CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

CARDIO-PERIPHERAL VASCULAR EFFECTS

OF INVERSION ON HUMANS

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by

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ABSTRACT

THE CARDIO-PERIPHERAL VASCULAR EFFECTS OF INVERSION ON HUMANS

by

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Master of Arts in Physical Education

A recent trend in health and exercise equipment has been the introduction of inversion gravity traction devices. Any individual, regardless of their medical status, can acquire one of these inversion traction devices with relative ease, considering the numerous sources available. Inversion gravity traction has been shown to increase spinal length and relax tightened paraspinal muscles in subjects tested. Early research, however, in the area of inverted tilting was scarce and recent literature limited. Therefore, the purpose of this study was to identify, monitor and record the cardio-peripheral vascular effects in humans when placed in the inverted gravity position.

Twenty normal, healthy volunteer subjects (10 males, 10 females; from ages 20-40 years) were utilized in this study. Variables of heart rate, blood pressure and intraocular pressure were measured

from sitting, standing, bent knee inversion and straight leg inversion; utilizing three time trials in each of the four positions. Data were analyzed by two-way analysis of variance (ANOVA) with repeated measures. Results indicated that heart rate increased significantly from sitting to the bent knee inversion position ($p = < .05$), systolic and diastolic blood pressure (observed and corrected) increased significantly from sitting to bent knee and straight leg inversion, as well as from standing to bent knee and straight leg inversion positions ($p = < .01$). Left and right intraocular pressure increased significantly from sitting to bent knee and straight leg inversion, from standing to bent knee and straight leg inversion, and finally from bent knee inversion to straight leg inversion ($p = < .01$). No significant changes were noted within the three time trials. No serious cardiac pathology was detected on EKG. These research findings reflect the need for additional research to establish better safety standards for the use of gravity inversion devices.

CHAPTER I

INTRODUCTION

Current trends in health and exercise programs include the use of inversion gravity traction devices. Such devices are readily available to the general public through mail order distributors, health clubs, spas, and sporting equipment outlets throughout the country (LeMarr, Golding & Crehan, 1983). Manufacturers (Inverta Chair™, Gym Mobile™, Orthopod™) of these various inversion traction devices claim they may relieve acute and chronic back pain (through spinal decompression), as well as improve circulation, relaxation, posture and performance. Additionally they claim reduction of back surgery and stress injuries as well as stimulation of metabolism. Many companies also advocate muscle strengthening exercises for abdominal and back extensors during inversion and provide accompanying training programs.

One speculates what the effects on the cardio-peripheral vascular system would be if an individual with unknown hypertension, or one who has a high risk profile for cerebrovascular accident (C.V.A.), or glaucoma should purchase or use one of these devices for low back pain, and assume the inverted position.

Physicians, clinicians and aerospace program personnel have been interested in the effects of change in body position on cardiovascular dynamics for many years. Musculoskeletal and cardiovascular

stresses imposed by the assumption of the vertical stance in man have been well summarized (Hellebrandt & Brogden, 1943).

There appears to be some controversy regarding the effects of standing on blood pressure. Sewall (1916) concluded from several hundred observations that in changing from the recumbent to the standing posture there is always a rise in diastolic blood pressure, little or no change in systolic pressure and a subsequent fall in pulse pressure. In another comprehensive study 56% of the subjects showed an increase in systolic pressure, 26% demonstrated a fall in pressure and 18% experienced no change. Seventy-nine percent of the subjects had a rise in diastolic pressure, 6% a fall and 15% no change (Schneider & Truesdell, 1922). Differences in these studies may be attributed to lack of standardized techniques in measuring blood pressures and/or subject's anxiety levels during testing.

Physiological interest in cardiovascular response and adaptation to passive tilting dates back over 50 years. An extensive review of the literature to 1941 was presented by Graybiel and McFarland. As the subject was tilted from the horizontal the most striking effect was on heart rate, which increased more sharply the closer the body was moved to the vertical position. Beyond the 45 degree angle the diastolic blood pressure increased significantly. Somewhere between 60 degrees and 70 degrees is the critical angle of tilting for most people; systolic pressure begins to fall, pulse pressure is seriously reduced and symptoms of syncope may appear.

Purpose

Early research in the area of inverted tilting was scarce, and recent literature is limited. Therefore, the purpose of this study

was to identify, monitor and record the cardio-peripheral vascular effects on humans when placed in the inverted gravity position.

Statement of the Problem

Will the inverted gravity position produce significantly different heart rates, blood pressures and intraocular pressures on humans, as contrasted with the neutral (sitting) and vertical positions?

Hypotheses

There will be no significant differences in heart rate, systolic and diastolic blood pressure, and left and right intraocular pressure on humans between the inverted, neutral and vertical positions.

The following null hypotheses were proposed:

1) There will be no significant differences between heart rate in any of the positions.

2) There will be no significant differences between systolic blood pressure (observed and corrected) in any of the positions.

3) There will be no significant differences between diastolic blood pressure (observed and corrected) in any of the positions.

4) There will be no significant differences between left intraocular pressure in any of the positions.

5) There will be no significant differences between right intraocular pressure in any of the positions.

Importance of the Study

Completed research on inversion with humans is scarce and limited. The majority of studies were conducted at 45 degrees tilt or less, whereas most commercial inversion devices utilize 70 degrees

or greater. Studies conducted at 90 degrees of inversion had subject's legs fully extended, but many commercial inversion devices are designed with hips flexed at approximately 90 degrees, presumably causing some femoral artery occlusion. Subjects utilized in most of these studies were young males (18-30 years) whereas most of the population with back pain using such commercial inversion devices would normally be 30 years or older. Finally, although animal studies are helpful and long term aerospace studies interesting, neither are practical for clinical application to the general population.

From the review of literature it was clear that a practical clinical study design was needed to determine the cardio-peripheral vascular effects on humans. Such study should be conducted with subject's legs extended on one test occasion and flexed on another test occasion to factor out the possible lower extremity occlusion effects. Another significant design factor would be to obtain a more representative age and sex grouping of the back patient population normally using inversion devices. The present study addressed all of the above research prerequisites.

Limitations

Due to the clinical requirements and highly technical nature of the tonometer utilized in the present study, there were relatively large differences in elapsed time between the three trials of various subjects. To elaborate on this point, three readings were required per eye per trial. If the eye was moving, or the subject was moving or blinking, the tonometer could not be focused and thus obtaining a reading was delayed. Those subjects who moved less and did not blink

had less delay between trials (as well as less overall time in the position) than the subjects who did not. Due to this individual subject variable, the range of time for one trial in the sitting position varied from 15 to 210 seconds, for the standing position from 34 to 210 seconds, for the bent knee position from 40 to 520 seconds, and for straight leg inversion from 30 to 211 seconds (Appendix A). These ranges are extreme because one subject was especially difficult to test. Inter trial delay times for the other subjects are more consistent. Ideally, three 1 minute trials per position would have been preferred; however, individual subject variability and the technical nature of the tonometer made this impossible. This time variability in measurement technique limits the validity of data interpretation insofar as physiological response to changes in body position (such as blood pressure) may be time related.

In addition, volunteer subjects were used in this study because subjects were required to undergo a relatively stressful situation which entailed possible health risks. Therefore, random selection of subjects cannot be claimed.

CHAPTER II

REVIEW OF LITERATURE

Physicians, clinicians and aerospace program personnel have been interested in the effects of change in body position on cardiovascular dynamics for many years. Most early investigations were concerned with the assumption of standing posture, although several studies were devoted to general cardiovascular changes (i.e., heart rate, blood pressure, pulse pressure, cardiac output, heart sounds, and ECG tracings) and blood flow, blood volume changes associated with positional changes.

Musculoskeletal and cardiovascular stresses imposed by assumption of the vertical stance in man were well summarized in 1943 by Hellebrandt and Brogden. Their research revealed that normal standing was associated with a significant increase in heart rate, although with large individual variation. When the subject assumes the standing posture, cardiac output falls slightly, along with a small drop in plasma volume. Finally, prolonged standing produces the same cardiovascular manifestations as sudden standing, but the changes are much greater.

As early as 1826 the medical literature described a syncopal attack which was probably analagous to postural hypotension (Plorry, 1826), although the clinical syndrome of orthostatic hypotension was not delineated until 1925 (Bradbury & Eggleston, 1925). Hellebrandt

and Brogden (1943) reported that the venous system is more profoundly affected by the force of gravity upon standing than the arterial structures. Presumably, this is attributed to lower venous pressure, the greater distensibility of the venous walls, and the fact that the height of the blood column which must be raised against gravity is much greater (from feet to heart) than that of the arterial blood column (from heart to brain).

Assumption of the erect posture causes pooling in the dependent veins below the level of the heart, with the result that venous return is sharply reduced and despite some reflex compensation, cardiac output also drops (Wright, 1961). One compensation that occurs is an increase in heart rate. In a comprehensive study of 2,000 subjects, Schneider and Truesdell (1922) observed an average increase of 18 beats per minute upon standing from the lying position. Parkinson (1928) reported an average increase of only 10 beats per minute in athletic soldiers.

Crampton attempted to use the change in heart rate from recumbency to standing as an index of physical fitness. His hypothesis was that a fit person shows a rise of fewer than 10 beats, whereas unfit subjects may show an increase of 20 to 40 beats per minute (Crampton, 1913). However, when Schneider and Truesdell compared athletes with sedentary subjects there was only one beat per minute difference between the two groups upon standing (Schneider & Truesdell, 1922). These data did not support the belief that greater physical fitness is associated with a smaller difference between reclining and standing heart rates. Excessive postural increase in heart rate may distinguish obviously physiologically abnormal people

from normal people, but not normal sedentary people from athletes (Morehouse and Miller, 1959).

There appears to be some controversy regarding the effects of standing on blood pressure. In 1919, Sewall concluded from several hundred observations that in changing from the recumbent to the standing posture there is always a rise in diastolic blood pressure, little or no change in systolic pressure (any changes observed were slight) and a subsequent fall in pulse pressure (SBP-DBP). In Schneider and Truesdell's comprehensive study (1922) 56% of the male subjects showed an increase in systolic pressure, 18% experienced no change in standing, and 26% demonstrated a fall in pressure. Seventy-nine percent of the men had a rise in diastolic pressure, 6% a fall and 15% no change. The effect on the pulse pressure was observed to be a drop in about two-thirds of the men. Mean pulse in recumbency was 47 and in standing 43.

In 1897, Hill and Harold concluded on the basis of observations of blood pressure in different functional activities that any influence which weakens the splanchnic vasomotor mechanism interferes with its normal compensation, with the result that there is a fall in systolic blood pressure. In 1955, Alan and Smirk hypothesized that a blood pressure elevating reflex arising from voluntary muscle would play an important role in maintaining normal blood pressure during transitions in body posture. In 1970, Shvartz and Meyerstein conducted a 20 minute tilt table test on young men and women. Both groups showed similar orthostatic responses of increased heart rate and blood pressure. Although the women had higher orthostatic heart

rates and lower orthostatic blood pressure volume than the men, this was attributed to similar sex differences found in recumbency.

Physiological interest in cardiovascular response and adaptation to passive tilting dates back over 50 years. An extensive review of the literature to 1941 is presented by Graybiel and McFarland, especially its uses in aviation medicine. As the subject was tilted from the horizontal with a crotch support the most striking effect was on heart rate, which increased more sharply the closer the body was moved to the vertical position. Beyond the 45 degree angle the diastolic blood pressure increased significantly. Somewhere between 60 degrees and 70 degrees is the critical angle of tilting for most people; systolic pressure begins to fall, pulse pressure is seriously reduced and symptoms of syncope appear.

Early research in the area of inverted tilting was scarce. In 1918, Yandell and Haggard conducted a study to determine whether in normal man an increase of the venous pressure and the venous supply to the heart can be produced by means of the inverted position and if so whether they will increase the diastolic filling and the systolic discharge of the ventricles, and the volume of the blood in circulation. Ten healthy young male subjects were tested in the erect, horizontal (180 degree) inverted (45 degree) and again in the horizontal position. In the inverted position (30 to 45 degree) the heart rate was slower than in the horizontal position by an average of 9.5 beats per minute (maximum 23, minimum 4.5), and slower than the erect position by 17 (maximum 34, minimum 10). The diastolic distending force of venous pressure was increased but arterial pulse pressure was not augmented. No third heart sound was audible in the inverted position.

Venous pressure was notably increased in all subjects during inversion.

In 1921 a superficial study was published in which it was noticed that general tilts which lowered the head resulted in a fall in pulse rate, a rise in systolic pressure and a fall in diastolic pressure (Ellis, 1921). In 1957 an unpublished master's thesis was completed which attempted to obtain the cardiovascular adaptations of two groups to inverted tilting; one with "good" cardiovascular efficiency, the other with "poor" cardiovascular efficiency, as measured by the Crampton Index. Heart rate and blood pressure measurements of each group in the lying and the inverted postures were compared to determine whether there were significant differences between the cardiovascular adjustments in these positions. Data analyses showed that the "fit" subjects increased significantly in systolic and diastolic blood pressure in changing to an inverted position, with no significant change in heart rate. "Unfit" subjects did not change significantly in any sort of the measured positions. The fit subjects also had a significant decrease in pulse pressure in changing from lying to an inverted position (mean lying 42.6, mean inverted 35.3) (Schwartz, 1957).

Rao (1963) published a study on cardiovascular response to the head stand posture. After 5 minutes in the supine position the subjects actively assumed the head stand posture against a wall support. The mean brachial artery pressure increased from 90 to 180 mm Hg. The posterior tibial arterial pressure dropped significantly from 98 to 10 mm Hg. The heart rate increased from an average of 67 beats per minute in supine to 69 beats per minute in the head stand

position. All data were recorded 5 minutes after the change in body position. The author concluded that large changes of blood pressure in the posterior tibial artery do not activate the blood pressure changes in the carotid sinuses (i.e., baroreceptor).

Nosse (1978) measured the effects of inversion on spinal length and electromyograph (EMG) activity of the superficial lumbar area musculature in 20 healthy men. This study concluded that inverted positioning for short periods of time significantly increased spinal length ($\bar{x}$ sitting = 56.3 cm vs. $\bar{x}$ post 1 minute inversion = 58.3 cm) and reduced EMG activity of the superficial lumbar area musculature on normal males. This study supported the manufacturer's claims that increased spinal length, relaxation, and stretching do occur with inversion.

Animal studies revealed that anesthetized dogs in head down positions showed a decrease in pericardial pressure (Prabha, Wood & Coulan, 1970). The authors investigated variation in intrapericardial, pleural, and esophageal pressures by measuring vertical heights in the thorax of these dogs. Gayeryy, Maltseu and Poyorelyy (1980) found increases in perfusion pressure in the carotid artery, cerebral blood flow, pressure in the venous system of the brain and resistance of cerebral vessels in anesthetized rabbits and cats, with tilt table changes from horizontal to vertical (head up and head down) positions at 40 degrees and 80 degrees. The auto regulation of cerebral blood flow correlated with changes of perfusion pressure in the carotid artery. In another study (Fedorav & Debenkina, 1982) the position of the trunk of anesthetized dogs in anti-orthostatic positions at -45 degrees and -90 degrees to horizontal caused sharp increases of

pressure of the fourth ventricle of the brain, decelerated rhythm at cardiac contractions, increased peripheral resistance of branches of the carotid artery and sharp increased resistance in the jugular veins. The authors speculated that under anti-orthostatic conditions increased resistance in the carotid branch and decreased volumetric rate of circulation may be emergency compensatory reactions to prevent overfill of cerebral vessels with blood.

Several recent aerospace studies have been conducted with subjects in the head down position by Russian scientists. In the first study, six test subjects remained in the head down position at -4 degrees for 182 days. Subjects were examined stabilographically before and during the test. During the first 30 days subjects showed impaired equilibrium. Continuation of the bed rest study did not drastically impair the stability of standing upright (Kotovskaya, Gavrilina & Galle, 1981). In another study, the accuracy of the head down tilt model of adaptation to zero gravity was assessed by comparing the test results of subjects undergoing 24 hour -5 degree tilts. Measures of heart rate, plasma volume, and urine production were obtained during and after space flight. The magnitude of change in body fluid distributions and cardiovascular dysfunction while in a negative tilt were almost equal to space results. The results indicated that the cardiovascular system adapts rapidly and efficiently to central fluid shift which occurs early during exposure to zero gravity. Hemodynamic changes were transient with a nearly complete return to the control state within 6 hours. The authors speculated that adaptation is achieved primarily by diuresis and decreased blood volume mediated by ADH, renin and aldosterone inhibition (Bloomquist,

Nixon, Mitchell & Johnson, 1981). Volicer, Clark and Chobanian (1976) reported results similar to those above when they experimented with subjects in the head down tilt for 24 hours at -5 degrees. They reported an increase in sodium excretion and decrease in plasma volume. The plasma renin activity and plasma aldosterone levels were not significantly different from supine readings for the first 6 hours, but increased significantly at the end of 24 hours. Potassium was not affected by the head down tilt. These findings indicated that head down tilting induces sodium diuresis and stimulation of the renin-angiotension-aldosterone system. Katkov, Chestukhin, Mikhailov, Troshin & Utkin (1979) tested subjects before and after 5 day head down tilts (-4.5 degrees). Blood pressure was measured in different cardiovascular compartments by techniques of selective catheterization, with the bulb in the internal jugular vein, superior and inferior vena cava, hepatic, renal and iliac veins, right atrium and right ventricle, coronary sinus, pulmonary and radial arteries. Post test exposure in extrathoracic vessels increased by 1.4 mm Hg (superior and vena cava) on the average: internal jugular increased 1.7 mm Hg; iliac veins increased 1.0 mm Hg. Blood pressure in intrathoracic vessels increased as a rule by no more than .5-.8 mm Hg. The pressure in pulmonary vessels--pulmonary artery and left atrium--decreased by 1.3 mm Hg. In another experiment (Volashin, Kaypreshev, Asymol, Bondarenko & Pachenko, 1982) 15 healthy male subjects were exposed to head down tilts at -15 degrees and -30 degrees. Subjects experienced increased central and cerebral circulation. The authors indicated these conditions could be normalized by a positive pressure breathing technique (15-10 mm Hg).

Katkov, Chestukhin, Rumyantsev, Troshin, and Zybin (1981) exposed subjects to head up and head down tilts at 10 degrees, 30 degrees, and 75 degrees for 5 minutes to measure blood pressure in the upper internal jugular vein and right atrium. Blood acid base equilibrium, hemoglobin content, and O_2 saturation were also determined. In head down positions, jugular pressure increased in proportion to tilt angle, amounting to a 32.3 mm Hg increase at -75 degrees. Atrial pressure changed in a different fashion. In seven cases it increased and in three it decreased. Throughout testing the O_2 arteriovenous differences in the brain and acid base equilibrium in outflowing blood remained essentially unchanged.

Most recent studies support earlier findings with respect to heart rate and blood pressure. LeMarr, Golding, and Crehan (1983) measured cardiorespiratory responses in 50 healthy young subjects at rest, before, and after inversion. Both systolic and diastolic blood pressure increased significantly and remained significantly elevated during inversion. Heart rate decreased significantly and remained so during inversion. Respiratory responses were unaffected except for a significant increase in oxygen uptake during the first two minutes of inversion. In another study (Klatz, Goldman, Pinchuk, & Tarr, 1983) young healthy volunteers were inverted for 3 minutes. They were tested before, during and after inversion for changes in blood pressure, central retinal arterial pressure, and intraocular pressure. Blood pressures rose from an average of 119/74 to 157/93 mm Hg. Intraocular pressure went well into the glaucoma range and central retinal, systolic and diastolic arterial pressures also showed a statistically significant increase. All pressures returned to pre

inversion levels after subjects resumed the upright position. A longitudinal study was conducted by LeMarr and Golding (1983) to determine cardiorespiratory adaptations to inversion. Subjects were measured before and after inverting 4 times per week for 4 weeks. Pretest inversion produced significant changes in systolic pressure (BPS, +25 mm Hg), diastolic blood pressure (BPD, +16 mm Hg), heart rate (HR, - 22 beats/minute) and oxygen uptake (VO_2 , +125 ml). Tidal volume (TV) and respiration rate increased slightly. After 4 weeks of inversion, posttest response to inversion was similar to pretest except for TV, which decreased slightly. Significant differences (pretest - posttest) occurred for systolic blood pressure, BPS (-5.7 mm Hg), HR (-7.2 beats/minute) and VO_2 (-43 ml). Apparently, short-term regular inversion does not have a practical effect on standing or inverted cardiorespiratory responses. The effects of gravity inversion upon border line hypertensive subjects (average blood pressure of 142/85 mm Hg) revealed significant elevations in systemic blood pressure, pulse rate, central retinal arterial pressure, and intraocular pressure when subjects were inverted for 3 minutes at -90 degrees (Klatz, Goldman, Pinchuk & Tarr, 1985). Another study (Goldman, Tarr, Pinchuk & Kappler, 1985) measured the effects of oscillating inversion on systemic blood pressure, pulse, intraocular pressure and central retinal arterial pressure. Twenty healthy men oscillated between the upright and inverted state from 80 to 150 times during a 15 minute period. Measurements were made in the completely inverted stage of a cycle at 5, 10, and 15 minutes. Systemic blood pressure fell throughout the 15 minute oscillation period. Both systolic and diastolic pressures were significantly

reduced in each measurement period. Pulse rate also decreased on inversion and throughout the oscillation period. Intraocular pressure rose initially, then fell slightly, but was still elevated above preinversion values. One final study on ocular manifestation of gravity inversion was conducted by Friberg and Weinreb (1985). They evaluated normal volunteers with applanation tonometry, fundus photography, fluorescent angiography, and ophthalmodynametry during a head down vertical position hanging from gravity boots. They compared data obtained in the sitting position as well, and found the intraocular pressure more than doubled in inversion (35.3 ± 4.0 vs. 14.1 ± 2.8 mm Hg, $n = 16$), increasing to levels well within the glaucomatous range. Pressures in the central retinal artery underwent similar increases, while the caliber of the retinal artery decreased substantially. External ocular findings associated with gravity inversion included orbital congestion, conjunctival hyperemia, petechiae of the eyelids, excessive tearing (epiphora) and subconjunctival hemorrhage.

Summary of Review

Assumption of the vertical stance leads to a significant increase in heart rate, slight decrease in cardiac output and a small drop in plasma volume. Data reviewed did not support the belief that greater physical fitness is associated with smaller differences between reclining and standing heart rates. Although there was variation in results of standing blood pressures the most comprehensive study revealed an increase in systolic blood pressure in 56% of the subjects and an increase in diastolic pressure in 79% of the subjects

tested. Variations may be attributed to lack of standardization in measuring blood pressure as well as increased subject anxiety before and during testing.

Positive passive tilting reveals a very significant increase in heart rate, which increases the more closely the body is tilted to the vertical position. Beyond the 45 degree angle the diastolic blood pressure increases significantly. Between 60 degrees and 70 degrees is the critical angle for most people; systolic pressure begins to fall, pulse pressure is seriously reduced and symptoms of syncope appear.

Passive inversion consistently had the effect of increasing systolic and diastolic blood pressure while decreasing heart rate when compared to the vertical position. A decrease in the carotid artery, cerebral blood flow, pressure in the venous system of the brain (especially in the 4th ventricle), and resistance of cerebral vessels (carotid artery and jugular veins) have been demonstrated in animals during inversion. The effects of inversion for prolonged periods (24 hours) reveals impaired equilibrium, increases in sodium excretion and decreases in plasma volume. Inversion has also been shown to increase pressure in the superior and inferior vena cava, internal jugular, iliac veins and in intrathoracic vessels in humans. Pressure in the pulmonary artery and left atrium decreased during inversion. Inversion can increase intraocular pressure well into glaucoma ranges as well as increasing central retinal pressure. Short term regular inversion does not have practical adaptive effects on standing or inverted cardiorespiratory responses. Inverted positioning for short periods of time significantly increased spinal

length and reduced EMG activity of the superficial lumbar area musculature on normal males. Oscillating inversion for a period of 15 minutes reduced systemic blood pressure and pulse rate while slightly elevating intraocular pressure. Finally, no research was reported on the differential physiologic effects of bent leg versus straight leg gravity inversion.

CHAPTER III

METHODS

Subjects

Twenty subjects utilized for this study were 10 male and 10 female medically screened, low cardiac risk (AHA) volunteers aged 20 to 40 years. The author and two other graduate students performed test procedures under the supervision of the California State University, Northridge (CSUN) exercise physiology staff. All laboratory personnel had special training in clinical EKG interpretation so abnormal tracings would be detected and the test terminated if necessary. All members of the team had current CPR training and certification. A physician and nurse were available for emergency medical assistance through student health services at CSUN.

Equipment

The Gym Mobile™ (Appendix H) was utilized for obtaining inversion of subjects with hips and knees flexed. The Hewlett-Packard Model 1500 single channel EKG Monitor was utilized for obtaining EKG strips and heart rate. A modified chest lead configuration (CM₅) was used with LA, RA, and RL. A standup mercury column sphygmomanometer and stethoscope were used to obtain blood pressure measurements. The A. O. Reichart Non-Contact II™ tonometer (Appendix I) was utilized for measuring intraocular pressure. The new applanation tonometer

(NCT) measures intraocular pressure without touching the eye. The NCT consists of three component systems. First, the pneumatic system, is designed to deliver an air pulse whose force increases linearly with time. Second, the applanation monitoring system, is designed to detect and identify with microsecond resolution, the occurrence of applanation. An optical electronic alignment system is the NCT's third component. It consists of a primary visual alignment system and an overriding automatic alignment verification feature that precludes measurement unless the incorporated spatial criteria are satisfied. A special purpose digital computer, located in the instrument's base, regulates each of the component systems, integrates their interaction, processes the acquired measurement information, and finally, displays the intraocular pressure (IOP) digitally in millimeters of mercury. Clinical evaluation has demonstrated good correlation between NCT and Goldman (1957) (which measures the force that is required to flatten a specific optically determined area). It is the currently accepted standard for evaluation of all clinical tonometer readings, thereby validating this new method of tonometry. (Grolman, 1976). The greatest discrepancies occur at very high pressure levels, where the NCT tends to produce readings somewhat higher than the Goldman tonometer. This type of discrepancy has little, if any, clinical significance (Forbes & Grolman, 1974).

The non-contact tonometer is placed 1/4 inch away from the cornea. Once the tonometer is focused, the trigger is squeezed and a puff of air is ejected against the cornea. The force increases linearly with time. As the cornea responds to the air by progressively flattening, the resulting lessening of the dispersion of reflected

light is monitored by a light detector within the tonometer. A maximum of detected reflected light is coincident with the occurrence of applanation (flattening of the cornea). The instrument measures the time it takes the cornea to reach this point, converts it to mm Hg, and displays the results in digital form on a screen.

A standard manual tilt table (Appendix J) was modified to provide inversion with hips and knees extended. Modifications consisted of a padded "T"-bar designed to slide down over the dorsum of the subject's feet. Subjects wore Gravity Boots™ (Appendix K) with hooks secured around the "T"-bar. Boots were additionally taped around subject's ankles for greater stabilization. When the "T"-bar was adjusted for comfort a wing nut locked it into place to further secure subjects for inversion.

The distal one third of the tilt board was prepared with several 1 inch holes on both inside borders with a double wing nut locking mechanism to adjust for variation in subjects' heights. Range of subjects' height accommodated by the modified tilt table was 4 feet to 6 feet 1 inch.

All testing equipment was placed on a specially designed heavy duty 8' x 8' x 4' platform for data collection (Appendix K).

Procedure

Data collection for this study was conducted during the Fall of 1984 and Spring of 1985 in the exercise physiology laboratory at California State University, Northridge.

Protocol consisted of: subjects reported to the lab after medical screening and conformed to AHA low risk guidelines. A pretest

for resting blood pressure was administered. Subjects whose resting blood pressure was 140/90, heart rate 100, or intraocular pressure 26 mm Hg or above were excluded from the study. Participating subjects were then informed of research details, including possible risk. Subjects were then asked to sign an informed consent form (Appendix D) using ACSM guidelines (1980).

Variables of heart rate, blood pressure and intraocular pressure were measured in three trials at each of the four positions from sitting, then standing, and finally during inversion (hips and knees flexed and hips and knees extended). Corrected blood pressure values were also collected since subjects' arms were not at heart level, while data was collected (see chapter IV, p. 44).

Subjects started in the sitting position and were given 5 minutes to establish a resting base level. Once a resting baseline was established, the blood pressure cuff was placed on the left arm and the head of the stethoscope secured over the brachial artery on the left arm. A standup mercury column sphygmomanometer was used to obtain measurements. One technician was solely responsible for all blood pressure measurements throughout the study.

Prior to testing, while subjects were lying quiescent and supine they were prepped (shaved if necessary, alcohol wiped, skin abraded) and electrodes applied for a modified V-5 EKG application (RA electrode to manubrium, LA over 5th rib, anterior axillary line on left side, RL or ground to right side 5th rib). A second technician was solely responsible for obtaining all EKG and heart rates for all positions. For this purpose an EKG strip was obtained for the last 10 seconds of each time interval.

A third technician was responsible for positioning the Non-Contact II™ tonometer for measuring the intraocular pressure during inversion in all positions.

Two different types of apparatus were used for inversion testing; the Gym Mobile™, which allows inversion of the subjects with hips and knees flexed (presumed vessel occlusion) and a modified tilt table with Gravity Boots™ and adjustable "T"-bar. The latter apparatus allowed inversion with hips and knees extended (presumed no vessel occlusion).

Prior to actual testing, data were obtained to establish reliability of the tonometer and technician in sitting, standing and bent knee as well as straight leg inversion. A Pearson correlation was run on pre and post measurements. Analysis of the data revealed positive correlations of .836, .945, .781, and .958 respectively (see Appendix F).

Subjects reported to the laboratory on one occasion and were tested in sitting, standing and inversion. Subjects were alternately given either bent knee or straight leg inversion first. For example, if subject one had the order of sitting, standing, bent knee inversion, recovery, straight leg inversion; then subject two received sitting, standing, straight leg inversion, recovery, bent knee inversion. This was done to rule out the effects of learning, training or adaptation to one type of inversion over the other.

A pilot study was also conducted after establishing the reliability data. The results of the pilot study in raw data form appear in Appendix G.

Statistical analysis of the data obtained from this study was conducted with a computer program. A two-way analysis of variance (ANOVA) with repeated measures for heart rates, blood pressure (systolic and diastolic), and intraocular pressure at trials one, two and three in the four positions of sitting, standing, bent knee inversion, and straight leg inversion. This statistical design was used to determine whether significant differences existed within trials or between positions on variables of heart rate, blood pressure or intraocular pressure.

For the data in which significant F scores appeared, a post hoc test was conducted. The Tukey H.S.D. (honestly significant difference) test was utilized to determine the level of significance, as well as where significant changes occurred.

CHAPTER IV

DATA AND DISCUSSION

Twenty volunteer subjects, 10 male and 10 female, between the ages of 20 to 40 years were utilized in this study. Variables of heart rate, systolic and diastolic blood pressures, and left and right intraocular pressures were observed, monitored and recorded. The variables were obtained from subjects in sitting, standing, straight leg and bent knee inversion positions.

A two-way analysis of variance (ANOVA) with repeated measures was used to statistically analyze all data. In two-way ANOVA, the effects of two independent variables on the dependent variable are considered simultaneously. Most commonly used variables for two-way ANOVA with repeated measures are training or testing conditions and time. Time is usually represented by a pre, mid and post test spread over several days, weeks or months, or it may be presented as multiple trials to criterion on a task, or multiple observations of some physiological condition (Vincent, 1985).

Variables of heart rate, systolic blood pressure, diastolic blood pressure, right intraocular pressure, left intraocular pressure, corrected diastolic blood pressure and corrected systolic blood pressure were each analyzed, using a two-way analysis of variance for trials one, two and three, over repeated testing conditions of sitting, standing, bent knee inversion and straight leg inversion.

Graphs representing the above data after computer analysis are presented in the following pages.

Heart Rate

Analysis of heart rate data (Figure 1) revealed a significant increase in heart rate from sitting to bent knee inversion positions.

Two-way analysis of variance with repeated measures revealed no significant difference in heart rate within trials ($F = .14$). Therefore, the mean score for the three trials was used as the base figure for comparison over positions. Only this mean value is plotted on the graph in Figure 1. There was, however, a significant change in heart rate ($F = 8.97$, $p < .0000$) between positions. Tukey's honestly significant difference post hoc test was conducted and revealed the difference occurred only between sitting and bent knee inversion ($p \leq .05$) (see Figure 1).

Pulse data collected in this study were consistent with earlier data collected by Yandell and Haggard (1918) who reported an average decrease of 17 beats in heart rate during inversion versus standing. LeMarr, Golding, and Crehan (1983) and also Klatz, Goldman, Pinchuk, and Tarr (1985) found a significant decrease in heart rate during inversion versus standing.

Other data in the present study revealed an average decrease of 1.03 beats per minute from standing to straight leg inversion which was not significant. Heart rate during bent knee inversion was highest; on the average of 7 beats per minute greater than during sitting. This difference was significant according to Tukey's post hoc test ($p \leq .05$).

Heart Rate: Mean Values over three trial by positions

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Trial	171.76	2;17	85.89	.14	.8676
Error	34379.33		603.15		
Position	1509.93	3;171	503.31	8.97	.0000
Error	9590.48		56.08		
PT (interaction)	254.10		42.35	.76	.6062

Mean Difference Table

	Sitting	Standing	Bent knee	Straight leg
Sitting	0	5.06	6.83*	4.03
Standing		0	1.77	1.03
Bent knee			0	2.80
Straight leg				

* = .05; ** = .01

HSD .05 = 5.63, HSD .01 = 7.03

Figure 1. Heart Rate Data Analysis. (N = 20)

Major control of heart rate is exerted reflexly by the baroreceptors of the carotid sinus and aortic arch. When the arterial pressure falls, there is a reflex which decreases vagal activity and increases sympathetic activity. Conversely, when pressure rises, vagal activity increases, tending to slow the heart. This is accompanied by a decreased sympathetic activity. This picture of reciprocal vagal and sympathetic activity originates largely from experiments on anesthetized animals (Ruch & Patton, 1974).

An analogy from aviation research states:

The gravitational force to which objects at the earth's surface are exposed is proportional to their mass and the gravitational constant of accelerating for this planet; these conditions are conventionally adopted as the standard for comparison, and such objects are said to be exposed to an acceleration of 1 gravity (g) vectorially directed toward the center of the earth. The action of gravitational stress on the body depends on both the magnitude of acceleration and its direction with respect to the long axis of the body. Rotation at 1 g in a human centrifuge, with the long axis of the body oriented radially and the feet toward the periphery, duplicates in essence the effects of the erect posture. With increasing acceleration the pulse rate rises, often reaching 130 to 160 beats per minute at 3 to 4 g. Cardiac output tends to decrease, but the decrease is surprisingly small up to 4 g of gravity (Lindberg, Sutterer, Marshall, Healy, & Wood, 1960, p. 817).

Baroreceptors are obviously responsible for at least some of the above indicated circulatory reactions; when the body is oriented so that acceleration tends to displace blood toward the head the heart rate slows, and the response has been shown to depend on the integrity of the vagus and carotid sinus nerves (Jongbloed & Noyome, 1934). The initial effects of positive gravity on arterial blood pressure differ in vessels about and below the heart; pressure rises in the iliac artery for example, and falls in the carotid artery (Lawton, Greene, Kydd, Peterson, & Crosbie, 1958).

A physiologic explanation of these changes in cardiac response may begin with the Frank-Starling Law, which states that:

within the physiologic limit of the heart, the heart will pump whatever amount of blood enters the right atrium and will do so without significant build-up of back pressure in the right atrium. To state this another way, under normal circumstances the major factor determining cardiac output is the rate of venous return (Guyton, 1981, p. 158).

No serious and consistent EKG aberrations were observed during any of the positions studied. Some transient irregularities observed includes those displayed in Figure 2.

Systolic Blood Pressure

Analysis of the systolic blood pressure data (Figure 3) revealed an average decrease in systolic blood pressure from sitting to standing. During bent knee and straight leg inversion SBP was significantly greater than sitting or standing ($p \leq .01$). However, there was no significant difference between bent knee and straight leg inversion.

Two-way analysis of variance with repeated measures revealed no significant differences in systolic blood pressure within trials ($F = .01$). Therefore, the mean score for three trials was used as the base figure for comparison over positions. Only this mean value is plotted on the graph in Figure 3. There was a significant change in systolic blood pressure ($F = 61.24$, $p \leq .0000$) between positions. Tukey's honestly significant difference post hoc test was conducted, revealing that the difference occurred between sitting and both bent knee and straight leg inversion ($p \leq .01$). There were also significant differences between standing systolic blood pressure versus bent knee and straight leg inversion ($p < .01$) (see Figure 3).

Position/Trial #		PVC	RonT	ST Elv.	ST Dep.	Tachycardia	p ¹
Sit	1					1	
	2						
	3		2		1		
Stand	1				1		
	2						
	3						
Bent Knee	1						1
	2					2	
	3					2	
Straight Leg	1	1			1	2	1
	2					1	
	3					1	
Pre-test strip		1			1		1
Pilot subj.			1	1	1		

Figure 2. EKG Tracings.

Systolic Blood Pressure: Mean values over three trials by position

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Trial	12.40	2;57	6.20	.01	.9917
Error	42446.41		744.67		
Position	6258.65	3;171	2086.22	61.24	.0000
Error	5825.34		34.07		
PT (interaction)	29.27		4.88	.14	.9902

(.05) HSD = 3.36 $\frac{34.06}{20}$ (.01) HSD = 4.2 $\frac{34.06}{20}$

Mean Difference Table

	Sitting	Standing	Bent knee	Straight leg
Sitting	0	.93	8.62**	10.64**
Standing		0	9.55**	11.57**
Bent knee			0	2.02
Straight leg				

* = .05; ** = .01

HSD .05 = 4.38, HSE .01 = 5.48

Figure 3. Systolic blood pressure analysis. (N = 20)

Data collected in this study support previous studies including Ellis (1921), Klatz et al., (1983), Le Marr, Golding, and Crehan (1983), and Rao (1963), in which all reported significant increases in systolic blood pressure during inversion. When compared to the vertical standing position, Klatz, Goldman, Pinchuk, and Tarr (1985) revealed significant elevations (from a $\bar{x}$ of 142/88 resting, to a $\bar{x}$ of 180/108 during inversion) in systemic blood pressure in ten borderline hypertensive people during inversion.

Blood pressure is one of the most constant of cardiovascular variables, but changing with the demands of an organism, especially with large variation in heart rate and cardiac output. The receptors for regulation of blood pressure are in the region of bifurcation of the carotid artery and around the arch of the ascending aorta. They consist of a plexus of nerve fibers with special edges sensitive to mechanical stretch or deformation of the wall of the vessel. The receptors in the carotid area are well defined and are approximately equal in the internal carotid artery and the carotid sinus. Different branches go to the carotid sinus nerve and branch into cranial nerve IX (glossopharyngeal). The portion of nerve fibers at the aortic arch are similar to the afferents in cranial nerve X (vagus nerve). As mentioned earlier these fibers are very sensitive to mechanical stretch or pressure and are called mechano, presso or baroreceptors. If there is an increase in arterial pressure this leads to an increase in afferent input to the CNS with decreases in sympathetic output. This leads to a decrease in vasomotor tone, decreased heart rate and eventual decrease in arterial pressure. So if blood pressure decreases (for example with standing up suddenly) pressure in the carotid sinus decreases, cardiac output decreases (due to venous pooling in the legs), which leads to increased sympathetic tone, thus increased heart rate, cardiac output and peripheral resistance, all of which return blood pressure to its normal limits. This whole system works as a negative feedback loop (Selkirk, 1975, p. 384).

To further delineate changes in blood pressure from sitting to standing to inversion, Mountcastle (1980) offers additional information.

When man rises from the recumbent position and stands erect, the weight of intravascular columns of blood in vessels above and below the heart places stress on the circulation that is absent in the supine position. These hydrostatic pressures do not

directly influence the driving force, or gradient of pressure, from arteries to veins; however, they do alter local transmural pressure so that the larger veins, being readily distended, tend to enlarge the legs and collapse in the upper portion of the body. The magnitude of the hydrostatic force at any point can be calculated from the vertical distance between that point and the right atrium, where the systemic circulation terminates, taking into account the density of blood and the gravitational constant (Mountcastle, 1980, p. 1039).

Two major factors that affect the pulse pressure are stroke volume output of the heart and the compliance (total distensibility) of the arterial tree. A third, less important, factor is the character of ejection from the heart during systole. In general, the greater the stroke volume output, the greater is the amount of blood that must be accommodated in the arterial tree with each heartbeat and, therefore, the greater is the pressure rise and fall during systole and diastole, thus causing a greater pulse pressure (Guyton, 1981).

Factors that affect pulse pressure by changing the stroke volume output are:

- 1) a decrease in heart rate while the cardiac output remains constant causes the stroke volume output to increase in inverse proportion to the decreased rate, and the pulse pressure increases accordingly,
- 2) a decrease in total peripheral resistance allows rapid flow of blood from the arteries to the veins. This increases the venous return to the heart and increases the stroke volume. Therefore, the pulse pressure is also greatly increased.
- 3) An increase in mean circulatory filling pressure, if all other circulatory factors remain constant, increases the rate of venous return to the heart and consequently increases both the stroke volume output and the pulse pressure.
- 4) The character of ejection from the heart affects the pulse pressure in two ways: first, if the duration of systole is long, a large portion of the stroke volume output runs off through the systemic circulation while it is being ejected into the aorta, therefore, the magnitude of the stroke volume effect on pulse pressure is decreased. Second, rapid onset of heart contraction sometimes occurs when a heart is beating vigorously, and this causes the pressure in the aorta to rise very high before the blood can run off through the peripheral circulation. Therefore, sudden ejection causes a greater pulse pressure than does more prolonged ejection (Guyton, 1981, p. 221).

Another fact to note is that vascular changes in arteriosclerosis greatly decrease compliance of the arterial system, which in turn causes the arterial pressure to rise very high during systole and to fall greatly during diastole as blood runs off from the arteries to the veins. Arteriosclerosis usually occurs in old age when the arterial walls lose elasticity and muscular tissues are replaced by fibrous tissues and/or calcified plaques that cannot stretch significantly. This process can occur at a much earlier age in some individuals and would put them at greater risk of increased systolic pressure during certain circulatory stresses (Guyton, 1981).

Diastolic Blood Pressure

Analysis of diastolic blood pressure (DBP) data (Figure 4) revealed an insignificant decrease in diastolic blood pressure from sitting to standing. During bent knee inversion, DBP was significantly greater ($p \leq .01$) than sitting or standing, but DBP did not differ significantly between bent knee and straight leg inversion.

A two-way ANOVA with repeated measures revealed no significant difference in DBP within trials ($F = .02$). Therefore, the mean score for three trials was used as the base figure for comparison over positions. Only this mean value is plotted in Figure 4. There was a significant change in diastolic blood pressure ($F = 120.25$, $p \leq .0000$) between positions. Tukey's honestly significant difference post hoc test was conducted, revealing that variance occurred between sitting or standing, and bent knee or straight leg inversion. All values were significant ($p \leq .01$) (see Figure 4).

Diastolic Blood Pressure: Mean values over three trials by position

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Trial	7.16	2;57	3.58	.02	.9850
Error	13527.09		237.32		
Position	15289.48	3;171	5096.49	120.25	.0000
Error	7247.66		42.38		
PT (interaction)	110.61		18.34	.43	.8548

Mean Difference Table

	Sitting	Standing	Bent knee	Straight leg
Sitting	0	.78	13.7**	17.07**
Standing		0	14.48**	17.85**
Bent knee			0	3.37
Straight leg				

* = .05; ** = .01

HSD .05 = 4.89, HSD .01 = 6.11

Figure 4. Diastolic blood pressure analysis. (N = 20)

Data collected in the present study support findings of previous studies by LeMarr, Golding, and Crehan (1983) and Klatz (1983) with regard to increased DBP during inversion. Klatz, Goldman, Pinchuk, and Tarr (1985) found the effects of gravity inversion on borderline hypertensives to significantly increase both systolic and diastolic blood pressure.

Many manufacturers recommend exercising in their inversion devices, therefore, an additional factor which must be considered is the effect of exercise during inversion.

The sympathetic discharge throughout exercise and the resultant vasoconstriction of most of the blood vessels besides those in the active muscles almost always increase the arterial pressure during exercise. This increase can be as little as 20 mm Hg or as great as 80 mm Hg, depending on the conditions under which exercise is performed. When a person exercises under very tense conditions but uses few muscles, the sympathetic response still occurs throughout the body but vasodilation occurs in only a few muscles. The net effect is mainly one of vasoconstriction, often increasing the mean arterial pressure as high as 180 mm Hg. Such a condition occurs in a person standing on a ladder and nailing with a hammer on the ceiling above (Guyton, 1981).

When a person performs whole-body exercise such as running or swimming, the increase in arterial pressure is usually only 20 to 40 mm Hg. Absence of a larger rise in pressure results from the extreme vasodilation occurring in large masses of muscles (Guyton, 1981).

Left Intraocular Pressure

An analysis of left intraocular pressure data (Figure 5) reveals no significant pressure decrease from sitting to standing. During bent knee inversion, left IOP was significantly greater than sitting or standing ($p < .01$). Left IOP was the highest during straight leg inversion, which was also significantly different from bent knee inversion ($p \leq .01$).

A two-way ANOVA with repeated measures revealed no significant difference in left IOP within trials ($F = .22$). Therefore, the mean score for three trials was used as the base figure for comparison over positions. Only this mean value is plotted on the graph in Figure 5. There was, however, a significant change between positions ($F = 1241.58$, $p \leq .0000$). Tukey's honestly significant difference post hoc test revealed that significant differences ($p \leq .01$) (see Figure 5) occurred between sitting versus bent knee and straight leg inversion, and finally between bent knee and straight leg inversion. Values during bent knee and straight leg inversion were into the glaucoma ranges as reported by Klatz et al. (1983, 1985).

Right Intraocular Pressure

Analysis of right intraocular pressure data (Figure 6) revealed an insignificant decrease in right intraocular pressure from sitting to standing. During bent knee inversion right intraocular pressure was greater ($p \leq .01$) than sitting or standing. Right intraocular pressure was the highest during straight leg inversion, which was significantly different than during bent knee inversion ($p \leq .01$).

Left Intraocular Pressure: Mean values
over three trials by positions

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Trial	11.99	2;57	5.99	.22	.8039
Error	1506.66		27.38		
Position	14252.03	3;171	4750.67	1241.58	.0000
Error	654.29		3.83		
PT (interaction)	8.79		1.47	.38	.8890

Mean Difference Table

	Sitting	Standing	Bent knee	Straight leg
Sitting	0	.40	13.79**	16.40**
Standing		0	14.19**	16.80**
Bent knee			0	2.61**
Straight leg				0

* = .05; ** = .01

HSD .05 = 1.47, HSD .01 = 1.84

Figure 5. Left intraocular pressure analysis. (N = 20)

Right Intraocular Pressure:
Mean values over three trials by positions

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Trial	6.01	2;57	3.00	.09	.9168
Error	1969.03		34.54		
Position	13760.78	3;171	4586.93	839.12	.0000
Error	934.75		5.47		
PT (interaction)	10.81		1.80	.33	.9207

Mean Difference Table

	Sitting	Standing	Bent knee	Straight leg
Sitting	0	.13	13.79**	16.18**
Standing		0	13.92**	16.31**
Bent knee			0	2.39**
Straight leg				

* = .05; ** = .01

HSD .05 = 1.757, HSD .01 = 2.196

Figure 6. Right intraocular pressure analysis. (N=20)

A two-way ANOVA with repeated measures revealed no significant differences in right intraocular pressure within trials ($F = .09$). Therefore, the mean score for three trials was used as the base figure for comparison over positions. Only this mean value is plotted on the graph in Figure 6. There was a significant change between positions ($F = 839.12$, $p \leq .0000$).

Tukey's honestly significant difference post hoc test revealed that significant differences ($p \leq .01$) occurred in right IOP between sitting versus bent knee and straight leg inversion, standing versus bent knee and straight leg inversion, and finally between bent knee and straight leg inversion (see Figure 6).

IOP values during bent knee and straight leg inversion were in the glaucoma range which supports data reported by Klatz et al. (1983) and Klatz (1985). It is important to note that average normal intraocular pressure is approximately 16 mm Hg, with a range from 12 to 20 mm Hg. When intraocular pressure exceeds 20 mm Hg it enters the glaucoma range (Guyton, 1981).

Glaucoma is one of the most common causes of blindness. It is a disease of the eye in which intraocular pressure becomes pathologically high, sometimes rising to 70 mm Hg. Pressures rising above at little as 25 to 30 mm Hg can cause a loss of vision when maintained for several years. Extremely high pressure can cause blindness within days (Guyton, 1981).

Friberg and Weinreb (1985) found that intraocular pressure more than doubled during inversion, central retinal arterial pressure increased, as well as the occurrence of orbital congestion, conjunctival hyperemia, petechiae of the eyelid, excessive tearing and

subconjunctival hemorrhage in the subjects they inverted from gravity boots.

Kanisely (1985) reports a physician writing to the New England Journal of Medicine stating that two non-hypertensive patients developed small retinal hemorrhages from increased blood pressure in the eyes during inversion. This doctor suggested that such "eye flares indicate pressure that could cause a stroke."

One cannot ignore the possible effects of inversion on cerebral blood flow considering the demonstrated effect inversion has on intraocular pressure. Cerebral blood flow is autoregulated extremely well between the arterial pressure limits of 60 and 140 mm Hg. The arterial pressure can decrease acutely as low as 60 mm Hg or increase as high as 140 mm Hg within a significant change in cerebral blood flow. In persons who have hypertension, this autoregulatory range shifts to even higher pressure levels, up to 180 or 200 mm Hg. If, however, arterial pressure falls below 60 mm Hg, cerebral blood flow becomes severely compromised, and if pressure rises above the upper limit of autoregulation, blood flow rises rapidly and can cause severe overstretch of cerebral blood vessels, resulting in serious brain edema (Guyton, 1981).

A serious complication of abnormal cerebral hemodynamics is the development of brain edema. This can occur because the brain is encased in inelastic duramater and a solid cranium. Thus, if accumulation of edema fluid compresses the blood vessels, depressed blood flow occurs with resultant destruction of brain tissue (Guyton, 1981).

The usual cause of brain edema is either greatly increased capillary pressure or damage to the capillary endothelium. One cause of

excessively high capillary pressure is a sudden increase in cerebral blood pressure to levels too high for the autoregulatory mechanisms to cope with (Guyton, 1981).

In addition, the fraction of intracranial space available for blood can be modified by changes in the volume of cerebrospinal, intracellular or intercellular fluid. Any rise in intracranial pressure will be transmitted equally throughout the contents of the cavity, including the blood vessels. Cerebral veins will be primarily affected, since they have the lowest intravascular pressure. But a rise in intracranial pressure resulting from a tumor or other extravascular encroachment on space will not seriously reduce blood flow until it exceeds the pressure within the arteries (Milnor, 1980).

Cerebral Blood Flow and Metabolism
in Man Under Various Conditions
(avg. fig. from studies in groups of various subjects)

Condition	Mean Arterial Pressure (mm Hg)	Cerebral Blood Circulation (mm Hg)	Cerebral Vascular Resistance (mm Hg)
Normal young man breathing at rest	85	750	1.6
Voluntary hyperventilation (low CO ₂)	98	473	2.9
Hypertension (no cerebral changes)	155	778	2.8

Source: Modified from C. T. Schmidt (1950), The cerebral circulation in health and disease (Springford, IL: CC Thomas Pub. and Solcoloft, L. and Ketys (1960), Regulation of cerebral circulation, 40 Supp. 4), p. 38.

Inversion traction exposes the body to effects that are physiologically similar to negative "G" forces. Guyton (1981) indicates

that negative "G" forces are less acutely dramatic but possibly more permanently damaging than the effects of positive "G." At -4 to -5 G of pressure there is intense momentary hyperemia of the head: 1) arterial pressure at the heart level increases significantly; 2) very high arterial pressure elicits extreme baroreceptor reflex that can lead to severe vagal slowing of the heart (sometimes actually stopping the heart for 5-10 seconds); 3) if arterial pressure becomes great enough, it can cause some of the small vessels on the surface of the head and possibly the brain to rupture.

The brain, unlike such organs as the liver, is divisible into distinct functional areas, it is reasonable to suppose that its vasculature is subject to local adjustment related to localized changes in neuronal activity. Several investigators have secured evidence that blood vessels dilate in cerebral areas that are specifically active. Schmidt and Hendrix (1950), using a thermoelectric probe in the anesthetized cat, found that illumination of one retina by a small flashlight caused an increase in blood flow that was restricted to the visual area of the cerebral cortex, when there was no change in arterial pressure or in the tensions of the respiratory gases in arterial blood. Serota and Gerard (1961) later obtained evidence of increased metabolism in appropriate areas of the brain on stimulation of sensory pathways.

Since intraocular pressure increases so dramatically and the eye is so active secondary to air being blown into it by the tonometer, it is speculated that this could increase activity on the ocular portion of the brain, and thereby contribute further to increasing intracranial pressure.

Finally, "the cerebro spinal fluid pressure in man when in the recumbent position averages 130 to 150 mm of water regardless of whether the pressure is measured in the cisterna magna or in the lumbar region. For the sitting position, the lumbar pressure rises to 200 to 250 mm of water. No demonstrable changes are produced by alternating the arterial pressure, but an increase in the venous pressure has an immediate effect. This may be demonstrated by pressing on the jugular veins (Queckenstedt's Test)" (Bard, 1961, p. 315).

Corrected Systolic and Diastolic Blood Pressure

The sphygmomanometer cuff measures transmural pressure, and it is important that the artery under the cuff be at the level of the heart or that a correction be made (Feigle, 1974). When arterial blood pressures are measured in the arm or leg or elsewhere in a patient not on a horizontal plane, they must be corrected to heart level for comparison with standards which are based on values at heart level. This correction factor is made by subtracting the hydrostatic factor (pgh) if the site of measurement is below the heart, or by adding this factor if the site is above. An approximate value in mm Hg is obtained by dividing the differences in level in centimeters by 13 (i.e., $17.6/1.055$). The clinical indirect measure of blood pressure is usually made on the forearm of a seated subject. In this case the level is close enough to that of the heart to require no correction (Ruch & Patton, 1965).

In the present study, the sphygmomanometer cuff was applied to the arm twelve inches distal from the reference point of the heart in all subjects. Twelve inches multiplied by 2.54 cm/1 inch yields a

correction factor value of 30.48 divided by 13 = 2.34 for corrected systolic and diastolic blood pressures in subjects during inversion (bent knee and straight leg). Since the subjects' arms were below their hearts, the correction factor value of 2.34 was subtracted from the clinical values obtained. In both sitting and standing positions the subjects' arms remained level to their heart as they rested on the tonometer table, therefore, no correction was made for these values.

Corrected values for both systolic blood pressure (SBP) and diastolic blood pressure (DBP) revealed exactly the same relationship among trials over all positions as did the uncorrected (observed) values (Appendices L and M).

Scores obtained within groups consistently revealed no significant differences in all positions. Therefore, the mean values over the three trials by position were plotted on graphs in Figures 1 through 6 and Appendices L and M since they were the most representative score obtained.

Subjective Observations

Two subjects in this study complained of increased pressure and pain in their sinuses. Several subjects complained of discomfort on the dorsal aspect of their feet as well as some numbness in their feet during straight leg inversion (hanging from the gravity boots). These symptoms diminished when subjects were removed from the inverted position.

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Summary

Cardiophipheral vascular effects of inversion on 20 human subjects were observed, recorded and analyzed. Variables of heart rate, blood pressure and intraocular pressure did not vary significantly within three repeated trials. Heart rate significantly increased from sitting to bent knee inversion ($p < .05$). Systolic and diastolic blood pressures (original values and those arrived at by application of a correction factor) significantly increased from sitting and standing positions to bent knee as well as straight leg inversion positions ($p < .01$). Left and right intraocular pressure increased significantly from the sitting and standing positions to the bent knee and straight leg inversion positions ($p < .01$). There were also significant increases in left and right intraocular pressure between the bent knee and the straight leg inversion positions ($p < .01$).

From data analyses it was clear that significant changes in variables of heart rate, blood pressure and intraocular pressure occurred upon inversion and that these changes remained stable over time (three trials per position). These findings should encourage manufacturers to conduct additional research to establish better

safety standards for utilizing gravity inversion devices and to be more selective in selling their equipment to the general public. One approach to the problem might be an FDA requirement for a physician's prescription to purchase an inversion unit. Presumably, a medical examination, including inversion screening, would determine the patient's safe clinical use of such devices.

Conclusions

1. The null hypothesis was not accepted for heart rate. Significant differences were found between sitting and bent knee inversion ($p < .05$).
2. The null hypothesis was not accepted for systolic blood pressure (observed and corrected). Significant differences were found between sitting and bent knee ($p < .01$), sitting and straight leg inversion ($p < .01$), standing and bent knee ($p < .01$), and standing and straight leg inversion ($p < .01$).
3. The null hypothesis was not accepted for diastolic blood pressure (observed and corrected). Significant differences were found between sitting and bent knee ($p < .01$), sitting and straight leg inversion ($p < .01$), standing and bent knee ($p < .01$), and standing and straight leg inversion ($p < .01$).
4. The null hypothesis was not accepted for left intraocular pressure. Significant differences were found between sitting and bent knee ($p < .01$), sitting and straight leg inversion ($p < .01$), standing and bent knee ($p < .01$), and standing and straight leg inversion ($p < .01$). Significant differences in left intraocular

pressure were also found between bent knee and straight leg inversion ($p < .01$).

5. The null hypothesis was not accepted for right intraocular pressure. Significant differences were found between sitting and bent knee ($p < .01$), sitting and straight leg inversion ($p < .01$), standing and bent knee ($p < .01$), and standing and straight leg inversion ($p < .01$). Significant differences in right intraocular pressure were also found between bent knee and straight leg inversion ($p < .01$).

Recommendations

Recommended areas for future study include:

1. Cardioperipheral vascular effects of variable exercise during inversion. These effects should be compared with passive inversion only in the same subjects.
2. Comparison of cardioperipheral vascular effects of inversion in smokers versus non-smokers.
3. Clinical experimentation of the effects of inversion on intracranial blood flow and pressure.
4. Comparison of cardioperipheral vascular effects during inversion on a wider strata of age and sex populations.

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APPENDIX A

TABLE OF STATISTICS ON TIME TRIALS VERSUS POSITION
(Raw Data Analysis)

	Sitting	Standing	Bent Knee Inversion	Straight-leg Inversion
N	= 60	60	60	60
$\bar{x}$	= 62.23	58.98	153.95	94.72
Variance	= 1112.05	1014.88	15587.20	1987.26
S.D.	= 33.35	31.86	124.85	44.58
Range (in seconds)	= 15-210	24-210	40-520	30-211

APPENDIX B

SUBJECT RECRUITMENT FORM

Subjects for graduate research at C.S.U.N. exercise physiology department are needed. The study involves taking blood pressure, heart rate, and intraocular pressure from the positions of sitting, standing and during inversion on a gravity traction device. We need ten subjects, five male and five female, between the ages of 30-39. The amount of time required by subjects is approximately thirty minutes during one visit to the exercise physiology lab at C.S.U.N. Dates and times for data gathering are as follows:

March 15	1-4 p.m.
March 22	1-4 p.m.
March 29	1-4 p.m.
April 12	1-4 p.m.

If you are interested in helping with the project and are available at any of the above dates and times please call.

(818) 361-0136 (M-F, 9 a.m. - 12 p.m.; 1-5 p.m.)

or

(818) 785-1318 (M-S, after 9 p.m.)

Ask for Steve Souza

The results obtained from this study may assist manufacturers and users of inversion devices in understanding the cardio-peripheral vascular effects during inversion. This understanding may lead to safer use of, as well as prevention of any potential risks to individuals utilizing inverted gravity traction devices.

APPENDIX C

PRE TEST CONDITIONS

- 1) Subjects shall report to C.S.U.N. exercise physiology lab on the dates and times designated.
- 2) On test days subjects shall:
 - a) not consume any solid food or liquids containing caffeine for four hours prior to designated test times.
 - b) not consume any liquid for one hour prior to test times.
 - c) refrain from any physical activity on designated test days.
 - d) wear comfortable attire--women should wear swim suit tops under tee-shirts--all subjects should wear walking shorts and short-sleeve tee-shirts.
- 3) Subjects shall have had a medical examination within the last year.
- 4) Purpose: To observe, monitor, and record the variables of heart rate, blood pressure and intraocular pressure on humans during inversion.
- 5) Subjects may ask questions prior to or following testing.

APPENDIX D

INFORMED CONSENT FORM

You will participate in an observational study of the cardio-peripheral vascular effects of inversion on humans. Your heart rate, blood pressure and intraocular pressure will be measured at three time trials from positions of sitting, standing and inversion. We may stop the test at any time if you express feelings of excessive discomfort or unusually high heart rate, blood pressure or intraocular pressure. We do not wish you to endure a test level which is abnormally uncomfortable for you; however, for maximum benefit from the test, try to tolerate the total test times as long as you are comfortable.

There exists the possibility of certain changes occurring during the test. They include increased blood pressure, headaches, dizziness, ringing of the ears, increased sinus pressure, seeing spots, or an irregular heart beat. Every effort will be made to minimize these through the preliminary examination and by observations during testing.

The results obtained from this study may assist manufacturers and users of inversion devices in understanding the cardio-peripheral vascular effects during inversion. This understanding may lead to safer use of, as well as prevention of any potential risks to individuals utilizing inverted gravity traction devices.

Any questions about the procedures used in this inversion study or in the estimation of any variables obtained are encouraged. If you have any doubts or questions, please ask us for further explanations.

Your permission to perform in this inversion study is voluntary. You are free to deny consent if you so desire.

I have read this form and I understand the test procedures that I will perform. I consent to participate in this test.

Signature of Subject

Date

Witness

Questions: _____

Response: _____

APPENDIX E

DATA FORM

Subject _____ Sex _____ Age _____

Height _____ Weight _____ Date _____

Position	Trial	Heart Rate	Blood Pressure	Intraocular Pressure
Sitting	1			
	2			
	3			
Standing	1			
	2			
	3			
Bent Knee Inversion	1			
	2			
	3			
Straight Leg Inversion	1			
	2			
	3			

APPENDIX F

TONOMETER RELIABILITY DATA

Subject	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	L ₁	Sitting L ₂	R ₁	R ₂	L ₁	Standing L ₂	R ₁	R ₂
1	13	13.6	12.3	13	12.6	11.6	10.6	12
2	12.3	13.3	11.6	11.3	10.6	13.3	13.6	12
3	15	10.6	14	13	12.3	13	12	11.6
4	11	10	10.6	9.3	10	8	9.3	9
5	11	9.6	11	11	10	9	11.3	10.3
6	12.3	12.3	12.3	13	13.3	12	14	14
7	17.3	13.3	14.3	15.6	14.6	15	14	15.6
8	21.3	20.3	16.3	16.3	21.3	22	22	21.3

	Corr.	Pre $\bar{x}$	Post $\bar{x}$	
Sitting	.836	13.4	12.8	n = 16
Standing	.945	13.2	13.1	n = 16

Subject	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Straight Leg L ₁	L ₂	Inversion R ₁	R ₂	Bent Knee L ₁	L ₂	Inversion R ₁	R ₂
1	26.3	23.6	23.6	23.3	22.6	23.3	26	25.3
2	29.6	28.6	31.6	30.3	30	29.6	29.6	29
3	32.3	34.6	32	33.3	25.6	26	27	31.3
4	35	34.3	33	35.3	30.3	29	32.6	32.6
5	37	37.3	37	37	29.6	30.3	31.6	28

	Corr.	Pre $\bar{x}$	Post $\bar{x}$	
Bent Knee Inversion	.781	28.5	28.4	n = 10
Straight Leg Inversion	.958	31.7	31.8	n = 10

APPENDIX G

PILOT DATA FORMS

Subject One Sex M Age 28
 Height 5'11" Weight 195 Date 3/4/85

Position	Trial	Heart Rate	Blood Pressure	Intraocular Pressure	
				Left	Right
Sitting	1	81	140/88	12.6	12.6
	2	83	140/92	10.3	9
	3	100	138/98	9	8
Standing	1	82	136/90	10.6	9.3
	2	80	136/88	10.3	9
	3	78	136/92	10.6	9
Bent Knee Inversion	1	80	168/112	23	23.3
	2	80	175/112	23.3	22
	3	75	168/120	23.3	22.6
Straight Leg Inversion	1	80	160/100	23.3	23
	2	78	152/104	22.3	19.6
	3	82	156/106	21.3	22.6

Subject Two Sex F Age 24
 Height 5'10-1/2" Weight 135 Date 3/4/85

Position	Trial	Heart Rate	Blood Pressure	Intraocular Pressure	
				Left	Right
Sitting	1	57	120/70	10	11.6
	2	58	124/78	10	12.3
	3	60	124/76	9.6	11.3
Standing	1	73	128/86	9.6	10.3
	2	65	128/88	9.3	11
	3	73	128/88	12	11.3
Bent Knee Inversion	1	78	126/84	29	28
	2	70	126/86	29	29
	3	65	128/86	30	29
Straight Leg Inversion	1	72	138/100	33	32.6
	2	67	138/98	33	33.6
	3	54	138/96	33.6	33.6

Subject Three Sex M Age 26Height 5'4" Weight 100 Date 3/6/85

Position	Trial	Heart Rate	Blood Pressure	Intraocular Pressure	
				Left	Right
Sitting	1	60	144/98	23	14.6
	2	59	144/98	22	14
	3	57	142/103	19	14.6
Standing	1	60	144/98	19	12.6
	2	62	136/100	15.6	15
	3	61	138/102	19.3	12.6
Bent Knee Inversion	1	64	164/136	31.3	29
	2	Terminated test due to elevated blood pressure			
	3				
Straight Leg Inversion	1				
	2				
	3				

Subject Four Sex F Age 25
 Height 5'10-1/2" Weight 125 Date 3/6/85

Position	Trial	Heart Rate	Blood Pressure	Intraocular Pressure	
				Left	Right
Sitting	1	62	116/78	8.6	8.6
	2	65	104/78	7	7.3
	3	70	104/78	7	8
Standing	1	74	114/76	9	7.6
	2	70	110/76	8	8.3
	3	69	108/76	8.6	8.3
Bent Knee Inversion	1	67	129/98	22.6	21
	2	71	118/98	22.3	22
	3	70	120/98	22.6	22.3
Straight Leg Inversion	1	73	140/110	26.6	27.3
	2	73	140/110	30	26.6
	3	75	144/112	26.3	29.3

FREE MOTION EXERCISE SYSTEM

**THE GREAT
NEW WAY TO
STRETCH OUT
STRESS AND
BACK PAIN!**

**BUILD A
STRONGER,
MORE FLEXIBLE
BODY!**

**INVERSION
AND A WHOLE LOT MORE!
INVERSION**

APPENDIX I

A. O. RIECHART NON-CONTACT IITM TONOMETER

APPENDIX J

MANUAL TILT TABLE MODIFIED

APPENDIX K

8' x 8' x 4' PLATFORM, GRAVITY BOOTS, AND OTHER
EQUIPMENT UTILIZED

APPENDIX L

SYSTOLIC BLOOD PRESSURE ANALYSIS (CORRECTED) (N = 20)

Systolic Blood Pressure (Corrected):
Mean values over three trials by position

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Trial	12.76	2;57	6.38	.01	.99
Error	42164.73		739.73		
Position	3653.30	3;171	1217.77	34.58	.0000
Error	6022.68		35.22		
PT (interaction)	37.74		6.29	.18	.99

Mean Difference Table

	Sitting	Standing	Bent knee	Straight leg
Sitting	0	1.04	6.14**	8.11**
Standing		0	7.18**	9.15**
Bent knee			0	1.97
Straight leg				0

* = .05; ** = .01

HSD .05 = 4.46, HSD .01 = 5.57

APPENDIX M

DIASTOLIC BLOOD PRESSURE ANALYSIS (CORRECTED) (N = 20)

Diastolic Blood Pressure (Corrected):
Mean values over three trials by position

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Trial	6.91	2;57	3.45	.01	.9857
Error	13681.84		240.03		
Position	11021.63	3;171	3673.88	83.72	.0000
Error	7503.91		43.88		
PT (interaction)	119.53		19.92	.45	.8414

Mean Difference Table

	Sitting	Standing	Bent knee	Straight leg
Sitting	0	.78	11.36**	14.56**
Standing		0	12.14**	15.34**
Bent knee			0	3.20
Straight leg				0

* = .05; ** = .01

HSD .05 = 4.98, HSD .01 = 6.22

APPENDIX N

RAW DATA ON TEST TIME TRIALS FOR FOUR POSITIONS

	<u>Sitting</u>	<u>Standing</u>	<u>Bent Knee</u>	<u>Straight Leg</u>
Sub. 1	48 72 60	95 50 75	105 155 175	167 93 103
Sub. 2	85 50 85	30 55 47	88 55 47	42 58 120
Sub. 3	45 40 35	40 30 50	75 40 107	100 120 101
Sub. 4	15 35 35	30 45 60	87 138 136	110 79 106
Sub. 5	45 35 58	45 55 70	240 213 247	30 53 45
Sub. 6	210 155 159	85 210 172	420 445 520	83 157 211
Sub. 7	79 54 73	70 58 79	114 121 241	115 81 107
Sub. 8	30 87 98	48 116 117	73 120 149	200 166 161
Sub. 9	50 60 120	60 90 80	230 425 290	90 85 70
Sub. 10	35 60 58	30 53 30	110 118 102	193 76 114
Sub. 11	75 57 69	63 52 62	119 101 99	105 103 194

	<u>Sitting</u>	<u>Standing</u>	<u>Bent Knee</u>	<u>Straight Leg</u>
Sub. 12	39 51 45	24 46 41	93 64 65	68 53 47
Sub. 13	70 56 89	48 52 65	83 92 240	87 43 63
Sub. 14	22 38 30	38 45 25	223 117 110	75 85 70
Sub. 15	53 52 75	38 43 54	97 203 200	115 145 87
Sub. 16	78 67 65	60 69 63	170 82 68	105 89 89
Sub. 17	45 30 67	55 40 60	118 77 150	60 61 204
Sub. 18	70 40 60	35 27 31	174 86 58	62 78 40
Sub. 19	90 30 45	50 45 35	60 50 57	120 80 40
Sub. 20	60 46 49	75 44 58	83 77 80	55 35 55

APPENDIX O

PHOTOS OF SUBJECT SITTING AND STANDING DURING DATA COLLECTION

APPENDIX P

INVERTA CHAIR^{T.M.}

Patent Pending

APPENDIX Q

ORTHOPOD GRAVITY TRACTION