the difference in slope (-0.058mm/cm, Table 4.30) is exceeded by measurement error (0.0875mm/cm). Thus, no difference in slopes can be detected for Map across wrist positions. Intercepts for MAP regression lines do not differ significantly by flexed and neutral wrist (Table 4.30). In addition, the difference in intercepts (1.4432mm, Table 4.30) falls below minimum detectable pressure change of 7mm. Thus, at α=0.05, the MAP regression lines for the test hand across flexed and neutral wrist positions do not exhibit interaction as statistical results may indicate, but rather are coincident (Figure 4.10).

For comparisons involving the control hand, MAP slopes and intercepts differ statistically from zero when classified by wrist position (Table 4.31). However, slopes for control hand (Table 4.31) by flexed wrist (0.05062mm/cm) and neutral wrist (0.04279mm/cm) are exceeded by the minimum detectable slope of 0.0875mm/cm. Thus, control hand slopes are not distinguishable from zero, regardless of wrist position.

Significant differences were found when comparing the MAP slopes for neutral wrist positions across test and control hands (0.7521mm/cm, Table 4.32), and for flexed wrists across test and control hands (0.8180mm/cm, Table 4.32). These differences in slope exceed the minimum detectable slope of 0.0875mm/cm, and thus identify interaction between test and control hand. When comparing the intercepts, no statistical difference for flexed wrists across test and control hands was seen (Table 4.32). A significant difference was seen for intercepts from control and test hands for the neutral wrist test hand (-3.5033mm, Table 4.32). However, this difference falls below the minimum detectable value of 7mm. Thus, the difference between intercepts for control and test hands is not distinguishable regardless of wrist position. As in systolic and diastolic pressures, mean arterial pressure varied compared to control hand, regardless of wrist position. Control hand intercepts were not distinguishable by wrist position.

ID no.	gender	aerobic exercise	height cm	weight kg	age yrs	wrist angle	right upper arm cm	right lower arm cm	right hand cm
1	male	yes	180.3	77.3	21	65	missing	missing	missing
2	male	yes	165.1	77.7	34	62	25	23.5	8
3	female	yes	175.3	79.5	22	75	28	27	7
4	male	yes	188	72.7	21	90	32	30	7
5	male	yes	185.4	100.9	25	80	30	27.5	8
6	male	yes	172.7	70.5	29	64	30	24	9
7	male	no	182.8	84.1	37	65	34	28	9.5
8	male	yes	177.8	68.2	40	65	31	27	9.5
9	female	yes	168.9	55.9	21	63	31	25	9
10	male	yes	172.7	81.8	31	45	30	25.3	9.5
11	female	no	164	63.6	28	67	25	21.3	7
12	male	yes	182.9	92.7	31	81	32	32	12.5
13	female	yes	160	72.7	47	66	25	24.5	7
14	male	yes	188	86.4	24	82	30.3	25	10.3
15	male	yes	182.9	86.4	23	80	33	28.5	9.5
16	male	yes	189.2	85	44	80	34	28	9.5
17	female	no	167.6	70	41	80	28	23.3	9
18	male	yes	193	100	29	76	33	28	11.5
19	male	yes	181	79.5	44	70	32	26.3	9.5
20	male	yes	184.8	75	31	63	31.5	27	10
mean			178.12	79.0	31	70.99	70.99	26.38	9.07
maximum			193.0	100.9	47	90	34.0	32.0	12.5
minimum			160.0	55.9	21	45	25.0	21.3	7.0
standard error			2.10	2.53	1.90	2.31	0.66	0.59	0.34

[1] Subject 1 ended participation prior to limb length data collection.

Table 4.1. Anthropometric data from subjects tested.

Variable	Mean	Standard Error	ICC
pre-test, right upper extremity			
systolic right arm	114.20	2.91	0.979
diastolic right arm	68.3	1.80	0.794
systolic right finger	115.6	2.39	0.951
diastolic right finger	73.70	1.75	0.800
pulse rate, chest (right finger)	66.14	1.83	0.866
pulse rate, chest (right arm)	66.94	1.88	0.923
pre-test, left upper extremity			
systolic left arm	111.42	2.34	0.959
diastolic left arm	69.20	1.60	0.734
systolic left finger	113.85	2.92	0.978
diastolic left finger	69.20	1.84	0.805
pulse rate, chest (right finger)	65.82	1.80	0.924
pulse rate, chest (right arm)	67.58	1.76	0.904
post-test, right upper extremity			
systolic right arm	111.11	2.14	0.967
diastolic right arm	70.55	1.72	0.753
systolic right finger	121.68	3.39	0.968
diastolic right finger	85.32	2.25	0.801
pulse rate, chest (right finger)	62.45	2.06	0.870
pulse rate, chest (right arm)	61.77	1.50	0.869
post-test, left upper extremity			
systolic left arm	112.24	2.85	0.958
diastolic left arm	71.60	1.74	0.824
systolic left finger	119.31	3.09	0.948
diastolic left finger	78.58	2.09	0.813
pulse rate, chest (right finger)	61.75	1.97	0.926
pulse rate, chest (right arm)	61.89	1.81	0.875

Table 4.2. Mean, standard error and ICC values for pre-test and post-test pulse rate and blood pressure data.

independent variable	F	probability>F	Tukey means	difference
Right, left hand	7.75	0.0117	115.7, 114.1	1.6
arm, hand	10.89	0.0038	117.9, 112.0	5.9
pre, post test hand	2.11	0.1628	113.9, 115.8	1.9

Table 4.3. Systolic blood pressure comparisons for baseline data in units of mm Hg, respectively.

interaction term	F	probability>F
left/right*arm/hand	0.55	0.4686
arm/hand*pre/post	10.70	0.0042
left/right*pre/post	0.64	0.4343
side*armhand*pre/post	1.69	0.2104

Table 4.4. Interaction terms and probabilities for baseline data systolic blood pressure model.

independent variable	F	probability>F	Tukey means	difference
right, left hand	20.4	0.0002	74.6, 72.3	2.3
Arm, hand	39.4	0.0001	70.1, 76.9	6.8
pre, post test hand	28.29	0.0001	70.5, 76.5	6.0

[2] Comparisons made by mm Hg, respectively.

Table 4.5. Baseline data diastolic pressure model.

interaction term	F	probability>F
left/right*arm/hand	44.15	0.0001
arm/hand*pre/post	34.71	0.0001
left/right*pre/post	2.31	0.1451
side*pre/post*armhand	1.40	0.2513

Table 4.6. Interaction terms for baseline data diastolic blood model.

independent variable	F	probability>F	Tukey means	difference
Right, left hand	17.7	0.0005	88.3, 86.2	2.1
arm, hand	31.14	0.0001	84.1, 90.6	6.5
pre, post test hand	16.32	0.0007	85.0, 89.6	4.6

[3] Comparisons by units of mm Hg, respectively.

Table 4.7. Baseline mean arterial pressure model.

interaction term	F	probability>F
left/right-arm/hand	25.4	0.0001
Arm/hand-pre/post	26.25	0.0001
Left/right-pre/post	0.23	0.6385
side*arm/hand*pre/post	1.66	0.2139

Table 4.8. Interaction terms for baseline MAP model.

Source	df	SS	MS	F	Pr>F
Hand position	4	226006	56502	500.09	<0.0001
subject	19	35101	1847.44	5.21	<0.0001
Error	76.224	8611.92	112.98		

Table 4.9. ANOVA summary for systolic finger pressure by vertical hand position, neutral wrist.

hand position (cm)	change (cm)	adjusted mean (mm Hg)	change (mm Hg)
-40	20	152.8	16.8
-20	20	136.0	16.3
0	20	119.7	18.1
+20	20	101.6	17.3
+40	80 total	84.3	71.5 total
			71.5mm/80cm=0.89mm/cm

[4] Measured at the long finger, neutral wrist.

Table 4.10. Bonferroni-adjusted mean values for systolic blood pressure.

Source	df	SS	MS	F	Pr>F
Hand position	4	139811	34953	737.71	<0.0001
subject	19	16107	847.74	5.59	<0.0001
error	76.385	3621.07	47.41		

Table 4.11. ANOVA summary for diastolic finger pressure by vertical hand position, neutral wrist.

hand position (cm)	change (cm)	adjusted mean (mm Hg)	change (mm Hg)
-40	20	109.2	13.5
-20	20	95.7	14.6
0	20	81.1	12.7
+20	20	68.4	12.8
+40	80 total	55.6	53.6 total
			53.6mm/80cm=0.67mm/cm

[5] Measured at the long finger.

Table 4.12. Bonferroni-adjusted mean values for neutral wrist diastolic pressure.

Source	df	SS	MS	F	Pr>F
hand position	4	166195	41549	758.65	<0.0001
subject	19	20063	1055.95	6.14	<0.0001
error	76.307	4179.08	54.77		

Table 4.13. ANOVA summary for finger mean arterial pressure by hand position, neutral wrist.

hand position (cm)	change (cm)	adjusted mean (mm Hg)	change (mm Hg)
-40	20	123.7	14.6
-20	20	109.1	15.1
0	20	94.0	14.6
+20	20	79.4	14.2
+40	80 total	65.2	58.5 total
			58.5mm/80cm=0.73mm/cm

[6] Measured at the long finger of the test hand.

Table 4.14. Bonferroni-adjusted mean values for neutral wrist MAP.

Source	df	SS	MS	F	Pr>F
wrist position	1	42.3127	42.3127	1.26	0.2747
hand position	4	131.0488	32.7622	3.11	0.0199
wrist*hand	4	101.6917	25.4230	1.63	0.1754
subject	19	25948	1365.7074	47.68	<0.0001
error	198	1413.5000	7.1389		

Table 4.15. ANOVA summary of pulse rate by wrist position and hand position.

Source	df	SS	MS	F	Pr>F
Wrist position	1	50.3030	50.3030	0.09	0.7638
Hand position	4	4705.6586	1176.4146	4.62	0.0022
Wrist*hand	4	260.5416	65.1353	0.29	0.8804
Subject	19	21011	632.1504	1.09	0.4281
Error	196	42551	217.0954		

Table 4.16. ANOVA summary of time in position by wrist position and hand position.

wrist position	adjusted mean (bpm)
flexed	66.9
neutral	66.6
	0.3 total change

[7] No significant difference.

Table 4.17. Bonferroni-adjusted means for pulse rate.

wrist position	adjusted mean (seconds)
flexed	46.8
neutral	46.2
	0.6 sec difference

[8] No significant difference.

Table 4.18. Bonferroni-adjusted means for time in position.

hand position (cm)	difference (cm)	adjusted mean (bpm)	difference (bpm)
-40	20	67.2	-0.9
-20	20	66.3	-0.1
0	20	66.2	0.8
+20	20	67.0	0.5
+40	80 cm total	67.5	1.3 bpm total

[9] No significant pairwise differences.

Table 4.19. Bonferroni-adjusted mean values for pulse rate.

hand position (cm)	differences (cm)	adjusted mean (seconds)	differences (seconds)
-40	20	53.3*	7.3
-20	20	46.0	2.8
0	20	43.2	-1.4
+20	20	44.6	-2.0
+40	80 cm total	46.6	10.1 sec total

[10] Significant pairwise differences.

Table 4.20. Bonferroni-adjusted means for time in position.

Effect	Wrist	Estimate	Std. Error	df	t-value	Pr>|t|, μ=0
Y-intercept	flexed	118.36	2.4332	705	48.65	<0.0001
Y-intercept	neutral	119.35	2.3381	705	51.05	<0.0001
regression slope	flexed	-0.8840	0.02940	705	-30.07	<0.0001
regression slope	neutral	-0.8360	0.02064	705	-40.50	<0.0001

Table 4.21. Slope and intercept estimates, test hand systolic pressure regression lines.

Parameter	Estimate Difference	Std. Error	df	t-value	Pr>|t|
slope, flexed vs. neutral	-0.04802	0.03316	705	-1.45	0.1480
intercept, flexed vs. neutral	-0.9910	1.8530	705	-0.53	0.5930

Table 4.22. Slope and intercept differences, test hand systolic pressure regression lines.

Effect	Wrist	Estimate	Std. Error	df	t-value	Pr>|t|, μ=0
regression slope	flexed	0.06728	0.02915	705	2.31	<0.0001
regression slope	neutral	0.05762	0.02064	705	2.79	<0.0001
Y-intercept	flexed	124.38	2.4320	705	51.14	<0.0001
Y-intercept	neutral	120.18	2.3381	705	51.40	<0.0001

[11] Classified by wrist position.

Table 4.23. Slope and intercept estimates for control hand.

Parameter Differences	Wrist	Estimate Difference	Std. Error	df	t-value	Pr>|t|
slope, control vs. test	flexed	0.9513	0.02780	705	34.22	0.0001
slope, control vs. test	neutral	0.8936	0.02726	705	32.78	0.0001
intercept, control vs. test	flexed	6.0187	0.7826	705	7.69	0.0001
intercept, control vs. test	neutral	0.8300	0.7710	705	1.08	0.2820

Table 4.24. Differences in systolic slopes and intercepts for test and control hands by wrist position.

Effect	Wrist	Estimates	Std. Error	df	t-value	Pr>|t|, μ=0
Y-intercept	flexed	83.4403	1.7008	705	49.06	<0.0001
Y-intercept	neutral	80.805	1.6547	705	48.83	<0.0001
regression slope	flexed	-0.7084	0.01751	705	-40.45	<0.0001
regression slope	neutral	-0.6460	0.01855	705	-34.82	<0.0001

Table 4.25. Long finger diastolic pressure slopes and intercepts by wrist and hand position.

Parameter	Estimate Difference	Std. Error	df	t-value	Pr>|t|
slope, flexed vs. neutral	-0.06238	0.02318	705	-2.69	0.0073
intercept, flexed vs. neutral	2.6353	1.1857	705	2.22	0.0266

Table 4.26. Differences in slopes and intercepts for long finger diastolic pressure by flexed and neutral wrist.

Effect	Wrist	Estimate	Std. Error	df	t-value	Pr>|t|, μ=0
regression slope	flexed	0.04331	0.01727	705	2.51	0.0124
regression slope	neutral	0.03537	0.01855	705	1.91	0.0570
Y-intercept	flexed	80.6183	1.6999	705	47.43	<0.0001
Y-intercept	neutral	75.1350	1.6547	705	45.41	<0.0001

Table 4.27. Long finger diastolic pressure slopes and intercepts, control hand, by wrist and hand position.

Parameter Differences	Wrist	Estimate Difference	Std. Error	df	t-value	Pr>|t|
slope, control vs. test	flexed	0.7517	0.02283	705	32.92	<0.0001
slope, control vs. test	neutral	0.6814	0.02242	705	30.39	<0.0001
intercept, control vs. test	flexed	-2.8220	0.6432	705	-4.39	<0.0001
intercept, control vs. test	neutral	-5.6700	0.6341	705	-8.94	<0.0001

Table 4.28. Differences in diastolic slopes and intercepts for test and control hands by wrist position.

Effect	Wrist	Estimates	Std. Error	df	t-value	Pr>|t|, μ=0
Y-intercept	flexed	95.0982	1.8982	705	50.10	<0.0001
Y-intercept	neutral	93.6550	1.8398	705	50.90	<0.0001
regression slope	flexed	-0.7673	0.01923	705	-39.91	<0.0001
regression slope	neutral	-0.7093	0.01787	705	-39.69	<0.0001

Table 4.29. Long finger mean arterial pressure slopes and intercepts by wrist and hand position.

Parameter	Estimate Difference	Std. Error	df	t-value	Pr>|t|
slope, flexed vs. neutral	-0.058	0.02358	705	-2.46	0.0141
intercept, flexed vs. neutral	1.4432	1.3151	705	1.10	0.2728

Table 4.30. Differences in slopes and intercepts for long finger MAP by flexed and neutral wrist.

Effect	Wrist	Estimate	Std. Error	df	t-value	Pr>|t|, μ=0
regression slope	flexed	0.05062	0.01902	705	2.66	0.0079
regression slope	neutral	0.04279	0.01787	705	2.39	0.0169
Y-intercept	flexed	95.2206	1.8974	705	50.18	<0.0001
Y-intercept	neutral	90.1517	1.8398	705	49.00	<0.0001

Table 4.31. Long finger mean arterial pressure slopes and intercepts, control hand, by wrist and hand position.

Parameter Differences	Wrist	Estimate Difference	Std. Error	df	t-value	Pr>|t|
slope, control vs. test	flexed	0.8180	0.02204	705	37.11	<0.0001
slope, control vs. test	neutral	0.7521	0.02163	705	34.76	<0.0001
intercept, control vs. test	flexed	0.1224	0.6207	705	0.20	0.8437
intercept, control vs. test	neutral	-3.5033	0.6119	705	-5.73	<0.0001

Table 4.32. Differences in mean arterial pressure slopes and intercepts for test and control hands by wrist position.

Figure 4.1. Baseline systolic finger pressure grouped by side, arm-hand and pre-posttest.

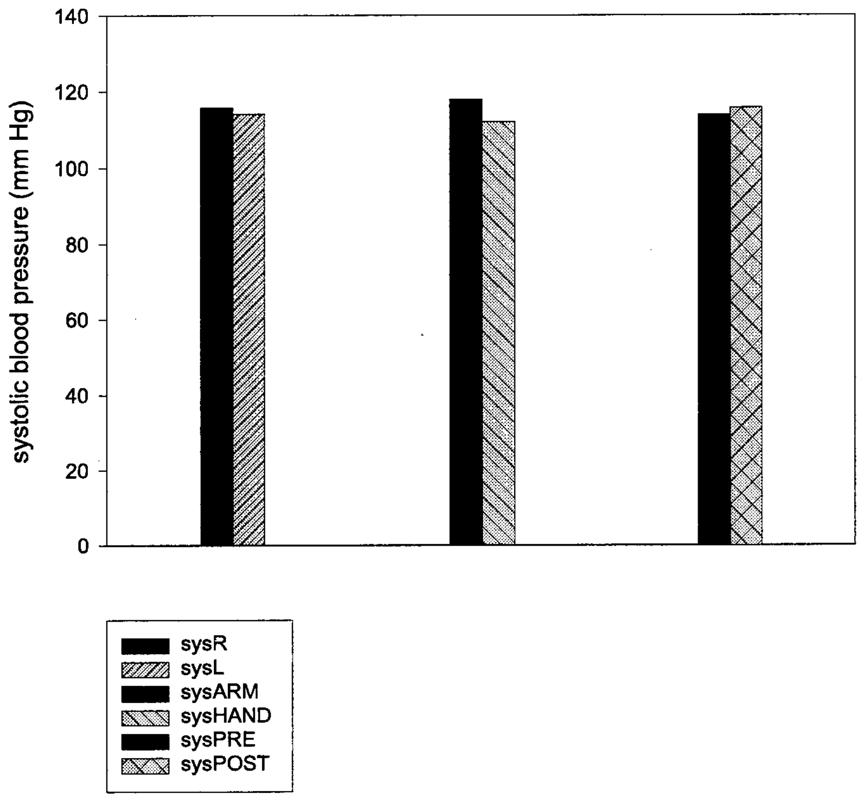


Figure 4.2. Baseline diastolic finger pressure grouped by side, arm-hand and pre-posttest.

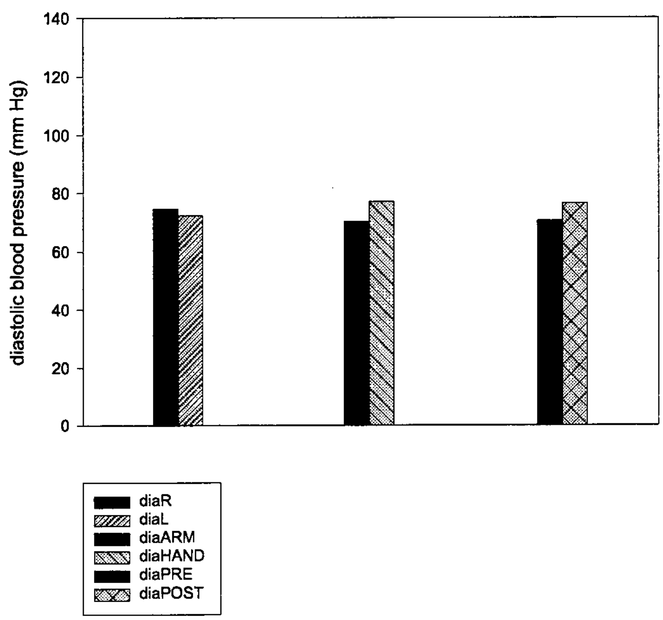


Figure 4.3. Baseline finger mean arterial pressure grouped by side, arm-hand and pre-posttest.

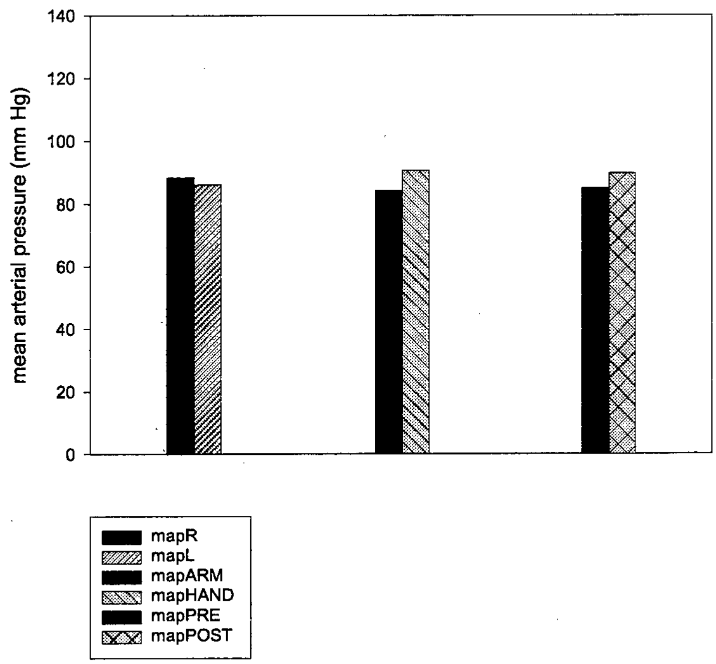


Figure 4.4. Pulse rate across 80-cm range of hand positions.

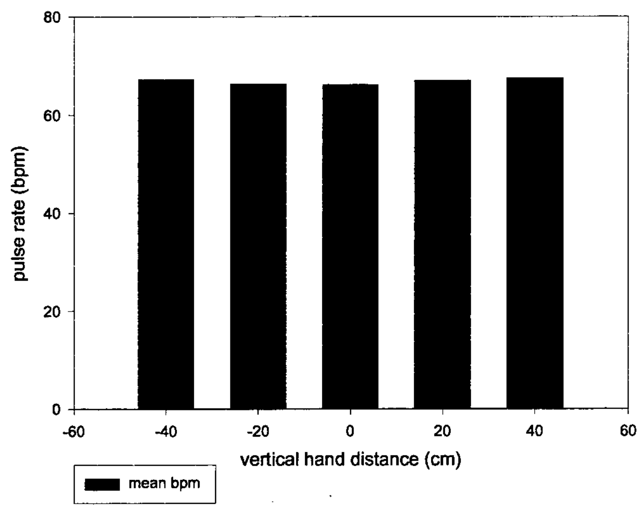


Figure 4.5. Mean time in position across 80-cm range of hand position, significant at –40 cm.

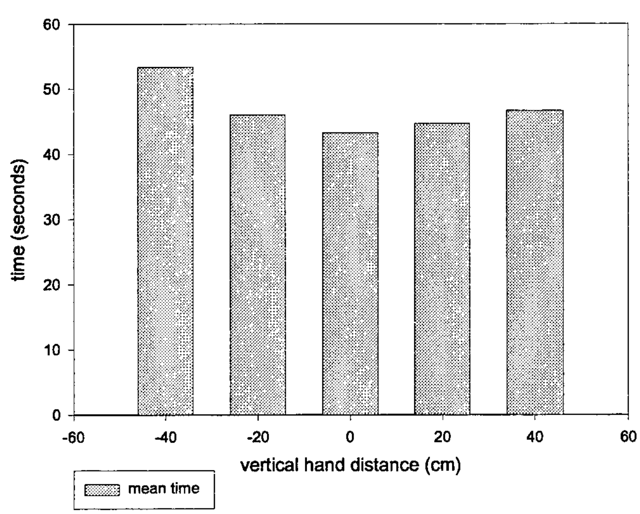


Figure 4.6. Systolic long finger pressure, neutral wrist, all subjects.

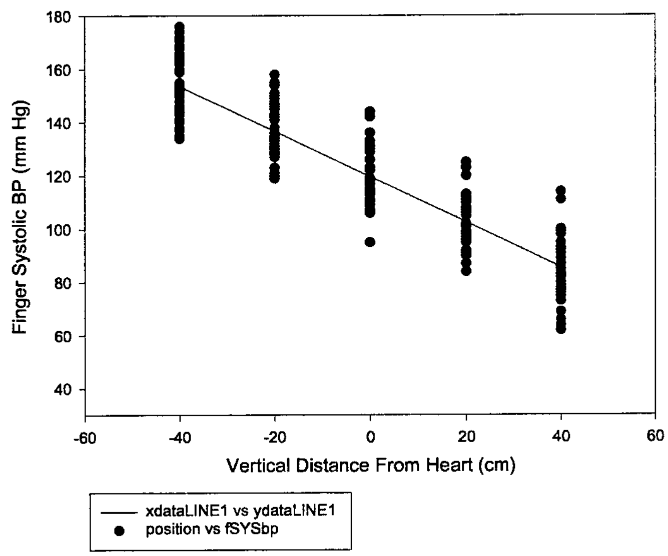


Figure 4.7. Diastolic long finger pressure, neutral wrist, all subjects.

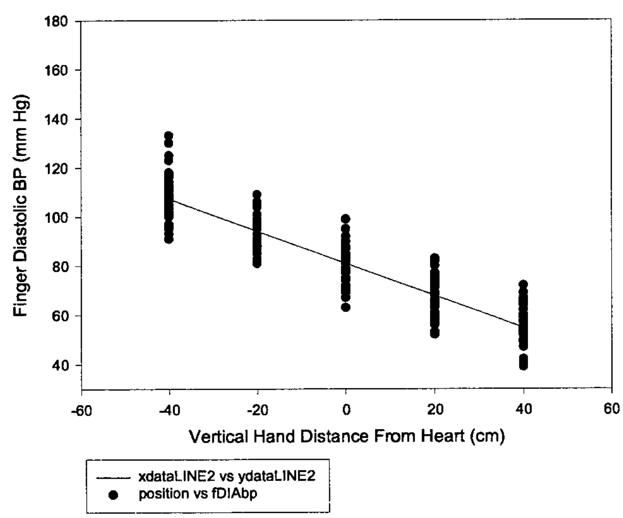


Figure 4.8. Long finger mean arterial pressure, neutral wrist, all subjects.

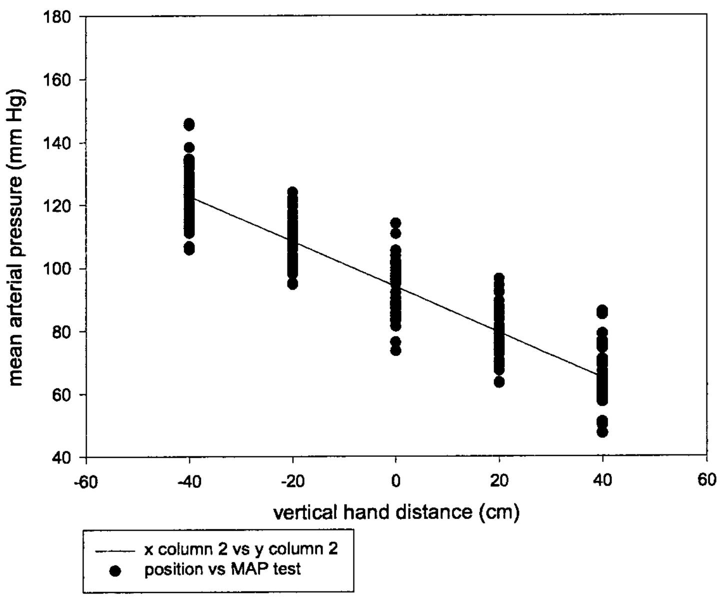


Figure 4.9. Predicted systolic pressure for neutral and flexed wrist positions across 80-cm range of hand positions.

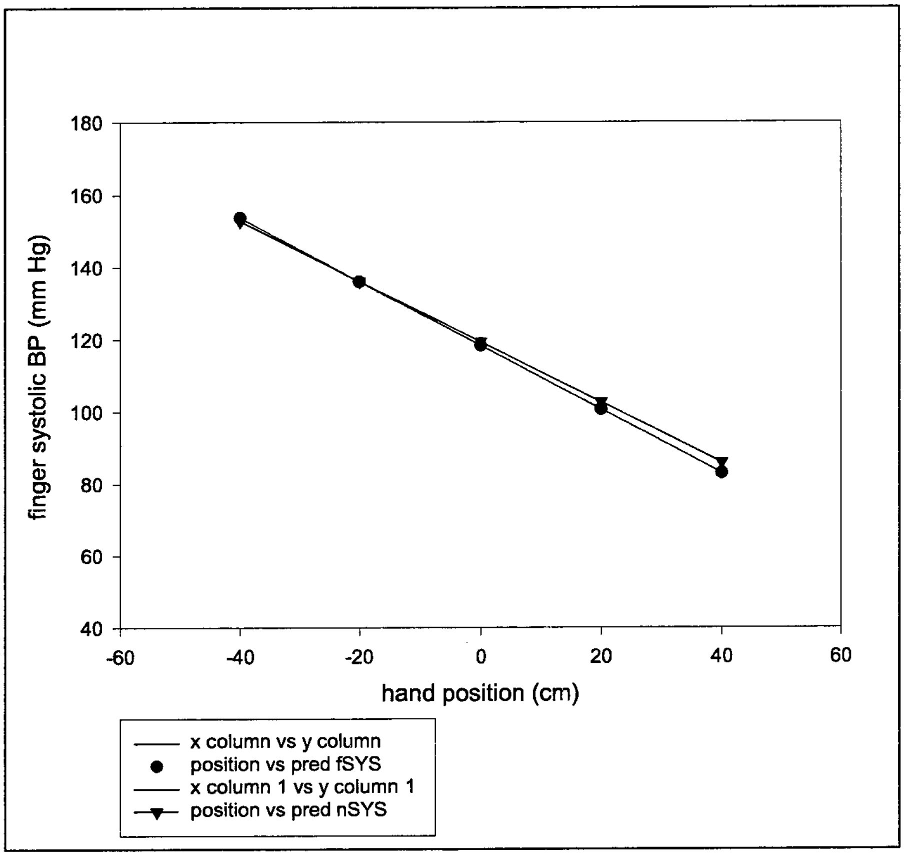


Figure 4.10. Predicted diastolic pressure for neutral and flexed wrist positions across 80-cm range of hand positions.

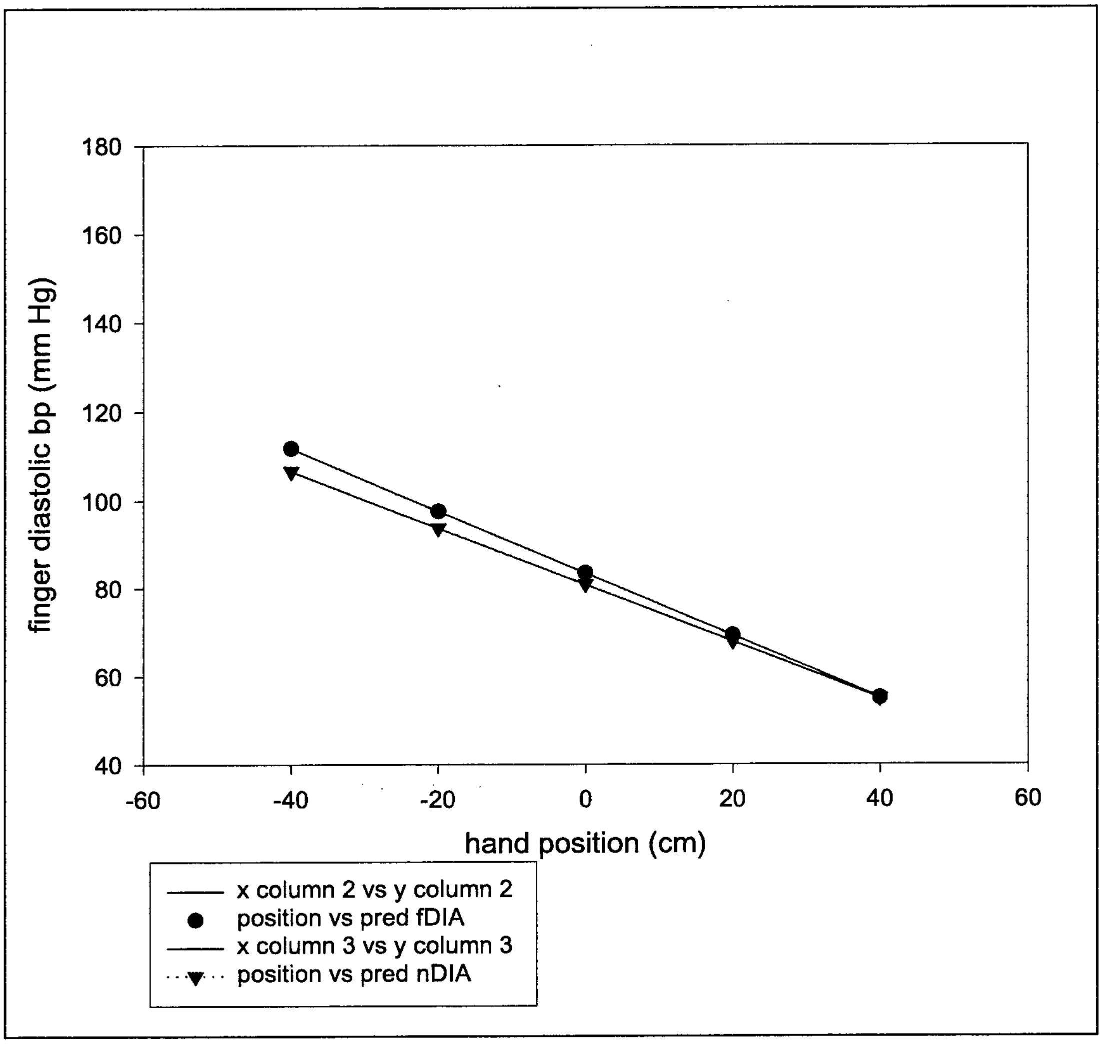
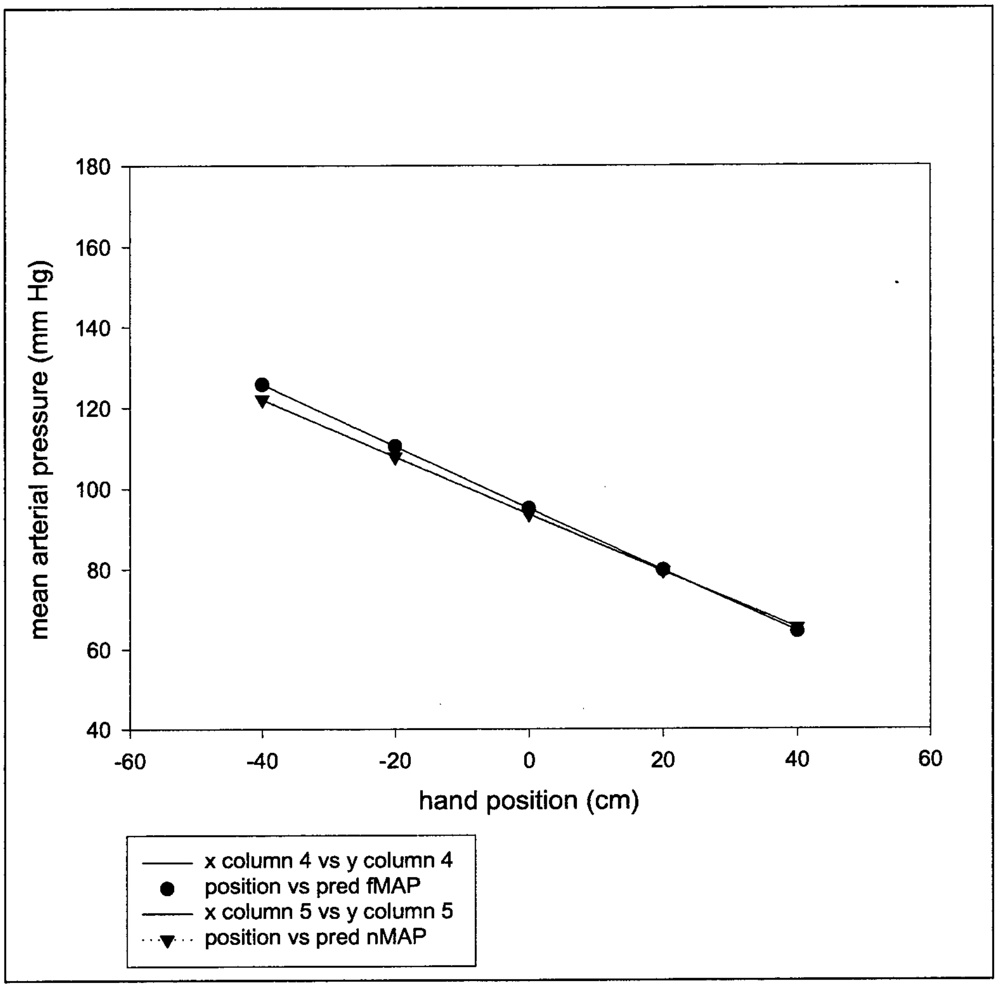


Figure 4.11. Mean arterial pressure for flexed and neutral wrists measured at the long finger.



CHAPTER 5
DISCUSSION

Introduction

The purpose of this study was to examine and evaluate some of the effects of placing the hand in an overhead position (similar to a common work posture), such as changes in pulse rate and blood pressure at the hand. Previous authors have reported blood pressure changes in the distal limb upon elevation (Ashton 1975, Hill 1909, Kahn 1919, Mitchell 1964, Hildebrandt et al 1993). Compared to previous reports, this study examined a broader range of positions (-40, -20, 0, 20 and 40 cm) in addition to two wrist positions common to workplace tasks (neutral and end range flexion) not previously studied. Specifically, this study examined the acute effects on the pulse rate and blood pressure of the long finger while placing the hand above and below the head in neutral and flexed wrist postures. These blood pressure values may then reflect the related tissue perfusion in the wrist and hand. Systolic and diastolic pressures were sampled indirectly in the long finger, then mean arterial pressure was calculated for each subject. Varying finger pressure responses to changing hand elevation and wrist position were found for each independent variable. In addition, time spent in test position was assigned as a dependent variable and compared to hand position and wrist position, to determine if time was a factor in finger pressure changes. Baseline testing was performed to establish measurement reliability and to compare long finger pressures to brachial pressures. Post hoc analysis was done for blood pressure comparisons and for pulse rate comparisons between hand positions in neutral wrist position with pre-planned comparisons between hand position, wrist position and hand/wrist interaction. The finger pressure regression line slopes and intercepts for neutral wrist were derived, and the slopes and intercepts for flexed wrist compared to neutral wrist data. To allow the control conditions to be compared to test conditions, the slopes and intercepts for test hand were compared to control hand slopes and intercepts.

This chapter will discuss the results obtained for each dependent variable. In addition, these results will be compared to previous research. This will be accomplished by comparing finger pressure and pulse rate for each condition. In addition, finger pressure slopes and intercepts of the test hand will be compared to that of the control hand. In addition, baseline pressures will be compared right to left side, hand to arm, and pretest to posttest baseline conditions. At the end of each section for the dependent variable, its null hypothesis will be accepted or rejected. The relationships of the independent variables with time in position and pulse rate will be discussed. Conclusions and summaries will be given. Finally, limitations of this study will be listed.

A general summary of these results demonstrates a statistically significant linear relationship and a negative correlation between hand position and long finger pressure. This linear and negative correlation is demonstrated for both flexed wrist and neutral wrist postures, producing coincident regression lines. Thus, no significant interaction exists between long finger blood pressure values associated with wrist-neutral and wrist-flexed postures. There exists no effect of the test conditions on pulse rate in either flexed or neutral wrist postures across the range of hand positions tested. With the exception of –40 cm position, there exists no effect of the test conditions on time in position in either flexed or neutral wrist postures across the range of hand positions tested. For all test conditions, control hand slopes differ significantly from test hand slopes, with control hand slopes indistinguishable from zero and thus interaction was found between test and control data. A discussion now follows, of the responses of systolic, diastolic and mean arterial pressures across baseline conditions, and upon the range of hand positions and wrist postures examined during test conditions.

Baseline Systolic Blood Pressure

Baseline systolic blood pressure model consists of right/left side sampling, arm/hand sampling, pretest/posttest sampling, subject variability, and interaction terms. After taking into account measurement error and instrument resolution, no significant difference was found between these conditions and systolic finger pressure. Specifically, no difference greater than 6 mm Hg instrument (measurement error) and 1 mm Hg resolution was found in systolic finger pressure and right/left side, arm/hand locations, and pretest/posttest periods.

Statistical differences were present in the initial findings but were overshadowed by measurement error. The model explained over 97% of the variation in finger systolic pressure, and thus appeared to appropriately represent systolic finger pressure during baseline conditions. Differences between left (control hand) and right (test hand) during test conditions were small (1.6 mm Hg), with right hand higher than left hand, and the difference well within measurement error. Thus, differences between right (test) hand and left (control) hand during the main body of the study can be attributed to the test conditions and not to inherent differences between right and left hand systolic finger pressure readings. Differences between pretest and posttest pressures were similarly small (1.9 mm Hg), with posttest higher than pretest. This indicates no differences in systolic finger pressures from pretest (initial data collection) to posttest (final data collection) on each day. Likewise, this indicates the changes in systolic finger pressure during test conditions are not attributed to inherent changes occurring over time or as a result of the test.

Differences between diastolic arm and hand pressures were found between all three baseline conditions. Differences between right/left hands of 2.3 mm Hg were found (right higher than left), as well as 6.0 mm Hg between pretest and posttest (posttest higher than pretest). As in systolic baseline data, these diastolic differences fall within measurement error. As with baseline systolic pressure, no differences between baseline diastolic conditions are present, and differences occurring during elevated hand test conditions can then be attributed to these test conditions.

Differences between arm (brachial artery) and hand (digital artery) systolic finger pressure of 5.9 mm Hg were found in this study, with arm systolic pressures recorded higher than hand systolic pressures. Diastolic pressure differences of 6.8 mm Hg were found, with hand higher than arm. These differences in pressure also fell within measurement error of 6 mm Hg and 1 mm Hg resolution. The findings of this portion of the study agree with findings of previous studies of finger systolic and diastolic pressure values showing agreement with brachial systolic pressure values, using automatic oscillometric blood pressure units (Nijboer et al 1988, Idema 1989, Iyriboz 1990, Bridges and Middleton 1997, Henneman and Henneman 1987, Epstein et al 1991). In contrast to the findings of this study, these previous authors have reported finger pressures greater than brachial pressures in these comparisons. Previous authors (Nijboer et al 1988, Idema 1989, Iyriboz 1990, Bridges and Middleton 1997, Henneman and Henneman 1987Epstein et al 1991) reported 4-8 mm Hg systolic differences, 8-13 mm Hg diastolic differences and 5-8mm Hg MAP differences between finger and brachial readings. The baseline hand-to-arm pressure differences found in this study are in general agreement with the magnitude of the differences in pressures previously reported by the above authors. However, the findings of this study differ from prior studies in that arm pressures are higher than finger pressures.

Mean arterial pressure (MAP) baseline findings followed systolic and diastolic pressure findings, with 2.1 mm Hg difference in right to left side (right higher), 4.6 mm Hg difference in pretest to posttest (posttest higher), and arm to hand difference of 6.5 mm Hg (hand higher). MAP is a measure of tissue perfusion (McArdle et al 1991) and its value is derived from systolic and diastolic values (one-third of difference between systolic and diastolic pressure, added to diastolic pressure) (McArdle et al 1991). Thus, in the absence of outliers in the baseline data, MAP results are expected to follow systolic and diastolic data. Again, measurement error and instrument resolution required conservative interpretation of these statistically significant results to conclude that no difference exists between all three baseline conditions for systolic, for diastolic and for MAP data. In the absence of statistical significance, no interaction can be shown. Thus, we accept the null hypothesis that no difference exists for conditions of systolic pressure, for diastolic pressure and for mean arterial pressure of right to left side, arm to hand, and pretest to posttest.

Systolic, Diastolic, and Mean Arterial Pressure vs. Hand Position

Three models were used to describe finger blood pressure changes during test hand position changes for neutral wrist: systolic, diastolic and mean arterial pressure each as a function of hand position and subject variability. Hand position and subject variability both contribute significantly to the model for each dependent variable, ranging from 96% to 98% of the variance explained by the model. Neutral wrist models were used to test the effects of vertical hand displacement. Later, responses from flexed wrist models were compared to responses from neutral wrist models, with neutral wrist models as a standard for comparisons purposes. Flexed wrist conditions provide an additional variable that neutral wrist conditions do not possess, that is, a flexed wrist may present a potential barrier to blood flow to the hand and thus affect finger blood pressure. Evidence for mechanical neurovascular compromise exists at the shoulder and wrist (Sanchez-Garcia 1997, Magee 1992, Farrell 1998). Blood vessels near the shoulder may become compromised when shoulder positions exceed 55° horizontal abduction (Magee 1992). Evidence exists for a "double-crush" phenomena, where an individual with CTS may also have proximal neurologic deficits near thoracic outlet and proximal brachial plexus at the shoulder (Farrell 1998). At the wrist, mechanical blockage of blood flow through radial artery by thrombus formation has been demonstrated to produce CTS symptoms and electrophysiological evidence, and all symptoms resolved when the thrombus resolved (Sanchez-Garcia 1997). As with neutral joint position at the shoulder stated above, neutral wrist conditions would then provide the least vascular compromise and thus the best opportunity of the two wrist conditions to test the hydrostatic column effect on finger pressure changes. Thus, neutral wrist results were selected as the results against which all other comparisons would be made.

There was a significant effect due to hand position and due to subject variability in all three models. The significant effect due to subject variability was expected. MAP varied across a range from 93-120 mm Hg at 0 cm hand position (Figure 4.8). Thus, notable variation between subjects was present. The effect due to subjects exhibits the appropriate placement of the remaining variability in the error term of the analysis of variance procedure. For all three models of finger pressure, Bonferroni-adjusted comparisons of mean finger pressure values showed statistical significance for each pairwise comparison. For all three models, finger pressure gets smaller as the hand moves higher, for every subject tested. For systolic finger pressure, Bonferroni-adjusted mean values range from 16.3 to 18.1 mm Hg change over 20 cm change. These mean values exceed measurement error and instrument resolution, and provide a ratio of 0.89 mm Hg/cm. The largest mean difference between subjects within a single hand position (for a 20 cm span) was 2.2 mm Hg, which fell well within measurement error. Thus, a consistent change of 0.89 mm Hg/cm was found between each hand position. Diastolic finger pressure changes ranged from 12.7 to 14.6 mm Hg, exceeding measurement error and providing a ratio of 0.67 mm Hg/cm change. Similarly, the largest mean difference between subjects within a single hand position was 1.9 mm Hg (Table 4.12). Mean arterial pressure ranges from 14.2 to 15.1 mm Hg, exceeding measurement error and possessing a ratio of 0.73 mm Hg/cm. Again the largest mean difference between maximum and minimum mean values over a 20 cm span is 0.9 mm Hg, which again fell within well measurement error. Mean arterial pressure (MAP) is the most appropriate measure to compare hydrostatic column effects, since MAP represents the average pressure in the artery at any point in time (McArdle et al 1991, Burton 1968, Ashton 1975). Thus, the changes in finger pressure from one hand position to the next are consistent within measurement error.

Previous authors have identified the hydrostatic column effect ratio to be 0.78 mm Hg/cm change in height from heart level (McArdle et al 1991, Burton 1968, Ashton 1975). MAP results identify 0.73 mm Hg/cm, which is lower than previous authors' predicted change due to hydrostatic forces (McArdle et al 1991, Burton 1968, Ashton 1975). Using 0.78 mm Hg/cm conversion factor over 80 cm range gives a 62.4 mm Hg range of pressures for MAP. Comparing the predicted 62.4 mm Hg range to the actual range of 58.5 mm Hg/cm, the difference is 3.9 mm Hg. This difference falls within measurement error of the instruments used in this study of finger pressure measurement. Thus, the difference between predicted and observed could be explained by measurement error alone. In addition, a range of hand positions larger than the 80 cm used in this study may provide values closer to the 0.78 mm Hg/cm conversion factor previously published and discussed above.

We may conclude from these findings that under these conditions and with a neutral wrist, the finger pressure values for systolic, diastolic and MAP of the elevated test hand vary by vertical distance from the heart. We therefore reject the null hypothesis, that there is no effect on finger pressure when the vertical hand distance changes from the heart and accept the alternative, that changing the vertical hand distance from the heart does have a significant effect on the finger blood pressure. Further, these mean arterial pressures are consistent with the predicted pressures of a hydrostatic column of fluid, based on the work of previous authors stated above, within measurement error.

Pulse Rate and Time in Position vs. Hand Position

The model with pulse rate as a function of wrist position, hand position subject variability and interaction terms was created. This model would then allow a test of the null hypothesis that changes in wrist position and hand position are associated with changes in pulse rate. Pulse rate could possibly increase as a physiological response to decreases in finger blood pressure, in an attempt by the body to maintain more constant tissue perfusion during periods when perfusion drops. For this pulse rate model, these variables accounted for greater than 95% of the variance, and thus appears to represent the model well. Hand position and subject variation explained virtually all the variance in the model and were significantly correlated with pulse rate, while wrist position and interaction terms did not. Mean pulse rate did not change when classified by wrist position or by hand position, and Bonferroni-adjusted pairwise comparisons were not significantly different. Differences in pairwise mean comparisons (0.3 to 1.3 bpm) did not exceed measurement error (4 bpm) with resolution of 1 bpm.

Pulse rate may increase during exercise and strenuous physical work (McArdle et al 1991, Burton 1968) and as a result of certain medications and psychological stressors (Wickens et al 1997). Medications and psychological stressors were controlled or eliminated during data collection. Strenuous physical effort was eliminated from the data collection protocol with consistent rest periods between test positions, and by the pre-planned low-intensity nature of the tasks involved. Thus, when acute decreases in MAP occur, the tissue perfusion likely decreases and no compensatory effect of increased pulse rate occurs.

We may conclude from the results that under these test conditions, the effects of hand position and wrist position had no effect on pulse rate. Above-heart and below-heart hand positions had no effect on pulse rate, and wrist position had no significant effect. We therefore fail to reject the null hypothesis that there is no effect on pulse rate when the hand is actively moved to five different hand locations relative to heart level and two different wrist positions, and accept the null hypothesis.

A model with time in test position was created, with time in position as a function of wrist position, hand position, subject variability and interaction terms. This model would identify any effect of hand position and wrist position on time in position. If time in position varied with hand position, a case could be made that time in position contributed significantly to changes in finger pressure, which would then confound the effect of the hydrostatic column on MAP and tissue perfusion. This model accounts for 59% of the variance present, and the only independent variable significantly associated with time in position was hand position. Bonferroni-adjusted pairwise comparisons revealed the lone significant position of –40 cm (53.3 seconds), with all other positions (43.2 to 46.6 seconds) non-significant. Range of time in position was 10.1 seconds, with 6.7 seconds separating the next largest time value, both of which are greater than measurement error (5 seconds). Thus, -40 cm position is significantly different from the remaining other hand positions.

One plausible explanation for this finding is the relatively large finger pressure values recorded at –40 cm position compared to the remaining test positions. The finger bladder must fill with air, and slowly deflate to accomplish the pressure transducer voltage changes that must occur during finger pressure recordings. The larger the pressure value, the longer the time to inflate/deflate the finger bladder. Manufacturer's specifications provide the pressure monitor with arbitrary pressure targets for the finger bladder, with increments of 40 mm Hg greater than the initial 180 mm Hg when pressure measurement starts. Since the –40 cm hand position has the largest pressure readings of all positions, it follows that this position would also have the largest time in position values. The data appears to support this explanation, with time in position grouped between 43.2 and 46.6 seconds for all remaining hand positions. With a difference of 3.4 seconds between the remaining hand positions, and measurement error of 5 seconds, no detectable difference exists between time in position at these other four hand positions.

If time were changing as a function of hand position for the remaining positions, time would not cluster at 40, 20, 0, and –20 cm hand positions but would rather appear to vary across these test positions as well. To test this further, finger pressure readings could be repeated on subjects at positions further below heart level than –40 cm, and time in position compared to -40 cm position. In addition, the highest finger bladder pressure initiated by the finger monitor could also be recorded to relate the time in position to peak finger bladder pressure.

We may conclude from these results that during test conditions, the effects of hand position and wrist position on time were not apparent. The time data clustered around a 60 cm span and showed a significant difference at the highest pressure test position only. Time to fill finger the bladder was likely the factor influencing time in position to the greatest degree, and thus time in position likely had no effect on finger pressure readings. We therefore fail to reject the null hypothesis that hand position has no effect on time in position, and accept the null hypothesis.

Flexed Wrist and Neutral Wrist Pressures vs. Hand Position and Interaction Between Wrist Postures

A model was established above for neutral wrist finger pressures as a function of hand position, subject variability and interaction terms. Then, an identical model for flexed wrist was created and compared to neutral wrist by comparing regression line parameters of slopes and intercepts. In addition, models were created for finger pressure at the control hand as a function of test hand position, wrist position, subject variability and interaction terms. Slopes and intercepts were compared to zero for statistical significance, compared across wrist positions to identify the effect of wrist position on slope and intercept, and compared across test and control hands to identify differences between test and control hand. For systolic finger pressure, no significant difference was found comparing slopes across wrist positions for test hands. Test hands with each wrist condition showed slopes and intercepts significantly different from zero for systolic, diastolic and MAP. Thus, systolic pressure revealed coincident lines between flexed and neutral wrist positions. For diastolic and MAP at the finger, results also revealed coincident lines for test hand within measurement error. That is, no effect of flexed wrist was shown for all three models compared to neutral wrist.

For control hands during test hand conditions, slopes were significantly different from zero, but across the 80 cm measurement range the control hand did not vary greater than measurement error. Control hand slopes for systolic, diastolic and mean arterial pressure did not exceed the critical value of 0.0875mm Hg/cm necessary to reveal detectable differences outside of measurement error. Thus, the control (left) hand pressures did not change during test (right) hand conditions. Control hand regression lines showed interaction with test hand regression lines in all cases, regardless of wrist position. In future research, using equipment with greater sensitivity across a range of hand positions >80 cm may reveal otherwise unexpected changes in the control hand during test hand variations.

Rationale for Acute Changes in Blood Pressure Observed During Changes in Hand Position

Blood is a colloidal suspension fluid with a specific gravity of approximately 1.06 grams/cm^3, and the movement or flow of blood possesses some of the characteristics of fluid mechanics (Burton 1968). Blood flow through an artery is dependent upon many factors, only one of which is the pressure of the blood created by the contraction of the ventricles during systole (Burton 1968). Rather than blood flowing from a point of higher pressure to one of lower pressure, blood more accurately flows down a gradient of total fluid energy. The complete driving force of blood that provides blood flow is the difference between the total fluid energy between any two points in the vessel (Burton 1968). The total fluid energy is the sum of the potential energy (blood pressure from contracting ventricles), the gravitational potential energy (based upon fluid level) and the kinetic energy of the fluid (inertia of the blood, mass multiplied by its velocity). This total fluid energy can be expressed in the equation:

$$E_{total} = P + \rho g h + \frac{1}{2} \rho v^2$$

where: E = total energy, ergs/cm^3
P = pressure of the blood, dynes/cm^2

ρ = density of blood, 1.06 grams/cm^3
g = acceleration due to gravity, 980 cm/sec^2
h = height relative to an arbitrarily defined datum level, cm
v = velocity of the blood at this datum level, cm/sec

All terms may be expressed equivalently as:

ergs/cm^3 = dynes/cm^2

and: 1330 dynes/cm^2 = 1 mm Hg.

These equivalent expressions allow conversion from units of energy (ergs) to standard measurement units of blood pressure (mm Hg). Thus, blood flow is dependent upon the sum of all three terms in the above equation, and measured blood pressure values may be directly affected by these three terms.

Provided the blood velocity and blood density is relatively constant at a given point in a vessel, the kinetic energy of the blood (represented by $\frac{1}{2} \rho v^2$) may be considered constant during steady-state conditions for a given segment of vessel. At the level of the capillary bed and thus the area of nutrient exchange and tissue nutrition, where blood velocity decreases to its lowest rate (0.5 cm/sec), the contribution of kinetic energy to total blood energy and blood flow is negligible (Burton 1968). The equation for total fluid energy would then be reduced to:

$$E_{total} = P + \rho g h$$

and static fluid conditions now largely exist.

Both terms now contribute all of the fluid energy available for blood pressure (Burton 1968). Elsewhere in peripheral vessels, the kinetic energy contribution to the total fluid energy is relatively constant during steady-state conditions, at a given segment of vessel. Thus, the two largest contributors of total fluid energy at the level of the capillary bed are that of the pressure energy from the contracting ventricles and the hydrostatic (gravitational) potential energy.

As a result of relatively low flow rates in the capillary bed, the blood is nearly static here and thus hydrostatic fluid mechanics largely apply (Burton 1968). Pascal's 1663 Laws of Hydrostatics (Burton 1968) states that: 1-Hydrostatic fluid pressure acts equally in all directions; 2-Fluid pressure is equal at all points at the same level of fluid; 3-Fluid pressure increases as the depth below the surface increases. Applying Pascal's Three Laws to blood in a continuous vessel, the hydrostatic fluid pressure is equal in all directions at the same level and will change depending upon the change in distance from its reference level. This change in hydrostatic pressure may then add to or subtract from the pressure energy from the contracting ventricles (Burton 1968). Therefore, assuming energy is constant, then the change in hydrostatic pressure is equal to the change in depth from the surface (or reference point), by the product ρgh (in units of dynes/cm^2 or mm Hg per cm) (Burton 1968). The conversion factor for changes in systolic blood pressure due to this hydrostatic or gravitational potential energy is:

$\rho gh = (1.06)(980)(h) = (h\text{ cm})\ (1038.8)\ \text{dynes/cm}^2$

with: $1330\ \text{dynes/cm}^2 = 1\ \text{mm Hg}$

then: $(h\text{ cm})\ (1038.8)\ \text{dynes/cm}^2\ /(1330\ \text{dynes/cm}^2) = 0.78\ \text{mm Hg}$ change and therefore: 1 cm change in height = 0.78 mm Hg change in pressure,

or 15.6 mm Hg change with 20 cm change in vertical height.

This mm Hg change in pressure is represented by mean arterial pressure, and may be added to or subtracted from the mean arterial pressure measured or estimated at the reference point of heart level (Burton 1968). Thus, in an example of a person 6 feet tall, their head is approximately 60 cm above the heart, the systolic pressure in the hand when raised to head level would be expected to decrease by:

(60) x (0.78) = 47 mm Hg

due to hydrostatic pressure changes. A similar magnitude change in mean arterial pressure would follow, when the hand is placed 60 cm *below* heart level. Here, an *increase* in mean arterial pressure of 47 mm Hg would be expected. Thus, a model of hand elevated positions can be formulated such that the mean arterial pressure (and ability of nearby tissue perfusion and nutrition) may be predicted, in the absence of confounding variables.

Adequate mean arterial pressure also provides adequate arterial transmural pressure, which allows the inside diameter of the artery (and its vascular bed of arterioles and capillaries) to remain sufficiently large to keep the vessel patent and allow blood to flow to the target tissues. If the transmural pressure falls below a critical closing pressure, the elastic nature of the vessel wall will cause it to collapse and all blood flow and its perfusion will cease, thus creating an ischemic condition for the tissue usually supplied (Burton 1968).

Transmural pressure of the vessel is directly proportional to mean arterial pressure (Burton 1968). Transmural pressure will decrease as mean arterial pressure decreases; if mean arterial pressure decreases sufficiently, the vessel no longer remains patent. Gaskell and Burton in 1952 found that transmural pressure was decreased and reached critical closing pressure upon elevating the human leg above the heart; upon collapse of the vessel wall, the flow of blood ceased in the distal portion of the limb and ischemia of the tissue resulted (Ashton 1975). Transmural pressures will elevate during conditions of increased pressure, with vasomotor tone counteracting this increased transmural pressure and preventing blowout injury (aneurysm) of the vessel wall (Burton 1968).

Critical closing pressure of the vessel may range in the wrist and hand from 10 mm (fully vasodilated) to 60 mm Hg (fully vasoconstricted) with a mean arterial pressure of 25 mm Hg in the capillary bed under resting steady-state conditions (Burton 1968). In a condition where transmural pressure drops past critical closing pressure coupled with vasoconstriction (as in hypotensive shock), the lumen no longer is patent and total fluid energy decreases at that point of the vessel which results in cessation of blood flow and perfusion. In other physiological states of vasoconstriction, such as cold, critical closing pressures may be reached at 60 mm Hg in the hand (Burton 1968). It may then be inferred that coupling cold work environments with hand overhead positions will likely lead to decreased tissue perfusion, vessel wall collapse and cessation of blood flow to nearby tissues with ensuing tissue ischemia and increased risk of MSD.

Mean velocity of blood flowing in the peripheral arteries of the limbs is dependent upon the cross-sectional area of the artery, and is approximately 10 cm/second; in the capillary bed, the flow slows to 0.5 cm/second (Burton 1968). Mean arterial pressure provides a measure of perfusion of the blood and its nutrients (in particular, oxygen) to move from the blood to the tissues and thus provide the necessary components for cell metabolism. In capillaries where flow velocity is near its lowest values, adequate mean arterial pressure is critical to providing adequate tissue nourishment. When flow rate is high and its contribution to total fluid energy is high, low perfusion pressure (and its corresponding low contribution to total fluid energy) can be compensated in part by relatively high blood velocity during nutrient exchange across the membrane. When blood pressure (and thus perfusion pressure) is low and blood velocity is low, blood velocity cannot provide compensation for decreased blood pressure to the total fluid energy, and thus transmural pressure remains low and the tissue cannot be adequately nourished. Venous blood contains approximately 75% oxygen compared to arterial blood, making the exchange efficiency 25% (Burton 1968). Compounding this 25% exchange efficiency with a reduced perfusion pressure may reduce oxygen further, approaching levels that produce ischemia to the supplied tissues. MSD risk factors such as vibration and cold may compound overhead hand postures to effectively lower the threshold of critical closing pressures and risk ischemic conditions in the wrist and hand.

As stated earlier, previous authors have reported blood pressure changes in the distal limb upon elevation (Ashton 1975, Hill 1909, Kahn 1919, Mitchell 1964, Hildebrandt et al 1993). The findings of this study generally agree with the findings of these previous investigators. However, a broader range of hand positions was tested in this study (80 cm) than in previous studies (Ashton 1975, Hildebrandt et al 1993) and wrist positions were studied that had not been examined previously. Ashton et al examined compartmental pressures in the foreleg, and derived blood pressure critical closing pressures without actually measuring blood pressure. Findings from the leg were then applied to the arm without actually measuring upper limb pressures. Hildebrandt et al measured blood flow in the arm by impedance and venous-occlusion plethysmography, in a 54 cm range from heart level and above only. This study examined both above-heart and below-heart test positions, using less precise measurement devices, identifying and confirming a continuous spectrum of finger pressure that can be completely explained by the hydrostatic effect on a fluid column (Burton 1968). Hildebrandt et al used passive positioning of the test arm, and utilized neutral wrist positioning only. Active arm placement and non-neutral wrist positioning may be a more valid representation of actual work environments, and allow more direct application to workers required to perform tasks with hands above head level. This study examined the acute effects of seated subjects, as did Hildebrandt et al (1993) and Cook et all (2000). Evidence exists to suggest blood pooling in the legs my occur with standing postures (Jacobsen et al 1994, Hildebrandt et al 1993). Standing postures may more accurately reflect tasks performed in the construction trades, where seated tasks may be more commonly seen in equipment operation, assembly line tasks and tasks of a more critical nature requiring fine dexterity (Wiker et all 1989). Standing postures would likely exacerbate decreased pressures in the hand and the corresponding decreased nearby tissue perfusion, and require more sensitive equipment to record such pressure changes.

Mitchell et al measured brachial artery pressures only, using Riva Rocci methods of blood pressure measurement. Blood pressure to the wrist and hand were not discussed. Kahn studied brachial arm pressures over a range of 0° shoulder abduction to 180° abduction, without mention of length of upper limb or measurement of vertical distance from heart level. In addition, possible differences between brachial and digital artery pressures were not discussed. Hill studied differences in blood pressure at the brachial and posterior tibial artery measured by Riva Rocci methods comparing differences between readings as dependent upon differences in vertical distance and due to hydrostatic column effect on blood pressure. Hill sampled blood pressure before and after exercise and before and after hot soaking the limb. During that era it was believed the rigidity of the arterial wall gave false positive readings of hypertension, and that by hot water soaks the artery could be made more elastic, and interpreted their findings of decreased pressures after hot soaks as successfully increasing arterial elasticity. Finger pressure measurements were not performed in this early research, as technologic advancements to make this possible came much later.

The findings of this study are consistent with findings of decreased speed and accuracy while attempting tasks performed overhead (Wiker et al 1989). Previous authors have demonstrated a performance decrement greater than 20% associated with overhead work (Wiker et al 1989), where speed and accuracy of movement were compared in various above-shoulder (90 to 135° shoulder elevation) and below-shoulder (<90° shoulder elevation) reach postures. Performance decrements were immediate, with slower and more difficult performances associated with overhead tasks, and dependent upon the difficulty of task load at the hand and length of duty cycle (Wiker et al 1989). These authors conclude that to minimize performance decrements, hands should be limited in the amount of time spent overhead to short duty cycles (<20seconds work:60 seconds rest cycle), < 35° above horizontal and hand loads <0.40 Kg (Wiker et al 1989). Decreased tissue perfusion in the wrist and hand is consistent with this performance decrement, especially with respect to fine motor coordination using the small intrinsic muscle groups of the hand with limited tolerance for decreased tissue perfusion in overhead postures. The authors suggested selecting taller workers and redesigning workstations to avoid repeated or prolonged overhead tasks performance. Further, another study (Wiker et al 1989) revealed localized muscle fatigue by EMG analysis to a higher degree in overhead tasks performance compared to below-head level tasks, even in light-weight manual assembly environments.

In a study of wrist postures and carpal tunnel pressures, investigators found wrist flexion >30° during finger flexor loading significantly increased carpal tunnel pressures (Keir et al 1997). Critical threshold pressures >30 mm Hg are shown to induce nerve damage when present for prolonged periods (Hargens et al 1979), with >30 mm Hg pressure present within the carpal tunnel during wrist postures of 45° flexion with loaded finger flexor tendons (Keir et al 1997).

Actual work environments likely provide a combination of factors that would hinder tissue perfusion and nourishment. The findings of decreased tissue perfusion with overhead flexed wrist may be compounded by the findings of Keir et al. The combined effect of overhead hand placement and wrist flexion with flexor tendons loaded is not described by these authors, but the combined effects of decreased tissue perfusion and increased carpal tunnel pressures would likely compound ischemic conditions at the elevated wrist and hand. When increased carpal tunnel pressures occur, the presence of an overhead hand would further starve these tissues of nutrients. Conditions of vasospasm such as cold, nicotine and caffeine would likely compound the decreased tissue perfusion in the wrist and hand upon overhead placement. In addition, combinations of these vasoconstricting elements may have a synergistic effect on reducing tissue perfusion in the wrist and hand, thus further starving tissues of nourishment. Vasospasm due to these factors was controlled or eliminated in this study, to avoid unwanted variability. These factors would likely require investigation in future studies, to resemble more closely the actual working environments in the construction trades and manual materials handling occupations.

Further, muscle contraction and mechanical tissue loading would likely increase metabolic demands of the tissues, this occurring at a time when tissue perfusion and nourishment is most sparse. Kagaya and Homma found that forearm muscle contractions of 30% of maximum impede blood flow when sustained contractions are performed. Also, these authors reported forearm contractions of 10% of maximum had little or no effect upon forearm blood flow when performed in an intermittent fashion. Arm position for these authors was described as near heart level. With hand overhead, and resulting decreased blood flow and tissue perfusion, contractions of magnitude less than 30% of maximum may impede blood flow through the arm. Also, the application of tools, prolonged and sustained overhead positioning, muscle contractions and application of loads on the wrist and hand would likely worsen tissue perfusion and contribute to position-induced ischemia of the wrist and hand.

This study examined arm and hand blood pressure in a group of non-smoking, generally healthy people, with caffeine and exercise effects excluded. Actual worker groups would likely be composed of nicotine and caffeine users, and include workers with health problems possibly affecting cardiovascular and peripheral circulation. Position-included ischemia of the wrist and hand would then predispose the person to ischemic-related tissue damage and increased risk of MSD.

Conclusions And Summary

1. No detectable difference was found between all baseline pressure readings by right/left side, by arm/hand, and by pretest/posttest conditions.
2. A detectable and statistically significant difference was found for finger systolic, diastolic and MAP as a function of hand position, for the neutral wrist condition. Highest finger pressure values were found at –40 cm hand position, with progressively lower pressures at each increasing 20 cm increment. Lowest pressures were found at +40 cm hand position.
3. No detectable difference in pulse rate was found over the range of hand positions or wrist positions examined.
4. A detectable and statistically significant difference for time in position was found for –40 cm hand position. All other times in position were indistinguishable from one another, and clustered around the remaining four hand positions. The significant difference at –40 cm was explained by predetermined finger pressure monitor settings, and related to the highest pressure readings occurring at –40 cm hand position.

5. Systolic, diastolic and MAP for flexed wrist were indistinguishable from systolic, diastolic and MAP for neutral wrist positions. All control hand finger pressure regression line slopes were indistinguishable from zero. Interaction between test hand and control hand regression lines were found for both wrist positions. Control hand pressures did not vary with hand position, greater than measurement error.

In summary, this study showed that finger blood pressure measurements are stable over right to left side, upper arm to finger blood pressure values do not vary beyond measurement error, and finger blood pressure values do not change beyond measurement error over the course of testing subjects.

Further, finger blood pressure decreased with hand elevation above heart level, and finger pressure increased with hand placement below heart level. Highest pressures were found at –40 cm position, and lowest pressures were found at +40 cm position. These findings were shown regardless of whether the wrist was actively placed in a neutral position or an end range flexed position. The hydrostatic effect on a fluid column explained all of the change in finger pressure associated with hand position, within measurement error.

No effect was seen for pulse rate as a function of hand position or wrist position. No effect was seen for time in position up to 43 seconds. A significant effect was seen for –40 cm and explained by longer air bladder deflation times at the –40 cm position higher pressures.

These results indicate an acute decrease in tissue perfusion of the tissues of the wrist and hand upon placing the hand in an overhead position. In addition, these results reveal that by placing the hand below heart level the tissue perfusion of the wrist and hand will increase acutely. These tissue perfusion changes occur regardless of end range wrist flexion position or neutral wrist position. No compensatory effect of increased pulse rate or effect of up to 43 seconds time in position was seen to accompany decreases in finger pressure. Longer air bladder inflation/deflation times are required at the highest pressure position of –40 cm. The hydrostatic column effect can explain the entire change in finger pressure during test positions, within measurement error.

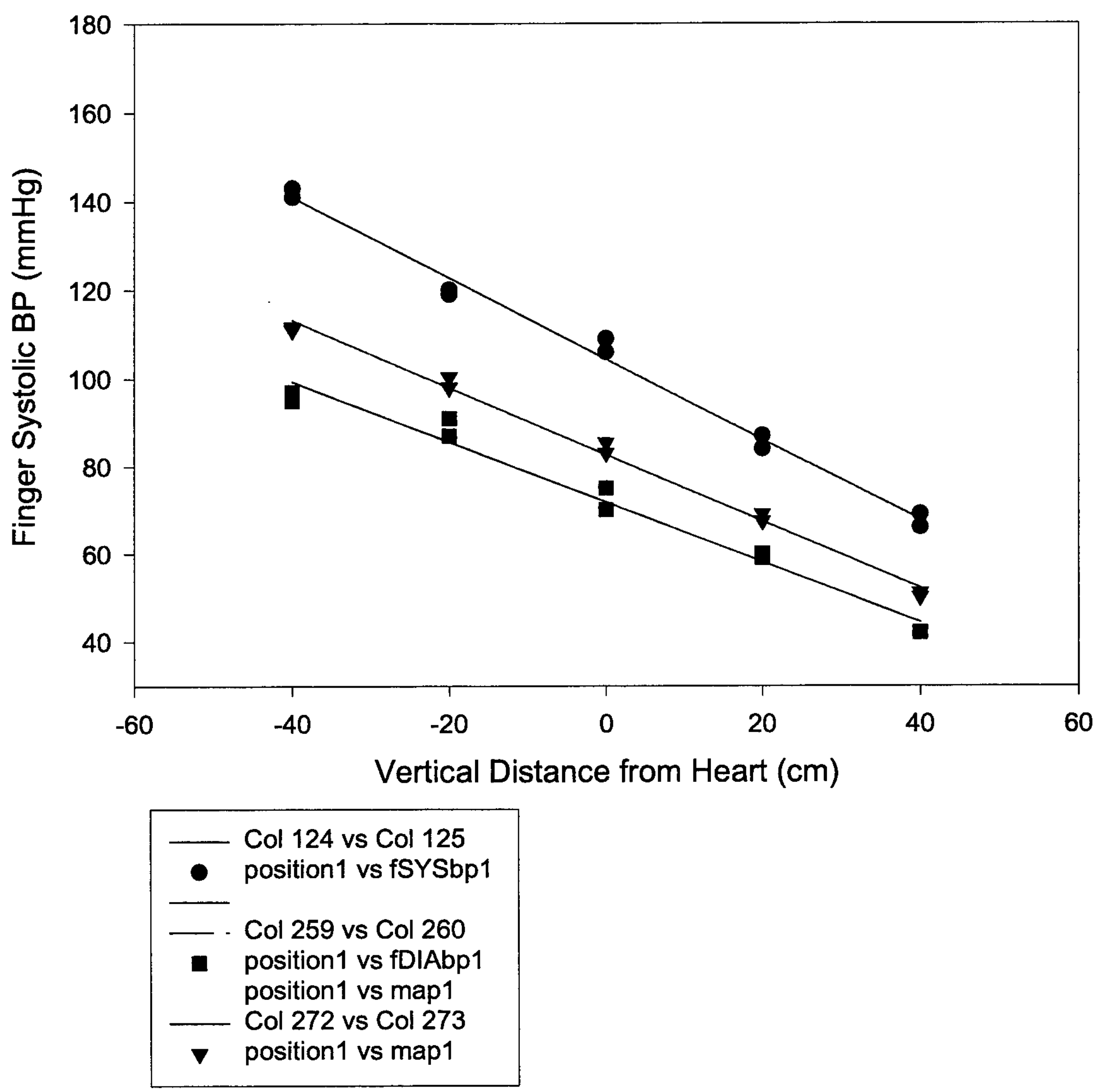
Limitations of the Study

1. Blood flow was measured indirectly with consumer grade equipment. The measurement of systolic and diastolic blood pressures were an indicator of mean arterial pressure. Invasive direct blood pressure measures or research-grade equipment could be a more precise measure of blood pressure.
2. Digital artery blood flow in the long finger represented blood flow to the tendon, bony and nerve structures of the wrist and hand. Direct blood flow to these specific structures was not studied.

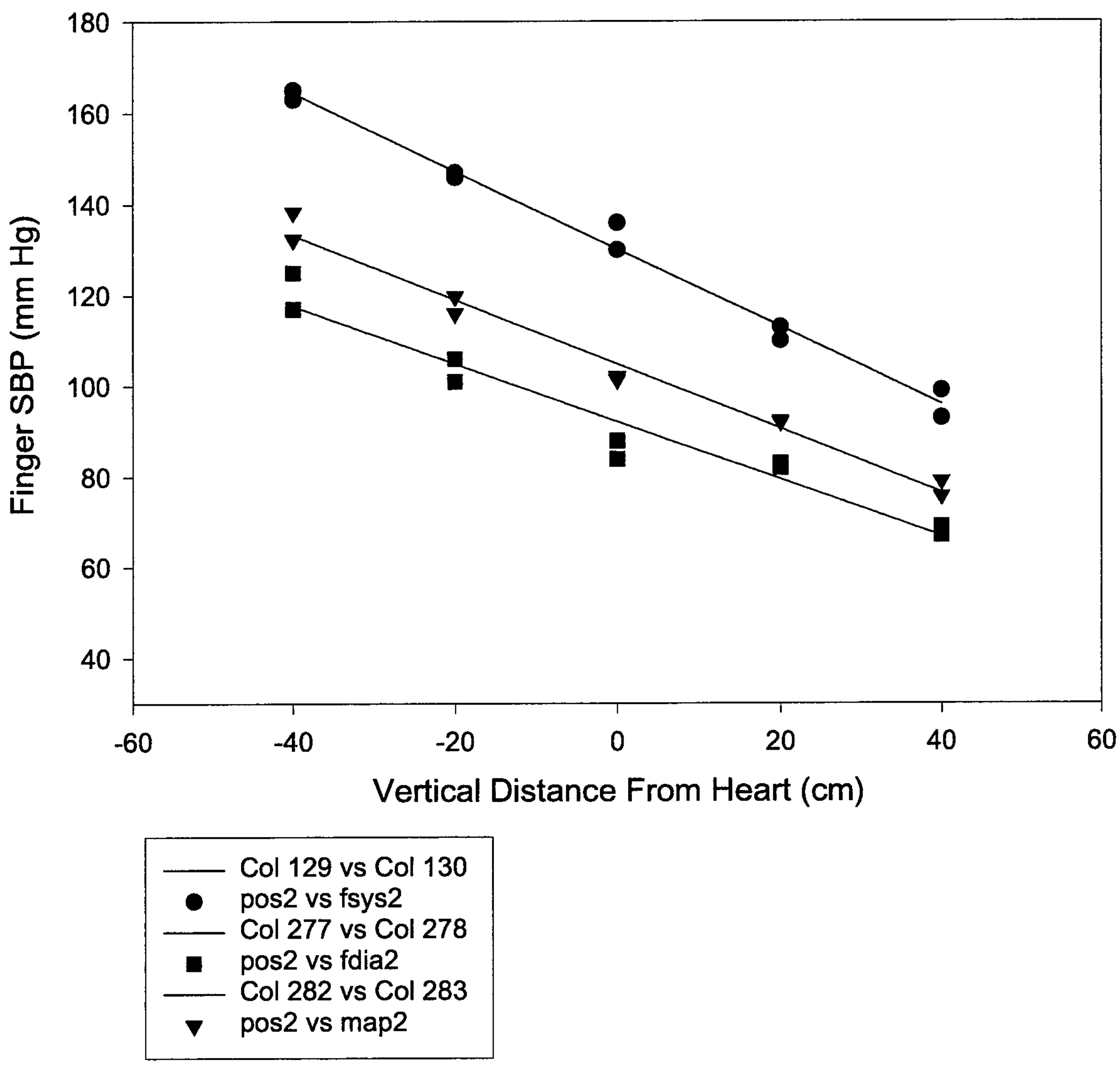
3. End-range wrist flexion test position is subject to variability between subjects, is dependent upon the subject's available range of motion, and may introduce variability.
4. Sensitivity of oscillometric finger blood pressure device may not be sufficient to detect subtle changes in pressure associated with hand placement and wrist position in all subjects. Due to missing data from some subjects, the sensitivity and measurement resolution of the finger blood pressure monitors actually allows a range of <80 cm. Thus, the range of measured hand positions is actually shorter than stated.
5. Other more sensitive methods of measurement are recommended. Finger blood pressure devices that gate the pressure signal to R-waves on electrocardiogram have a much higher sensitivity than non-gated devices.
6. Sampling frequency of blood pressure is limited by the indirect devices used, and may introduce unwanted variability in the data. Continuous blood pressure signals would allow the periodicity of the signal to be identified and an appropriate sampling frequency determined, and are not possible with these instrumentation and measurement devices. Associated risks of invasive pressure monitoring would then be balanced against the benefit of greater accuracy and sensitivity of measurement.

APPENDIX A
RAW DATA OF SYSTOLIC, DIASTOLIC AND MEAN ARTERIAL PRESSURE FOR THE LONG FINGER

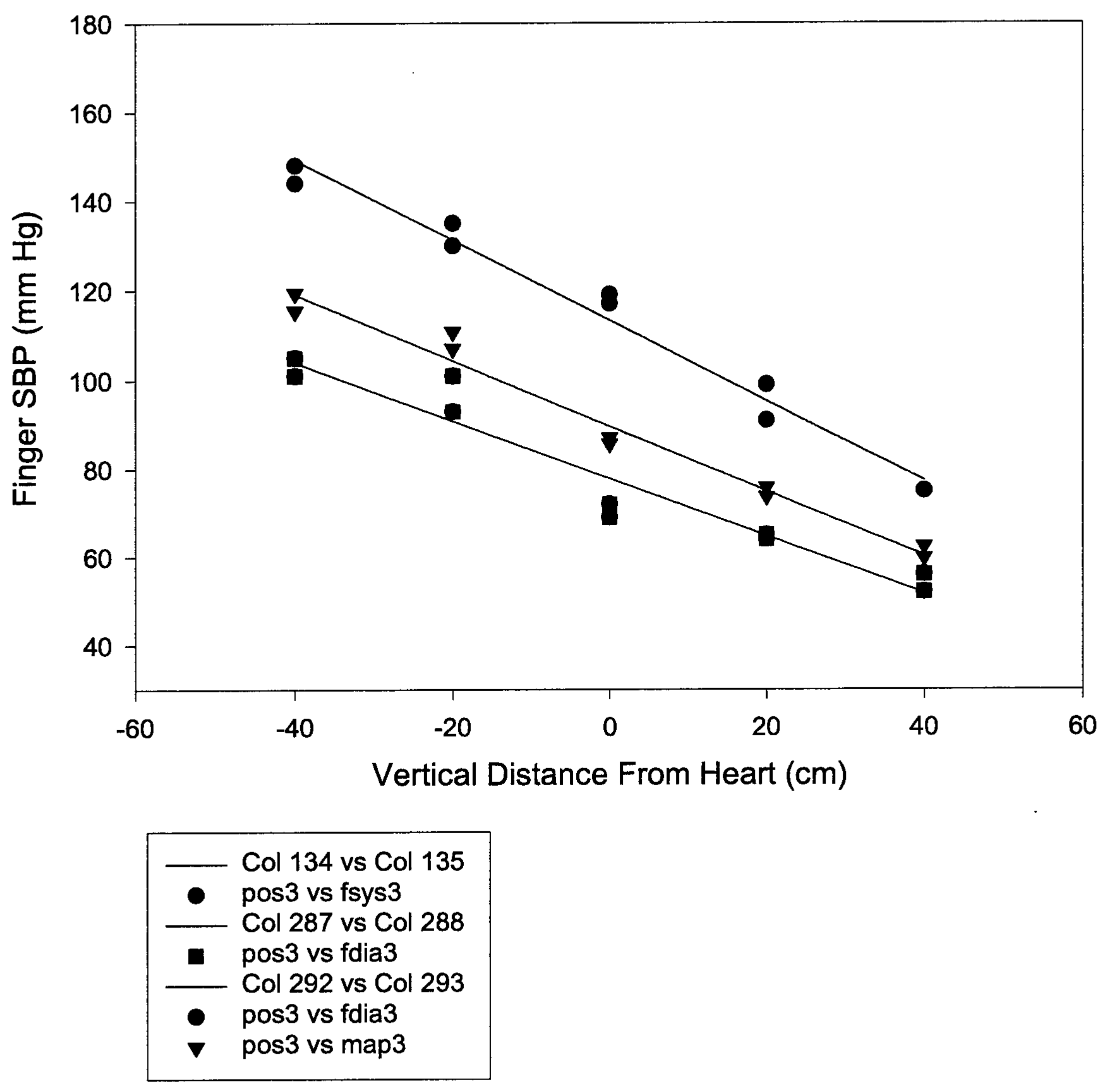
Graph 1: Finger SBP1, DBP1, MAP1 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



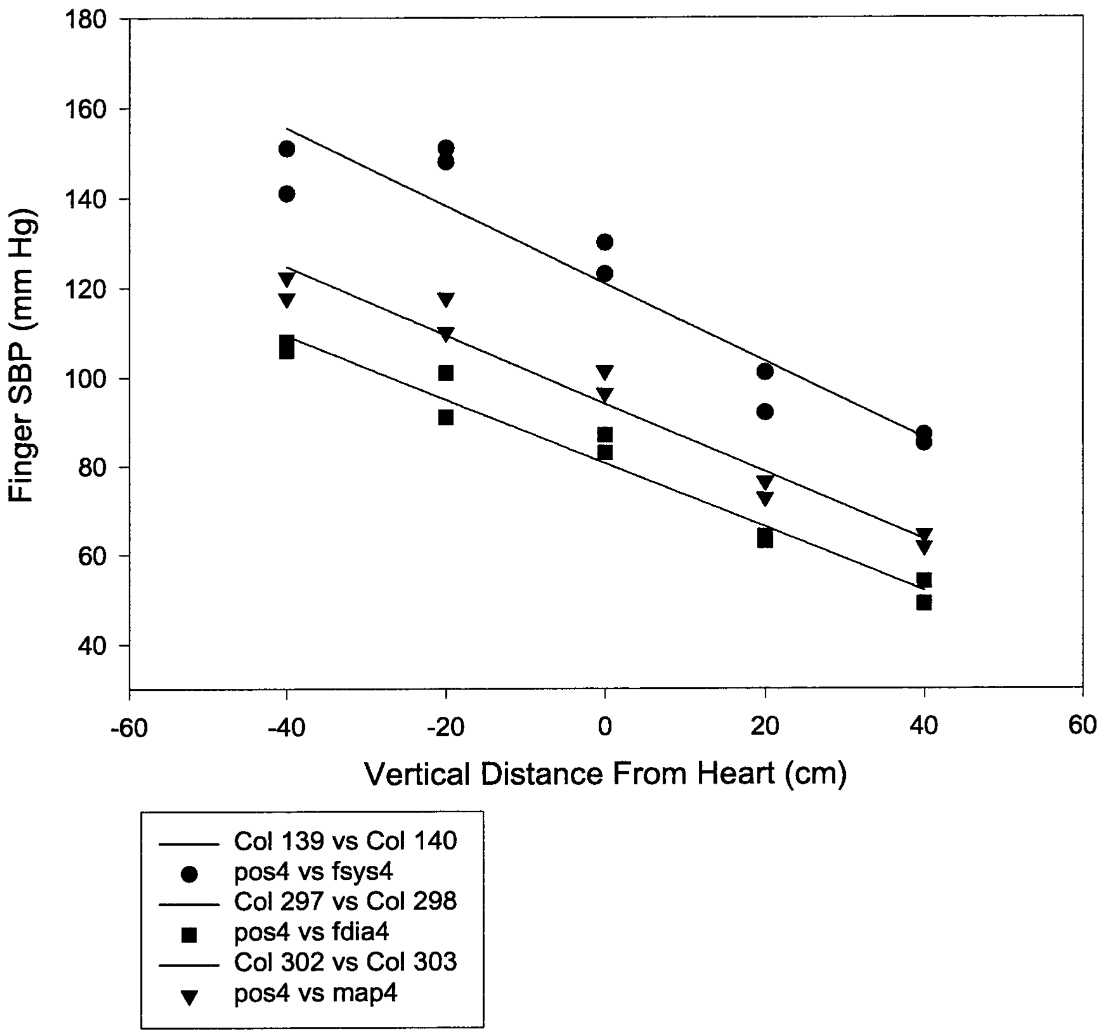
Graph 2: Finger SBP2, DBP2, MAP2 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



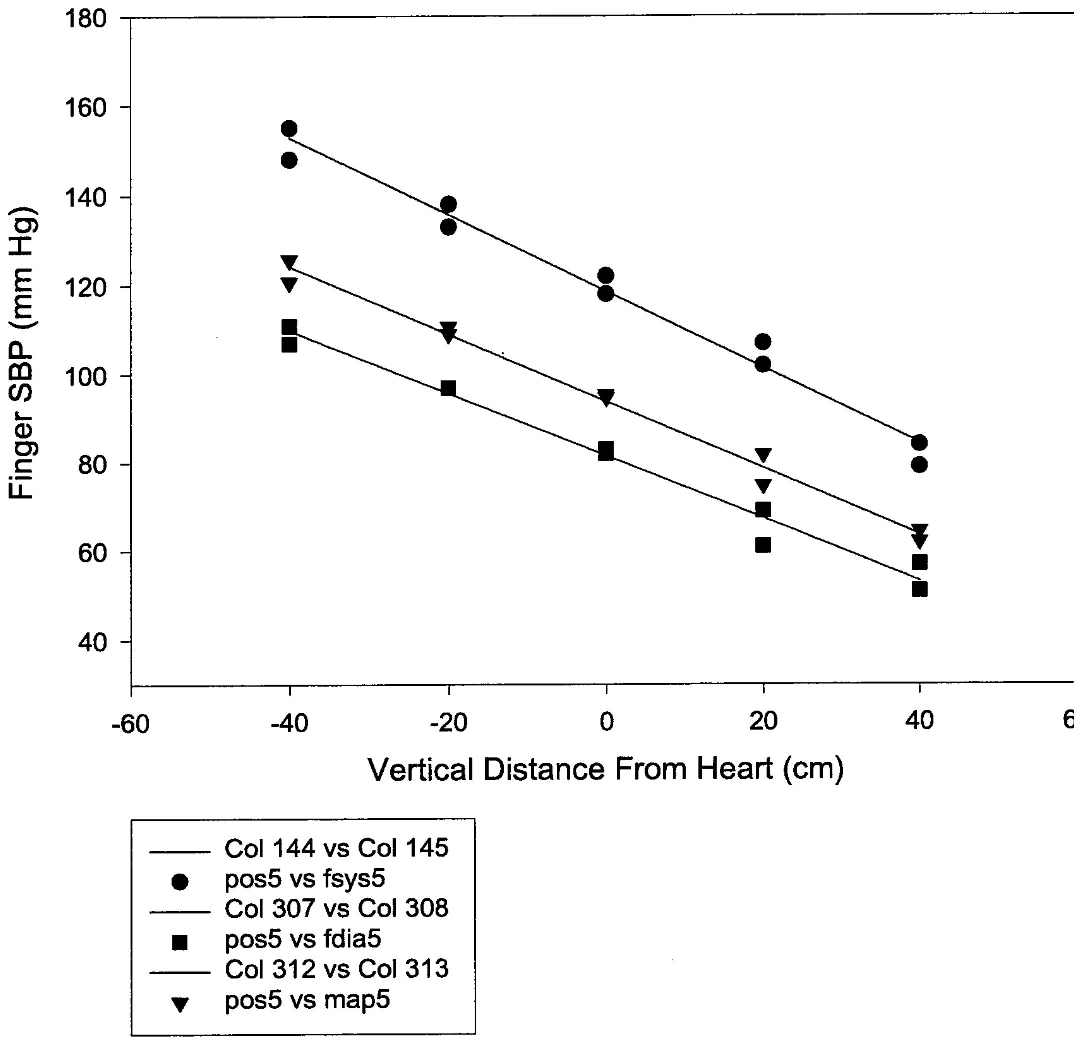
Graph 3: Finger SBP3, DBP3, MAP3 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



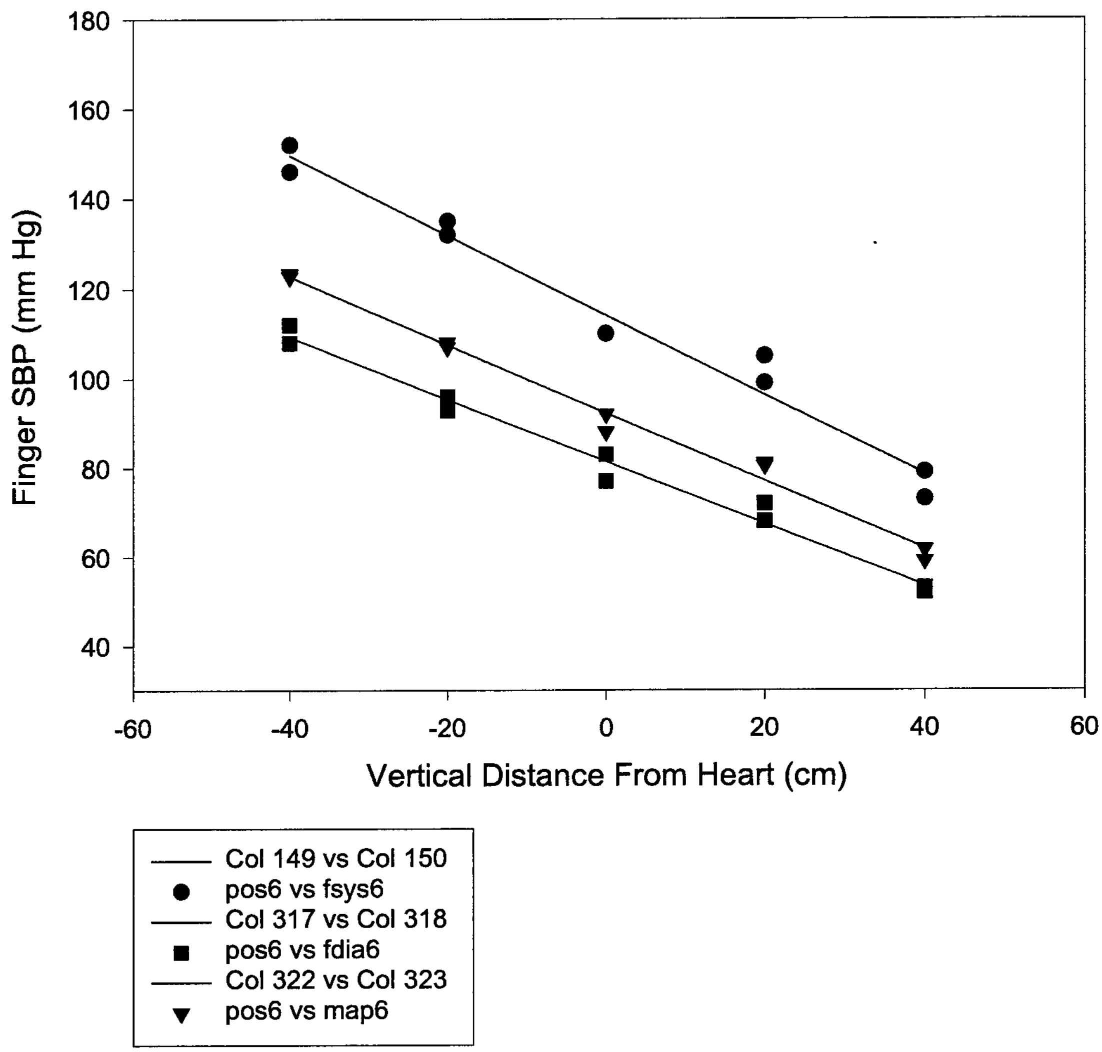
Graph 4: Finger SBP4, DBP4, MAP4 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



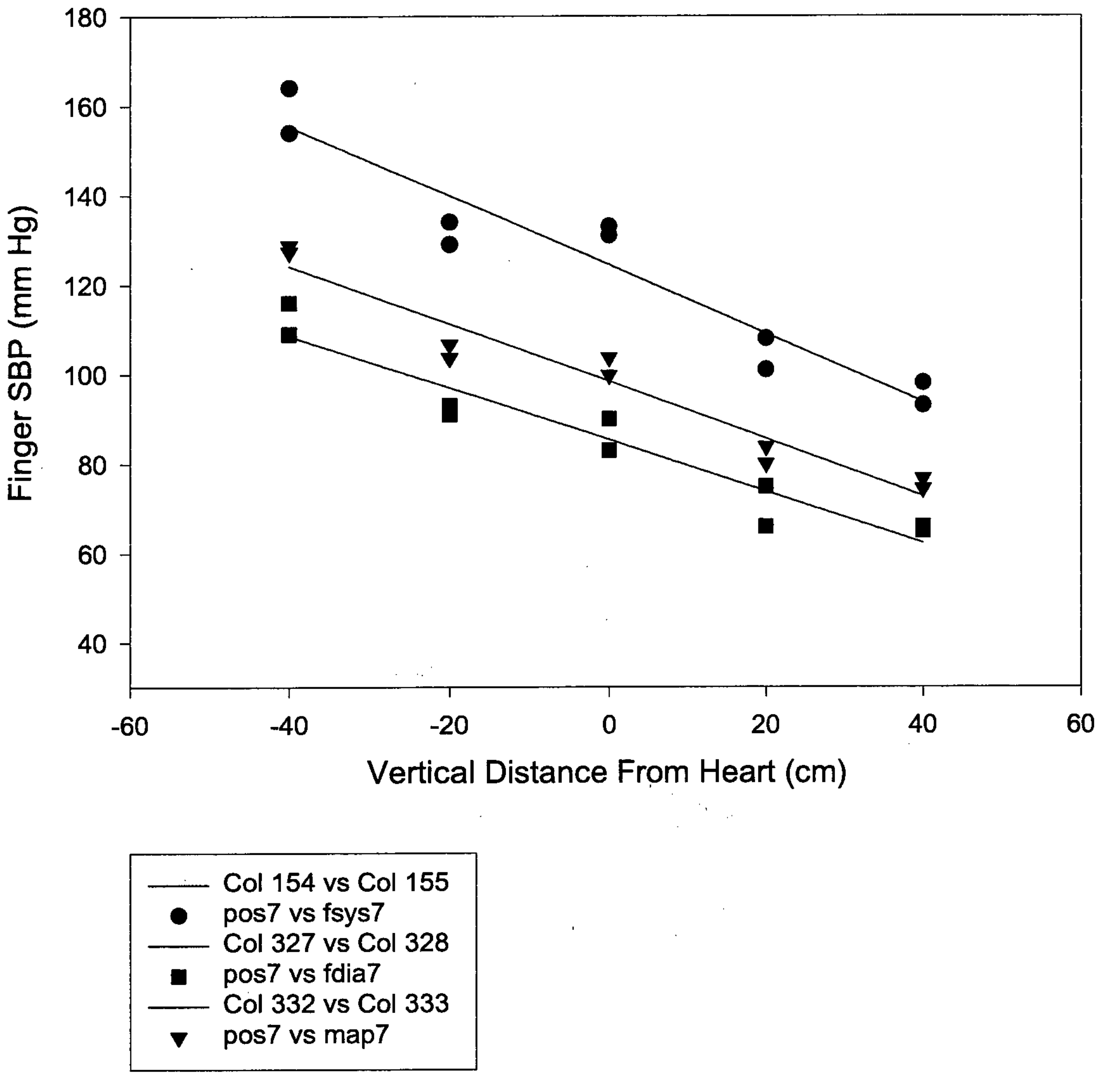
Graph 5: Finger SBP5, DBP5, MAP5 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



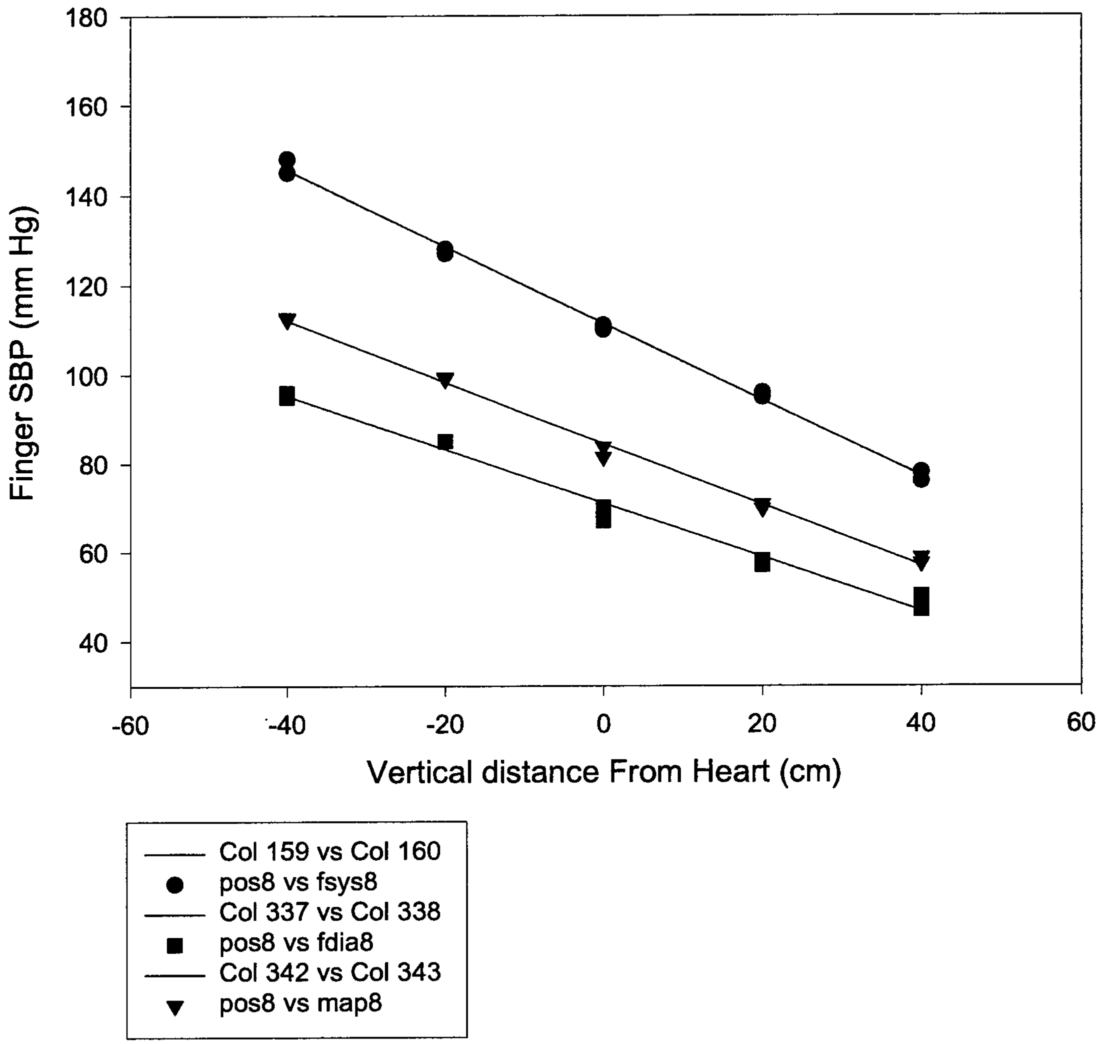
Graph 6: Finger SBP6, DBP6, MAP6 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



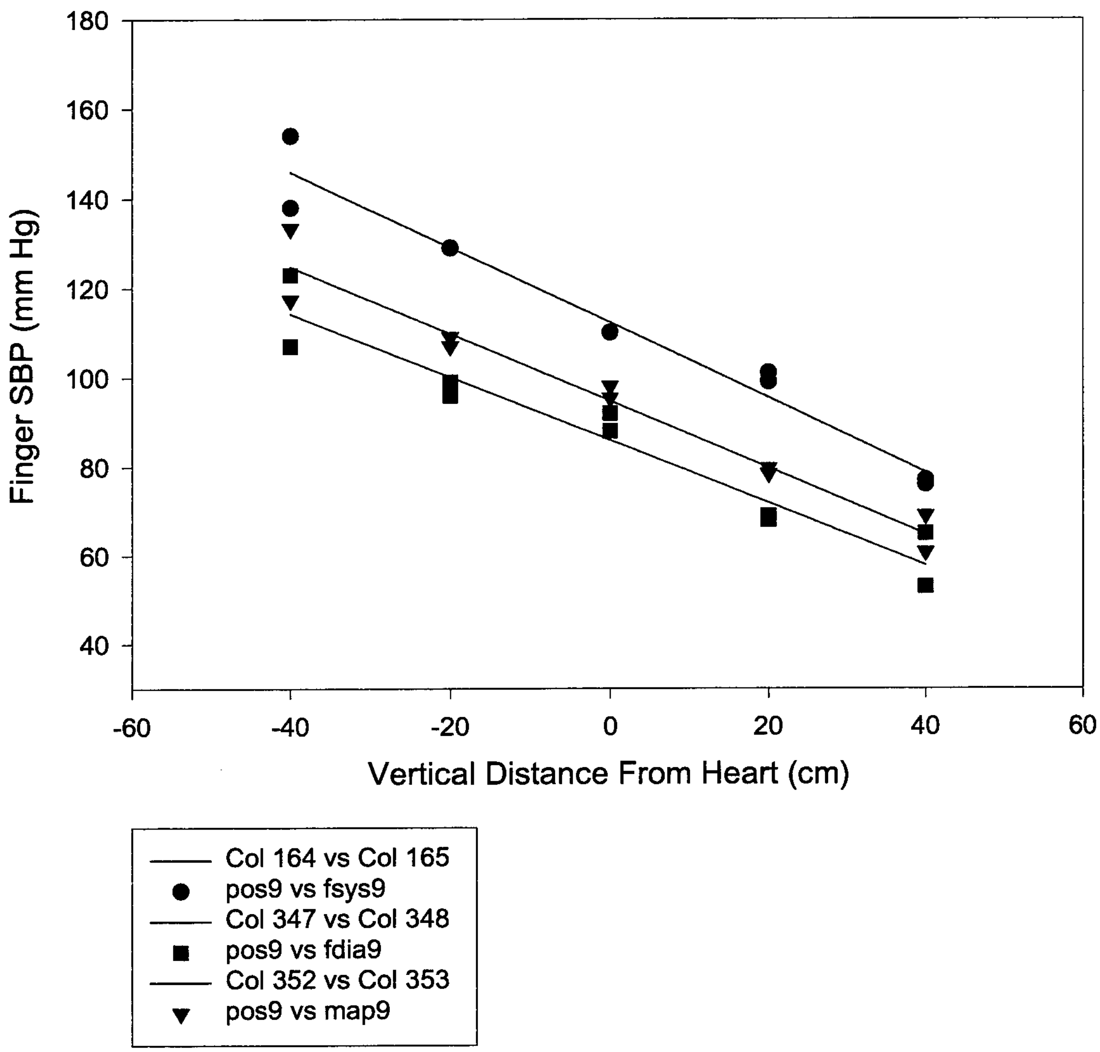
Graph 7: Finger SBP7, DBP7, MAP7 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



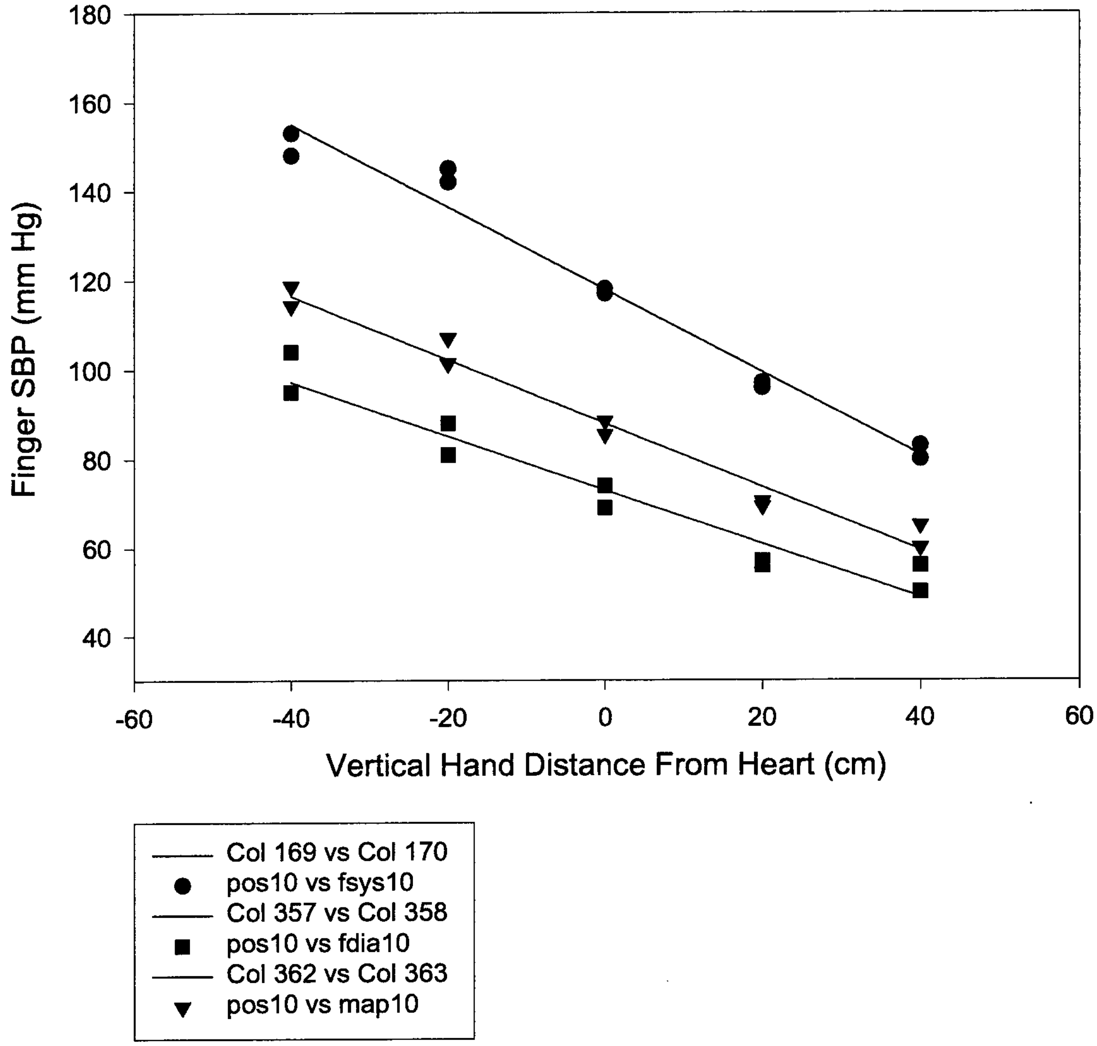
Graph 8: Finger SBP8, DBP8, MAP8 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



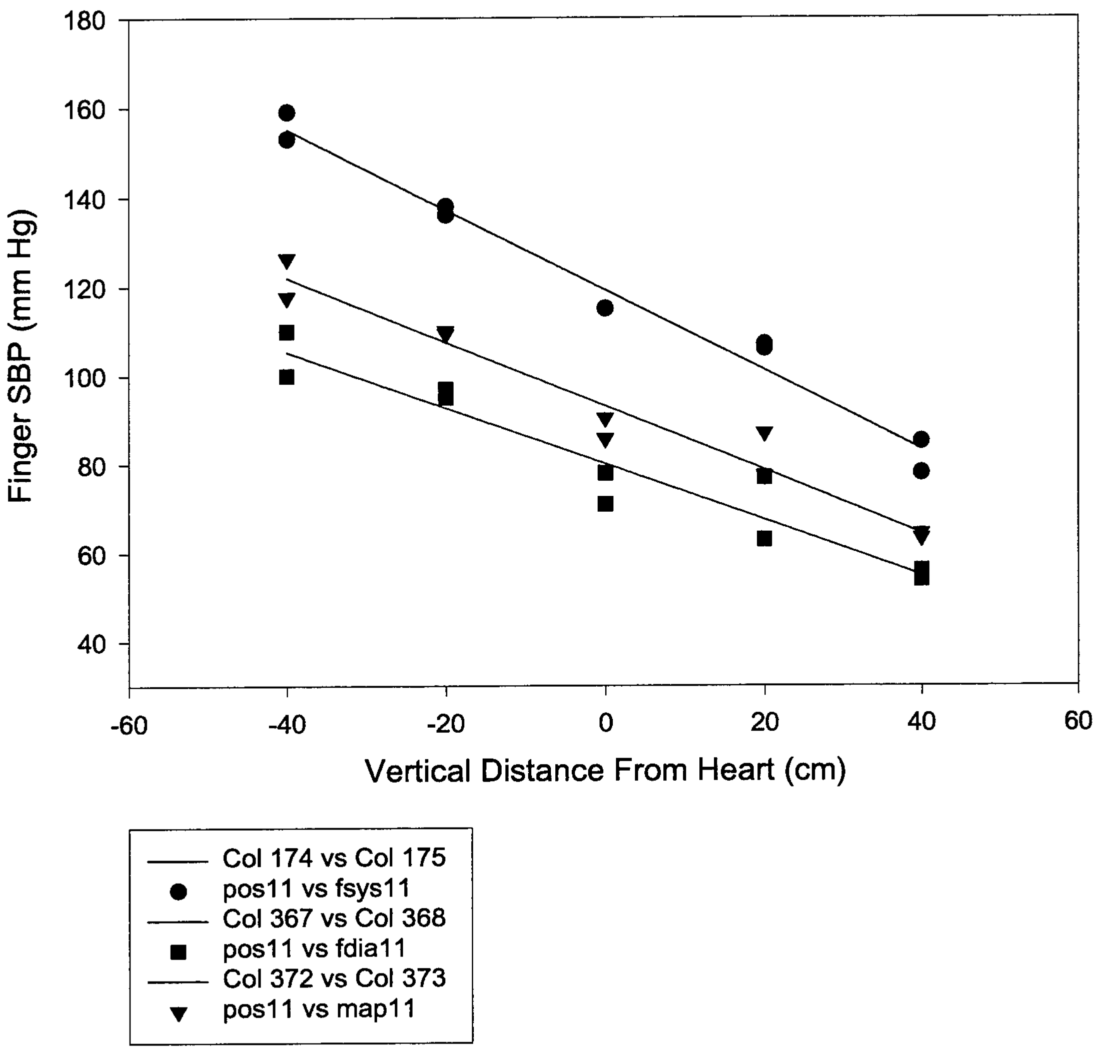
Graph 9: Finger SBP9, DBP9, MAP9 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



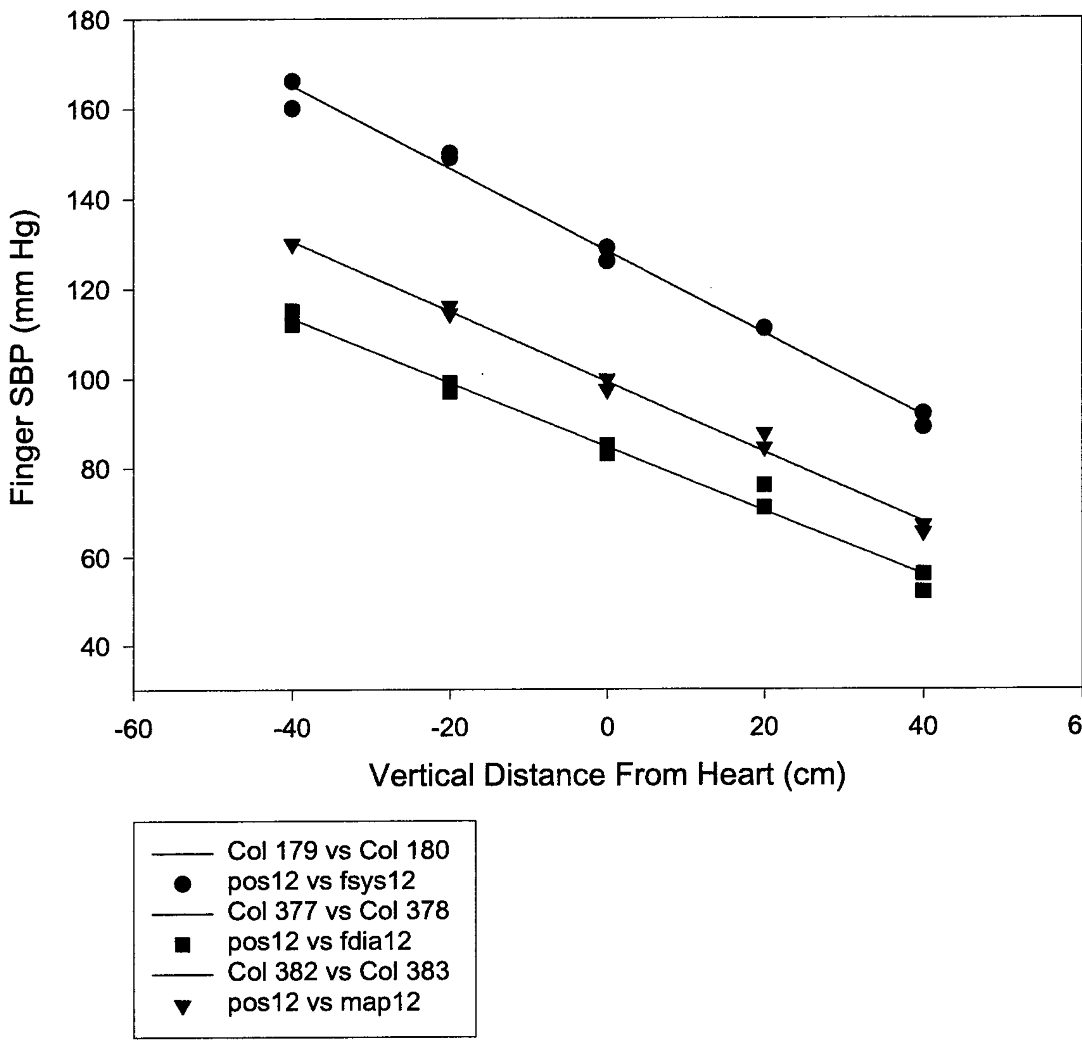
Graph 10: Finger SBP10, DBP10, MAP10 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



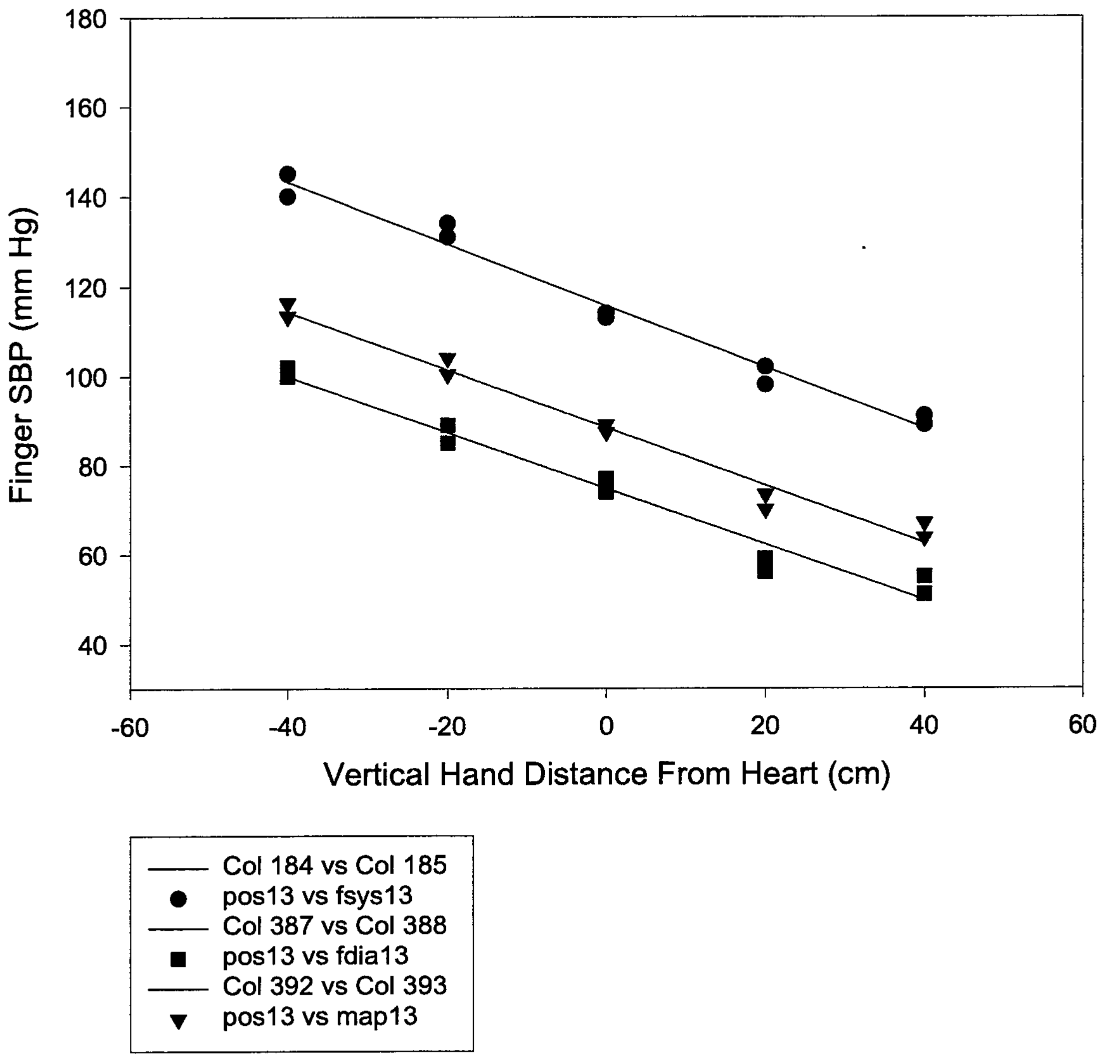
Graph 11: Finger SBP11, DBP11, MAP11 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



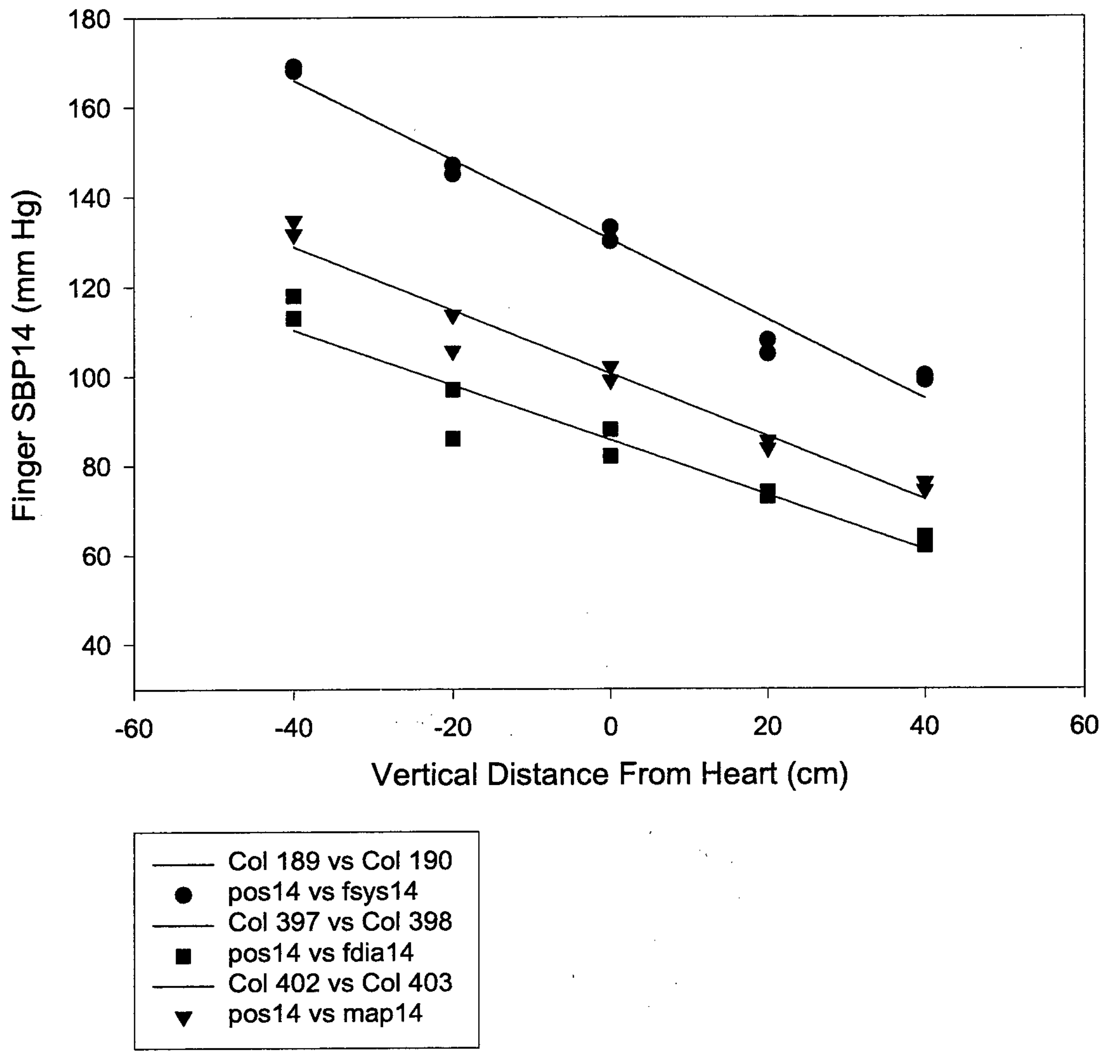
Graph 12: Finger SBP12, DBP12, MAP12 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



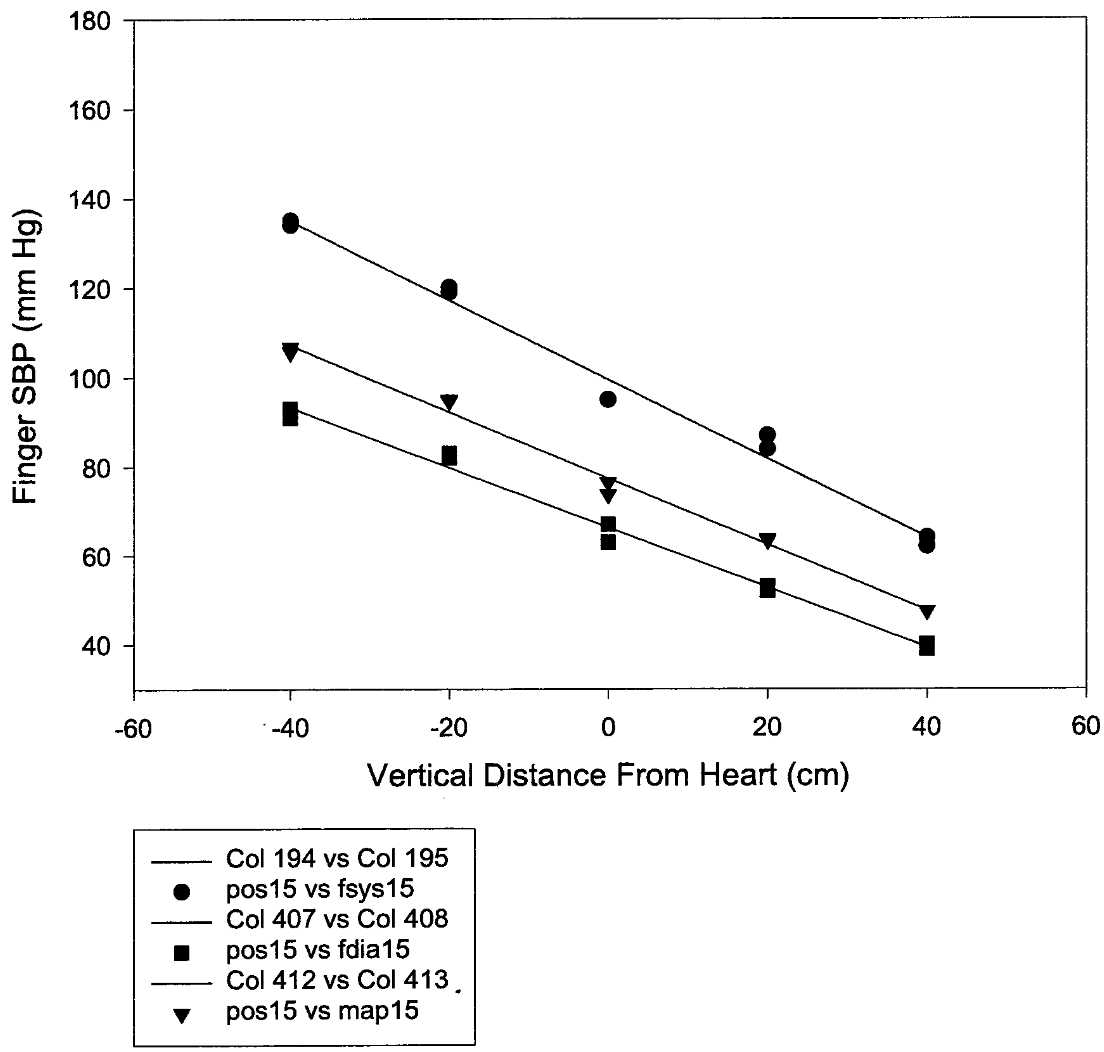
Graph 13: Finger SBP13, DBP13, MAP13 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



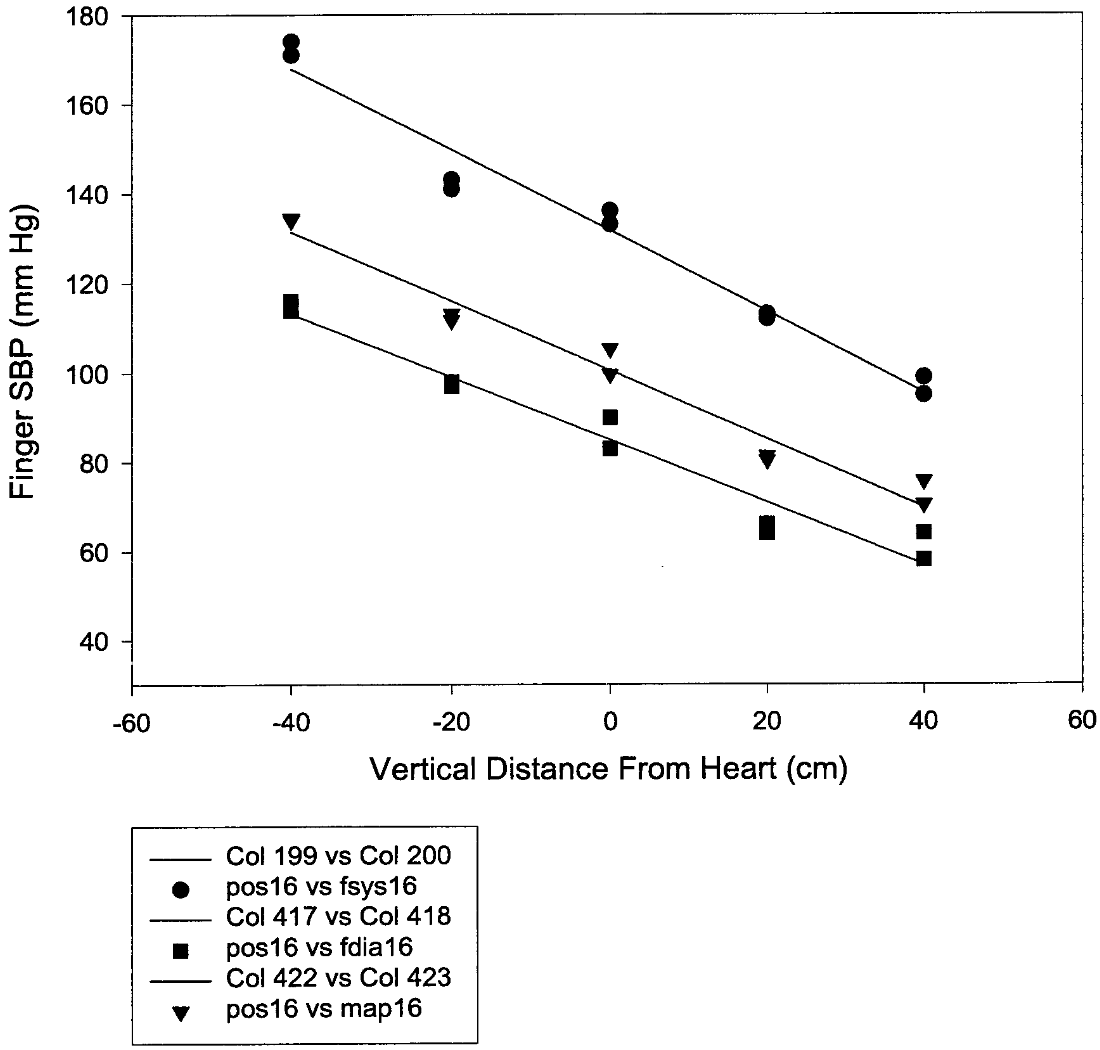
Graph 14: Finger SBP14, DBP14, MAP14 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



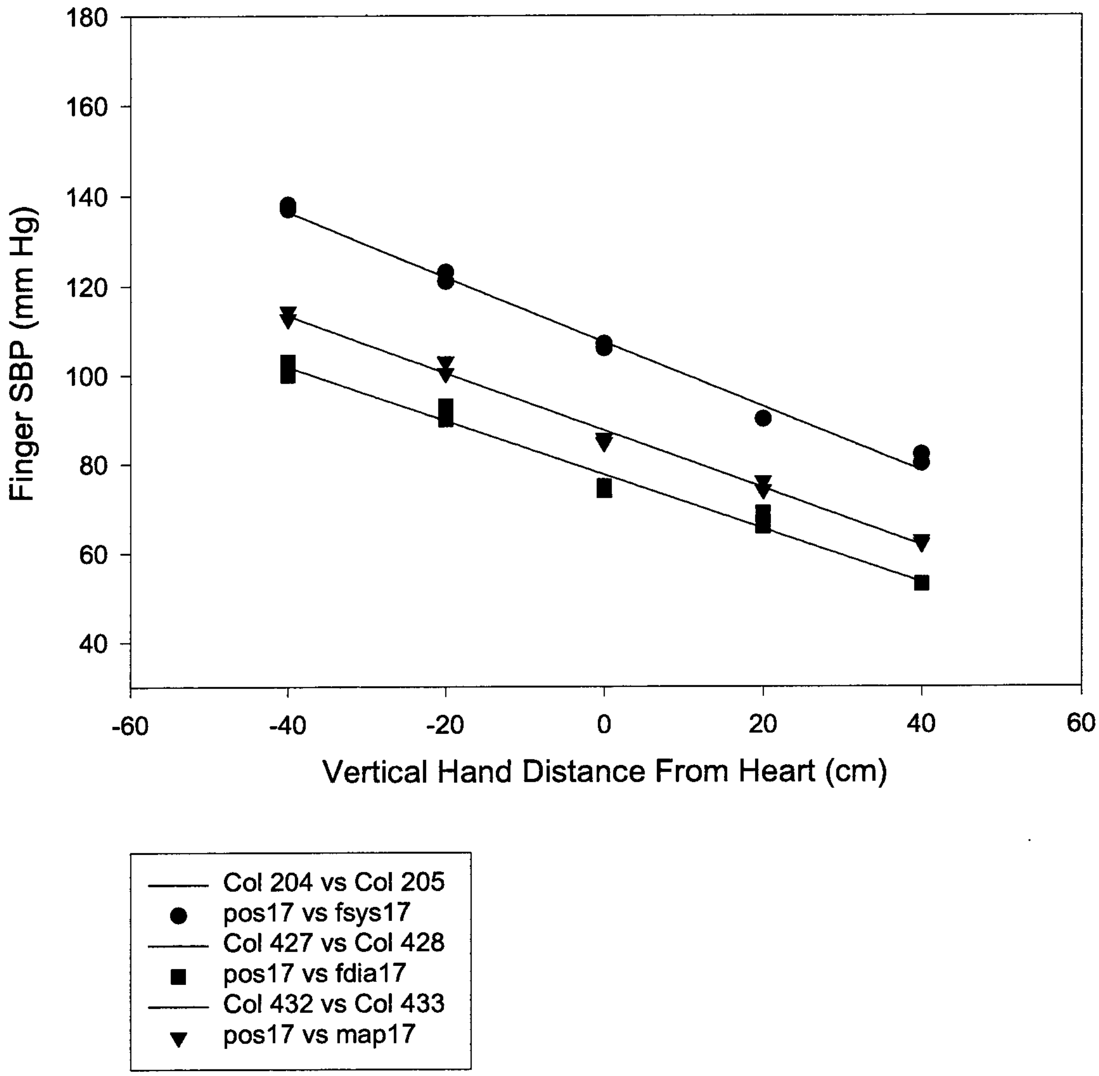
Graph 15: Finger SBP15, DBP15, MAP15 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



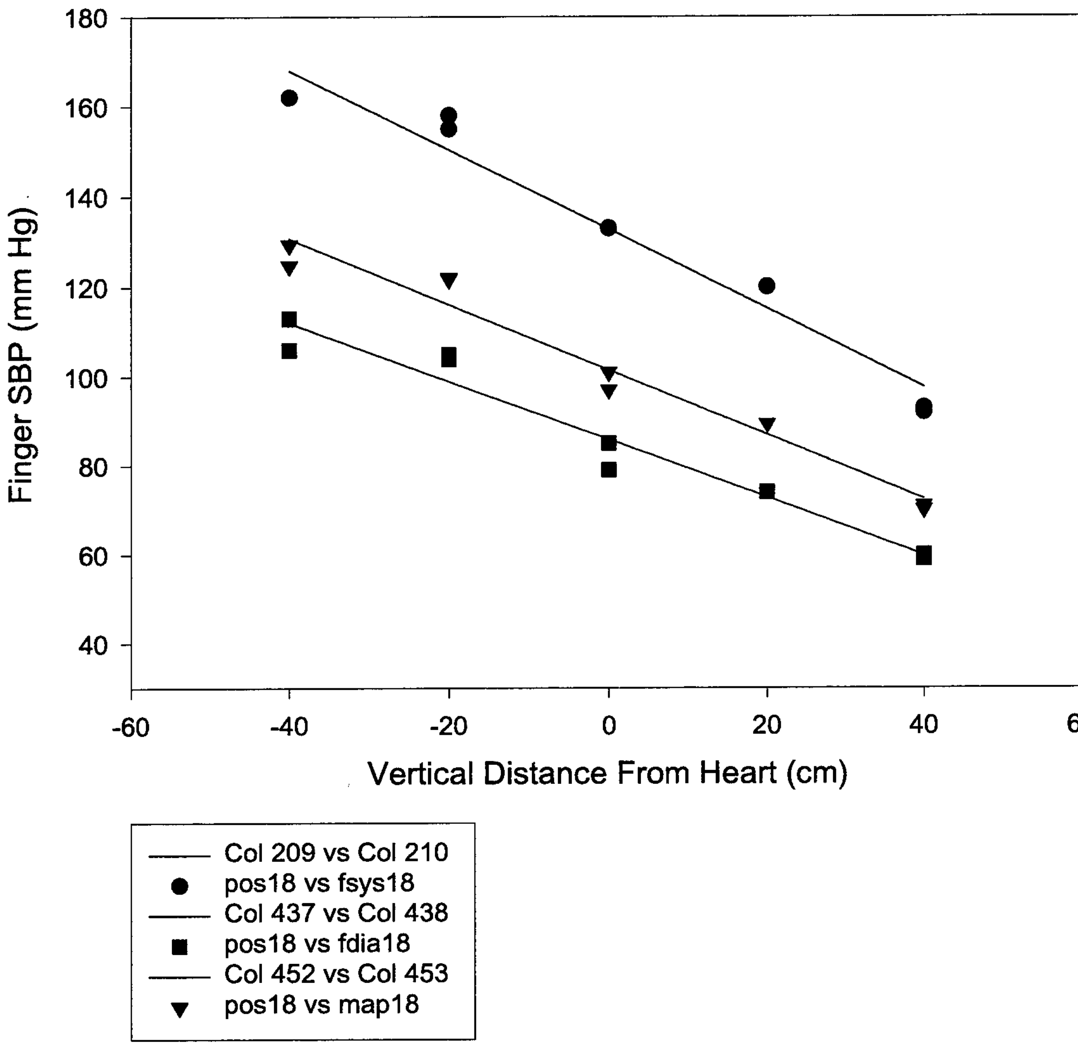
Graph 16: Finger SBP16, DBP16, MAP16 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



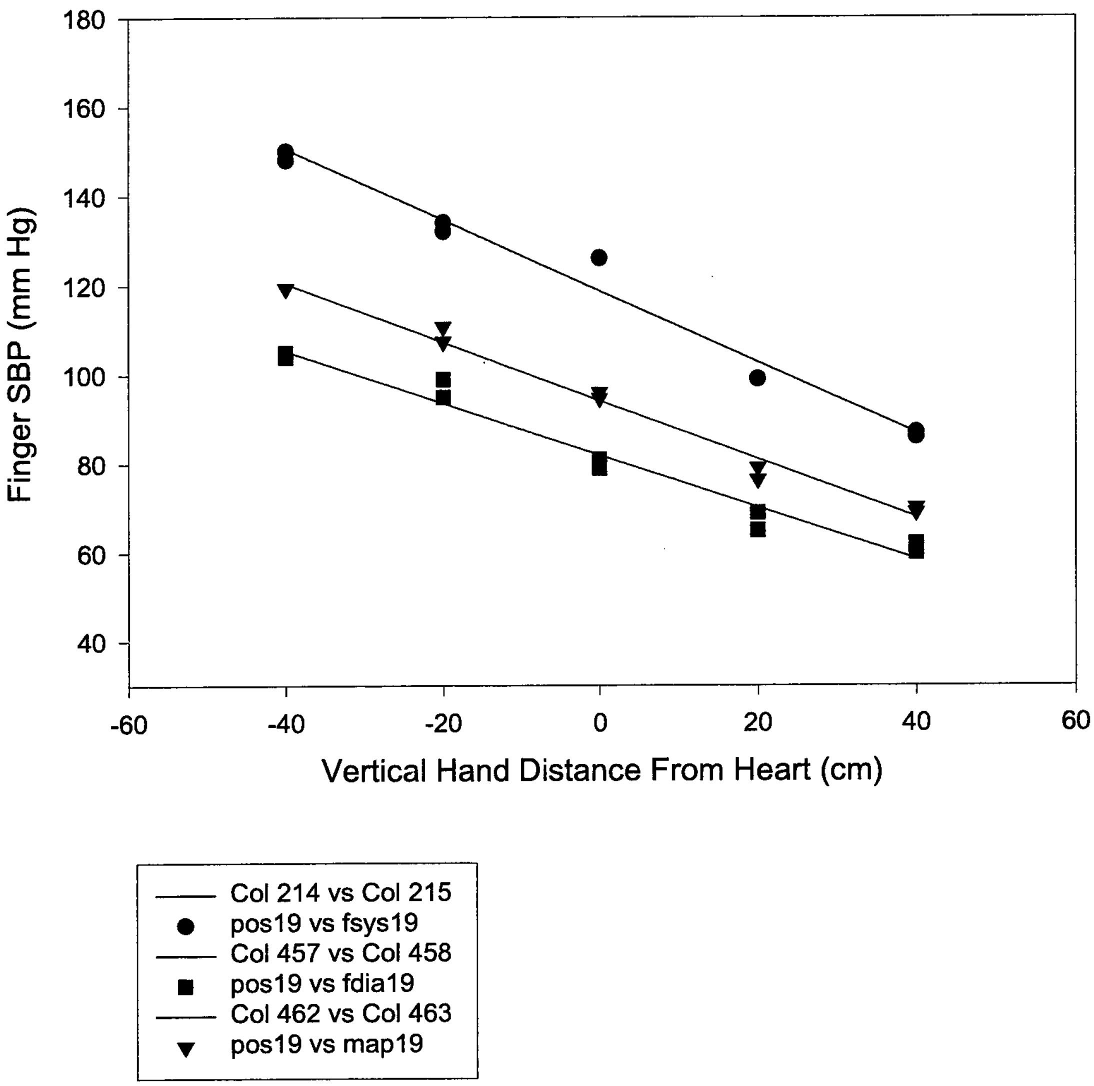
Graph 17: Finger SBP17, DBP17, MAP17 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



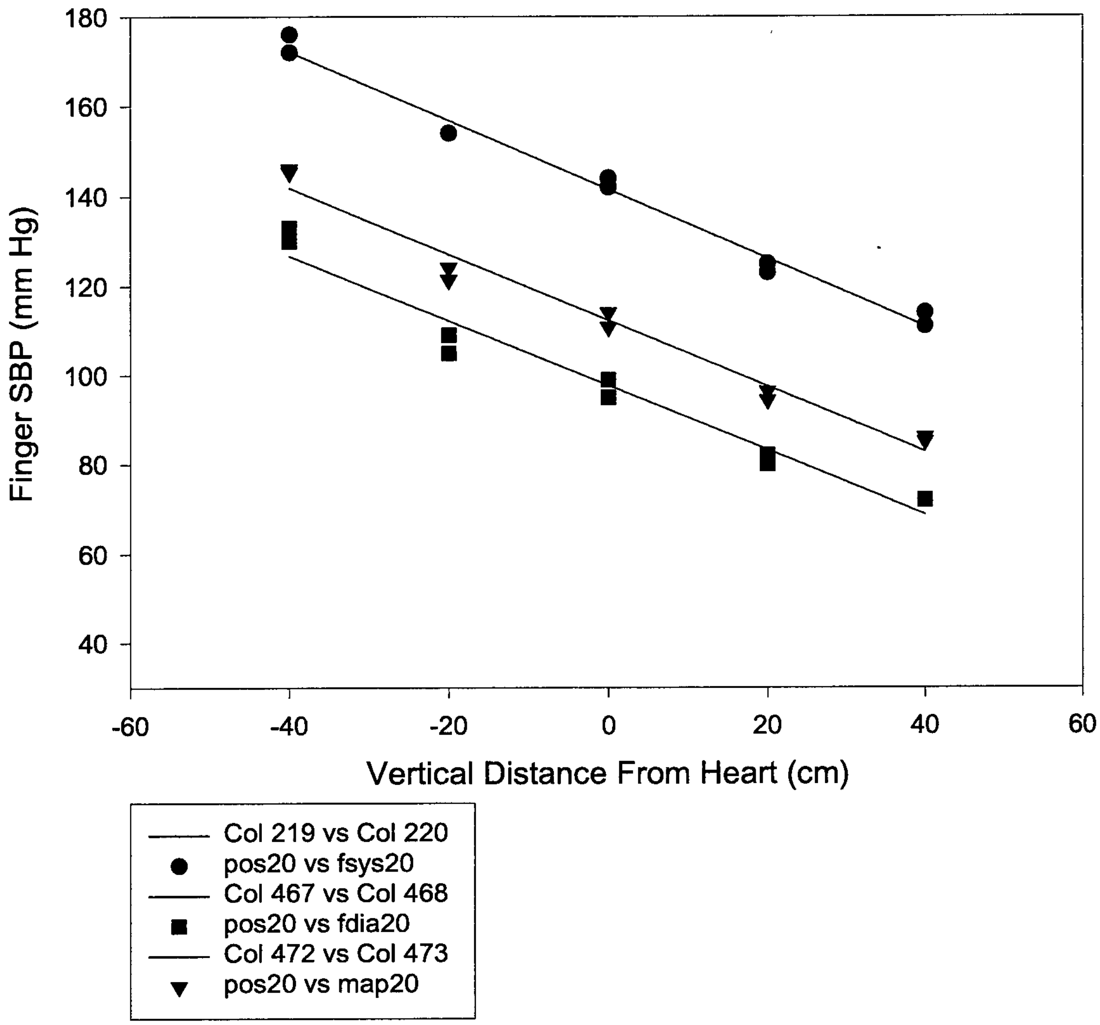
Graph 18: Finger SBP18, DBP18, MAP18 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



Graph 19: Finger SBP19, DBP19, MAP19 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



Graph 20: Finger SBP20, DBP20, MAP20 vs Vertical Distance From Heart, Neutral Wrist, Test Hand.



APPENDIX B
SUBJECT EVALUATION QUESTIONNAIRE

Questionnaire for Distal Blood Flow Study Spring Semester 2000
ID#______
Acute Effects of Hand Elevation and Wrist Position on Pulse Rate and Mean Arterial Pressure Measured in the Hand
Subject's Name (last, first, MI)_______________________________________
Date________________________
Gender________________________ Age (years)________________
Height (cm)____________________ Weight (kg)_______________
Acromion to lateral epicondyle (cm)__________________________
Lateral epicondyle to ulnar styloid (cm)________________________
Wrist joint center to tip of long finger (cm)______________________
Please answer the following truthfully. This form will be kept in strict confidence, and will be destroyed once the study is completed.

1-Do you have past experience working in the construction tradesor manual labor where you performed work above head level? YES NO

2-Do you have now, or have you ever had injury, pain or surgery to your shoulder, elbow, wrist or hand? YES NO

3-Are you right-handed? YES NO

4-Do you use tobacco, in any form? YES NO

5-Do you use prescription medication on a regular basis? YES NO

if so, what kind, how often and how much?_____________________________

6-Have you had food or caffeine in the previous two hours? YES NO

7-Have you emptied your bowel and bladder in the previous 15 minutes? YES NO

8-Have you exercised with the past 24 hours? YES NO

9-Do you feel ill today? (fever, chills, nausea, diarrhea, vomiting, menses) YES NO

10-Do you have a medical history of anemia? YES NO

11-Do you exercise aerobically at least 7x/month? YES NO

12-Do you have any questions you would like to ask me today? YES NO

In order to avoid unwanted variability in the data, please remember the following:
a--necklaces, rings and wristwatches must be removed
b—tight-fitting clothing must be removed or loosened
c—talking must be kept to a minimum once data collection has started
d—please attempt to use the restroom, to void your bowel and bladder, prior to data collection

Thank you for participating in this study!

APPENDIX C
SUBJECT PROTOCOL DATA COLLECTION FORM

THE ACUTE EFFECT OF SHOULDER AND WRIST POSITION ON BLOOD FLOW AND PULSE RATE MEASURED IN THE HAND

Subject________________________________ Height (cm)______ Weight (kg)______ ID#____

Test Date______________________ Age__________

Rest RIGHT brachial BP____________ ____________ ____________ ____________ ____________

Rest LEFT brachial BP______________ ____________ ____________ ____________ ____________

*Elevated arm values listed below, with *chest strap HR values* listed in brackets, BP monitor HR in *parenthesis*

	fBP (mm Hg)	fBP (mm Hg)	fBP (mm Hg)
Initial (finger BP) Rest R	_________, _________	________, ______	________, ______
Initial (finger BP) Rest L	_________, _________	________, ______	________, ______

TEST ORDER____

TEST ONE**

-40 Position TRIAL #1 fBP pulse rate position time resting hand fBP pulse rate position time

N Wrist____________ ____________ ____________ ________ __________

F Wrist____________ ____________ ____________ ________ __________

-20 Position

N Wrist____________ ____________ ____________ ________ __________

F Wrist____________ ____________ ____________ ________ __________

0 Position

N Wrist____________ ____________ ____________ ________ __________

F Wrist____________ ____________ ____________ ________ __________

+20 Position

N Wrist____________ ____________ ____________ ________ __________

F Wrist____________ ____________ ____________ ________ __________

+40 Position

N Wrist____________ ____________ ____________ ________ __________

F Wrist____________ ____________ ____________ ________ __________

TEST TWO***

-40 Position TRIAL #2 fBP pulse rate time in position resting hand fBP
pulse rate
N Wrist_____________ _____________ _____________ __________ ___________
F Wrist_____________ . _____________ _____________ __________ ___________

-20 Position
N Wrist_____________ _____________ _____________ __________ ___________
F Wrist_____________ _____________ _____________ __________ ___________

0 Position
N Wrist_____________ _____________ _____________ __________ ___________
F Wrist_____________ _____________ _____________ __________ ___________

+20 Position
N Wrist_____________ _____________ _____________ __________ ___________
F Wrist_____________ _____________ _____________ __________ ___________

+40 Position
N Wrist_____________ _____________ _____________ __________ ___________
F Wrist_____________ _____________ _____________ __________ ___________

Final RIGHT brachial BP____________ ________________ ____________ ____________
Final LEFT brachial BP____________ ____________ ___ ____________ ____________
Final Rest R __________ __________ _________ __________ __________
Final Rest L __________ __________ _________ __________ __________

Test Order ______, ________, ________, _________, _________

APPENDIX D
HUMAN SUBJECTS REVIEW COMMITTEE FORM

INFORMED CONSENT DOCUMENT

Project Title: **The Effect of Arm and Wrist Position on Hand Blood Flow.**
Investigator(s): **Thomas Cook, Ph.D.; John Rosecrance, Ph.D.; Lee Shibley, PT**

PURPOSE
This study involves research. The purpose of this research is to determine if overhead work is a risk factor in carpal tunnel syndrome and related musculoskeletal disorders of the wrist and hand. Such disorders, if left untreated, can lead to permanent disability. Early detection reduces the potential for the occurrence of a serious wrist and hand disability. Identification of new risk factors for these disorders allows high-risk work tasks to be identified and modified, preventing or reducing the severity of these disorders.

We are inviting people to participate in this research because they perform work that may be at risk for developing carpal tunnel syndrome and these related disorders. In addition, we are inviting people who do not have a high risk for developing these disorders to allow comparison of at risk and low risk test results. Actual testing requires a single session and takes 15-45 minutes.

PROCEDURES

Those agreeing to participate can expect the following to occur. A member of the research staff will ask you for your name, age, height, weight and measure your arm length. In addition, your blood pressure will be measured at the upper arm and continuously monitored using the finger blood pressure device. Your pulse rate and the oxygen saturation of your blood will be measured using a finger-clip pulse oximeter, where an infrared light beam is reflected from your fingernail area. These measurements will be taken as you move your arm and wrist to differing pre-determined positions, while you stand on the floor.

RISKS
There are no possible risks associated with participating in this research project.

BENEFITS

There is no personal benefit for participating in this study. If your blood pressure results indicate you have signs of high blood pressure, you will be informed and encouraged to see your health care provider. It is hoped that, in the future, society could benefit from this study by determining safer methods for performing overhead work tasks.

COSTS AND COMPENSATION

Subjects will be compensated for time and inconvenience involved in participating in this research. Subjects will be paid $5.00 for having the tests performed.

CONFIDENTIALITY

Records of participation in this research project will be maintained and kept confidential to the extent permitted by law. However, federal government regulatory agencies and the University of Iowa Institutional Review Board may inspect and copy a subject's records pertaining to the research, and these records may contain personal identifiers. Any data that includes personal identifiers will be stored in a locked file cabinet in the primary investigator's office (Dr. Thomas M. Cook). This office will also remain locked when not occupied by the primary investigator. The tabulated data will be coded such that it does not include personal identifiers. In the event of any report or publication from this study, the identity of subjects will not be disclosed. Results will be reported in a summarized manner in such a way that subjects cannot be identified.

VOLUNTARY PARTICIPATION

All participation is voluntary. There is no penalty to anyone who decides not to participate. Nor will anyone be penalized if he or she decides to stop participation at any time during the research project

QUESTIONS

Questions are encouraged. If there are any questions about this research project, please contact: John Rosecrance, (319) 335-4554. Questions about the rights of research subjects or research related injury may be addressed to the Human Subjects Office, 300 College of Medicine Administration Building, The University of Iowa, Iowa City, Iowa, 52242, (319) 335-6564.

Subject's Name (printed):

____

______________________________________ ____________________

(Signature of Subject) (Date)

INVESTIGATOR STATEMENT

I have discussed the above points with the subject or the legally authorized representative, using a translator when necessary. It is my opinion that the subject understands the risks, benefits, and obligations involved in participation in this project.

________________________________ ____________________

(SIGNATURE OF INVESTIGATOR) (DATE)

APPENDIX E
ORDER OF SUBJECTS

RANDOMIZATION TABLE OF TESTING SEQUENCE

sequence	sequence	subject #
1 3 5	4 2	1
1 5 3	2 4	2
3 1 5	4 2	3
3 5 1	2 4	4
5 1 3	4 2	5
5 3 1	2 4	6
2 4	1 3 5	7
4 2	1 5 3	8
2 4	3 1 5	9
4 2	3 5 1	10
2 4	5 1 3	11
4 2	5 3 1	12
1 3 5	4 2	13
1 5 3	2 4	14
3 1 5	4 2	15
3 5 1	2 4	16
5 1 3	4 2	17
5 3 1	2 4	18
2 4	1 3 5	19
4 2	1 5 3	20
2 4	3 1 5	21
4 2	3 5 1	22
2 4	5 1 3	23
4 2	5 3 1	24

LEGEND (CM VERTICAL DISTANCE FROM HEART LEVEL)
1 = 40 CM ABOVE
2 = 20 cm above
3 = 0 cm above (ie, at heart level)
4 = 20 cm below
5 = 40 cm below

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