Artificial Gravity as a Countermeasure to Spaceflight Deconditioning: The Cardiovascular Response to a Force Gradient

by

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Abstract

Before intermittent short-arm centrifugation can be tested as a countermeasure to space deconditioning, a number of ground-based studies must be conducted to determine the effects of a gravity gradient both on normal subjects and individuals undergoing bed rest. This investigation focused on determining several of the cardiovascular effects of a gravity gradient on normal subjects. The purposes of the investigation were to answer the following questions: 1) how cardiovascular performance measures change with G level and duration of stimulation, 2) how do cardiovascular parameters change during force gradient stimulation as compared to their response to standing in 1 G, and 3) what levels of force gradient stimulation promote significant cardiovascular regulation? It was hypothesized that G levels of 1 and less at the feet would produce few cardiovascular changes in normal subjects. This investigation will enable future researchers to more precisely outline centrifuge studies necessary on individuals undergoing bed rest treatments as models for spaceflight deconditioning. The hope is that a SAC may someday be used in space to keep the cardiovascular system stimulated to minimize orthostatic intolerance.

Eight subjects, four men and four women, participated in one control and three rotation trials on a horizontal short-arm centrifuge (SAC) such that the G_z levels at the feet were 0.5, 1.0, and 1.5. Trials consisted of 30 min. of supine rest, 1 hour of rotation (or in the control, 30 additional min. of rest and 30 min. of standing), and a final 30-minute rest period. Measurements of heart rate, calf impedance, calf volume, and blood pressure were obtained. Post-trial analysis explored the relationships between the physical characteristics of the subjects, rotation time, G level, and the cardiovascular parameters measured. Most measured cardiac parameters suggest that rotation levels causing 1.0 G at the feet or less produced regulatory responses not significantly different from continued supine rest. In addition, the cardiovascular responses to SAC rotation with 1.5 G at the feet were statistically similar to standing, at least for a comparison based on 30 min. The primary effects of 1.5 G were an elevated diastolic pressure, increased heart rate, and increased calf volume. While some cardiovascular changes were found to be correlated to gender, mass, and height, their influence was considered minor. Most importantly, since standing intermittently during bed rest trials has been shown to decrease orthostatic intolerance and rotation at 1.5 G was found here to be similar to standing, short-arm centrifugation should be considered as a possible countermeasure to cardiovascular space deconditioning. Rotation durations on the order of 30 min. may be required for promotion of sufficient cardiovascular regulation in inactive subjects.

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We are the children of gravity. We can't touch it or see it. But it has guided the evolutionary destiny of every plant and animal species, and has dictated the size and shape of our organs and limbs. Every bone and muscle is aligned to maximize mobility in 1 G.

-- Dr. Ralph Pelligra, NASA Ames

INTRODUCTION

The Case for Artificial Gravity

Living in a weightless environment often produces physiological changes referred to as space adaptation syndrome (SAS). The effects of SAS have been well documented (Grymes 1995; Convertino and Sandler 1995), and generalized symptoms are listed in Table 1 (Sander, et al. 1995). Changes in the skeletal and cardiovascular systems are particularly alarming. 1-2% of bone mass is lost per month in space (Sandler 1995). This is a critical problem affecting long-term spaceflight. Issues related to loss of orthostatic tolerance are also of concern. Astronaut faintness during reentry or during an emergency landing on earth or another planet is a real danger caused by cardiovascular deficiencies.

Table 1. Space Adaptation Syndrome Effects

	Anorexia		Decreased Exercise Capacity
	Nausea		Muscular Incoordination
*	Motion Sickness		Muscle Atrophy
*	Disorientation		Fluid Shift
	Restlessness		Dehydration
	Sleeplessness		Weight Loss
	Fatigue	*	Gastrointestinal Disturbances
	Lethargy		Renal Calculi
	Immune System Degradation		Reduced Plasma Volume
*	Demineralization of Bones		Reduced Blood Volume
*	Loss in Bone Mass	*	Cardiac Arrhythmias
	Spine Length Increase/Pain		Tachycardia
*	Decreased G Tolerance		Hypertension
*	Postflight Syncope	*	Hypotension

* May cause an emergency situation in flight.

Current countermeasures against SAS include exercise, the Russian Penguin suit, fluid loading, diet modification, lower body negative pressure (LBNP), preflight adaptation training, drugs, and electrical muscle stimulation. The primary inflight exercises practiced in the Russian and American space programs are use of a cycle ergometer, running on a treadmill, and resistance training. These maintain aerobic capacity and do a somewhat sufficient job of maintaining muscular strength. Similar to the exercise training is the Penguin suit, an elasticized garment that requires extra force to be exerted for normal movements. Fluid loading in-flight corrects for plasma volume loss and helps prevent disorders such as renal stone formation (Heer, et al. 1995). Fluid loading prior to reentry is intended to help maintain orthostatic tolerance during the large reentry G forces (up to 2 G). The potential of diet modification as a countermeasure has not fully been explored, but it can only attenuate some of the effects of SAS. Current ground-based

research on the use of LBNP is showing promise (Güell 1995); however, few in-flight studies of LBNP as a countermeasure to orthostatic intolerance have proven its effectiveness. At the moment, preflight adaptation training may consist of occasional flights in the KC-135 (to experience 0 G), underwater training, acceleration G profiles similar to Shuttle launch, and exposure to disorienting vestibular stimuli in the JSC Pre-Adaptation Trainer. However, a formal preflight adaptation program does not exist. No psychological preflight training is currently practiced either. Promethazine, for motion sickness, is the most advanced pharmacological countermeasure in place today. Altered pharmacokinetics and pharmacodynamics in microgravity have prevented most drug treatments available on Earth from being applied as countermeasures to SAS in space (Vernikos 1995). Electrically stimulating the muscles has been practiced for years by the Russians to prevent atrophy and has met with some success (Convertino and Sandler 1995).

While current countermeasures attack many aspects of space deconditioning, not one preserves bone density. Orthostatic tolerance and muscular strength are not totally sustained either. Russian cosmonauts have made extensive use of the Penguin Suit and exercise countermeasures for durations longer than one year, but they cannot walk unassisted for at least 48 hours after landing. Russell Burton, Chief Scientist at the U.S. Air Force School of Aerospace Medicine (USAFSAM), stated the problem nicely when he said (1989), "The Occupational Safety and Health Association would probably not allow employees to work in such a hazardous environment on earth, so why should it be permitted in space?" The failure of existing therapies for dealing with the debilitating effects of long duration weightlessness may call for artificial gravity (AG) as the only way to prevent SAS.

Why do we need something as extreme as artificial gravity (AG) when we can allow the astronauts to recuperate when they return? That question may be valid for short-term flights and even space station missions, but for long-term explorations such as a Mars venture certain additional considerations merit use of the extreme countermeasure. Current technology dictates that a Mars trip will require at least two years in microgravity because "the diverse capabilities of such energy sources as the dilithium crystals used on the U.S.S. Enterprise are as yet unavailable to NASA" (Grymes 1995). Providing astronauts with AG on the trip to Mars could produce several benefits. The gravity level of Mars is only 37.5% of Earth's. No one has ever lived in microgravity for one year and returned to a gravity environment without medical treatment available. AG would maintain the astronauts' ability to perform emergency extravehicular activities (EVA's), prevent bone fractures, and maintain the pilots' ability to perform their duties. Also, adaptation time to the Mars environment might decrease if 0.375 G could be provided prior to a Mars landing. Thus, few of the precious days on Mars would be wasted due to astronauts' limited functionality. Finally, it is not inconceivable that someday humans will live in space for many years, in orbit, on a Mars base, or on a lunar base. The effects of living in the partial gravity

environment of the moon (0.16 G) or Mars are unknown. AG may need to be provided even on the surface. The challenge is to determine what kind of AG (what G level and for how long in the context of this paper) is necessary in any of these situations.

Performing AG research has been difficult at best because the human 1 G requirements are unknown and all experiments on Earth are subject to a 1 G force. Critical studies that have been conducted pertaining to the physiological effects of AG are summarized in Appendix A. They are categorized according to the rotation environment or purpose of study. Some general observations can be made. Most of the experiments were conducted long before acquisition of the current knowledge of SAS. Usually, a handful of subjects were tested, making the validity of the findings questionable. In addition, many of the tests were not comprehensive and varied considerably so that comparisons are nearly impossible. Still, the results of these studies, the fact that bed rest can approximate the physiological effects of microgravity exposure (for some but not all major body systems), and recent orthopedic research indicate that it is not just the G force that maintains the human system but the activities carried out in the G force (Schneider, et al. 1993). That different activities stimulate different body systems seems to be clear as well. The conclusions of the intermittent stimulation investigations, added to the knowledge that humans sleep horizontally each night with no ill effects, imply that humans do not require constant exposure to gravity along the vertical axis of the body. As a final observation, each of the studies in Appendix A is concerned with only a specific aspect of AG, usually intermittent or constant exposure. While some suggestions have been made (Kotovskaya, et al. 1977; *Workshop on the Role of Life Science in the Variable Gravity Research Facility* 1988; Burton 1989), an overall research approach to determine the physiological AG requirements for long-term spaceflight is decidedly absent.

Before deciding what research is necessary to determine the physiological requirements for AG, a comprehensive set of questions must be compiled. As complete a list as possible is shown in Table 2. Note that only questions necessary to provide AG for long-term spaceflight are listed. Many more could be added if the entire physiological response to force levels were desired. These questions include those that must be answered for both AG provided by a rotating spacecraft and AG provided by a short-arm centrifuge (SAC) in a nonrotating spacecraft.

Motivation

As mentioned previously, one of the methods of providing artificial gravity to astronauts is by using short-arm centrifugation in space. This would most likely occur via intermittent stimulation on a SAC since a space crew would not be likely to live and work in a small volume, as would be the case if short-arm centrifugation were applied by spinning the entire spacecraft. Before a SAC can be tested as a countermeasure in space, a number of ground-based studies must

be conducted to determine the effects of a gravity gradient both on normal subjects and individuals undergoing bed rest, a treatment that mimics microgravity exposure.

Table 2. Questions Regarding the Physiological Requirements for Artificial Gravity

1. How much time in 1 G is necessary to maintain normal physiological status?
2. What activities in 1 G keep humans fit?
3. Since the activities we perform in a gravitational field stimulate us, then passive exposure to rotational G during sleep is of little benefit. Is there a best time of day to provide 1 G?
4. Should 1 G be provided in a lump sum or intermittently during a day?
5. If exposed to the microgravity environment for a period of time, how long does reconditioning via AG take, or can it be done at all?
6. Does exposure to G levels greater than 1 decrease the total stimulation time?
7. What the relationship between the steady-state physiological response and the G level?
8. What is the character of the physiological transient response to a G level?
9. What is the relationship between the G-level physiological response and age, gender, fitness, etc.?
10. What is the physiological response to a G gradient along the body?
11. The effects of motion sickness caused by angular cross-coupling in a rotating environment on the general body system can be determined by comparing the response of subjects who have lost vestibular function to that of normal subjects. After this knowledge is gained, how can it be applied to reduce the severity of or eliminate the detriments of rotational motion sickness in a normal person?
12. Does the Coriolis stimulation of the rotating environment affect physiological responses?
13. What is the best way to adapt to a rotating environment?
14. Burton cites data implying that animals can adapt to increased G environments while maintaining adaptation to 1 G (1989). Can a human maintain adaptation to two G levels for a period of time without experiencing major side effects from transition between the two levels?
15. If partial gravity could only be provided because of engineering/cost concerns, how much more stimulation time is necessary, or can partial gravity exposure be beneficial at all?
16. How similar are adaptation and physiological responses to a rotating environment on earth to those caused by a rotating environment in space?

This investigation focused on determining several of the cardiovascular (CV) effects of a gravity gradient on normal subjects. Specifically, one purpose of the investigation was to determine how cardiovascular performance measures change with G level and duration of stimulation. Additional questions considered were: (1) how do cardiovascular parameters change during force gradient stimulation as compared to their response to standing in 1 G, and (2) what "safe" levels of force gradient stimulation promote significant cardiovascular regulation? In essence, partial answers to questions 7-10 in Table 2 were sought. As a result of previous research in this area and physical principles, it was hypothesized that G levels of 1 and less at the feet would produce few cardiovascular changes in normal subjects.

This research will enable future investigators to more precisely outline centrifuge studies necessary on individuals undergoing bed rest treatments as models for spaceflight deconditioning.

The added benefit is increased knowledge about gravitational physiology. The hope is that a SAC may someday be used in space to keep the cardiovascular system stimulated to reduce the likelihood of orthostatic intolerance, among other effects.

Background

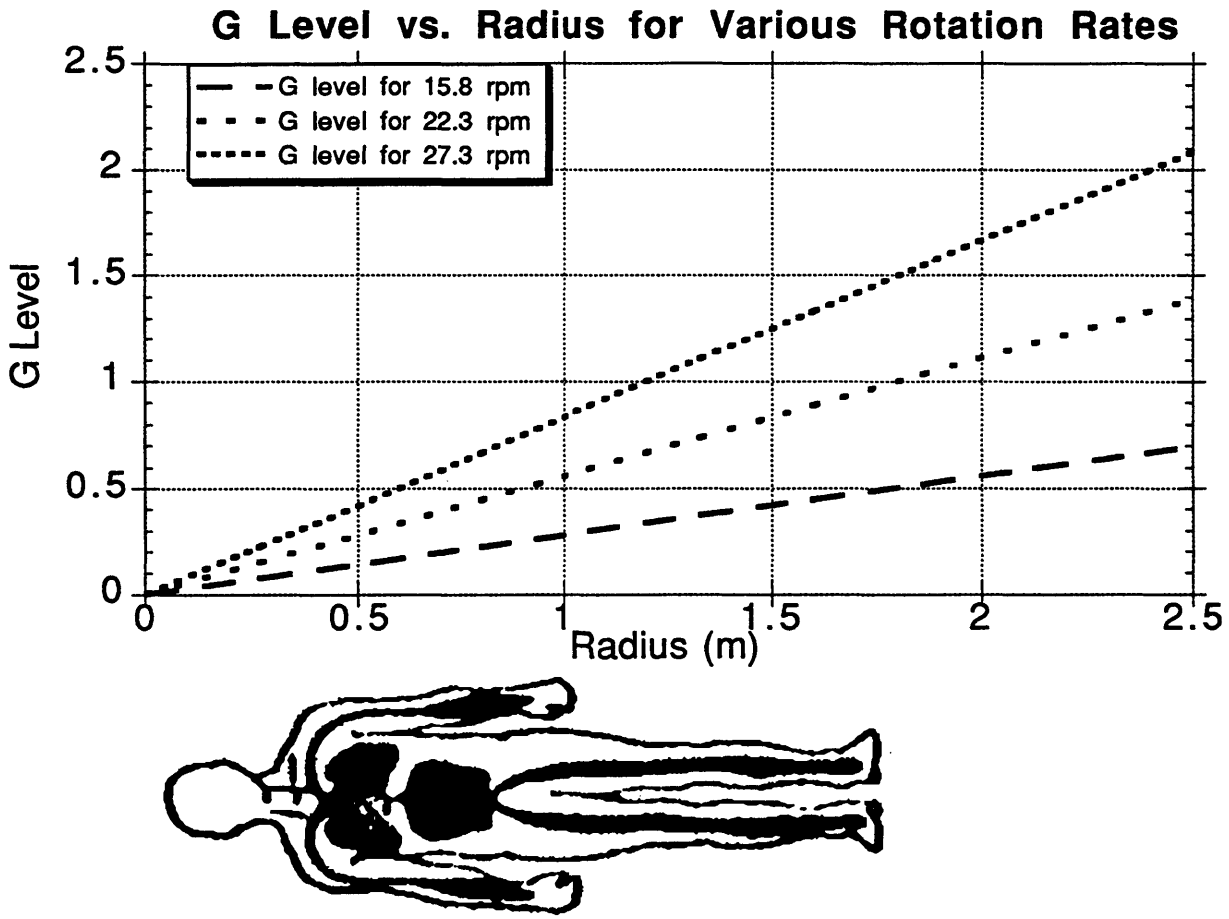


Figure 1. Variation of G_z Level Along a Body with Radius and Rotation Rate

A consequence of short-arm centrifugation is a force, or gravity, gradient along the body. Centrifugal acceleration, a, obeys the law

$$a = r\,\omega^2, \tag{1}$$

where ω is angular velocity and r is the radius. Thus, a body subjected to a constant angular velocity on a SAC will experience a different force at each location along its longitudinal, or z, axis. The following equation can be used to calculate G level, were ω is in rpm and r is in meters:

$$\text{G level} = \frac{r\left[\omega\left(\frac{2\pi\,\text{rad}}{1\,\text{rev}}\right)\left(\frac{1\,\text{min}}{60\,\text{s}}\right)\right]^2}{9.81\ \text{m/s}^2}. \tag{2}$$

Figure 1 displays curves for G level along a body for various angular rotation rates. As specified by question 10 in Table 2, the effect of the variation in force on humans has not been completely characterized.

Obviously, no centrifuge on Earth can subject a body to less than 1 G in three-dimensional space. Rather, a centrifuge rider is subjected to the vector sum of the centrifugal force and Earth's gravity. In general, studies conducted on centrifuges refer only to the G level along the rotation radius. In addition, since a force gradient exists, experimenters often refer to the G level in SAC studies as being the force felt at the feet. For example, a rotation rate of 22.3 rpm will cause a G level of 1 at the feet of a 1.8 m person whose head is placed at the center of rotation. The same rotation rate will only produce 0.80 G in a person 1.5 m tall whose head is at the center of rotation as well. The force component felt through the x-axis of a supine person, gravity, is generally considered of negligible importance to the results (of studies such as the present where subjects are horizontally supine) because the height of the x-axis hydrostatic column is small compared to the z-axis column and most major systemic blood vessels are aligned with the body's z-axis (Breit, et al. 1996).

Standing under the influence of normal gravity creates a pressure gradient along the z-axis of the body. The normal hydrostatic pressure relation is given by

$$P = \rho g z + P_o, \tag{3}$$

where ρ is density, g is normal gravitational acceleration, z is the height from a reference level, and P_o is the reference pressure. For rotation on a centrifuge the pressure relation becomes

$$P = \tfrac{1}{2}\rho\omega^2\left(z^2 - z_o^2\right) + P_o, \tag{4}$$

with z now representing the distance along the radius. If the heart is considered to be at the reference level, with a mean arterial pressure of 100 mmHg, then Figure 2 compares the pressure gradients induced by standing and rotation at 0.5, 1.0, and 1.5 G in a 1.8 m person. While supine, the arterial pressure over the body is much more uniform than any of the curves in Figure 2.

Before discussing the mechanisms responsible for orthostatic intolerance and how to prevent the condition, several CV variables and relations should be defined. Cardiac output (CO) is the volume of blood pumped out of the heart per unit time. It is calculated by

$$CO = SV \times HR, \tag{5}$$

where HR is the heart rate and SV is the stroke volume, the volume of blood pumped out of the heart with each beat. The pulse pressure, PP, the difference between and systolic and diastolic pressures, can be directly related to SV through

$$PP = \frac{SV}{C_a}, \tag{6}$$

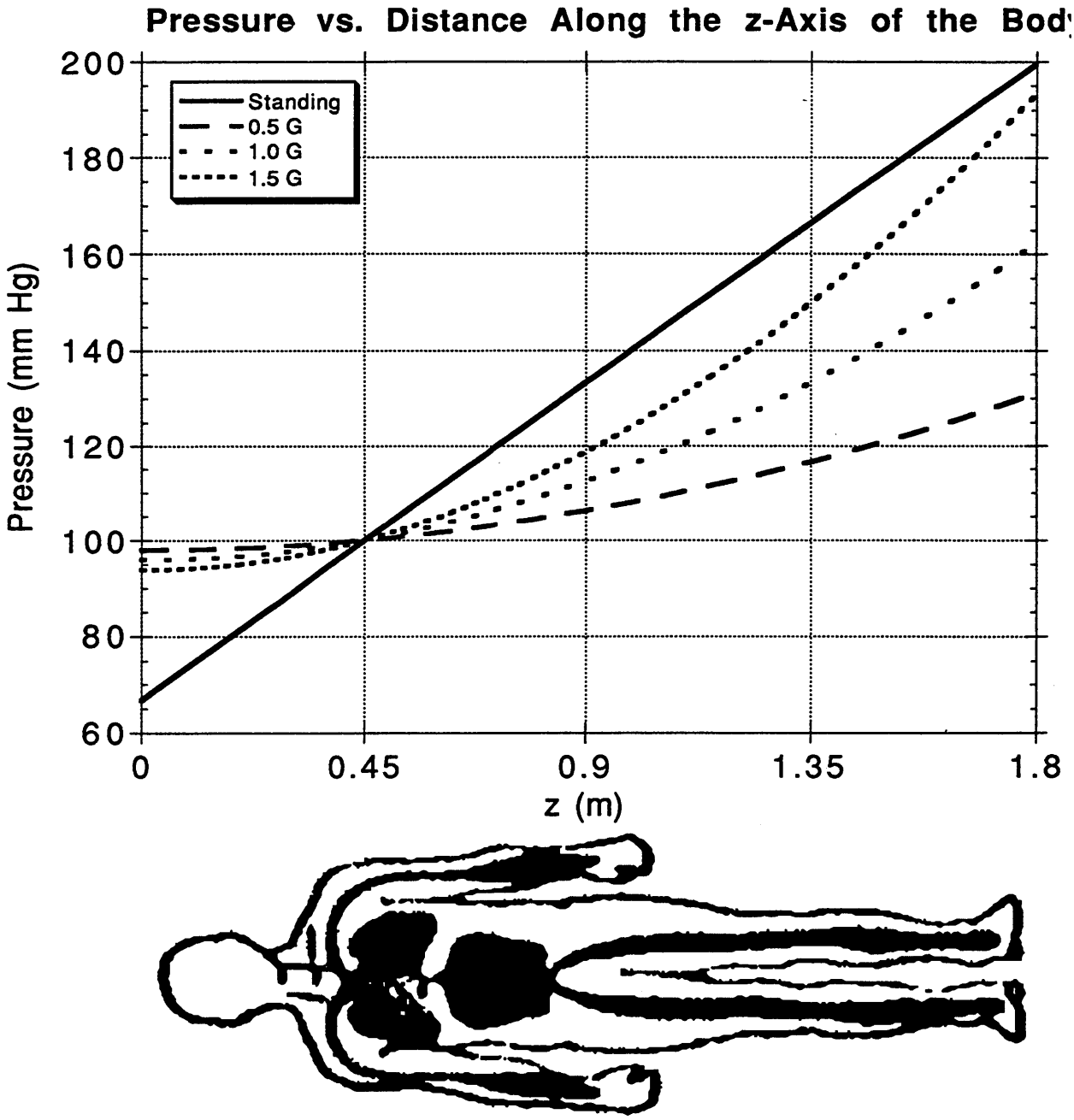


Figure 2. Pressure Gradients Induced by Orthostatic Stresses
Calculations are based on a 1.8 m person with the heart located 0.45 m from the top of the head. The curves were produced assuming 100 mmHg was the pressure in the heart for comparison purposes. However, centrifugation normally raises the mean arterial pressure above 100 mmHg.

where C_a is the arterial capacitance. Unlike SV, C_a is a relatively invariant to stresses induced on the body. Generally, one of the fundamental functions of CV regulation is to maintain cardiac output at a level sufficient to sustain perfusion to the brain and to maintain pressure in the circulatory system. Mean arterial pressure can be found using

$$\overline{P}_a = \tfrac{1}{3}P_S + \tfrac{2}{3}P_D, \tag{7}$$

where P_S is the systolic pressure and P_D is the diastolic pressure.

Alterations in posture or the gravity environment create increased pressure in the lower body which leads to venous pooling in legs. A postural example that demonstrates this is the transition to standing after being supine for a period of time. Hypergravity conditions will also cause venous pooling. If the increased blood flow to the periphery is not regulated, venous return to the heart is impeded. This leads to decreased cardiac output, decreased blood pressure, and eventual syncope, the classic sign of orthostatic intolerance. Orthostatic tolerance is normally maintained by compression of leg veins through local regulation and baroreflex-mediated sympathoexcitation and vagal withdrawal.

The primary mechanisms related to cardiovascular responses to orthostatic stress that will be discussed here are autonomic control of the cardiovascular system and the baroreflex response. For a further discussion of CV regulatory mechanisms the reader is referred to Blomqvist (1983) or Churchill and Bungo (1997). Autonomic control of the CV system is mediated by sympathetic and parasympathetic innervation. The parasympathetic system innervates the heart via the vagus nerve and acts to reduce heart rate. In the context of the present experiment, activation of the sympathetic system increases heart rate, increases contractility of the heart, and causes vasoconstriction. The arterial baroreflex is a mechanism for regulating arterial pressure by sensing pressure in the arteries and responding with changes in control of cardiac output or peripheral resistance to achieve a desired CV set-point. The pressure sensors, termed baroreceptors, are found in the aortic arch and a region of the neck called the corotid sinus. In the case of the present study, the barorecptors will sense a decrease in arterial pressure when the body transitions from supine rest to an orthostatic stress. The baroreceptors will then normally cause the following changes, among others, to occur: a decrease in vagal activity, an increase in sympathetic activity to all portions of the CV system, arteriolar and venular vasoconstriction (increasing total peripheral resistance), and an increase in heart rate.

When astronauts return to the gravity environment of Earth from a stay in space, the cardiovascular regulatory mechanisms that prevent excessive blood pooling in the legs do not function properly. It is for this reason that 9 to 64% (depending on the particular study) of astronauts fail a 10 min. standing test after return to Earth (Buckey, et al. 1996). According to recent studies, the major hemodynamic defect related to orthostatic intolerance resulting from spaceflight is a lack of vasoconstriction in the lower limbs (Buckey, et al. 1997). Total peripheral resistance does not rise adequately. Changes in the baroreflex sensitivity have not been confirmed (Arbeille, et al. 1997; Buckey, et al. 1996) so sympathetic circulatory control alterations are suspect. In a simplified explanation, current theory believes these alterations in the CV regulatory system occur as a result of disuse in space. In a sense, the CV reflexes "have not been practicing."

It has been suggested that standing intermittently could be an effective countermeasure to the orthostatic intolerance seen in SAS (Vernikos 1994). A study was performed in which subjects were exposed to four days of -6° head-down bed rest interrupted by 15-minute periods of standing. Two conditions, standing 8 times per day (2 hours total) and standing 16 times per day (4 hours total), were tested. Orthostatic tolerance was assessed by 30 min. of 60° head-up tilt. Presyncope indicated failure of the test. Standing 8 times per day partially prevented and standing 16 times per day completely prevented orthostatic intolerance. To stand in space, a gravity field would need to be created. This paper investigates SAC rotation as the mechanism for providing the gravity field.

Several studies have investigated the effects of a gravity gradient on the cardiovascular system. Shulzhenko and Vil-Viliams (1992) monitored the orthostatic intolerance during 3-day dry immersions (another analog of microgravity exposure) of 4-6 subjects who were intermittently exposed to rotation on a 2 m-radius centrifuge. Orthostatic function was assessed by time tolerance to rotation on a 7.25 m centrifuge at +3 G_z. In one study, subjects experienced 40-60 min. of 0.8, 1.2, or 1.6 G two to three times daily. As compared to pre-dry immersion, orthostatic tolerance decreased 18%, 7%, and 1%, respectively, at the end of the three days. The control decrease was 21%. When water and salt supplements were added and the experiment was repeated for the 0.8 and 1.2 G levels, the orthostatic tolerance only decreased 7% and 1%, respectively. The same experimenters conducted a 28-day trial with the following time profile: 7 days of no-exposure dry immersion, 7 days with 40-60-minute blocks of 0.8, 1.2, or 1.6 G 2-3 times daily, 7 days with periodic supine bicycle ergometer training, and 7 days with SAC rotation combined with bicycle ergometry for 60 min. twice daily. It was found that after the first 7 days, orthostatic tolerance had decreased by 56%. After 28 days, orthostatic tolerance was 8% less than normal. While this last experiment clouds the issue because of the combined interventions, the combination of the three trials proves that rotation at hypergravity attenuates loss of orthostatic tolerance due to physiological microgravity analogs.

Cardús (1993a, 1993b) performed a study on six men with measurements of general cardiovascular signals for one hour durations on a 2 m-radius SAC. G levels of 0.5, 1.0 (with only 3 subjects in this case), and 1.5 at the feet were tested. Time profiles for the trials included a 30-minute supine rest period, one hour of rotation, and a final 30-minute rest period. The experimenters observed few cardiovascular changes for G levels below 1 at the feet. Cardiovascular alterations did occur for G levels in the 1-1.5 range. Above 1.5 G, cardiovascular changes became more dramatic, with 2 G inducing syncope in some subjects. Figure 3 displays some of the results of the experiment for three rotation rates. It should be noted that the authors used rates of 17, 20, and 24 rpm to produce estimated G levels of 0.5, 1.0, and 1.5 G. Rotation rates were not adjusted for subject height. No statistical comparisons were performed although it

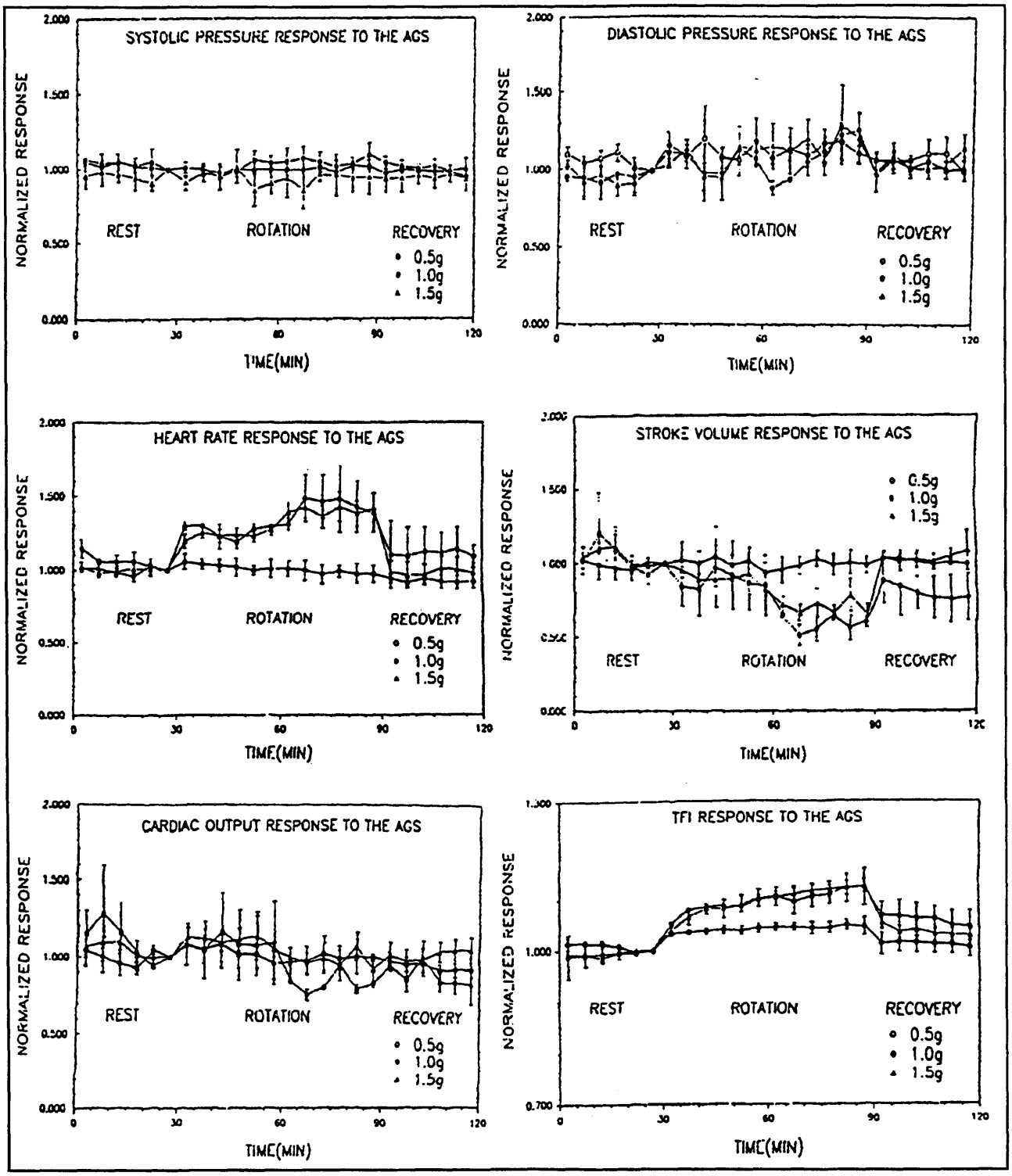


Figure 3. The Cardiovascular Response to Short-Arm Centrifugation in Cardús's Study Results of experiments conducted by Cardús (1993b) for 6 male subjects at three rotation rates. (Only three subjects participated in the middle rotation rate trial). Trials consisted of 30 min. rest, 1 hour of rotation, and a final 30-minute rest period. Rotation was performed on a SAC termed the Artificial Gravity Simulator (AGS). TFI = thoracic fluid index

was noted that diastolic pressure tended to increase slightly. In addition, data were not compared to continued supine rest substituted for rotation. From Figure 3, one can see that systolic pressure changed little and diastolic pressure showed some increase as the rotation rate was raised. Heart rate increased and stroke volume decreased for the 1.0 and 1.5 G cases. Careful study shows that after the initial change in these two parameters, a small recovery took place, followed by a much larger alteration occurring at approximately 30 min. The thoracic fluid index (TFI) was measured via electrical impedance. An increase in impedance (or TFI) corresponds to a decrease in volume over the area measured. The plots show that TFI increased with rotation, especially at the higher G levels. This can be interpreted to mean that fluid was transferred from the thoracic cavity to the lower body. Note that this effect does not reach steady state in the one hour of rotation for the higher G levels.

Researchers at NASA Ames Research Center (Breit, et al. 1996) also conducted a study on eight men and seven women to compare the effects of short-arm centrifugation (with a 75% G_z gradient), long-arm centrifugation (with a 25% G_z gradient), whole-body tilting, and lower body negative pressure on regional cutaneous microvascular flow, mean arterial pressure, and heart rate. Stimuli were applied for only 30 s at a time, and transitions between stimuli levels were performed in 10 s without stopping the stimulus. Their investigation was limited to G levels of 1 and below (0.2, 0.4, 0.6, 0.8, and 1.0) at the feet. LBNP was found to cause the greatest relative flow reduction in the lower body. All stressors except short-arm centrifugation resulted in an increased heart rate. Head-up tilt was the only orthostatic stressor which produced a change in mean arterial pressure. The experimenters found no correlation between height and gender and the cardiovascular responses to centrifugation. Centrifugation was also found to produce the least severe vasoconstriction. Their results showed flow inconsistency among the subjects when exposed to centrifugation as opposed to the other orthostatic stressors. Vestibular stimulation was suggested a possible explanation. The experimenters concluded that centrifugation, especially using a SAC, may be disadvantageous for baroreflex stimulation because the carotid sinus is near the top of the pressure column and because they observed little heart rate change in their study.

The goals of the studies mentioned above and of the present experiment are to determine what stressors cause cardiovascular regulation sufficient enough to keep the CV system in practice. This paper details an investigation of short-arm centrifugation as a method for CV stimulation. Rotation trials at 0.5, 1.0, and 1.5 G were conducted for one-hour durations with pre- and post-stimulus supine periods. Since standing has been proposed as a countermeasure to SAS-induced orthostatic intolerance, responses to rotation were compared to those that standing produces to determine if adequate stimulation is caused by SAC rotation.

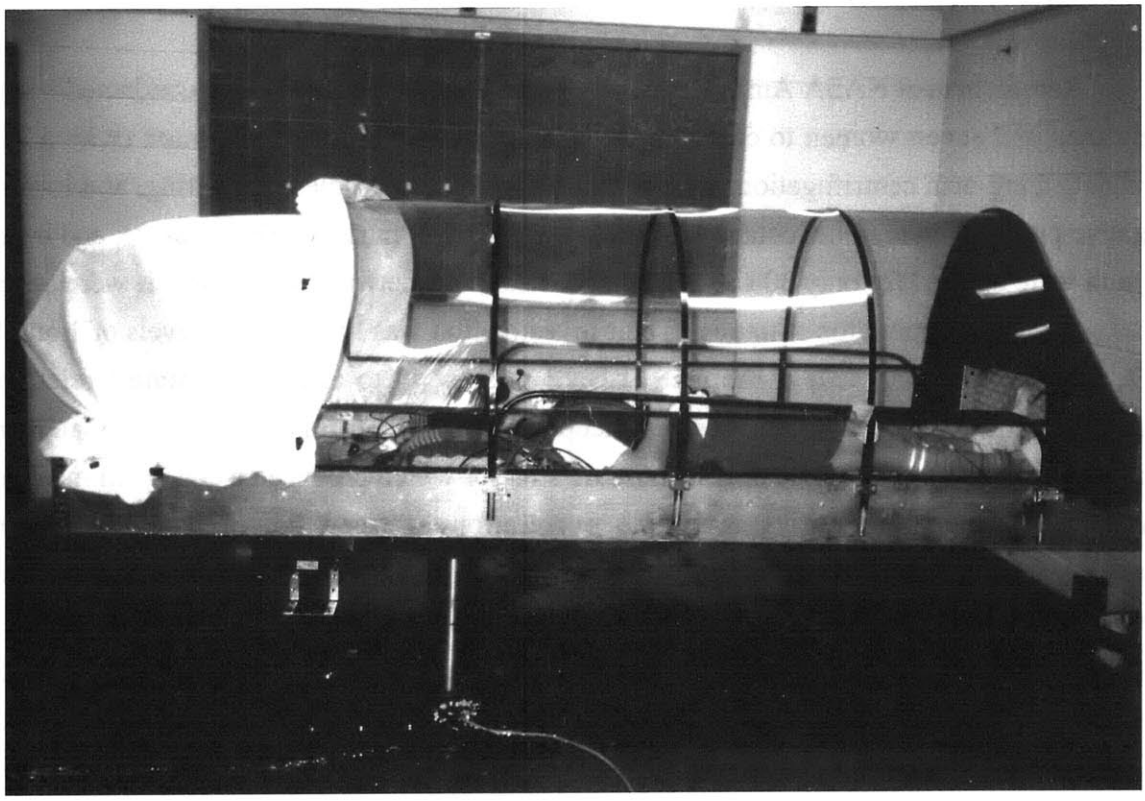


Figure 4. Subject on the MIT-Artificial Gravity Simulator (AGS)

METHODS

General

The rotation research was conducted using the MIT-Artificial Gravity Simulator (AGS) (Massachusetts Institute of Technology Man-Vehicle Laboratory), pictured in Figures 4 and 5, a 2 m-radius rotating platform with the ability to exceed 30 rpm (Diamandis 1988). Modifications to the AGS can be found in another document (Tomassini 1997). Rotation rate, subject position, and mounted physiological monitoring equipment were variable for the AGS. Subjects were placed supine on the AGS, such that the tops of their heads were at the center of rotation (made possible by the AGS's adjustable foot plate). As seen in Figure 4, the AGS is covered by a transparent (so that the experimenter could easily view the subjects) wind canopy, to prevent cooling of the subjects from wind. Linen material loosely sealed both ends of the canopy. Rotation rate was determined via a tachometer mounted on the motor (seen immediately below the AGS platform and mid-picture in Figure 4). The AGS tended to increase rotation speed as time progressed, so manual feedback was employed to maintain a constant angular speed. A video camera (Sony # PVM-122), as seen in Figure 5, was available for viewing the subjects and physiological monitoring equipment. The floor of the AGS platform and the foot plate were padded with foam for subject comfort. An emergency stop button, with the ability to stop the rotator in 15 s for G levels up to 1.5, was available for both the experimenter and subject. Rotation was commenced at a rate of less than 1 rpm/s. Generally, the target rotation rate was achieved 30 s from rotation onset.

This experiment was approved by the MIT Committee on the Use of Humans as Experimental Subjects. Appendix B contains the COUHES application, subject consent form, and subject selection questionnaire. Experimental participants were required to be in good health, have no cardiovascular abnormalities, and not to be pregnant. Subjects were asked to abstain from caffeine and alcohol intake 24 hours prior to each experimental session. In later trials, subjects were asked if they had eaten well, how much sleep they had had, and if they had taken any medications prior to each experiment. Subjects were blindfolded to prevent motion sickness induced by conflicting vestibular-visual cues. They were also instructed to move as little as possible. This was especially true while blood pressure measurements were being taken. It was made imminently clear that any head movements would induce motion sickness and would be counter-productive to the experiment. The experimenter and subject were in continuous two-way communication via radio headsets (Voice-Operated 49 MHz Two-Way Communication System, cat. no. 21-406, Radio Shack). To prevent the subjects from falling asleep, the experimenter read to them, talked with them, and played music during rest periods.

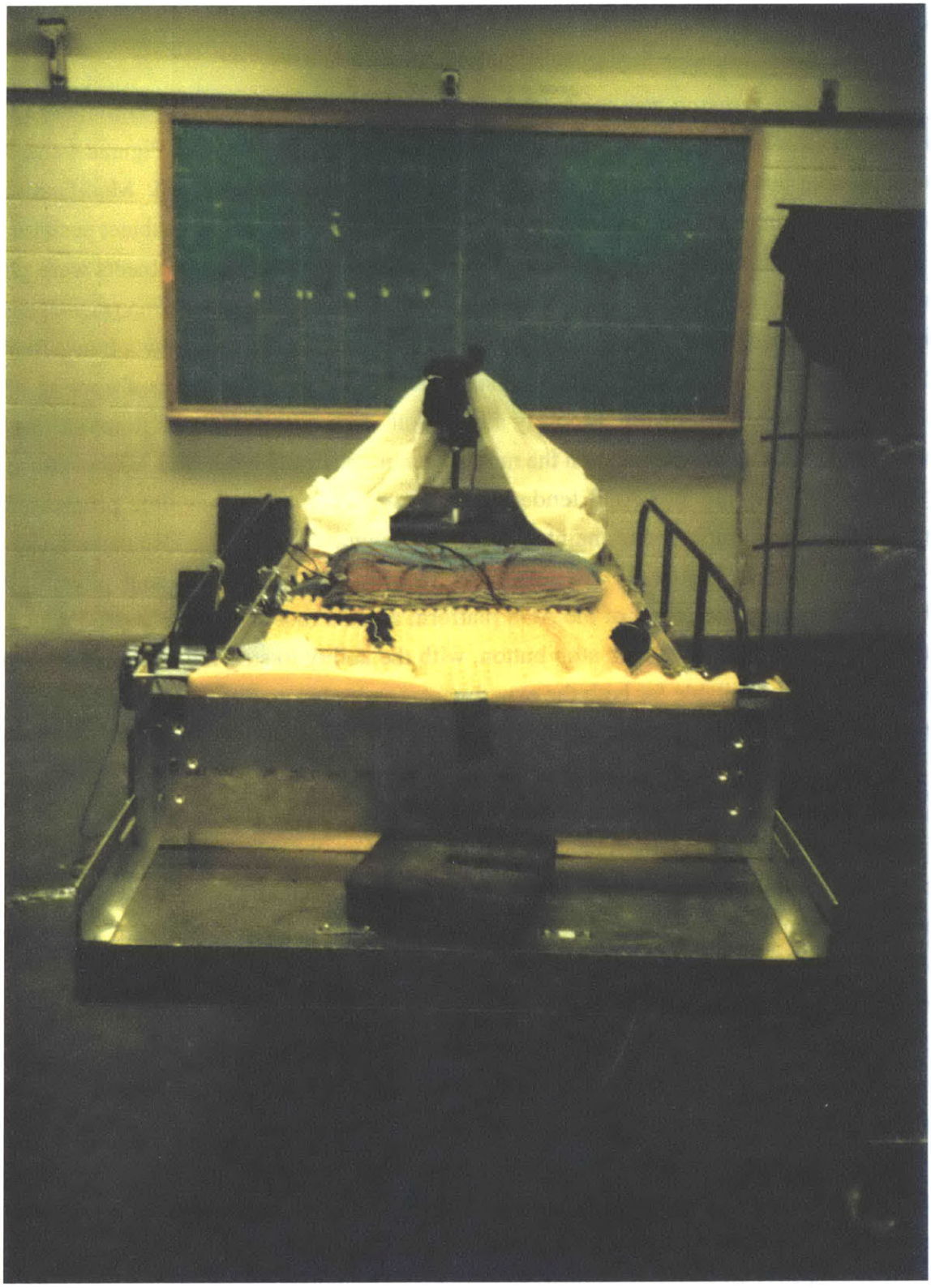


Figure 5. The MIT-Artificial Gravity Simulator (AGS)

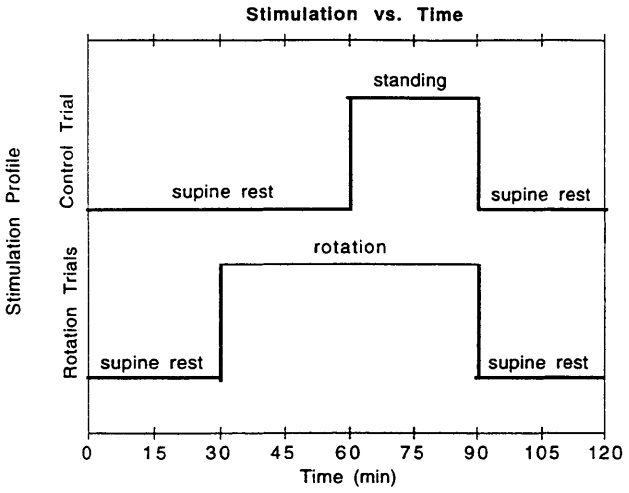


Figure 6. Stimulation Profiles for Trials

Figure 6 shows the stimulation profiles for the four trials. Rotation trials included a 30-minute supine rest period, 1 hour of rotation, and a final 30-minute supine rest period (with the exception of the 1.0 G trial for subject D in which only 25 min. of rest followed rotation). Each subject participated in three rotation trials, otherwise termed G trials, such that the G levels at the feet during rotation were 0.5, 1.0, and 1.5. Table 3 shows the rotation rates, calculated from Equation 1, that were required for each subject to produce the appropriate G levels at their feet. A control trial for each subject was performed before the rotation trials, involving 1 hour of rest, 30 min. of standing, and a final 30-minute rest period. For each subject, only one trial was performed per day, all four trials were completed within 1.5 weeks, and the time of day of experimentation was controlled to within one hour. The protocol checklist is presented in Appendix C. Subjects performed the rotation trials in a pre-determined, semi-random order. The order for each subject is shown in Table 3. Because only eight subjects were studied and it was desired to have one man and one woman perform the same trial order, a full Latin square randomization of rotation trials could not be fulfilled. Since 1.0 and 1.5 G were likely to produce the greatest effects, it was decided to have these two levels as the two initial rates available in the partial Latin square. Subjects were not told how much time had elapsed during the trials nor were they told what G level they were experiencing.

Table 3. Biometric Characteristics and Rotation Parameters of the Subjects

Subject	Gender	Age (years)	Height (cm)	Mean Mass (kg)	Blood Pressure at Rest (mm Hg)	Heart Rate at Rest (bpm)	ω for 0.5 G (rpm)	ω for 1.0 G (rpm)	ω for 1.5 G (rpm)	Order of G Trials
C	F	22	166.4	53.0	110/69	71.9	16.4	23.2	28.4	1.0,0.5,1.5
D	M	19	175.3	77.8	117/66	73.8	16.0	22.6	27.7	1.0,1.5,0.5
E	M	19	180.3	97.8	140/76	66.1	15.8	22.3	27.3	1.0,1.5,0.5
F	F	27	172.7	67.6	109/71	73.8	16.1	22.8	27.9	1.0,1.5,0.5
G	M	26	190.5	98.4	116/63	77.5	15.3	21.7	26.5	1.5,0.5,1.0
H	M	27	182.9	80.6	115/66	73.9	15.6	22.1	27.1	1.5,1.0,0.5
I	F	23	160.0	73.3	128/70	80.8	16.7	23.6	29.0	1.5,0.5,1.0
J	F	19	160.0	55.3	106/63	69.2	16.7	23.6	29.0	1.5,1.0,0.5

For the control trial, subjects performed the supine portions on the AGS. They were allowed to sit up approximately 20 s prior to standing. The experimenter aided them in the

transition from the AGS to standing. While standing, subjects positioned their back against a wall but were allowed to place their feet naturally (as long as the angle the legs made with the wall was not too great). They were allowed to make minor movements of their legs such as shifting weight but were not required to "stand at attention." The experimenter remained at the side of the subject at all times to observe any presyncopal symptoms.

Four male and four female healthy volunteers, coded C-J, provided written consent to participate in this study, comprised of four trial sessions. The subjects had the following physical characteristics (mean ± standard deviation): age = 22.75 ± 3.6 years, height = 1.74 ± 0.11 m, mass = 75.5 ± 17.0 kg, resting blood pressure = 118/68 ± 11/4 mm Hg, and resting heart rate = 73.4 ± 4.6 bpm. Table 3 displays the individual biometric statistics for the subjects. The mean mass was the average of the masses measured on each of the four trial days. The maximum coefficient of variation for mass was 1.7%.

Calf Impedance and Volume

Calf impedance (I) was measured at 0.2 Hz with a Minnesota Impedance Cardiograph (Model 304B), pictured in Figure 7. The impedance cardiograph was utilized as an impedance plethysmograph in this experiment. Four circumferential electrical leads, as seen in Figure 8, were attached to one leg of a subject, two near the ankle and two near the knee. The leads were formed by wrapping electrode tape (Cardiograph Electrode Tape, IFM T-8001, Instrumentation for Medicine, Inc.), with electrode gel (Signa Gel, # 0341-15-25, Parker Laboratories, Inc.) applied to the electrode portion, around the limb and meeting the two ends. The impedance cardiograph leads were then clipped to the joined ends of the tape. Subjects were not required to remove hair from their calves. At times the electrode tape did not stick properly; so medical tape (Kendall Tenderskin Hypoallergenic Paper Tape, # 1914) was employed to improve attachment. The two outer leads ran a 4 mA AC current between them. The inner two leads measured the mean resistance (Z_o = I) of the limb between their positions. Since the impedance cardiograph leads ran through the slip rings, calibration was verified at the AGS end of the circuit with an ordinary resistor attached between the four leads. The impedance cardiograph was accurate to within 1% for a range of up to 99.9 Ω. The impedance readings were sent to a computer (90 MHz Pentium PC) through an A/D board (Keithley Metrabyte DAS-1600), which had a input voltage range of ± 10 V and 12-bit quantization. The impedance leads could not be placed in exactly the same position for every trial, but the average standard deviation in the distance between the inner two leads was 0.87 cm. For each subject, the leads were placed on the same leg for all of the trials.

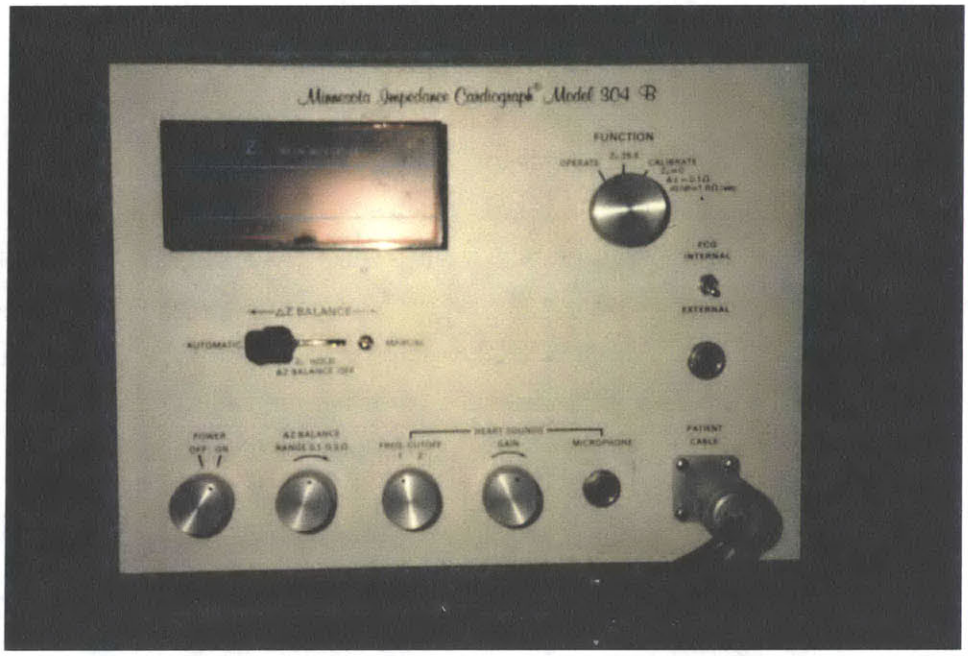


Figure 7. Minnesota Impedance Cardiograph

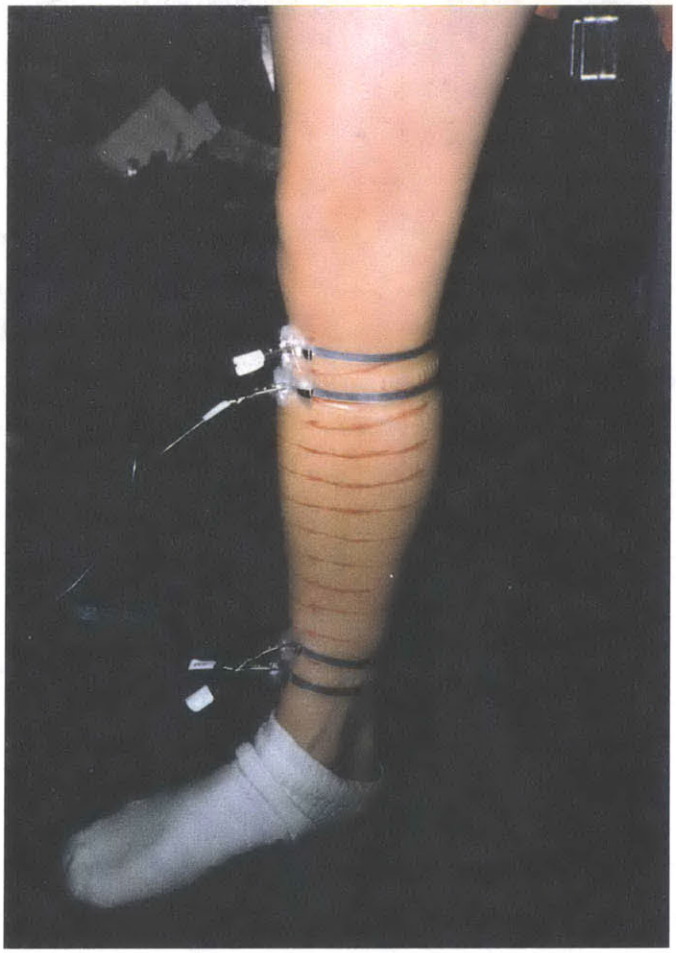


Figure 8. Example of Impedance Leads and Circumference Lines

The impedance data was normalized based on values averaged over 1 min. around $t = 20$ min. It was necessary to choose $t = 20$ min. as the resting value in order to compare impedance with volume. For purposes of statistical comparison, the normalized impedance values were extracted from the data at discrete times: $t = 0$, 20, 30 (for the rotation trials 30^- and 30^+, 60 (for the control trial 60^- and 60^+), 90^-, 90^+, and 120 min. These values were determined by averaging over the 1-min. period around the specific time. The - and + values refer to the fact that onset or cessation of a stimulus immediately produced a large change in the impedance. The - value is for the normalized impedance preceding the change, and the + value is for the normalized impedance immediately following the change. For the averages over 1 min. to find the critical points, the largest coefficient of variance was 0.99% but the majority were much lower. For statistical comparisons between trials, differences in normalized impedance between two times were compared.

In order to correlate the impedance readings with actual volumes, calf volume was measured at certain times during the trials. The volume measurements were taken from the same calf on which the impedance leads were attached. For every trial (except for the control trial with subject F), calf circumferences at 9 to 15 positions (depending on the size of the subject's leg) between the two inner impedance leads were measured with a flexible tape measure at $t = 20$ and 90 min. ($t = 20$ min. was the latest time before rotation that measurements could be taken because of the preparations required for rotation.) For some trials, additional recordings were taken at $t = 0$ and 120 min. Generally, the circumference measurements took less than one minute. They were accurate to within 1 mm. During that time, a subject was required to raise his leg approximately 2 cm to facilitate measurement. The circumference measurements were made 2 cm apart. To insure that the readings were acquired at the same positions within each trial, the circumferences were demarcated on the subjects' calves with water-proof marker (Crayola Classic Washable Markers, # 7808, Binney & Smith, Inc.). An example is depicted in Figure 8. For each subject, the same experimenter measured the circumferences whenever a reading was taken in all four trials. From the circumference, the radius of the calf at that position could be found via

$$r = \frac{C}{2\pi}. \tag{8}$$

Statistical methods were used to fit a third--order equation to the radius profile. An example profile is shown in Figure 9. The solid of revolution method was used to estimate a volume:

$$V = \int_0^{2\left(\begin{smallmatrix}\#\text{ of}\\ \text{positions}\end{smallmatrix}\right)} \pi[f(x)]^2\,dx, \tag{9}$$

where $f(x)$ is the equation fit for the radius profile.

The volume acquired from the circumference readings taken at $t = 20$ min. was considered to be the resting volume value. The maximum coefficient of variance for the 20-minute volume

readings over four trials was 1.9% but the majority were much lower. Volumes obtained within each trial were proportionally normalized by the resting value.

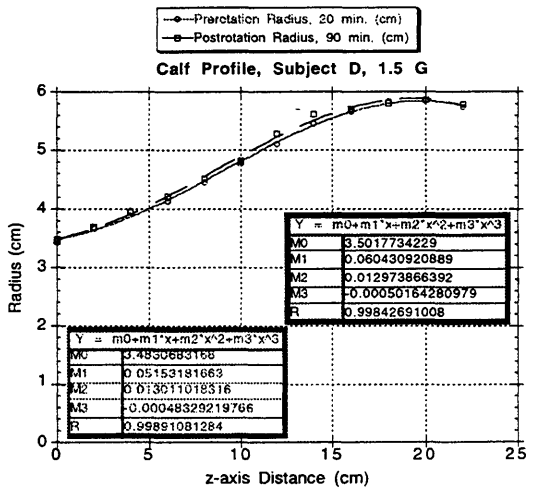


Figure 9. Example Calf Profile and Curve Fits

Blood Pressure

Blood pressure (BP) was recorded at 5-minute intervals with a Omron Smart-Inflate Blood Pressure Monitor (Model HEM-711), which had an arm cuff. The device was accurate to within 2% of the actual blood pressure. The subjects themselves initiated the measurement at the request of the experimenter. A BP measurement generally took 30 s from initiation. In some instances, the device would not take a reading because of subject movement. The BP measurements were monitored via the video camera. With respect to transitions between rest and stimuli, a BP reading was taken immediately after steady-state rotation or standing was achieved and immediately after complete rotator stop or return to the supine position. The pulse pressure was calculated post-hoc.

To obtain BP statistics, values were averaged over 15-min. intervals because of the limited number of data points. The reading at t = 120 min. was excluded because of suspected unreliability due to the subjects' anticipation of the end of the experiment. BP comparisons between trials were based on differences while within-trial comparisons looked at the raw values. The BP value obtained from the average of the last 15 min. of the initial supine period was considered the resting value for the subject for each trial. The mean resting BP for each subject was the average of these four measurements. The mean resting values for the subjects were then averaged, resulting in a group mean of 118/68 mm Hg.

Blood pressure was normalized based on differences because BP changes in the body seldom depend on initial pressures normally. For the purpose of normalization, the values at t = 25 min., 5 min. before rotation was initiated, were assumed to represent resting states for the individual trials. The group mean resting BP (118/68 mm Hg) became the value at resting (t = 25 min.) for the normalized blood pressure data for each subject. (Since the normalization was based on differences, no information was lost by using the group average for the individual normalized values at t = 25 min.) The normalized blood pressures at other times for the subjects were then calculated by adding to 118/68 the difference between their actual BP at that time and the subject's actual BP at t = 25 min. The following example will illustrate the normalization method. Subject

G had a BP of 115/63 mm Hg at t = 25 min. in 0.5 G trial. The normalized BP value at t = 25 min. for this case was set to 118/68 mm Hg. For the same trial, subject G had a BP of 110/69 mm Hg at t = 70 min. The difference between subject G's BP measurements at t = 70 and t = 25 min. was -5/6 mm Hg. This difference was then added to 118/68 mm Hg to achieve the normalized BP value for subject G in the 0.5 G trial at t = 70 min. of 113/74 mm Hg.

Heart Rate

Electrocardiograph (ECG) signals were recorded at 250 Hz (except for two of the 32 trials, in which a lower rate was employed) using a laboratory-constructed device (a human-rated differential amplifier with a gain of 1000). Two ECG electrodes were attached to the subjects subclavicular and towards the axilla. Another was mounted laterally on the abdomen. The self-adhesive electrodes (Electro Blue ECG Electrodes-Foam, catalog number AF310, LMI Medical) were prepared with electrode gel (Signa Gel, # 0341-15-25, Parker Laboratories, Inc.) prior to attachment. The ECG signal was sent through the AGS slip rings, a low-pass analog filter (Krohn-Hite model 3340) with a 60 Hz cutoff frequency and a DC gain set at 20 dB, the A/D board, and into the computer.

Instantaneous heart rate (HR) was calculated from the ECG data via peak detection using a matched filter. Appendix D contains the MATLAB© computer code used to do this. Since the subjects did not produce extremely high heart rates, it was acceptable to reduce the sampling rate of the data by 50%. The ECG data displayed typical baseline drift characteristics (low frequency noise) and in some cases extreme high frequency noise. The high frequency noise was a consequence not only of 60 Hz noise due to standard AC power supply voltage but also of AGS and subject movement. As a result, it was necessary to filter the signals. To see what frequency range the data were in, a 4096-point fast Fourier transform (FFT) of the first 10 s of data for each trial was performed. Figure 10 displays an example of the first 10 s of ECG data and its corresponding FFT. Note the large spike at 60 Hz due to standard AC power supply voltage. This spike was present in all of the ECG data. Also note the very strong frequency component near 1 Hz. This is most likely the baseline drift mentioned earlier. Since this experiment was interested only in heart rate, i.e. finding the QRS complexes, it was possible to use a very dramatic filter to eliminate as much noise as possible. The downside of the filter was to nearly eliminate recovery of P and T waves. A MATLAB© bandpass filter ("fir1") of order 100 with cutoff frequencies of 10 and 30 Hz was used to "clean up" the ECG signal. The narrow frequency range of the filter was necessary to eliminate as much noise as possible (low frequency drift and high frequency noise) while still maintaining recovery of the QRS complexes after filtering. The impulse response of the filter is shown in Figure 11. One can see that it resembles a QRS

complex, hence the term matched filter. The MATLAB© function "fftfilt" was utilized to filter the ECG data. For our example in Figure 10, we see that the filtered data contains very little noise. One can actually detect P and T waves in this case. The FFT of the filtered data is also presented in Figure 10. Power at the main noise frequencies has been eliminated.

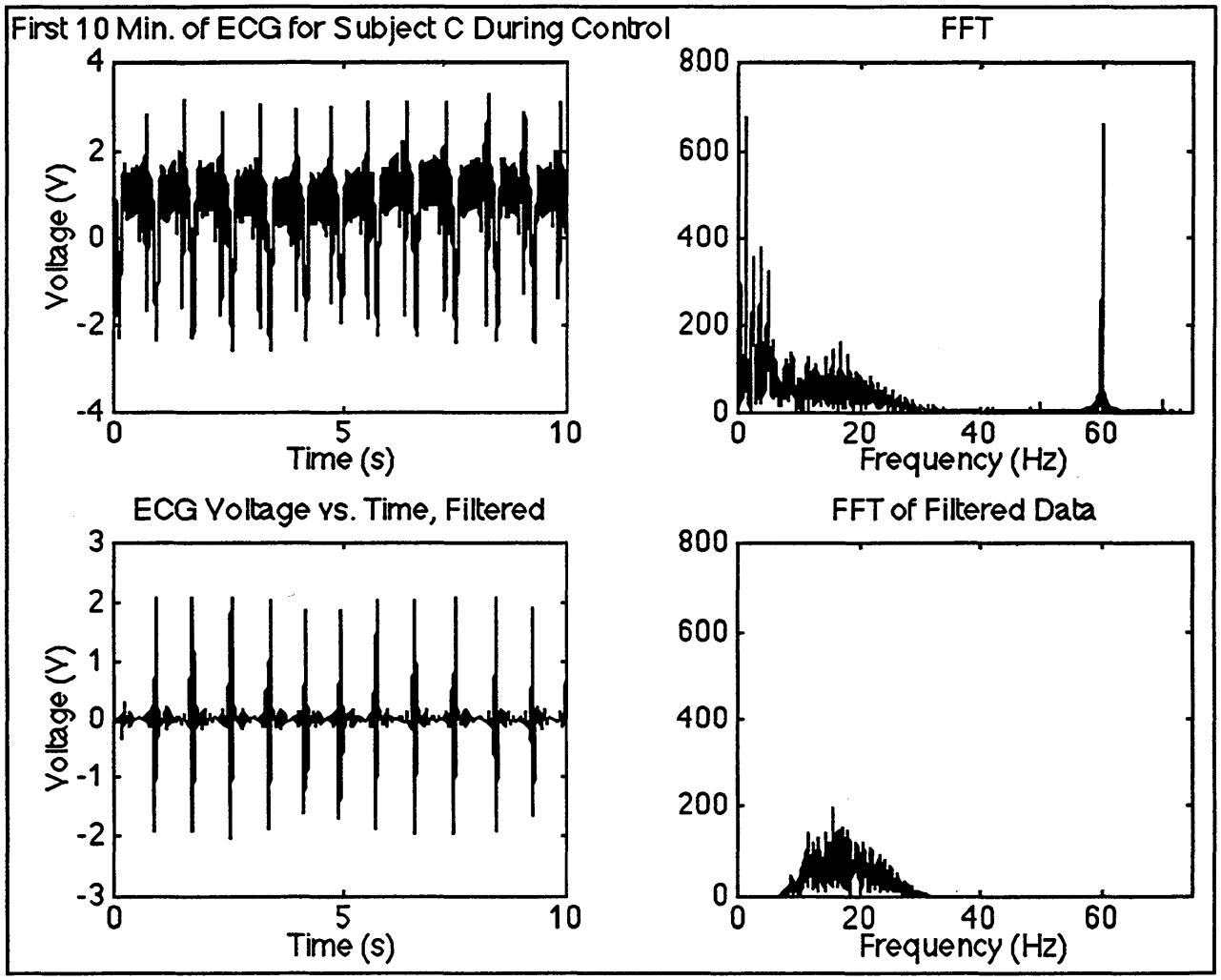


Figure 10. Example of Filtering of ECG Signals
The top left picture shows 10 s of the original ECG signal. The top right picture displays the FFT of the original signal. Note the large spike at 60 Hz. The bottom left picture shows the filtered version of the same 10 s of ECG signal. Note that P and T waves can be seen. The bottom right picture displays the FFT of the filtered data.

Peak detection was performed by looking for local maximums over time. Because noise could still be present in the filtered data, it was necessary to define a range of possible heart rates. The range used was 40-133 bpm. While transient, extreme increases in heart rate were lost, all of the averaged HR data points were well within this range. The times between successive peaks, R-R intervals, were found by simple subtraction of the peak times. Instantaneous HR was then

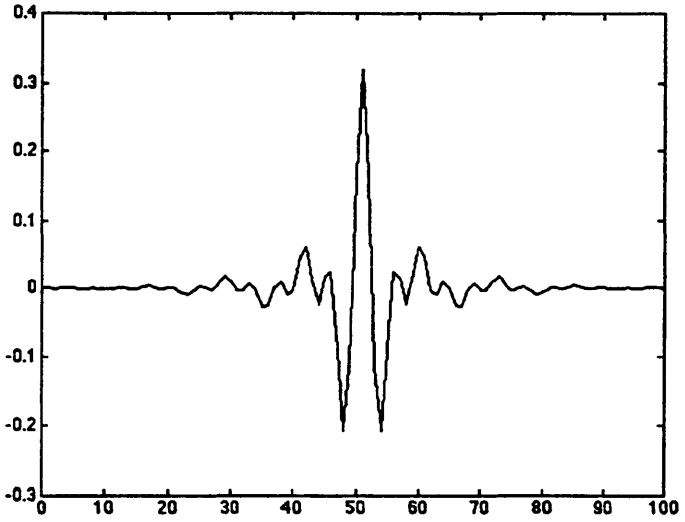


Figure 11. Impulse Response of the ECG Filter

calculated by inverting the R-R intervals. At this stage some noise still remained. In some cases the level of remaining noise was enough to severely alter the average heart rate, in most cases causing an elevation. Generally, the noise data points were distinguishable from the real data by having exceptionally high or low R-R intervals compared to the main portion of the data. Steps were taken to remove the remaining noise data by setting bounds on the R-R intervals. The bounds were set individually for each ECG signal and sometimes varied over the signal. The bounds used for each signal are shown in the MATLAB© codes entitled "heart*.m" in Appendix D, where * represents the individual subject code letter. Using the bounded instantaneous HR data, the average HR over 30 s and 5 min. intervals was found. Statistical analysis of HR utilized the values averaged over 5 min. HR comparisons between trials were based on differences while within-trial comparisons looked at the actual values.

Since no evidence attests that heart rate will change proportionally under the conditions of the experiment, the HR averaged over 5 min. was normalized based on differences (similar to the BP normalization). The values at t = 25 min. were assumed to represent resting states. The mean resting values for the subjects (the average of the resting values from the four trails) were averaged, resulting in a group mean of 73.4 bpm. This group mean resting value became the value at rest (t = 25 min.) for the normalized HR data for each of the subjects. (Since the normalization was based on differences, no information was lost by using the group mean for the individual normalized values at t = 25 min.) The normalized HR at other times for the subjects was then calculated by adding to 73.4 bpm the difference between the actual HR at that time and the subject's actual HR at t =25 min.

Additional Procedures

Data were statistically analyzed using Student's t-tests for matched pairs. Unless otherwise stated, the n for all comparisons was 8. The primary comparisons explored were between the following pairs of time intervals: the first half hour of rotation in the G trials and the second half hour of supine rest in the control trial (comparison I), the first half hour of rotation in the G trials and the half hour of standing in the control (comparison II), and the one-hour rotation periods at

the different G levels (comparison III). Comparisons can be made between standing and the first half hour of the rotation trials even though supine periods of different lengths precede these trials because the major transient changes in cardiac parameters during supine rest occur within the first 30 min. CV parameters change minimally from t = 30 to 60 min. of supine rest (or -5-6° head-down tilt bed rest) as verified experimentally (Hughson, et al. 1995; Lathers and Charles 1994) and with mathematical models (Simanonok, et al. 1994). Statistical significance was assessed at the 5% level. Additional comparisons explored how the parameters varied within trials and between resting values on different days. A multivariate analysis of variance (ANOVA) was used to explore correlations between CV responses and gender, age, height, mass, resting blood pressure, and resting heart rate.

It should be mentioned that one major deviation from the standard protocol occurred. Subject F accidentally pressed the AGS emergency stop button in the 1.0 G trial immediately after reaching steady-state rotation. Because the dynamic braking mechanism of the AGS required a 7 min. cooling period between uses, it was decided to allow the subject to remain supine for an additional 10 min. and complete the remainder of the trial. For purposes of data analysis, the first 10 min. of supine rest for subject F were generally dropped from the trial. This was assumed acceptable because CV parameters change minimally from additional rest after 30 min. and because the transient changes caused by the initiation of rotation recovered to their previous levels almost immediately after the rotator stopped.

RESULTS

General

No subject issued any major complaint from the protocol. Vestibular stimulation was experienced minutely during initial rotation and was quite apparent during deceleration. No subjects complained of any lasting motion sickness; however, some subjects requested that the blindfold be kept on for a while post-rotation. Several subjects mentioned feeling cold due to improper seal of the wind canopy. At the higher rotation rates, subjects felt almost as if the lower part of their body was standing while the upper portion was still resting. In the 1.5 G case, many subjects noticed discomfort in the legs, most often in the knees or ankles. Some reported that their feet felt "asleep." Many mentioned that their legs felt heavy. Subject J, for instance, requested that she be allowed to move her legs a little more than previously to relieve some of the discomfort. She was allowed to do so. Subject D also complained of a mild headache in the last half hour of rotation in the 1.0 G trial. No subject reported any immediate or delayed side effect after each 2-

hour trial. While the experimenter attempted to keep the subjects from knowing how much time had elapsed during the trials, many subjects were able to surmise when rotation or the experiment would end by counting the number of BP readings which were spaced 5 min. apart.

To even be able to compare different trials, it was necessary to test whether the resting cardiovascular (CV) values were different on the days of the trials. Table 4 shows the comparisons between the resting values of CV parameters for the different trials. For blood pressure, the resting value here was taken to be the average of the last 15 min. of the initial supine rest period. Note that no significant difference was found between resting calf volumes for the different trials. While the same area of the calves could not be used for the different trials, as explained previously, the resting volumes were similar enough to perform statistical comparisons.

Table 4. *p* Values for Comparisons Between Resting Values of the Different Trials
C = control trial, * = statistical significance

Matched Pair	Systolic BP *p* Value	Diastolic BP *p* Value	Heart Rate *p* Value	Volume *p* Value
C and 0.5 G	0.167	0.028*	0.010*	0.509
C and 1.0 G	0.133	0.264	0.011*	0.633
C and 1.5 G	0.764	0.496	0.345	0.133
0.5 and 1.0 G	0.879	0.036*	0.178	0.685
0.5 and 1.5 G	0.422	0.099	0.539	0.185
1.0 and 1.5 G	0.387	0.566	0.208	0.274

Resting systolic pressure (SP) seemed relatively invariant, as evidenced by the *t*-test results in Table 4. However, the resting diastolic pressures (DP's) for the 0.5 G trial appear to differ from those of the other trials. Since the order of the G trials was semi-randomized, the effect was not due to order. Analysis of the data shows that five of the subjects had their lowest resting DP when they participated in the 0.5 G trial. Post-hoc analysis assessing a correlation between those five subjects and body type, day of the week of the 0.5 G trial, and gender did not show a linkage. It was found that all but one who had their lowest DP for the 0.5 G trial participated in that trial last. These subjects may have guessed that this was the 0.5 G trial and were more relaxed; or they were more relaxed because it was their last trial. However, it cannot be said that this is a statistically significant correlation because an ANOVA that assessed the correlation between resting DP in the 0.5 G trial and position of the 0.5 G trial in the subject's G trial order resulted in a p value of 0.108. Simple probability expectations predict that one third of the subjects would have their lowest DP in the G trials for the 0.5 G trial. Using this fact, a Yates-corrected χ^2 test (χ^2 = 1.78) shows that the finding concerning resting level diastolic blood pressure is not statistically significant ($0.20 < p < 0.25$). Since BP comparisons between trials looked at differences and no evidence is known showing that a lower original BP will produce a different response, it was felt that comparisons between other trials and 0.5 G for DP were justifiable.

Table 4 also shows that the resting heart rates in the control were somewhat different than those in the other trials. Examination of the data shows that five of the subjects had their highest resting heart rate during the control trial. Since every subject performed the control trial first, it is likely that this was an order effect. Subjects could have been more relaxed for the other trials having already experienced the supine rest period at least once before. A Yates-corrected χ^2 test ($\chi^2 = 4.5$) for the four trials, expecting only two subjects would show their highest HR in any trial, shows that the high HR's in the control are significant ($0.025 < p < 0.05$). Still, since HR comparisons between trials examined differences and no evidence is known showing that a higher resting HR will produce a different response, it was felt that comparisons between other trials and the control for HR were justifiable.

In order to include male and female subjects together for a complete statistical analysis, two criteria had to be satisfied. The resting cardiovascular parameters between the two genders had to be not statistically different. Also, the changes induced by a stimulus must not have been significantly different between the men and women. To compare resting values, an F test was first performed to test the equality of the underlying variances of the two groups. If the variances proved equal, a two-sample t test for independent samples with equal variances was performed. Table 5 shows the means, standard deviations, and p values for these tests on the different cardiovascular parameters. We see that for no CV parameter does a variance inequality exist between the two genders. The p values for the unpaired t tests indicate that the male and female subjects did not have significant differences (at the 5% level) between their resting states.

Table 5. Statistics for Comparisons Between the Resting Cardiovascular Parameters Between Male and Female Subjects

CV Parameter	Male Mean	Male Standard Deviation	Female Mean	Female Standard Deviation	p Value for F Test	p Value for Unpaired t Test
Systolic BP	122 mmHg	12.1 mmHg	113 mmHg	9.87 mmHg	0.747	0.284
Diastolic BP	67.8 mmHg	5.71 mmHg	68.0 mmHg	3.44 mmHg	0.427	0.950
Heart Rate	72.8 bpm	4.80 bpm	73.9 bpm	4.98 bpm	0.952	0.756
Volume	1941.2 cm^3	300.9 cm^3	1497.3 cm^3	239.4 cm^3	0.717	0.060

ANOVA was used to assess any correlations between gender and all of the response differences tested in the remainder of the results presentation. Only significant findings will be presented here. A correlation was found with the change in diastolic blood pressure (DP) over the first 30 min. of rotation at 0.5 G ($p = 0.002$). The raw data indicate that the women displayed less of a change in DP over the 30 min. However, no gender correlation was found with the change in DP over the hour of rotation at 0.5 G nor in any other BP changes. Since only one significant correlation arose among numerous comparisons, it is unlikely that gender is actually correlated with changes in DP. In all probability, the effects of a small number of subjects, resulting in a low

statistical power, are being observed. Some gender correlation was found with impedance changes: the ΔI due to one hour of rotation at 0.5 G ($n = 7, p = 0.046$), the immediate ΔI due to cessation of rotation at 0.5 G ($n = 7, p = 0.041$), and the ΔI due to 30 min. of standing in the control ($n = 7, p = 0.037$). Close examination of the impedance data indicates that the relationship to gender is very minor and statistical significance probably arose as a result of only having the measurements of three of the women available in the first two cases and only three men in the last case. In conclusion, combining male and female subjects for complete statistical analysis is justified.

Multivariate ANOVA was utilized to assess any correlations between the changes in the CV parameters and mass, height, age, average resting blood pressure, and average resting heart rate. The resting CV parameters were assessed in an analysis separate from the biometric characteristics of the subjects. Only significant results are reported here, and correlations with changes in CV parameters are shown in Table 6. A correlation was also found between the average resting volume (at $t = 20$ min.) and mass, with a p value of 0.041.

Table 6. Significant Correlations Between Experimental Results and Subject Resting CV Parameters and Biometric Characteristics

SP = systolic blood pressure, DP = diastolic blood pressure, HR = heart rate, I = impedance, V = volume, † implies $n = 7$, ††† implies $n = 5$

Cause	Change in What CV Parameter	Correlation	p Value
20 min. of initial supine rest	I (average)	mass	0.019
	V (average)	average resting SP	0.038,†
30 min. of standing in the control	I	mass	< 0.050, †
		age	0.048,†
	SP	height	0.047
onset of rotation at 0.5 G	I	mass	0.014
		height	0.029
	HR	mass	0.022,†
		height	0.044,†
first 30 min. of rotation at 0.5 G	DP	mass	0.003
		height	0.032
		age	0.002
onset of rotation at 1.0 G	HR	height	0.038
		age	0.029
first 30 min. of rotation at 1.0 G	SP	mass	0.029
one hour of rotation at 1.0 G	SP	mass	0.027
one hour of rotation at 1.0 G and 30 min. of supine rest following	V	average resting HR	0.015,†††
		average resting SP	0.021,†††
		average resting DP	0.027,†††
onset of rotation at 1.5 G	DP	average resting HR	0.002
one hour of rotation at 1.5 G	DP	mass	0.019
cessation of rotation at 1.5 G	I	mass	0.049

Calf Impedance and Volume

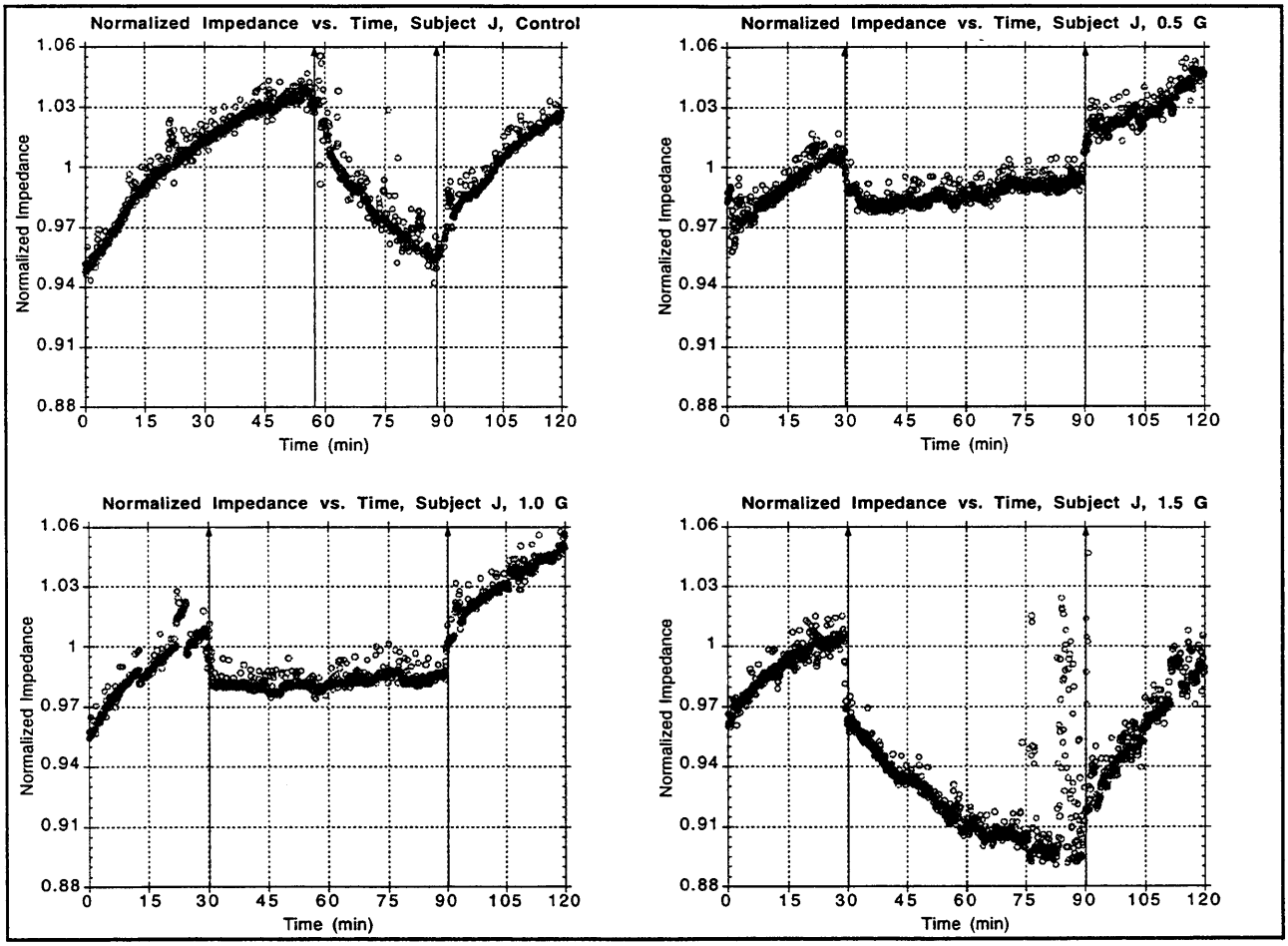


Figure 12. Normalized Calf Impedance Data for Subject J.
The vertical lines with arrows represent the beginning or end of a stimulus.

The raw and normalized calf impedance measurements are shown in Appendix E. As an example, Figure 12 displays the normalized impedance plots for the four trials for subject J. Figure 13 shows the normalized calf impedance, averaged over the 8 subjects, at the specific points extracted for statistical comparison. (The data for these points are presented in Appendix E.) Some general trends can be seen in these plots. During the supine periods, impedance tended to increase exponentially. Exponential decreases were observed during standing and rotation at 1.5 G. Attempts were made to fit exponential curves to the different segments of the trials, but not enough data were available. Often, especially for rotation, a large shift in impedance was observed at the beginning or end of a stimulus. During rotation at 0.5 G, impedance increased for 5 subjects, decreased for one, and stayed roughly the same for two. During rotation at 1.0 G, impedance increased for 3 subjects and decreased for three. Those subjects who showed an

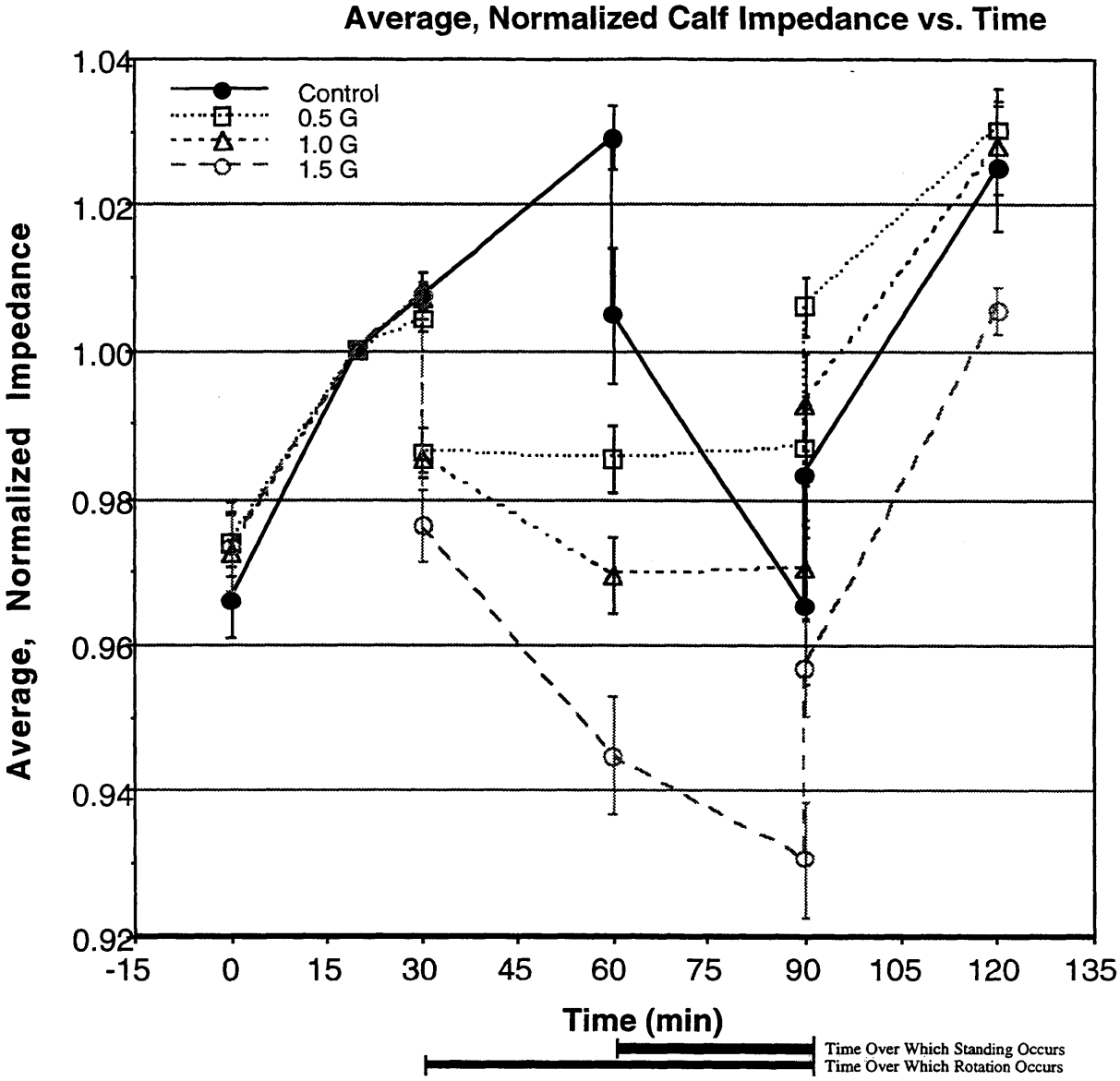


Figure 13. Calf Impedance Data.
The plot shows the data points determined for statistical comparison. Normalization was proportionally based, referenced to volumes at 20 min. Vertical changes in the impedance are due to the change immediately before and immediately after stimulus onset or termination. Note that the stimulus in the G trials begins at 30 min. while standing begins at 60 min. in the control trial. Error bars represent standard error of the mean.

increase in impedance during 1.0 G also exhibited the same effect at 0.5 G. Also notice from Figure 12 that many data points appear to be peripheral to the main body of the curve. A majority are due to subject movement. These points were excluded when finding points for statistical comparisons. Often, a large jump in impedance occurs around $t = 20$ min. This was the effect of measuring calf volume, which required that a subject elevate his leg slightly. In general, the calf volume measurements caused no large change in the impedance trend. By examining the plots

closely in Appendix E, one notices that at times the impedance seems to shift suddenly. If this occurred, data either before or after the shift were excluded from statistical analyses.

It can be seen from Figure 13 that calf impedance increased nearly uniformly over the initial 30-min. supine period in each trial. The increase in impedance continued during the second half hour of supine rest in the control trial, but at a lower rate than during the first half hour. This is consistent with the actual data points in Appendix E, which show exponential increases over the hour of supine rest in the control. Note that when rotation began in the G trials, the impedance fell several percent immediately. The drop was nearly the same for the 0.5 and 1.0 G cases, 1.8% and 2.2%, respectively. The drop for 1.5 G was 3.2%. During the first half hour of rotation at 1.0 and 1.5 G, impedance seemed to decrease. The decrease for 0.5 G was minimal. The impedance for 0.5 G increased on average over the last half hour of rotation. An average increase was also observed over the last half hour of rotation at 1.0 G. However, while these increases resulted in a net increase in impedance for an hour of rotation at 0.5 G, they did not cause a large change in the net impedance over one hour at 1.0 G. Impedance clearly kept increasing over the last half hour of rotation at 1.5 G but at a slower rate than the first half hour. When transitioned from supine to standing in the control, an immediate drop in impedance was observed. Then, impedance decreased at a rate that appears similar to that for the first half hour of rotation at 1.5 G. For all of the trials, an immediate increase in impedance was observed post-stimulus. Impedance then seemed to increase to a similar normalized value in the post-stimulus supine period for all but the 1.5 G trial.

Statistical analysis of impedance assessed within-trial and between-trial comparisons using the data points for each subject taken at $t = 0$, 20, 30 (for the rotation trials 30^- and 30^+, 60 (for the control trial 60^- and 60^+), 90^-, 90^+, and 120 min. The first statistical test confirmed that the average (over all four trials) change from $t = 0$ to 20 min. for each subject was different from 0 ($p < 0.001$). To determine whether the trials produced different impedance responses, the impedances at certain times were compared as shown in Table 7. It can be seen that impedance did not change significantly for the G trials from $t = 20$ to 30 min. Thus, these trials can be safely compare to each other. The impedances caused by an hour of rotation at 0.5 and 1.0 G were found to be statistically similar and that caused by 1.5 G was dissimilar to both of these. The p values comparing $t = 90^+$ and 120 min. generally indicate that impedance changed differently in the final supine period for the control and 1.5 G than it did for 0.5 and 1.0 G. From Figure 13, one can see that the impedance was increasing at a faster overall rate in the former two trials for this time interval. With one exception (when comparing the beginning of 0.5 to that of 1.5 G), the immediate change in impedance caused by the start or end of a stimulus was not significantly different for any of the trials. t tests were also performed to see how the impedance during the first half hour of rotation compared to what would have happened if supine rest had continued. These

comparisons, between $t = 30^+$ and 60^-, indicate that a significant change was induced by all rotation levels. The most critical statistical test looked at how the first half hour of stimulation in all of the trials differed. Standing and 1.5 G are found to induce similar changes in impedance, and 0.5 and 1.0 G were different from standing. It is also shown that 1.0 and 1.5 G produced similar changes (decreases) in impedance over the first half hour of rotation. Thus, it is the last half hour of rotation that produced the opposite effect (net increase) when an hour of rotation was completed.

Table 7. *p* Values for Impedance Comparisons Between the Trials

* = statistical significance, , CH1 = 60^- for the control trial and CH1 = 30^- for the G trials, CH2 = 60^+ for the control trial and CH2 = 30^+ for the G trials, C = control trial, † implies $n = 7$, †† implies $n = 6$

	Time Comparison (min)						
Matched Pair	**20 and 30^-**	**CH1 and CH2**	**30^+ and 90^-**	**30^+ and 60^-**	**(CH2 and 90^- in C) with (CH2 and 60 in G trials)**	**90^- and 90^+**	**90^+ and 120**
Control and 0.5 G		0.473		0.001*,†	0.003*,††	0.825†	0.001*
Control and 1.0 G		0.606†		0.001*	0.033*,†	0.346	0.116
Control and 1.5 G		0.453†		0.001*	0.459,†	0.234	0.216
0.5 and 1.0 G	0.159	0.276	0.064†		0.039*,†	0.056†	0.075
0.5 and 1.5 G	0.109	0.006*	0.002*,†		0.021*,†	0.075†	0.003*
1.0 and 1.5 G	0.932	0.105	0.002*		0.073	0.465	0.003*

Within-trial comparisons for impedance were performed as well. Table 8 shows the *p* values for the time comparisons. It can be seen that impedance changed significantly in all of the trials during the initial supine rest period. The drop in impedance caused by the onset of stimulation produced a value that was significantly different from the resting level in every case but standing. Thus, the immediate action of standing corrected for 40 min. of supine rest. In the G trials, the drop put the impedance far below the resting value. By the end of the standing period, impedance had fallen far below the resting value as well. Immediately after cessation of stimulation, the impedance rose to levels not different from resting levels for all trials except 1.5 G, where it was still less. In the half hour of supine rest following rotation at 1.5 G, impedance increased to a value near that at $t = 20$ min. For the rest of the trials, the effect of being supine again raised impedance beyond the stated resting values. Both of these findings are consistent with the final row of statistics in Table 8, showing that impedance greatly changed over the final supine period. Table 8 also indicates that all immediate impedance changes induced by the start or end of a stimulus were statistically significant. Perhaps the most important comparison is between the start (60^+ for the control trial and 30^+ for the G trials) and end (90^-) of stimulation. Here it can be seen from the significant *p* values that impedance decreased significantly for standing and the 1.5

G case. The change during rotation at 1.0 G was nearly significant ($p = 0.070$), and it was not for 0.5 G ($p = 0.565$).

Table 8. p Values for Impedance Comparisons Within the Trials
sig. diff. = significantly different, * = statistical significance, CH1 = 60^- for the control trial and CH1 = 30^- for the G trials, CH2 = 60^+ for the control trial and CH2 = 30^+ for the G trials, † implies $n = 7$

Time Comparison (min)	Control	0.5 G	1.0 G	1.5 G	Purpose of Test
0 and 20	< 0.001*	0.001*,†	0.002*,†	0.004*,†	to see if any sig. diff. from resting
20 and CH1	< 0.001*	0.039*	0.003*	0.003*	to see if any sig. diff. from resting
20 and CH2	0.624†	0.005*	< 0.001*	0.002*	to see if any sig. diff. from resting
20 and 90^-	0.015*	0.047*,†	0.003*	< 0.001*	to see if any sig. diff. from resting
20 and 90^+	0.086	0.182	0.325	< 0.001*	to see if any sig. diff. from resting
20 and 120	0.022*	0.001*	0.003*	0.115	to see if any sig. diff. from resting
CH1 and CH2	0.009*,†	< 0.001*	< 0.001*	< 0.001*	to see if transient response to stimulus start was sig.
CH2 and 90^-	0.003*,†	0.565†	0.070	< 0.001*	to see if any sig. change from start to end of stimulus
90^- and 90^+	0.007*	< 0.001*,†	< 0.001*	< 0.001*	to see if change immediately after stimulus ends was sig.
90^+ and 120	< 0.001*	< 0.001*	< 0.001*	< 0.001*	to see if change over last supine period was sig.

Appendix F contains the calf profiles and their associated curve fits for the subjects. The data and plots of the resulting volumes are also displayed in Appendix F. For all subjects, volume increased post-stimulus from its resting level for rotation at 1.5 G and standing. Post-stimulus volume for 0.5 G decreased from resting for six subjects. Of these six, four showed increased volume and two (subjects D and G) showed an even greater decrease in volume at $t = 90$ min. in the 1.0 G trial. Figure 14 shows the normalized calf volume averaged over the 8 subjects for all four trials. Note that $n < 8$ for the $t = 0$ and 120 values.

Statistical analysis of calf volume assessed within-trial and between-trial comparisons. The first statistical test showed that the average (over all four trials) change from $t = 0$ to 20 min. was significantly different from 0, with $p < 0.001$. To determine whether the G levels due to rotation produced different responses, the normalized volume changes between $t = 90$ and 20 were compared. The p values for the matched pairs of 0.5 and 1.0 G, 0.5 and 1.5 G, and 1.0 and 1.5 G were 0.063, 0.001, and 0.002, respectively. The volume change induced by an hour of rotation at 1.5 G was clearly different than that produced by the other two G levels, which were not significantly different from each other. The change during the control stimulus was not compared to the change during the G trials because volume measurements were not taken at $t = 60$ min. The p values for the within-trial comparisons of actual volume change for the G trials are shown in

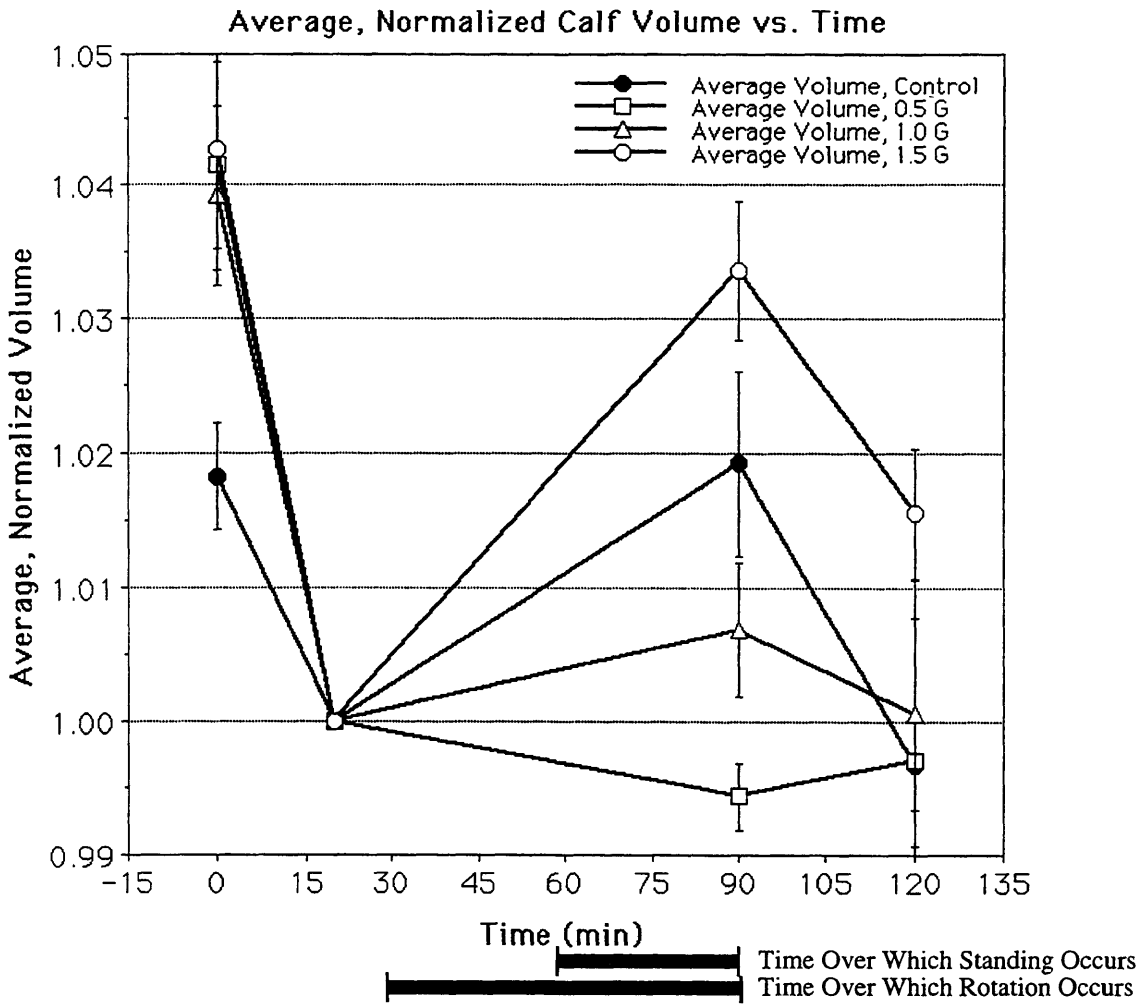


Figure 14. Calf Volume Data.
Data were acquired at discrete points before and after rotation. Normalization was proportionally based, referenced to volumes at 20 min. The measurements at $t = 90$ min. were taken immediately post-stimulus. The error bars represent standard error of the mean. The bars below the time axis indicate the times over which the stimuli occur in the trials.

Table 9. The volume change during rotation at 0.5 G is not significant at the 5% level, but that could be because of the dissimilar directional responses among the subjects. After the stimulus began in the 0.5 and 1.0 G trials, no calf volumes were significantly different from the resting volumes. The 1.5 G trial, on the other hand, produced significant volume changes during rotation and in the post-stimulus supine period. The statistical data confirm that the calf volumes did not recovered to their resting levels in the 30 min. post-rotation in the 1.5 G trial. Incidentally, the p value for the comparison between $t = 20$ and 90 min. in the control is 0.032. Interpretation of this value is not trivial since standing only occurs during the second half of the time interval. However, the volumes at $t = 60$ min. would have undoubtedly been less than those at $t = 20$ min. had measurements been taken. Even greater volume changes would have resulted between $t = 60$

and 90 min. than were observed between 20 and 90 min. Therefore, since the change between the latter interval was significant, the volume changes between the former time interval must have been significant as well.

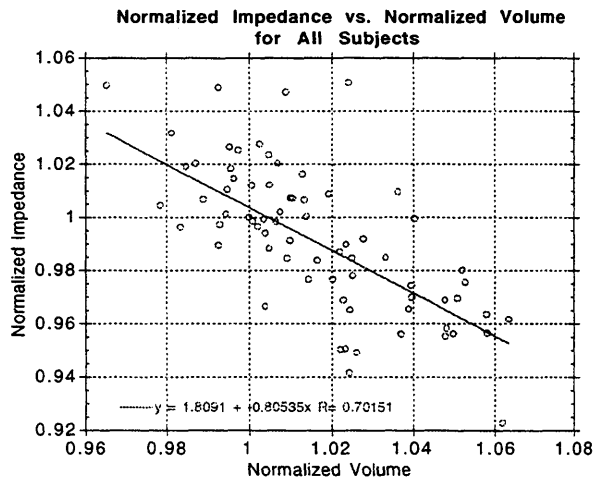
Table 9. *p* Values for Volume Comparisons Within the G Trials
* = statistical significance, † implies $n = 7$, ††† implies $n = 5$

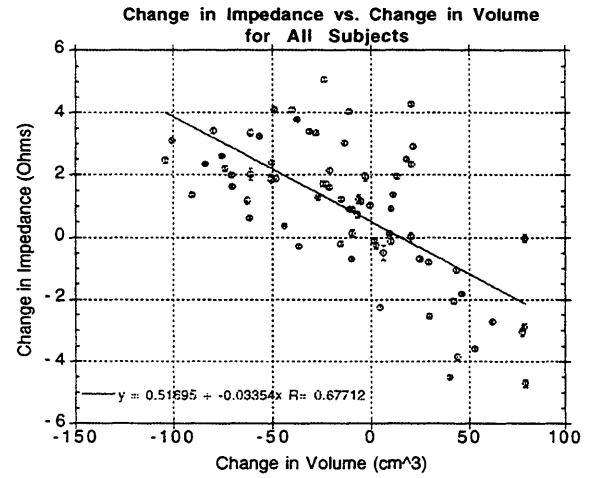
Time Comparison	0.5 G	1.0 G	1.5 G	Purpose of Test
20 and 90 min.	0.066	0.295	< 0.001*	to see if any sig. diff. from resting
20 and 120 min.	0.451,†	0.844,†††	0.041*,†	to see if any sig. diff. from resting
90 and 120 min.	0.318,†	0.142,†††	0.030*,†	to see if change over last supine period was sig.

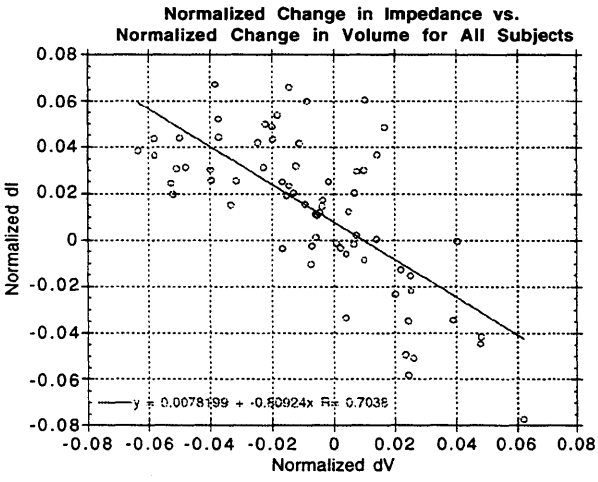
To determine how calf volume and impedance were related, the impedance values corresponding to the volume measurements were extracted. This data appears in Appendix G. Plots of actual volume versus actual impedance serve no purpose because the same area of the calf could not be assured for the different trials. A relationship might exist, however, between normalized values of volume and impedance. Plots showing this relationship appear in Appendix G. An inversely proportional relationship was observed for all subjects. The linear correlation coefficients are between -0.642 and -0.895. If the data points for all subjects are grouped together, as in Figure 15a, the correlation coefficient becomes -0.702. A relationship might be expected between a change in impedance and change in volume. These plots for each subject can also be found in Appendix G. An inversely proportional relationship (with correlation coefficients between -0.521 and -0.955) was noted for all subjects. While the lumped data for the comparison between changes (shown in Figure 15b) has a correlation coefficient of -0.677, the differences in the proportion and types of body materials between impedance leads on the different days make this comparison questionable. Therefore, the change in normalized impedance was plotted against the change in normalized volume. The plots are in Appendix G and Figure 15c. The correlation coefficient seen in Figure 15c is -0.704. The author considers this last analysis to be the most accurate way to determine the relationship between changes in impedance and volume. In summary, a positive change in volume will produce a negative change in impedance, in accordance with the physical principles. The linear correlation coefficient can be estimated as -0.70 ($n = 68$, $p < 0.001$).

Blood Pressure

The measured and normalized blood pressure data and plots for the subjects for all trials appear in Appendix H. While it is difficult to derive conclusions from the raw data, it is clear that the pulse pressure decreases over time for most subjects during rotation at 1.5 G. A pulse pressure



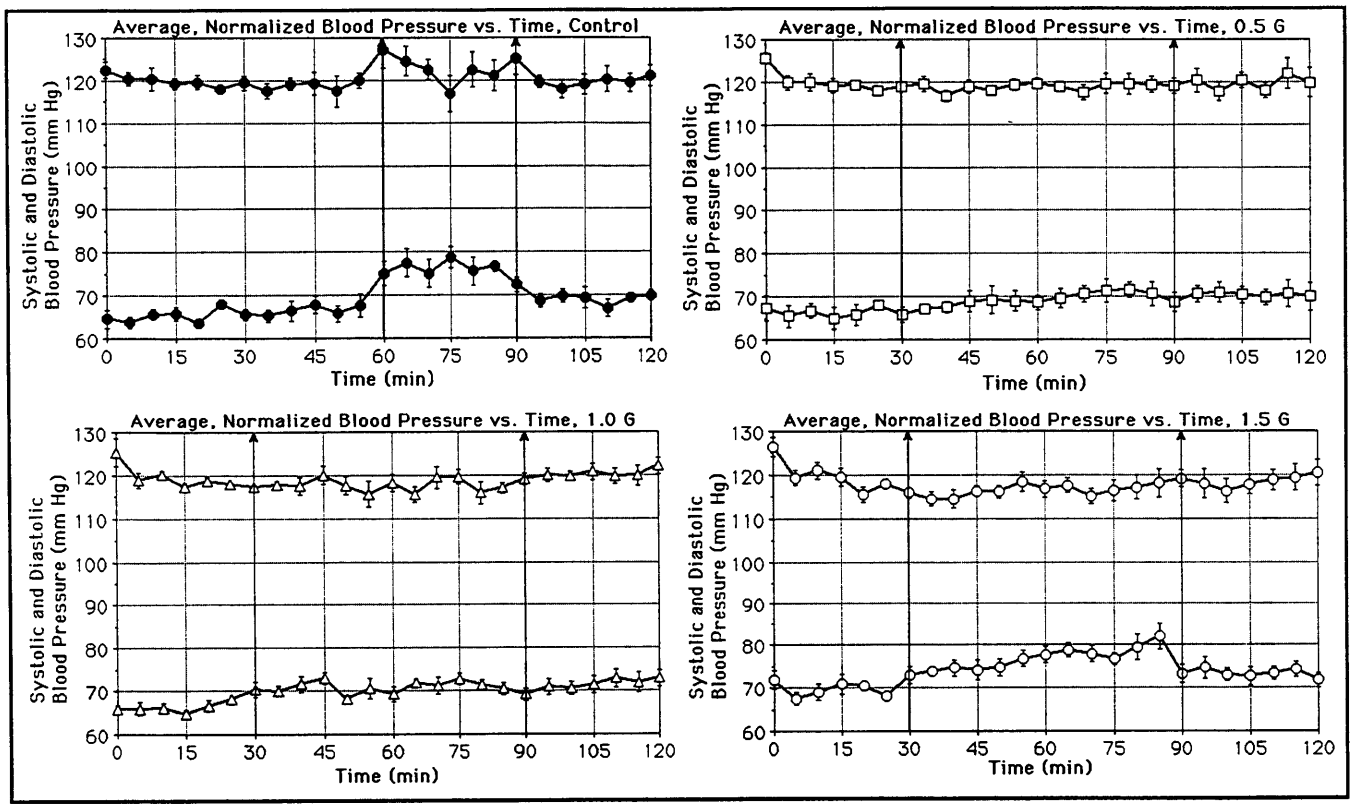




Figures 15a-c. Plots for Assessing the Relationship Between Calf Impedance and Volume

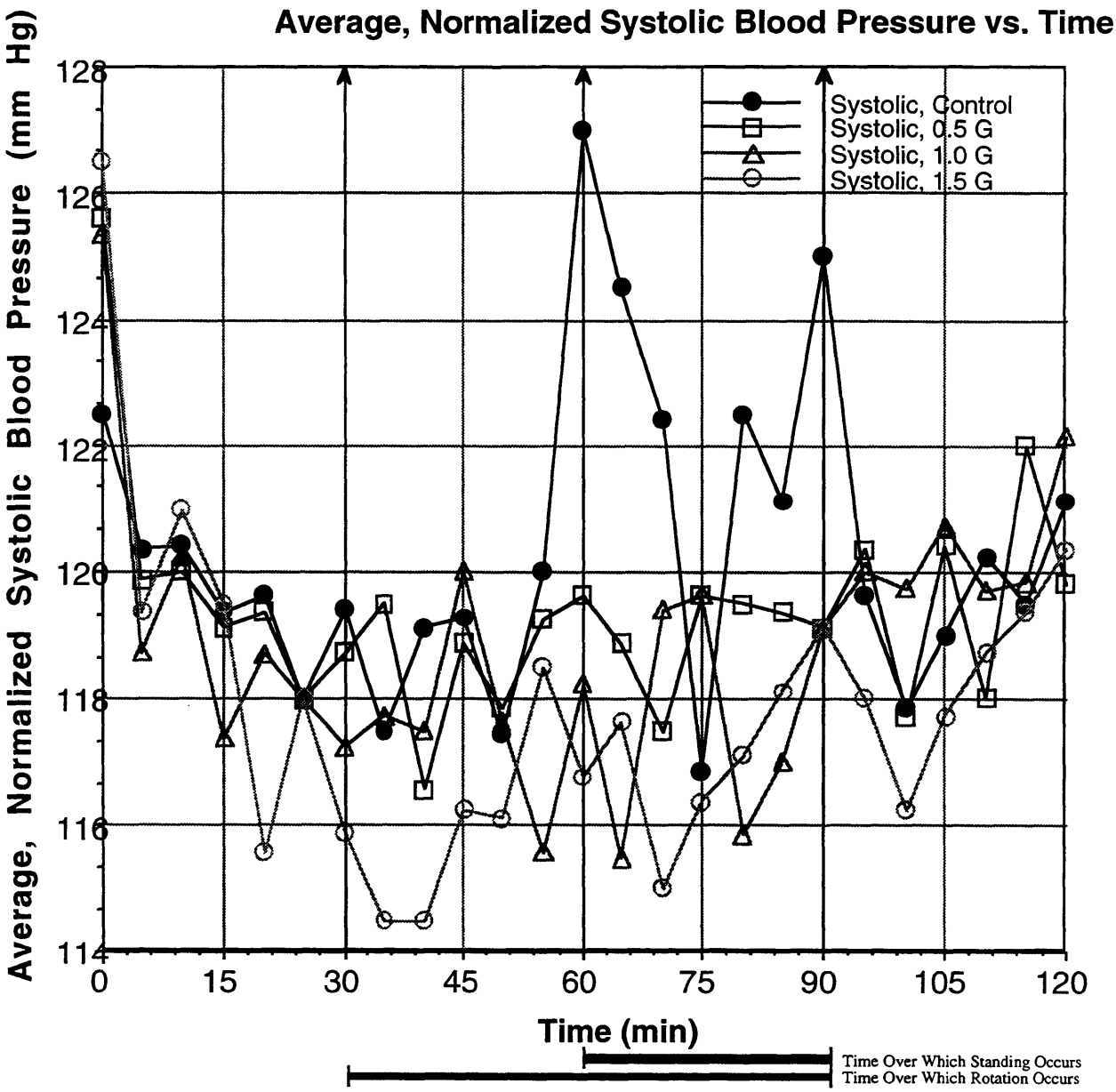
decrease is also observed for standing. Gross viewing indicates that the change in pulse pressures is mostly due to an increase in diastolic pressures. The only instance where a noticeable transient response occurs is immediately upon standing. Six of the subjects displayed increases in systolic and diastolic pressures immediately upon standing. However, two of the females, subjects F and I (also the two women with the largest masses), displayed a decreased systolic pressure and an increased diastolic pressure.

Figure 16 shows the normalized blood pressures for the four trials averaged over all eight subjects. Figures 17 and 18 display the systolic and diastolic pressures, respectively, without error bars so that comparisons between the trials can be seen more clearly. Several interesting trends can be noticed. During the initial supine rest periods, the systolic pressure appeared to fall. The immediate response, on average, to standing in the control was an increase in both systolic and diastolic pressures. SP then appeared to fall for the first 15 min. and recover in the last 15 min. In sum, the transient response was a systolic increase, but the systolic pressure after 30 min. of standing did not appear much different than the resting pressure. Diastolic pressure remained consistently elevated during standing. Post-standing, both pressures appeared to recover to their resting levels. No trends are immediately apparent from the 0.5 and 1.0 G data. The 1.5 G data, on the other hand, clearly show that DP immediately increased and continued to increase over time as a result of rotation. Post-stimulus, DP did not seem to recover exactly to its post-stimulus level in the half hour of supine rest.



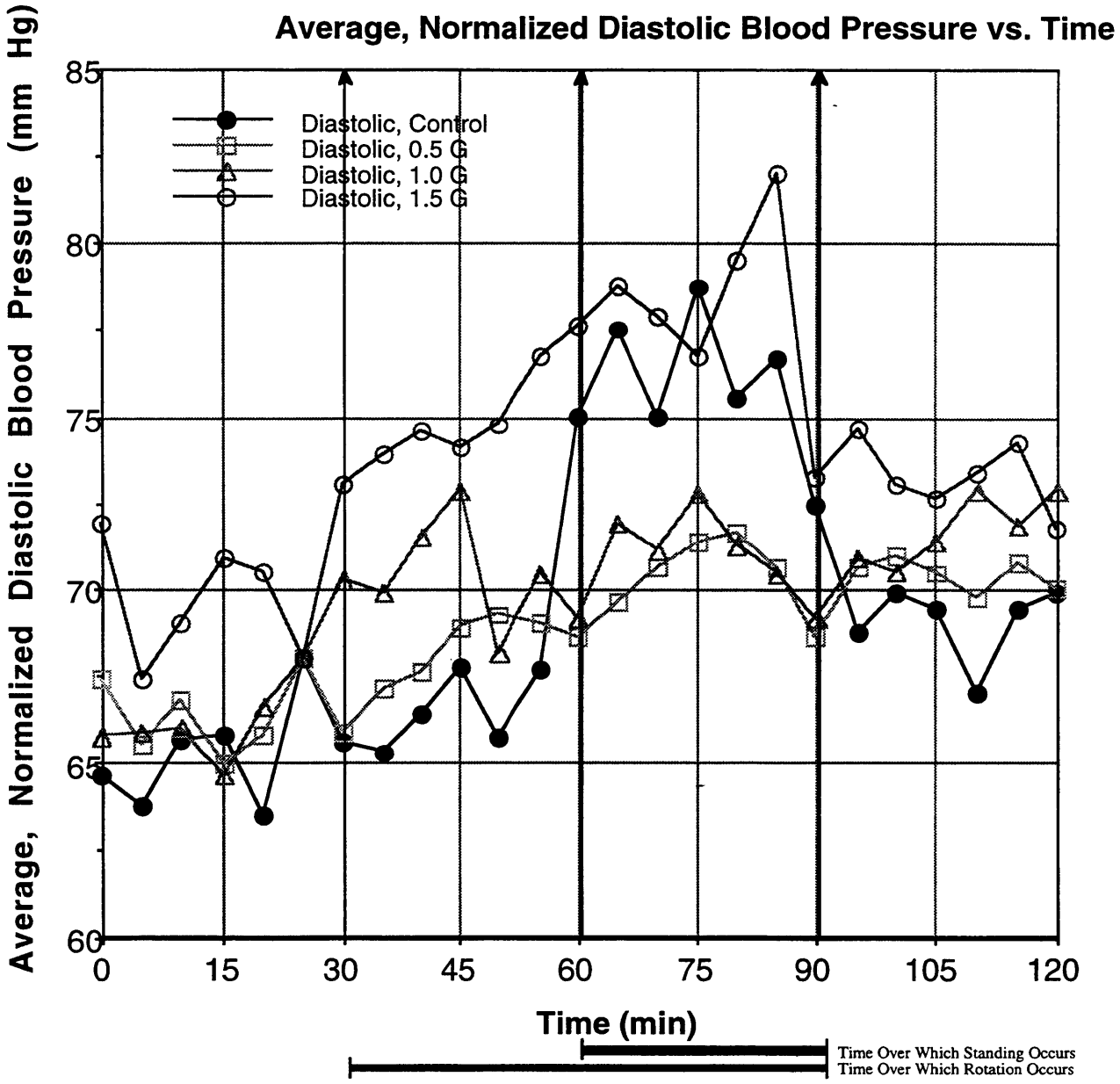
Figures 16. Average, Normalized Blood Pressure Results for the 4 Trials. Normalization was based on differences from the resting values, assumed to occur at 25 min. The vertical lines with arrows represent the onset or cessation of a stimulus. The error bars represent standard error of the mean.

Statistical analysis of blood pressure assessed within-trial and between-trial comparisons. As mentioned previously, comparisons were made between 15-minute periods, corresponding to when BP measurements were taken: (0-10), (15-25), (30-40), (45-55), (60-70), (75-85), (90-100), and (105-115) min. The average BP's at time (0-10) min. were compared to those at time (5-25) to elicit the response to 30 min. of supine rest. The *p* values for systolic, diastolic, and pulse pressures were 0.010, 0.517, and 0.022, respectively. Thus, systolic pressure clearly changed during the initial rest period. Since diastolic pressure did not change significantly, the pulse pressure change was due to the altered systolic pressure. To determine whether the G levels produced different responses after one hour of rotation, times (75-85) and (15-25) min. were compared. The *p* values are shown in Table 10. It was found that SP was not different over any of the G trials. The diastolic pressures caused by 0.5 and 1.0 G were similar and that caused by 1.5 G was dissimilar to both of these. The first half hour of rotation in the G trials was compared to the second half hour of the control trial to determine if the changes in BP were different from what would have occurred had supine rest continued. Table 10 shows that SP was relatively



Figures 17. Average, Normalized Systolic Blood Pressure Results for the 4 Trials. Normalization was based on differences from the resting values, assumed to occur at 25 min. The vertical lines with arrows represent the onset or cessation of a stimulus. Error bars are not present here so that the data may be seen more clearly; however, it should be noted that the SP after 25 min. of standing was not significantly different from that produced from 25 min. of rotation at 1.5 G for a comparison based on the measured BP data.

invariant. Only 1.5 G produced a DP elevation that was significantly different from continued supine rest. The most important statistical comparison is the last in Table 10. The first half hour of rotation in the G trials is compared to standing in the control. Again systolic pressure did not



Figures 18. Average, Normalized Diastolic Blood Pressure Results for the 4 Trials. Normalization was based on differences from the resting values, assumed to occur at 25 min. The vertical lines with arrows represent the onset or cessation of a stimulus. Error bars are not present here so that the data may be seen more clearly.

change significantly. However, 1.5 G and standing were found to produce statistically similar elevations in DP, and standing was found to be different from 30 min. of rotation at 0.5 G and 1.0 G.

Table 10. *p* Values for Blood Pressure Comparisons Between the Trials
* = statistical significance

Time Comparison: (15-25) and (75-85) min.		
Matched Pair	**Systolic *p* Value**	**Diastolic *p* Value**
0.5 and 1.0 G	0.484	0.4579
0.5 and 1.5 G	0.553	0.0194*
1.0 and 1.5 G	0.938	0.0204*
Time Comparison: (15-25) and (45-55) min.		
Matched Pair	**Systolic *p* Value**	**Diastolic *p* Value**
Control and 0.5 G	0.878	0.358
Control and 1.0 G	0.800	0.082
Control and 1.5 G	0.393	0.037*
Time Comparison: (75-85) and (45-55) min. in the Control with (45-55) and (15-25) min. in the G Trials		
Matched Pair	**Systolic *p* Value**	**Diastolic *p* Value**
Control and 0.5 G	0.888	0.005*
Control and 1.0 G	0.845	0.011*
Control and 1.5 G	0.778	0.067

Within-trial comparisons for BP were performed as well. Tables 10-13 show the *p* values for 15-min. interval comparisons within the trials. Note that in all four trials, no significant difference was detected in SP. From the control comparisons in Table 11, one can see that the transient systolic increase, seen in Figures 16 and 17 when standing begins, lost significance when averaged over the first 15 min. of standing and eight subjects. Indeed, only the changes in diastolic pressure were significant when posture was changed. As seen in Table 11, during standing, and even during the 15-min. period following standing, diastolic pressure was significantly different from the resting level. (Figure 16 shows that it was elevated.) However, after the final 30-min. rest period, DP neared its resting value again. For 0.5 G, DP was significantly different from resting by the end of rotation and for the final supine period. The facts that the first DP measured after rotation was not different from resting and $p = 0.013$ for the comparison between times (30-40) and (75-85) min. point to an increasing DP over the course of rotation. For the 1.0 G trial, the heightened G force had now caused a significant difference (from resting levels) in DP at the start of rotation. As a consequence, no statistically significant change was observed over the course of rotation. Like the 1.0 G trial, DP was significantly different from resting during all rotation periods at 1.5 G. However, at 1.5 G, DP kept increasing significantly over the rotation time. With 1.5 G, it is seen for the first time that a statistically significant change, a large drop as evidenced in Figure 15, occurred immediately after rotation stops. Notice that for all three G trials the DP elevation did not decrease to resting levels during the final 30-min. supine period. It is clear from Tables 10-13 that any significant changes in pulse pressure, most notably

Table 11. *p* Values for Blood Pressure Comparisons Within the Control Trial
SP = systolic pressure, DP = diastolic pressure, PP = pulse pressure, sig. diff. = significantly different, * = statistical significance

Time Comparison (min)	SP *p* Value	DP *p* Value	PP *p* Value	Purpose of Test
(15-25) and (45-55)	0.603	0.513	0.855	to see if any sig. diff. from resting
(15-25) and (60-70)	0.093	0.007*	0.080	to see if any sig. diff. from resting
(15-25) and (75-85)	0.570	0.001*	0.013*	to see if any sig. diff. from resting
(15-25) and (90-100)	0.463	0.001*	0.156	to see if any sig. diff. from resting
(15-25) and (105-115)	0.795	0.056	0.296	to see if any sig. diff. from resting
(45-55) and (60-70)	0.375	0.011*	0.054	to see if transient change to standing was sig.
(60-70) and (75-85)	0.159	0.960	0.159	to see if change over period of standing was sig.
(75-85) and (90-100)	0.943	0.005*	0.028*	to see if change immediately after standing was sig.
(90-100) and (105-115)	0.453	0.077	0.441	to see if change over last supine period was sig.

Table 12. *p* Values for Blood Pressure Comparisons Within the 0.5 G Trial
SP = systolic pressure, DP = diastolic pressure, PP = pulse pressure, sig. diff. = significantly different, * = statistical significance

Time Comparison (min)	SP *p* Value	DP *p* Value	PP *p* Value	Purpose of Test
(15-25) and (30-40)	0.293	0.377	0.165	to see if any sig. diff. from resting
(15-25) and (75-85)	0.716	0.005*	0.055	to see if any sig. diff. from resting
(15-25) and (90-100)	0.898	0.025*	0.028*	to see if any sig. diff. from resting
(15-25) and (105-115)	0.636	0.010*	0.080	to see if any sig. diff. from resting
(30-40) and (75-85)	0.538	0.013*	0.188	to see if any sig. change from start to end of rotation
(75-85) and (90-100)	0.723	0.467	0.662	to see if change immediately after rotation was sig.
(90-100) and (105-115)	0.425	0.806	0.680	to see if change over last supine period was sig.

Table 13. *p* Values for Blood Pressure Comparisons Within the 1.0 G Trial
SP = systolic pressure, DP = diastolic pressure, PP = pulse pressure, sig. diff. = significantly different, * = statistical significance

Time Comparison (min)	SP *p* Value	DP *p* Value	PP *p* Value	Purpose of Test
(15-25) and (30-40)	0.413	0.010*	< 0.001*	to see if any sig. diff. from resting
(15-25) and (75-85)	0.726	0.004*	0.001*	to see if any sig. diff. from resting
(15-25) and (90-100)	0.287	0.019*	0.118	to see if any sig. diff. from resting
(15-25) and (105-115)	0.339	0.006*	0.064	to see if any sig. diff. from resting
(30-40) and (75-85)	0.889	0.408	0.440	to see if any sig. change from start to end of rotation
(75-85) and (90-100)	0.139	0.264	0.073	to see if change immediately after rotation was sig.
(90-100) and (105-115)	0.725	0.076	0.278	to see if change over last supine period was sig.

Table 14. *p* Values for Blood Pressure Comparisons Within the 1.5 G Trial
SP = systolic pressure, DP = diastolic pressure, PP = pulse pressure, sig. diff. = significantly different, * = statistical significance

Time Comparison (min)	SP *p* Value	DP *p* Value	PP *p* Value	Purpose of Test
(15-25) and (30-40)	0.100	0.013*	0.020*	to see if any sig. diff. from resting
(15-25) and (75-85)	0.784	0.000*	0.013*	to see if any sig. diff. from resting
(15-25) and (90-100)	0.862	0.072	0.210	to see if any sig. diff. from resting
(15-25) and (105-115)	0.805	0.023*	0.286	to see if any sig. diff. from resting
(30-40) and (75-85)	0.260	0.002*	0.062	to see if any sig. change from start to end of rotation
(75-85) and (90-100)	0.834	0.005*	0.008*	to see if change immediately after rotation was sig.
(90-100) and (105-115)	0.132	0.868	0.510	to see if change over last supine period was sig.

the decrease that occurs during stimulation, were due to changes in DP. In conclusion, a narrowing of the pulse pressure due to an increase in DP occurred by the end of the stimulus in all four trials.

Heart Rate

ECG readings were not always available at all times during the trials. On several occasions, the ECG output exceeded 10 V, saturating the A/D board. In some instances, one of the leads became detached from the subjects. Also, the headsets periodically induced noise in the ECG signal when they were in use during rotation. The filter was able to "clean" most of the ECG signals except when the noise was similar in magnitude or frequency to the QRS complexes.

Appendix I shows the plots of R-R intervals and instantaneous heart rate for the subjects. Figure 19 displays example graphs. Note that the noise in Figure 19 is hardly visible. A brief look at Appendix I reveals that in some cases the level of remaining noise was enough to severely alter the average heart rate, in most cases raising it. Also in Figure 19, notice that HR increased dramatically near the transitions from supine to stimulus and vice versa. This finding was true for most subjects during all transitions. The plots of HR averaged over 30 s and 5 min. intervals, the measured and normalized data for the 5 min. intervals, and the plots of normalized data for the individuals are shown in Appendix I.

Figure 20 displays the normalized heart rates averaged over all eight subjects. Note that each data point represents heart rate averaged over the previous 5 min. Several observations can be made from this plot. In general, heart rate decreased during the initial supine rest periods. This is seen most dramatically in the first hour of the control trial, except for a slight elevation at t =25

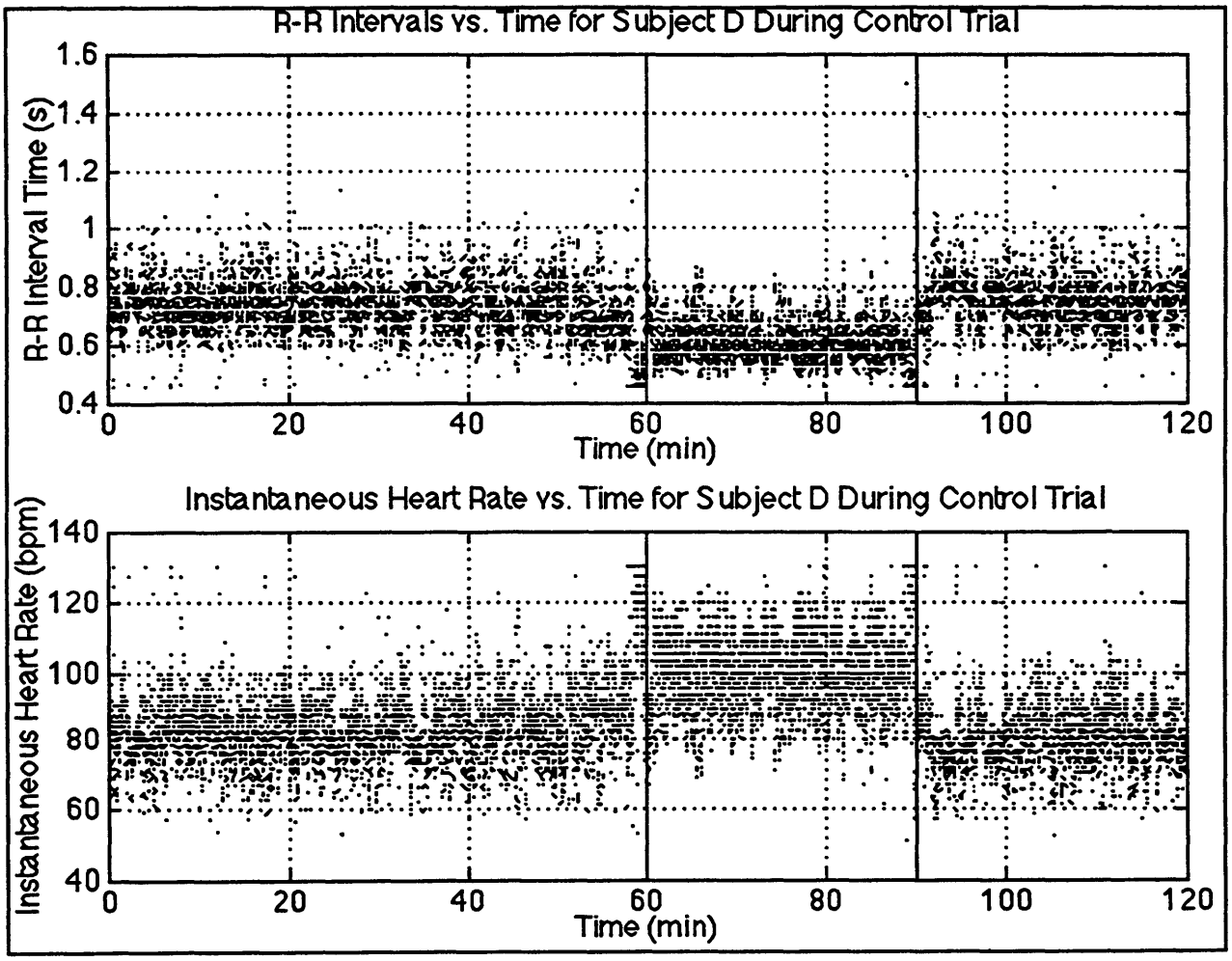


Figure 19. Examples of R-R Interval and Instantaneous Heart Rate Plots
The vertical lines represent the onset or end of standing.

min. From the plot, it appears that HR actually increased right before standing began in the control. This averaging artifact was due to the fact that subjects were allowed to have a longer transition between rest and the stimulus in the control, causing anticipation of the stimulus which increased HR. While standing, heart rate steadily increased until 25 min. of standing had occurred, at which point it began to decrease. The large increase in HR observed at the end of standing was once again an artifact of the transition. HR continued to decrease during the first half hour of rotation at 0.5 G but then increased during the last half hour. Rotation at 1.0 G caused some unusual affects in HR. The transient response (first 10 min.) was an increase. Then, HR fell to near resting level for the remainder of the first half hour of rotation. A HR increase was observed for the last half hour. Rotation at 1.5 G produced a similar effect: first increase, then decrease, and then increase (although the error bars suggest that this effect may not have been significant). However, the larger G level did not allow HR to fall back to resting levels. For all of

the G trials, the HR quickly fell to near resting levels when the subjects returned to the nonrotating state. A different post-stimulus response was seen for the control trial. HR fell far below the resting level and even below its value before standing. It then increased in the final supine period to a value somewhere near what it was pre-stimulus. In terms of gross responses, 0.5 and 1.0 G seemed to produce similar HR's over an hour of rotation. Standing and 1.5 G also were similar.

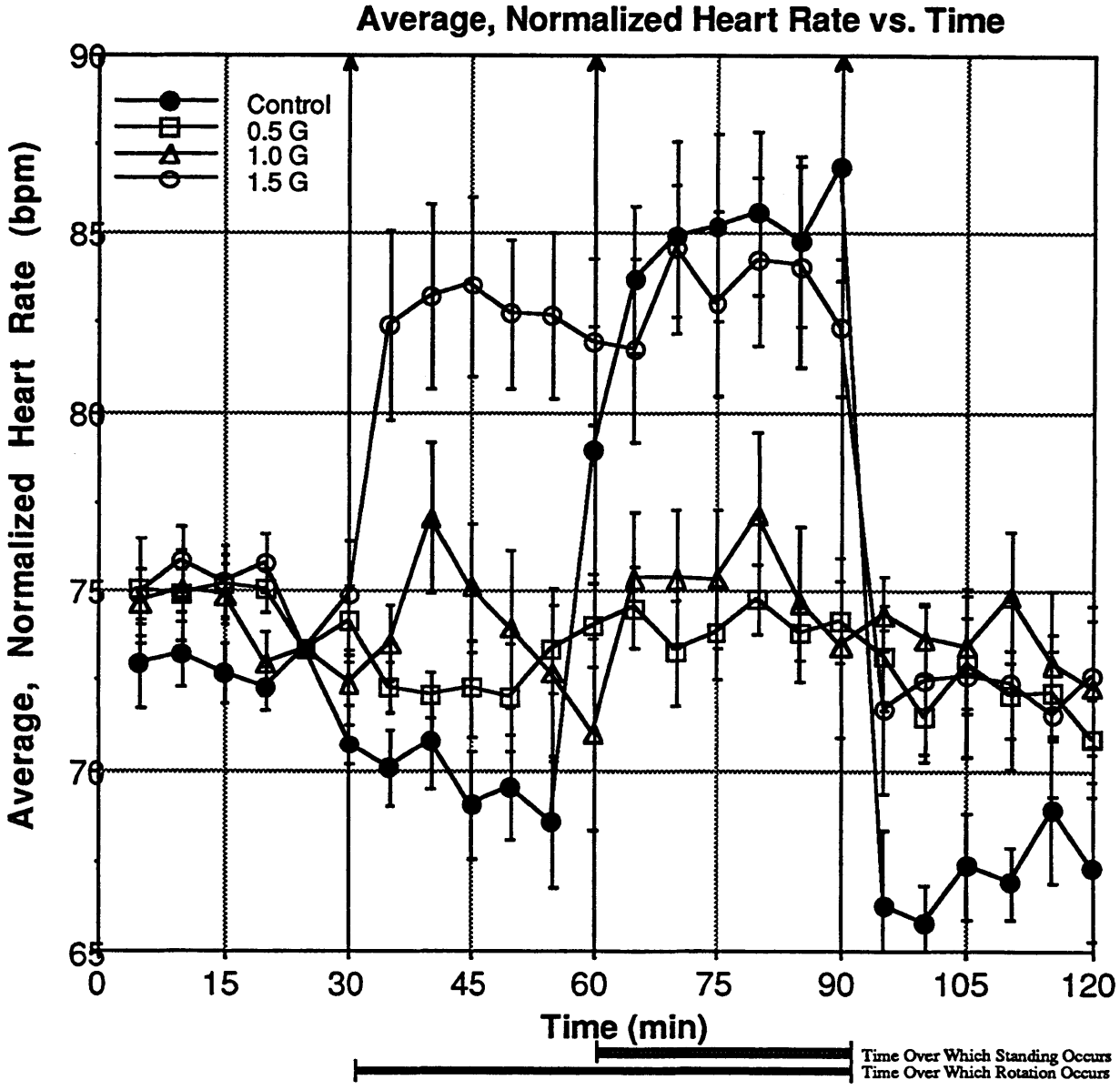


Figure 20. Heart Rate Profiles.
Each data point represents heart rate averaged over the previous 5 min. Normalization was based on differences from resting values, assumed to occur at approximately 25 min. Note that the stimulus in the G trials begins at 30 min. while standing begins at 60 min. in the control trial. The error bars represent standard error of the mean.

Statistical analysis of heart rate, with the data averaged over 5 min., assessed within-trial and between-trial comparisons. The first statistical test showed that the average (over all four trials) change from $t = 0$ to 25 min. for each subject was statistically not different from 0, but the p value (0.069) suggests that heart rate actually decreased during the initial supine rest period. To determine whether the G levels produced different responses after rotation, times 85 and 55 min. were compared to $t = 25$ min. The p values are shown in Table 15. Heart rates at 0.5 and 1.0 G were similar to each other, and the heart rates at 1.5 G were different from the those in the 0.5 and 1.0 G conditions for both 30 min. and one hour of rotation. The first half hour of rotation in the G trials was compared to the second half hour of the control trial to determine if the changes in HR were different from what would occurred had supine rest continued. Table 15 shows that 30 min. of rotation at 0.5 or 1.0 G was similar to continued rest. 1.5 G was different from continued supine rest. The most important statistical comparison in Table 15 is that between the first half hour of rotation in the G trials and standing in the control. 1.5 G and standing were found to statistically similar, and standing was found to be different from 30 min. of rotation at 0.5 and 1.0 G. When comparing the transient responses, going from rest to stimulus or vice versa, the recurrent trends were again observed. Standing in the control produced a response similar to 1.5 G, both of which were different from the other two G levels. 0.5 and 1.0 G were statistically similar. The final comparison in Table 15 shows that heart rate did not change differently for any of the trials in the last 30 min.

Table 15. p Values for Heart Rate Comparisons Between the Trials
* = statistical significance, CH1 = 55 for the control trial and CH1 = 25 for the G trials, CH2 = 65 for the control trial and CH2 = 35 for the G trials, C = control trial, † implies $n = 7$, †† implies $n = 6$

	Time Comparison (min)					
Matched Pair	**CH1 and CH2**	**25 and 85**	**25 and 55**	**(CH2 and 85 in C) with (CH2 and 55 in G trials)**	**85 and 95**	**95 and 120**
Control and 0.5 G	< 0.001*,†		0.096	< 0.001*	0.001*,†	0.200,†
Control and 1.0 G	< 0.001*		0.152	0.001*	0.005*,†	0.080,††
Control and 1.5 G	0.060,†		0.001*,†	0.094,†	0.403,††	0.988,†
0.5 and 1.0 G	0.243,†	0.756	0.840		0.897	0.522,†
0.5 and 1.5 G	0.023*,††	0.011*,†	0.011*,†		0.005*,†	0.157
1.0 and 1.5 G	0.014*,†	0.006*,†	0.015*,†		0.002*,†	0.221,†

Within-trial comparisons for heart rate were performed as well. Table 16 shows the p values for the time comparisons. Interestingly, no changes in HR during the 0.5 and 1.0 G trials were significant. As seen in Table 16, HR changed significantly over the second half hour in the control. The increase in HR caused by standing more than made up for the drop since the HR at $t = 65$ min. was statistically different from that at 25 min. 1.5 G was the only rotation trial that

produced a significant change in HR from resting during the stimulus. All of the G trials produced HR's close to resting immediately after rotation, and the HR's did not change significantly over the last supine period. With respect to transitions, only standing in the control and rotation at 1.5 G produced immediate changes that were statistically significant.

Table 16. *p* Values for Heart Rate Comparisons Within the Trials
sig. diff. = significantly different, * = statistical significance, CH1 = 55 for the control trial and CH1 = 25 for the G trials, CH2 = 65 for the control trial and CH2 = 35 for the G trials, † implies $n = 7$

Time Comparison (min)	Control	0.5 G	1.0 G	1.5 G	Purpose of Test
25 and 55	0.032*	0.999	0.680	0.007*,†	to see if any sig. diff. from resting
25 and 85	0.002*	0.572	0.575	0.009*,†	to see if any sig. diff. from resting
CH1 and 95		0.871	0.382	0.481	to see if any sig. diff. from resting
CH1 and 120		0.065	0.592,†	0.730	to see if any sig. diff. from resting
CH1 and CH2	< 0.001*	0.190,†	0.885	0.014*,†	to see if transient response to stimulus start was sig.
CH2 and 85	0.581	0.284,†	0.607	0.445,†	to see if any sig. change from start to end of stimulus
85 and 95	0.003*,†	0.535	0.913	0.005*,†	to see if change immediately after stimulus ends was sig.
95 and 120	0.640,†	0.146	0.369,†	0.461	to see if change over last supine period was sig.

Summary

Table 17. *p* Values for Comparisons
The time ranges shown are those for which the differences in cardiac parameters were compared. At the 5% significance level, it can be seen that the 0.5 and 1.0 G trials were generally not different from supine rest. Rotation at 1.5 G and standing in the control were similar. * = statistical significance † n = 7 †† n = 6

Comparison I	C Rest/0.5 G	C Rest/1.0 G	C Rest/1.5 G
Heart Rate: 25-55 min.	0.096	0.152	0.001*,†
Systolic Blood Pressure: 25-55 min.	0.878	0.799	0.393
Diastolic Blood Pressure: 25-55 min.	0.358	0.082	0.037*
Calf Impedance: 30-60 min.	0.001*,†	0.001*	0.001*
Comparison II	**C Standing/0.5 G**	**C Standing/1.0 G**	**C Standing/1.5 G**
Heart Rate: 25-55 min. G's, 55-85 min. Control	< 0.001*	0.001*	0.094,†
SP: G's 25-55 min., 55-85 min. Control	0.888	0.845	0.778
DP: G's 25-55 min., 55-85 min. Control	0.005*	0.011*	0.067
Calf Impedance: 30-60 min.	0.003*,††	0.033*,†	0.459,†
Comparison III	**0.5 G/1.0 G**	**0.5 G/1.5 G**	**1.0 G/1.5 G**
Heart Rate: 25-85 min.	0.756	0.011*,†	0.006*,†
Systolic Blood Pressure: 25-85 min.	0.484	0.553	0.938
Diastolic Blood Pressure: 25-85 min.	0.458	0.019*	0.020*
Calf Impedance: 20-90 min.	0.064†	0.002*,†	0.002*

Table 17 summarizes the p values for primary comparisons I, II, and III for heart rate, calf impedance, and blood pressures. (In the remainder of this document, these comparisons will be referred to by their corresponding Roman numeral.) Changes in SP were not significantly dissimilar for any of the trials. Rotation at 1.5 G was similar to standing when the gross responses over 30 min. were compared (comparison II) for the other CV parameters. 1.5 G was significantly different from supine rest (I). The other two G levels were different from standing (II) but similar to supine rest (I), with the exception of calf impedance. Calf impedance in all of the G trials was significantly different from supine rest (I). The final comparison (III) shows that the lower two G levels were similar to each other and different from 1.5 G.

DISCUSSION

Major Findings

The results repeatedly affirm several conclusions. First, standing in the control and rotation at 1.5 G were similar. Second, rotation at 0.5 and 1.0 G were not significantly different from continued supine rest. These two conclusions were based on comparisons made over 30 min. periods only. Finally, one hour of rotation at 0.5 or 1.0 G produced CV responses that were significantly different from those induced by 1.5 G.

The blood pressure curves showed that pulse pressure was significantly decreased in the standing and 1.5 G cases due to an increase in diastolic pressure. A significant change was not observed for the 0.5 and 1.0 G cases. For all trials, no major change in systolic pressure was seen (comparison I). (The reader should be reminded that references are being made to systolic values at the end of 30 min. or one hour, not the transient response.) The p values also showed that diastolic pressures for 0.5 G and 1.0 G were similar (III) and diastolic pressures for 1.5 G and standing were similar (II). These two groups were dissimilar to each other. The changes in blood pressure were undoubtedly a result of sympathetic activation of the cardiovascular system. The degree of activation was proportional to the level of stimulus. It can be seen in Figure 16 that the diastolic pressure continuously increased during rotation ($p = 0.002$ for the comparison between times 30 and 85 min. for 1.5 G). Also, it should be pointed out that pulse pressure did not show statistically significant differences at every time interval that DP did because of insignificant variations in systolic pressure and because PP is a derived quantity, hence its standard deviation is higher.

Heart rate decreased during supine rest, as evidenced by the first 60 min. of the control trial in Figure 20. The p values in Table 17 indicate that the changes in heart rate during the 0.5 and 1.0

G trials were not different from supine rest (I) but were different from the 1.5 G trial (III) and standing (II). A large, sustained increase in heart rate, comparable to that for standing, was observed for the 1.5 G trial. These elevations in heart rate are a typical baroreflex response to a change in the pressure gradient along the body's z-axis.

The changes in blood pressure and heart rate indicate that the body was trying to maintain a constant cardiac output for standing and the high G levels in this study. Rotation and standing increase the mean arterial pressure compared to the supine state. This increase in mean arterial pressure is produced by an increase in diastolic pressure. Since the diastolic pressure increases and systolic pressure remains relatively the same, pulse pressure decreases. Through Equation 6, stroke volume decreases as a consequence. The decreased SV and increased HR combine via Equation 5 to keep CO relatively constant. Thus, it is not surprising that systolic blood pressure experienced no significant changes.

Figures 15a-c indicate that calf impedance and volume were inversely related with a linear correlation coefficient of approximately -0.70. The correlation was not expected to be perfectly linear because the data is empirical. In addition, the actual relationship between calf volume and impedance may not be perfectly linear. Tissue inhomogeneity and inter-subject variabilities certainly argue for some nonlinear component. Qualitative inferences regarding whether volume is increasing or decreasing can certainly be derived from the continuous impedance measurements. As shown in Figure 13, the control trial attests that continued supine rest increased impedance (decreased volume). For the 0.5 G trial, impedance actually increased during one hour of rotation, and the volume data support this finding. The other G trials and the standing in the control displayed an opposite effect, namely that impedance decreased (volume increased) during the stimulus. The latter was the expected effect of a $+G_z$ force. The decrease in volume during the 0.5 G trial suggests that the effects of being supine outweighed the effects of the G force at this level. The *p* values in Table 17 indicate that the calf impedances caused by rotation producing 0.5 and 1.0 G at the feet were significantly different from those that would be produced by continued supine rest (I), 1.5 G (III), and standing (II). This implies that 0.5 G at least attenuated the effects of being supine. The calf impedances produced by 30 min. of 1.5 G at the feet and 30 min. of standing (II) were similar. The plateauing of the impedance curves in the G trials in the last 30 min. of rotation is likely due to sympathetically-activated vasoconstriction.

Careful study of the data reveals the existence of half hour trends for the G levels. As seen in Figure 13, for both 0.5 and 1.0 G, the average normalized impedance decreased in the first half hour and increased in the last half hour. For the lower G level, the combination over one hour resulted in a net increase in calf impedance. Impedance in the 1.5 G trial changed at a slower rate during the second half hour. It can be assumed that actual calf volume is changing inversely with these impedance changes. Eliciting similar trends from the blood pressure data is difficult.

Observations can be made from Figure 18, though. Heart rate for the 0.5 G trial continued to decrease for most of the first half hour. An elevation occurred over the last half hour. The heart rate responses to 1.0 and 1.5 G showed the increase-decrease-increase trend described previously. The transition from decreasing to increasing HR appeared to occur at approximately 30 min. The mechanism for the 30 min. trends is not entirely clear. The sustained pooling of blood in the legs may finally require additional cardiovascular regulation after 30 min. This would explain the increase in HR and decreasing rate of volume shift to the legs. However, it would not explain a volume decrease during the last 30 min. at the lower G levels. Again, this may be due to the additional cardiovascular effects caused by supine posture.

While it was unexpected that the effects of being supine would outweigh the effects of the 0.5 G level for calf volume, it was expected that 0.5 and 1.0 G at the feet would not produce a response similar to standing. Not until the G level is increased to 1.5 do the legs experience at least 1 G over most of their length. As can be seen in Figure 2, with 1.5 G at the feet the pressure over the lower portion of the body nears that due to standing. With a slightly increased mean arterial pressure, as occurs during SAC rotation, the pressures will be very similar for the two orthostatic stressors. The implication is that 1 G over most of the legs, or something that produces a pressure gradient over the lower body similar to standing, is required to achieve significant cardiovascular regulation using a SAC. The idea that hypergravity on a SAC may be required to prevent space deconditioning has been promoted by other authors as well (Burton 1989). However, this finding may not be true for subjects undergoing bed rest.

Additional Findings

The correlations between changes in CV parameters and subject biometric characteristics, as well as resting CV values, shown in Table 6 do not display consistency across the trials. It is primarily for this reason that the correlations are considered to be of negligible importance. For instance, it is highly unlikely that changes in SP could be correlated with mass for only one G trial, especially since no significant changes in SP were observed during the trial. It is reasonable that a mass, height, or age correlation might exist with some of these parameters, but the small number of subjects in the present experiment may prevent the appearance of a solid correlation across all trials. Other experimenters have observed correlations between CV changes due to standing and age (Frey, et al. 1994a; Smith, et al. 1994) and height (Smith et al. 1994). However, Breit, et al. (1996) discovered no height correlation in their orthostatic stressor experiment. One correlation shown in Table 6 is logical, that of mass and the average change in impedance during supine rest. This seems valid because the average resting volume, which is related to impedance, is correlated to mass. Also, few significant gender correlations were observed in the present experiment. Frey,

et al. (1994a) has reported gender correlations with CV changes due to 10 min. of standing, but Breit, et al. (1996) observed none. Again, the lack of a significant correlation here may be due to the small number of subjects.

Several deviations in the impedance and volume data should be discussed. The two subjects who showed a greater decrease in calf volume at 1.0 G than at 0.5 G were anomalous. The findings conflict with the impedance data for the same subjects. Most likely, measurement limitations are being observed. The impedance data for the control trial of subject H, shown in Appendix E, appears erroneous. The electrode tape becoming detached is the most probable cause.

Transient changes in the impedance curves corresponding to the onset or end of a stimulus, as shown in Figure 13, were assumed here to be due to nearly immediate changes in volume caused by transfer of blood from above the calves. This issue is controversial. Smith, et al. (1994) claim such impedance shifts are due to blood transferal but Montgomery (1997) has suggested they may be the result of changes in interstitial fluid location in the area.

The lack of any motor coordination or vestibular-induced side effects following each trial suggests that a half hour of supine rest following each stimulation period was sufficient for recovery. Had a final rest period not occurred, subjects may very well have reported vestibular-induced motion sickness phenomena. The discomfort in the legs during the 1.5 G trials was probably due to the pooling of fluid in the legs at this G level. In addition, the large centrifugal force required subjects to remain with their knees locked. Otherwise, the large force would have pushed their entire body towards the foot plate. Indeed, in the 1.5 G case, as opposed to the other G levels, subjects felt more like they were actively standing.

Some of the experimental data, heart rate for instance, have rather large standard deviations. It has been suggested that this is a result of combining male and female subjects for the statistics and not performing the experiments at the same time of day for each subject (Vernikos 1997). Since no major gender differences were found, the variation may also be due to a disparate level of alertness among the subjects. In some cases it was hard to keep the subjects awake. Often, a subject's alertness varied during the course of a trial. The claim that time of day may have affected the results could have merit, but the subjects were taken from a student population, which tends to display inconsistent diurnal rhythms.

In addition to the eight subjects presented here, two additional female subjects were disqualified from the protocol after failing to complete the control session. In both cases, orthostatic intolerance, in one case leading to vasovagal syncope, became apparent after approximately 15 min. of standing. The response was likely due to insufficient sympathetic activation precipitated by an extended period of being supine. Dehydration may have also been a complication in the syncope case. While these events were unfortunate, 10% (Smith, et al. 1994),

or more according to some researchers (Vernikos, 1997), of the population will exhibit poor orthostatic tolerance to periods of standing longer than 15 min.

Significance of Findings

The results of this experiment should be compared to those of Cardús's experiment (1993a, 1993b) mentioned previously. He also found no major change in systolic blood pressure. The diastolic increase seen in the present experiment was more pronounced than that seen in his and showed a definite relationship with G level. In contrast to the present experiment, Figure 3 shows that HR decreased continuously in the 0.5 G trial in Cardús's experiment. The same increase-decrease-increase trend was observed for 1.0 and 1.5 G, but Cardús's experiment had HR's that were similar in magnitude for these two G levels. His exponential increase in TFI at the two higher G levels corresponds to the exponential decrease in calf impedance observed in this experiment. Combined, the two studies show that fluid is leaving the thoracic and abdominal cavities exponentially to enter the legs. Overall, his experiment presented a larger CV response to 1.0 G. The result differences may be explained by different normalization procedures, subject population, and method of calculating the G level. Cardús normalized his data proportionally while the present experiment utilized normalization based on differences for HR and BP. Although no significant gender differences were observed, the present experiment employed more subjects, half of which were women. Finally, Cardús maintained the same rotation rate for all subjects whereas the rotation rate that would produce the correct G level at the feet was chosen for each subject here.

Additionally, it should be noted that the observed CV effects due to standing after a period of supine rest have been reported by other authors. Smith, et al. (1970, 1994) also observed increases in DP, PP, and HR as a result of standing. This fact, in addition to the similarities in responses due to rotation with Cardús's investigation, lends validity to the present data.

The author disputes the opinion of Breit, et al. (1996) that SAC rotation may not be sufficient to promote baroreflex stimulation because the pressure change produced in the upper body is minimal. Their study only rotated subjects for 30 s at the different G levels, rotation did not stop between the G levels (thus causing interaction affects in the results), and they only explored G levels at the feet of 1 and below. Rotation for only 30 s is insufficient to determine the effects of rotation on a SAC as a countermeasure and brings vestibular interactions into play, as the authors mentioned. The longer rotation time investigated in the present study clearly shows that rotation times on the order of 30 min. are required to induce sufficient cardiovascular regulation for resting subjects. Increases in heart rate and mean arterial pressure were observed here. Rotation on a SAC does not produce a large transient response, as compared to LBNP for instance, because

1) no large pressure change is present over the upper portion of body (to cause a large initial baroreflex response) and 2) it takes a while for the blood pooling in the legs to severely inhibit venous return to the heart. Still, a longer rotation time, perhaps somewhere between 30 and 60 min., should be sufficient to maintain the CV mechanisms that prevent orthostatic intolerance. With a longer rotation time, baroreflexes are stimulated when venous pooling causes a reduction in systemic arterial pressure provoked by a reduced cardiac filling pressure. Most importantly, since standing intermittently during bed rest trials has been shown to decrease orthostatic intolerance and rotation at 1.5 G was found here to be similar to standing, short-arm centrifugation should clearly be considered as a possible countermeasure to cardiovascular space deconditioning.

While significant results were obtained from the present study, it was not without limitations. First, factors such as diet, fluid intake (correlation to responses to standing shown by Frey, et al. (1994b)), sleep-wake cycles, quality and quantity of sleep, drugs, and menstrual cycles could not be controlled. Although, it should be mentioned that these variables cannot easily be controlled with astronauts either. Second, the target astronaut pool is between the ages of 28 and 63. All the subjects utilized here were younger than this range and may not have the same physiological responses as older people. In addition, blood pressure measurements may not have been entirely accurate in some cases when subjects reported that the cuff slipped down their arm (due to the centrifugal force) and they had to pull it up without the experimenter's assistance. Muscle movement during impedance and circumference measurements tended to confound results. In a few cases, taking the circumference measurements caused the impedance to shift to a different curve. In addition, it should be mentioned that subject movement during the stand test, although slight, was difficult to control. The magnitudes of volume shifts and pressure changes can be affected by muscle activity (Blomqvist and Stone 1983). Also, the volume shifts during the 1.5 G trial were so large that subjects noted visual changes in the size of their calves. The tape electrodes near the top of the calves were tight enough by the end of the experiment to visibly indent the calves in most subjects. This tightness may have hindered further volume shift to the lower legs. Finally, the reader should also be reminded that the subjects actually experienced hypergravity during all rotations and were not subjected to -6° head-down tilt (to approximate the deconditioning effects of weightlessness). Despite these limitations, it should not be forgotten that significant results were obtained across all CV parameters.

CONCLUSION

Summary

Calf impedance, calf volume, blood pressure, and heart rate were measured from eight subjects during one hour rotations on a SAC with 0.5, 1.0, and 1.5 G at the feet. The changes in cardiovascular parameters were compared to pre- and post-rotation supine periods, continued supine rest, and standing. Post-trial analysis explored the relationship between rotation time, G level, biometric characteristics of the subjects, and the cardiovascular parameters measured. Most measured cardiac parameters suggest that rotation levels causing 1.0 G at the feet or less produced regulatory responses not significantly different from continued supine rest in normal subjects. In addition, the cardiovascular responses to SAC rotation with 1.5 G at the feet were statistically similar to standing, at least for a comparison based on 30 min. The results imply that for normal subjects hypergravity may be required to prevent deconditioning in space. On the other hand, while few significant changes were observed for the lower G levels in these normal subjects, the same may not be true for bed rest subjects.

Since standing intermittently during bed rest trials has been shown to decrease orthostatic intolerance and rotation at 1.5 G was determined to be similar to standing, the results demonstrate the efficacy of short-arm centrifugation as a possible countermeasure to the cardiovascular deconditioning that occurs in space. Determining how a force gradient affects the cardiovascular system will enable future researchers to more precisely outline SAC studies necessary on individuals undergoing bed rest treatment. The hope is that a SAC may someday be used in space to keep the cardiovascular system stimulated and minimize orthostatic intolerance.

Suggested Future Research

Additional research could also performed with the data acquired for this experiment. The instantaneous change in calf impedance is available, recorded from the impedance cardiograph. This data could be used to make conjectures about blood flow rates during the trials. The effects of the G gradient on the CV parameters could be determined by comparing the data to that caused by a long-arm centrifuge, namely to answer question 10 in Table 2. In turn, these results could be compared to the effects of rotation on a centrifuge 3 m in length, which still has a G gradient although it is less than 100%. Thus, the effects of different G gradients could be determined.

With respect to cardiovascular research on the AGS, an obvious next step would be to add a mechanism for exercise while rotating. Pedaling (as on a bicycle) or deep knee bends are possibilities. After all, passive exposure to a gravity field will not counteract all of the effects of

SAS. Undoubtedly, exercise will alter the cardiovascular responses enough to reduce the required rotating time and perhaps lower the required G level to prevent deconditioning.

Computer modeling of the cardiovascular system on a SAC is a logical next step as well. Only one computer modeling study of humans on centrifuges has been conducted (Pancratz, et al. 1994). The details of the study, performed by the Biodynamic Research Corporation (BRC), are listed in Appendix A. Computer modeling research is critical because it provides a cost effective method to rule out centrifuge use scenarios and determine what actual trials should be performed. The method is also favored because it can estimate the differences between the physiological effects of ground- and space-based centrifuges. The data acquired in this study could be utilized to validate a computer model.

A bed rest study in which subjects experience -6° head-down tilt and undergo intermittent SAC rotation is suggested as an important follow-up to the present investigation. The author suggests rotation periods on the order of 30 min. With respect to how many times per day, not enough information is provided by the present experiment to make a recommendation. Certainly, several studies should be conducted which examine at this effect and how it varies with biometric characteristics.

On a more global research scale, the author feels that six categories of research are needed to answer the questions posed in Table 2: 1) computer modeling, 2) studies of simulated microgravity by bed rest or water immersion, 3) short-arm centrifuge studies, 4) long-arm centrifuge studies, 5) rotating room studies, and 6) experiments in space. Presumably, these levels would be carried out in the specified order, but certain aspects, such as adaptation research, do not require completion of research at the previous level. A detailed outline of this research strategy is presented in Appendix J. The discussion includes a recommendation for a trip to Mars using a SAC.

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APPENDIX A

Previous Studies Related to Artificial Gravity

Year	Researcher(s)	Number of Subjects	Experimental Conditions	Results
			Computer Centrifuge Modeling	
1994	Pancratz, David J., John B. Bomar, and James H. Raddin		2 m centrifuge with subject's head at 1 m, used dynamic mathematical models of the vestibular and the cardiovascular system	- predicts static pressure of cardiovascular system on space centrifuge will be similar to that of centrifuge riders on earth
			1 G Requirements to Maintain Conditioning	
1963-1964	Birkhead, N.C., et al.	6	bed rest for 24-42 days with 30 min. twice daily of upright bicycle exercise at 600 kpm/min.	- maintained aerobic capacity - did not prevent tilt intolerance or increased urinary calcium loss
1964	Birkhead, N.C., et al.	4	bed rest with 4 hours twice daily of quiet sitting	- resulted in minor decreases in maximal oxygen uptake - had no effect on urinary calcium loss - reduced tilt intolerance
1966	Birkhead, N.C., et al.	5	quiet standing for 3 hours daily during 18-24 days of bed rest	- reduced increased urinary calcium excretion to ambulatory levels - reduced tilt intolerance
1992	A.C. Ertl, A.S. Dearborn, and J. Vernikos	8	4 days -7° head-down bed rest interrupted by 15 min. of standing or walking to total 2 or 4 hours/day	- the stimulation attenuated but did not prevent decrease in maximal oxygen uptake
1992	C.E. Wade, J. Vernikos, J. Evans, and D. Ohara	9	4 hours of -6° head-down bed rest interrupted by 15 min. standing or moderate upright exercise at end of each hour	- standing or moderate upright exercise negated the decrease in aldosterone and plasma neurohormone levels due to head-down bed rest
1994	Vernikos, Joan and David A. Ludwig	9	4 days of -6° head-down bed rest interrupted by 15 min. standing 8 times daily (2 hours total)	- partially prevented orthostatic intolerance - had no effect on plasma volume loss or urinary calcium excretion - partially effective in preventing decrease in maximal oxygen uptake

1994	Vernikos, Joan and David A. Ludwig	9	4 days of -6° head-down bed rest interrupted by 15 standing 16 times daily (4 hours total)	- totally prevented orthostatic intolerance - prevented plasma volume loss - attenuated decrease in maximal oxygen uptake - had no effect on urinary calcium excretion
1994	Vernikos, Joan and David A. Ludwig	9	4 days of -6° head-down bed rest interrupted by 15 of walking at 3 mi./hr. 8 times daily (2 hours total)	- barely helped orthostatic intolerance - had no effect on plasma volume loss - effective in reducing the decrease in maximal oxygen uptake - prevented excess urinary calcium excretion
1994	Vernikos, Joan and David A. Ludwig	9	4 days of -6° head-down bed rest interrupted by 15 of walking at 3 mi./hr. 16 times daily (4 hours total)	- did not prevent orthostatic intolerance - prevented plasma volume loss and excess urinary calcium excretion - effective in reducing the decrease in maximal oxygen uptake
			Short-Arm Centrifuge (SAC) Studies	
1965	White, W.J., J.W. Nyberg, P.D. White, R.H. Grimes, and L.M. Finney	3	1.1 m-radius centrifuge, 14 days of bed rest, 4 daily 4-G exposures (measured at the foot) of 11.2 min. each.	- totally prevented orthostatic intolerance - reduced increased urinary calcium output by half - eliminated increased urinary phosphorous output - had no effect on plasma volume - 4 G was more effective than 1 G
1965	White, W.J., J.W. Nyberg, P.D. White, R.H. Grimes, and L.M. Finney		1.1 m-radius centrifuge, 20 days bed rest with no countermeasures, testing during 16 days of additional bed rest, periodic 1 G or 4 G exposures with a total of 30 min. daily	- prevented further deconditioning after the 20 days of bed rest - 4 G was more effective than 1 G
1966	White, PD., et al.		2.5 m-radius centrifuge, 4 daily exposures of 7.5 min. each of 7 G (foot level) during 10 days bed rest	- prevented orthostasis - failed to affect weight, plasma volume, and red blood cell loss
1970	Cramer, D.B. and Ashton Graybiel	2	3-m radius partial room, subject suspended horizontally to counteract Earth's gravity and so he could walk on the walls in partial gravity; 1 G exposure accomplished by standing up normally; pre-deconditioning for 7 days by bed rest and dry immersion; after pre-deconditioning, exposure plan: walking at 0.18 G for 2.5 hours/day for 7 days, 3 days bed rest only, 3 days walking at 0.5 G for 1 hour/day, 1 day bed rest	- pre-deconditioning decreased orthostatic tolerance by 50%, walking at 0.18 G increased it by 10-40%, walking at 0.5 G increased it by 20-45% - maximum strength unaffected - exercise tolerance decreased by 50% during pre-deconditioning and did not improve with treatments

1970	Cramer, D.B. and Ashton Graybiel	2	3-m radius partial room, subject suspended horizontally to counteract Earth's gravity and so he could walk on the walls in partial gravity; 1 G exposure accomplished by standing up normally; pre-deconditioning for 7 days by bed rest and dry immersion; after pre-deconditioning, exposure plan: passive 0.18 G for 2.5 hours/daily for 7 days, 1 day bed rest, walking at 0.5 G for 30 min. daily for 3 days, 1 day bed rest, walking in 1 G for 1 hour/day for 3 days, 1 day bed rest	- pre-deconditioning decreased orthostatic tolerance by 40-50%, passive exposure to 0.18 G helped little, walking at 0.5 G helped little, walking at 1 G eliminated orthostasis - passive exposure did not increase orthostatic and exercise tolerance as much as walking at 0.18 G had - maximum strength unaffected - exercise tolerance decreased by 50% during pre-deconditioning and improved only with 1 G walking
1973	Hoche, J. and Ashton Graybiel	8	3-m radius partial room, subject suspended horizontally to counteract Earth's gravity and so he could walk on the walls in partial gravity; 14 days of bed rest interrupted by 4 hours/day of exercise on normal or inclined treadmills at 0.5 G	
1980	Vil-Viliams, I.F. and Ye. B. Shulzhenko	4-6	1.74 m radius of rotation, 1.3, 1.6, or 1.9 G 2-3 times daily for a total of 120 min. with different non-stimulation times in between during 3-day dry immersion	- the time between exposures (simulation 2 or 3 times/day) created a significant difference in the response
1988	Diamandis, Peter	1	2 m-radius rotating bed, 9 nights of sleep at 0-1 G at the feet	- adequate sleep levels were achieved
1992	Burton, R.R. and L.J. Meeker	7	1.5 m-radius centrifuge, tested G tolerances to 1 G/s and 0.1 G/s onset rates on a larger centrifuge and on a SAC	- cardiovascular reflexes useful in maintaining orthostatic tolerance were stimulated - 2 G's more can be sustained with a 0.1 G/s onset rate than a 1 G/s onset rate on the SAC - elevating the feet by having the person bring their knees to their chest increases the 0.1 G/s onset rate tolerance by 1 G
1992	Shulzhenko, E.B and I.F. Vil-Viliams	5-6	2 m-radius centrifuge, 40-60 min. blocks 2-3 times daily of 1.3, 1.6, or 1.9 G during 3-day dry immersion rest, orthostatic intolerance to 3 G was tested before and after on a 7.25 m-radius centrifuge for 5 min.	- control study of 3 days of dry immersion caused decrease in orthostatic tolerance of 21% - exposure to 1.3, 1.6, or 1.9 G periodically during same test caused decrease in orthostatic tolerance of 18%, 7%, and 1%, respectively
1992	Shulzhenko, E.B and I.F. Vil-Viliams	6	2 m-radius centrifuge, 40-60 min. blocks 2-3 times daily of 1.3 or 1.6 G during 3-day dry immersion rest, water and salt supplements were an added countermeasure, orthostatic intolerance to 3 G was tested before and after on a 7.25 m-radius centrifuge for 5 min.	- control study of 3 days of dry immersion caused decrease in orthostatic tolerance of 21% - exposure to 1.3 or 1.6 G periodically with water and salt supplements during same test caused decrease in orthostatic tolerance of 13% and 4%, respectively

1992	Shulzhenko, E.B and I.F. Vil-Viliams	4	2 m-radius centrifuge; time profile: 7 days of no-exposure dry immersion rest, 40-60 min. blocks 2-3 times daily of 1.3, 1.6, or 1.9 G during next 7 days , supine bicycle ergometer training periodically during next 7 days, during next 7 days SAC rotation for 60 min. twice daily during which 600 kpm/min. of bicycle exercise was performed for ten min. three times; orthostatic intolerance to 3 G was tested before and after on a 7.25 m-radius centrifuge for 5 min.	- after first 7 days, orthostatic tolerance had decreased by 56% - after the 28 trial period, orthostatic tolerance was 8% less than normal
1995	Greenleaf, J.E., et al.	7	1.8 m-radius pedal-powered centrifuge, subjects blindfolded, protocol of 1 G for 2 min., 2 min. rest, 2 G for 2 min., 2 min. rest, max. acceleration for 2 min., rest, 25% of max. rpm for 2 min., rest, 50% of max. acceleration for 2 min., rest, 75% of max. acceleration for 2 min.	
			Long-Arm Centrifuge (LAC) Studies	
1959	Clark, C.C. and J.D. Hardy	1	rotated for 24 hours at 2 G	- only adverse symptom was "anesthesia sensation" in one hand that resolved in 2 months - exhibited positive fluid balance and doubled white blood cell count
1971	Green, J.A., J.L. Peacock, and A.P. Holm	4	crew module 3 m by 12 m located at 22 m and freely aligned with resultant force vector, experienced 4 rpm for 12 days	- adaptation and recovery occurred within two days - little motion sickness
			Rotating Room Studies	
1960	Graybiel, Ashton, Brant Clark, and J.J. Zarriello	6	room was 4.6 m in diameter and 2.1 m high, 2 day exposures at either 1.71, 2.22, 3.82, 5.44, or 10 rpm	- mild nausea was felt at the first three rotation levels - the two highest rotation levels were highly stressful; nausea and extreme fatigue were observed - one control subject, who had lost vestibular function, only experienced problems with walking - most subjects adapted with the 2 days - readaptation was seen after cessation of rotation

1965	Graybiel, et al.	4	10 rpm for 12 days, room was 4.6 m in diameter and 2.1 m high	- onboard observer was experienced rider and required little time to adapt (no nausea) when moving into and out of the rotating environment - subjects were extremely motion sick during the first few days - none of the subjects had fully adapted to the environment by the end of 12 days - lethargy and fatigue were observed - cessation of rotation was less traumatic than the onset - it was unclear which effects were due to rotation and which were due to confinement - subjects all felt unfit to carry out duties of astronauts during experiment
1965	Bergstedt, M.		attempted to adapt subjects to 10 rpm by incrementally increasing the rotation rate, 2 studies tried three incremental steps over 3 days	- subjects did not adapt
1965	Bergstedt, M.		attempted to adapt subjects to 10 rpm by incrementally increasing the rotation rate, 40 incremental steps over 40 hours	- subjects did not adapt
1969	Graybiel, Ashton, F. Robert Deane, and James K. Colehour	4	room was 6 m in diameter and 3 m high, attempted to adapt subjects to 10 rpm by incrementally increasing the rotation rate, total rotation time lasted 25 days; started rotating at 2 rpm, every 2 days rotation rate was increased by 1 rpm until 10 rpm reached, 9 days total of 10 rpm exposure were completed	- no motion sickness in subjects observed and the subjects adapted - lethargy observed - onboard experimenter who alternated between rotating and non-rotating environments did experience motion sickness
1971	Graybiel, Ashton	3	room was 6 m in diameter and 3 m high, attempted to adapt subjects to 10 rpm by incrementally increasing the rotation rate, reached 10 rpm over 2 days through increases by 1 rpm, at each rotation rate change subjects were required to make 1000 head movements	- 2 subjects experienced no side effects - 1 was nauseated and lethargic

Space-Based Research

1975	Shipov, A.A., et al.		turtles on Cosmos-782 were spun at 0.3 G for 19.5 days on a 0.32 m arm	- no muscular changes were observed as being different from ground controls
1977	Gazenko, O.G., Ye. A. Il'in, V.S. Oganov and L.V. Serova; Gurovsky, N.N., et al.		rats on Cosmos-936 were spun on a 0.32 m arm to achieve 1 G in space for 18.5 days	- except for a depression of brain metabolism, semicircular canal stimulation, and a radial bone growth deficiency, the rats were protected from all physiological responses to spaceflight experienced by the control group on the biosatellite

Appendix B

COUHES Application, Subject Consent Form, and Subject Selection Questionnaire

Application Number 2318

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Committee on the Use of Humans as Experimental Subjects

Application for Approval to Use Humans as Experimental Subjects

PART I. **DATE:** 5/7/96

Title of Study: The Effect of Short-Arm Centrifugation on Human Performance and Physiology

Principal investigator: Professor Laurence Young

Department: Aeronautics & Astronautics

Room No.: 37-219

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Associated Investigators :

Dawn Hastreiter	253-7509
Anna Tomassini	253-7509

Collaborating Institution(s), if applicable: none

Financial Support: NASA Grant NAGW-3958 Visual-Vestibular Interaction

Purpose of Study: The investigation is divided into two components: human performance and human physiology. Please see the following pages for discussions of the purposes of each of the components.

The Effects of Short-Arm Centrifugation on the Cardiovascular System

Purpose of Study

Exposure to microgravity causes significant physiological changes. One of the proposed mechanisms for countering these affects for long-duration missions is artificial gravity in space. Proposals include spinning the entire spacecraft or incorporating a short-arm centrifuge (SAC) into the spacecraft. Short-arm centrifugation in a non-rotating craft may ease some engineering and astrodynamic requirements. Before a SAC could be tested in space, a significant number of ground studies must be conducted to determine the effects of a gravity gradient both on a normal person and individuals undergoing treatment, such as bed rest, that produces similar physiological microgravity effects.

This study focuses on determining several of the cardiovascular effects of a gravity gradient on a normal person. Two contemporary investigations have recently been performed. Cardús (1993) performed a study on six men with measurements of general cardiovascular signals for one hour durations on a device similar to the MIT-Artificial Gravity Simulator (AGS), a short-arm centrifuge. He found that few changes were seen for G levels below 1 at the feet. Cardiovascular trends did change in the range 1-1.5 G at the feet. Above 1.5 G, cardiovascular changes became more dramatic with 2 G at the feet being near the safe physiological limit. Researchers at NASA's Ames Research Center (Breit, et al. 1996) also conducted a study on men and women to compare the effects of short-arm centrifugation, long-arm centrifugation, whole-body tilting, and lower body negative pressure on blood flow rates and baroreceptor stimulation. Their investigation was limited to G levels of 1 and below at the feet. Confirming Cardús's earlier study, few significant overall cardiovascular changes were seen below 1 G at the feet. Some baroreceptor stimulation did occur.

The purpose of this study is to extend the work of the previous researchers. Heart rate variability, heart rate, ECG signals, fluid shift to the legs, and blood pressure will be assessed in men and women for G levels at the feet up to 1.5. Determining how a gravity gradient affects the cardiovascular system will enable future researchers to more precisely outline studies necessary on individuals undergoing bed rest treatments as models for spaceflight deconditioning.

The Effect of Coriolis Forces on the Human Performance of Two-Handed Tasks While in a Rotating Environment

Purpose of Study

One of the proposed means of preventing physiological deconditioning during long-term space missions, such as traveling to Mars, is to create artificial gravity by rotating the spacecraft. However, while artificial gravity may help prevent the physiological problems induced by microgravity, the unfamiliar gravity gradients and Coriolis forces which result cause problems with motions attempted in the rotating environment (Loret, 1963; Stone, 1970; Ramsey, 1971; Lackner, 1993). Ever since the idea of rotating space vehicles evolved, studies have been conducted on the effects of artificial gravity on human performance. The studies conducted at the Pensacola Slow Rotation Room consisted of various tests to assess human performance while in a rotating environment, however, the researchers were mainly concerned with the effects on the vestibular system and the brain-stem activating system (Graybiel, Clark, and Zarriello, 1960; Clark and Graybiel, 1961; Kennedy and Graybiel, 1962; Graybiel et al., 1965; Guedry, 1962). In addition, the subjects were not oriented as they would be in an artificial gravity environment. Studies conducted by the North American Rockwell Corporation and Langley Research Center were in simulators where the subjects were rotated about an axis perpendicular to their body axis, as if in a rotating space vehicle (Stone and Letko, 1962(1), 1962(2), 1964; Piland et al., 1970; Green and Peacock 1972). Unfortunately, experiments involving complex two-handed tasks that would be affected by Coriolis forces were not conducted.

The purpose of this portion of the study is to investigate how the Coriolis forces created by rotation affect the subjects' ability to perform motor tasks requiring two-handed hand-eye coordination. The importance of two-handed tasks lies in the different Coriolis forces which must be compensated for when the two hands do not move with identical direction and speed. The motivation is that during long-term missions it is very important for astronauts to still be able to complete their required tasks efficiently while experiencing artificial gravity. Stone and Letko looked at how Coriolis forces affect the performance of simple perceptual motor skills, as did Lackner and DiZio (1994) with their experiments on the ability of subjects to point at targets while rotating. However, neither used complex two-handed tasks, and Lackner and DiZio performed their experiments in Brandeis University's rotating room with subjects in a different orientation to that of an artificial gravity environment.

PART II.

EXPERIMENTAL PROTOCOL

Please see the following comments for the two experimental protocols of the investigation.

Experimental Protocol for Human Physiology Study:

Experimental subjects will be chosen with the aid of the attached selection questionnaire. Volunteers with histories of heart conditions, loss of consciousness, respiratory disorders, and other medical conditions that contraindicate participation will be asked not to participate. Individuals with the above histories may be placed in physical danger during rotation on the MIT-Artificial Gravity Simulator (AGS). Susceptibility to motion sickness should not necessarily eliminate a volunteer for the physiological studies because it is not anticipated to be a major side effect.

The height, weight, and certain characteristic lengths of the subject will be measured. Subject height is necessary to determine what rotation rate will produce a certain G level at the feet. Subject weight will be used to determine if any correlation exists between weight and the results of the experiment. Distance measurements referenced from the top of the head, such as location of the vestibular system and heart, will also be obtained to calculate the force stimulation level of these body systems.

Subjects will be placed supine on the AGS, pictured in Figure 1, such that the top of their head is at the center of rotation. Since the AGS is of such short-radius, subjects experience a 100% z-axis force gradient along their body. All subjects will be rotated up to the experimentation speed with an onset rate no greater than 1 rpm/s. Rotation rate will be such that the equivalent G level in the plane of rotation at the subject's feet will not exceed 1.5 G. 1.5 G at the feet corresponds to a rotation rate of 27.1 rpm and 29.7 rpm for 5-ft. and 6-ft. individuals, respectively. Rotation will last for no more than one hour. For the actual physiological trials, rotation will be preceded by at least a ten minute stationary period with cardiovascular monitoring. Also, at least a fifteen minute monitoring period will be observed after each one hour rotation.

Three cardiovascular measuring devices will be attached to the subject during the protocol: a electrocardiograph (ECG), a blood pressure monitor, and an impedance plethysmograph. The ECG will trace the heart rhythm, which will be studied afterwards for heart rate variability and any abnormalities. ECG leads will be placed near each clavicle and on one side of the abdomen. The leads have an adhesive undersurface and an attempt will be made to place them in hairless areas. Blood pressure and heart rate will be measured every five minutes by an automatic blood pressure cuff placed on the subject's right arm. The impedance plethysmograph to be used will measure the electrical resistance in the calf. Resistance in the calf corresponds to volume in the calf. The impedance plethysmograph requires four circumferential electrodes to be placed on the subject. 4 mA of AC current at 100 kHz is passed through the outer 2 electrodes, and the resistance measurement is taken from the inner two electrodes. The Minnesota Impedance Cardiograph Model 304 B will be used for the impedance plethysmography. The device has been used for approximately 20 years for safe resistance measurements of the body. Circumferential measurements of the calf before and after trials will be used to correlate actual volume change to resistance changes. Circumference measurements will be taken at pre-administered marks on the subject's calf. All leads from the physiological monitoring equipment are attached to slip rings in the shaft of the AGS support rod and terminate at a computer system. In addition, the leads will be well insulated for the safety of the subjects.

After testing equipment on several volunteers, actual experimental trials will begin. The protocol will require at least four sessions with each subject. We anticipate one control session consisting of approximately: one hour of supine rest on the AGS, one half hour of standing, and a final half hour of supine rest on the AGS. The three experimental runs will likely include: one half hour of supine rest on the AGS, one hour of rotation, and a final half hour of supine rest on the

AGS. Three rotation rates are anticipated for each subject, resulting in 0.5, 1.0, and 1.5 G's at the feet. Additional trials at intermediate rotation rates or durations may be requested from subjects. Trials will most likely take place on different days at the subject's convenience. From the long duration physiological measurements at different G levels, investigators hope to discover the time and force dependent cardiovascular effects of a gravity gradient.

In addition to the informed consent form for AGS rotation, experimental trial subjects will receive an outline of the trials with a statement of purpose.

Experimental Protocol for Human Performance Study:

The experiment will be conducted at the MIT Man-Vehicle Laboratory on a rotating platform originally designed in a previous Master's thesis project to investigate sleeping during rotation (Diamandis, 1988). (This project received COUHES approval #1688 in June of 1986.) The platform is 3 ft wide with a radius of 7 ft and has a counterweight at one end. Subjects will be rotated at 10 rpm with their head at the center of rotation. This rotation rate matches that which would be used for a 4m radius vehicle, creating a centripetal force of about 0.5G at the rim, which is a proposed design for a Mars vehicle. The head placement at the center of rotation will help prevent motion sickness.

An experiment hood will be placed above the subjects near eye-level so that they may perform their tasks while lying on the rotating platform with minimal head movement. There are various means of measuring performance, including vigilance, serial reaction, tracking, and memory tasks; however, alertness, speed, accuracy, and short-term memory capacity are considered more reliable measures of the effect of stressors (Boff and Lincoln, 1988). Speed and accuracy will be used in this study as measures of the performance of motor tasks while under the stress of a rotating environment.

Preliminary static tests will be performed to assess the learning curve for the different tasks. Preliminary tests are required since subjects naturally improve in their performance of a certain task logarithmically each time they perform that specific task. Speed and accuracy are increased by fifty percent between the first and second time a task is done. Completion time is again improved by half the previous amount the next time that task is executed, and so on. The purpose of the initial tests is to reach an asymptotic level of performance, which should occur after three to five trials, before conducting the experiments so that the effect of Coriolis forces can be differentiated from any learning process. Two different tasks will be considered: a modified Stromberg Dexterity Test and a modified Bolt Test. The original Stromberg Dexterity Test (Peacock and Green, 1971) required erect subjects to place 54 cylindrical blocks of three different colors into correspondingly colored holes that were on a flat plane in front of them using only one hand. The modified test used in this study will involve having the cylindrical blocks dispersed to the right, left, and in front of the subject while the he switches the order of the blocks using both hands. The performance of this task will be measured by time to completion of the test run. The other task being considered, the Bolt Test (Kennedy, Tolhurst and Graybiel, 1965), involves placing three washers onto a bolt and placing the bolt into a hole. Here the washers and bolts will be picked up from different locations to the left and to the right of the subject, and the finished product will be placed into a hole in front of the subject. Performance for the Bolt Test will also be measured in time to completion of the test run, which involves 30 bolts. Two test runs will be performed for each session of the chosen task. The exact task which will ultimately be performed will be determined during the preliminary learning curve study according to the reliability associated with each task.

The actual experimentation will involve a training session before rotation and test sessions during and after rotation for the task chosen during the preliminary study. Subjects will be loosely strapped onto the platform and a communication check will be made of the headsets prior to spin up. The platform will be gradually accelerated to a constant velocity of 10 rpm over a period of about 30 seconds. Two minutes will elapse before starting the tests in order to allow the subject to get accustomed to the accelerated environment. After completing two runs of the selected task, the platform will be gradually spun down to 0 rpm. Two minutes will again elapse before post-

rotation tests begin, which will be an exact repetition of the test runs performed before and during rotation. In addition, to look at adaptation to the artificial gravity environment, the subjects will be asked to do another set of pre-, per-, and post-rotation test sessions about three days following the initial testing and again five days after the second test session. Subjects will have the ability to stop rotation by pressing a button if so desired at any time, and they will be constantly monitored through a video monitor and audio communication. If the subject should try to sit up during rotation, the two quick-release safety belts would open the same circuit as the subject's emergency button and stop the platform. The emergency cessation of rotation will occur gradually, but at a faster rate than normal spin up or spin down so as to reach 0 rpm in 5 seconds.

PART III. Please answer each question below, and indicate "NA" where not applicable to your application. Positive answers should be briefly explained, with detailed information included in PART II.

1. How will subjects be obtained?
Subjects will be volunteers recruited from the MIT community.

   Number of subjects needed? Preferably, at least 10.

   Age(s) of subjects?
Subjects must be at least 18. Participation will be limited to subjects under the age of forty except for the Principal Investigator and trained astronauts.

2. Will women and minorities be recruited? Yes.
If not, explain why.

3. Will subjects receive any payment or other compensation for participation?

   Subjects who are not members of the Man Vehicle Laboratory will receive compensation.

4. Will your subjects be studied outside MIT premises? No.
If so, please indicate location.

5. Will the facilities of the Clinical Research Center be used? No.
If so, the approval of the CRC Advisory Committee is also required.

6. Will drugs be used? No.
Any Investigational New Drugs (IND)? No.

7. Will radiation or radioactive materials be employed? No.
If so, your study must also be approved by the Committee on Radiation Exposure to Human Subjects. Application forms are available from Mr. Francis X. Masse, Radiation Protection Office, 20C-207, x3-2180.

8. Will special diets be used? If so, please state proposed duration(s).

   Subjects in the physiological studies will be asked to refrain from alcohol and caffeine intake for 24 hours prior to each experimentation period.

9. Will subjects experience physical pain or stress?

   Subjects may possibly feel slight, non painful pressure in their legs due to fluid shift caused by centrifugation. Some subjects may experience a headache due to fluid shift. While they will be instructed not to move their head, motion sickness may result if the subjects do not comply. Claustrophobia may be experienced by some subjects in the human performance study. Subjects can end rotation gradually and safely at any point with an emergency stop switch near their hand position.

10. Will a questionnaire be used? Yes. (Copy is attached.)

11. Are personal interviews involved? No.
If so, include an explanation in Part II and attach an outline.

12. Will subjects experience psychological stress? No.

13. Does this study involve planned deception of subjects? No.

14. Can information acquired through this investigation adversely affect a subject's relationships with other individuals (e.g. employee-supervisor, patient-physician, student-teacher, co-worker, family relationships)? No.

15. Please explain how subject's anonymity will be protected, and/or confidentiality of data will be preserved.

Subjects will be coded. Only the code number will appear in any dissemination of data.

PART IV.

A. ***Please summarize the risks to the individual subject and the benefits, if any;***

include any possible risk of invasion of privacy, embarrassment or exposure of sensitive or confidential data, and explain how you propose to deal with these risks.

1. Headaches, Pressure in the Legs
These possible effects are caused by a fluid shift in the body due to centrifugation. On initial report of a headache from a subject, an investigator will suggest relaxation techniques to relieve the headache. If the headache persists for the longer than 5 minutes, the experiment will stop. The subject also has the option of ending the experiment at any time for any reason. In previous studies of this nature, no subject elimination was reported based on these effects.

2. Nausea/Motion Sickness
Motion sickness is primarily due to sensory conflict. The subject tactually perceives himself as lying on a still bed after an initial period on the bed. Movements of the head and the resulting vestibular stimulation reveal the influence of Coriolis forces due to rotation. The canopy of the AGS is translucent and the subject sees a blurring of external objects during rotation. The consequent sensory conflict may cause nausea. For the physiological studies on the AGS, the subjects will be blindfolded and instructed not to move their head. In both experiments subjects will be told that moving their head may make them nauseous. In addition, the canopy will be covered with an opaque material for the performance studies and subjects will be asked to focus of the experiment hood (which is stationary with respect to them) and their tasks. If the subject reports intolerable motion sickness, the experiment will be stopped. The subject also has the option of ending the experiment at any time for any reason with an emergency switch.

3. Claustrophobia
Subjects in the human performance study may experience claustrophobia due to the placement of the experiment hood. Volunteers with known claustrophobia will be asked to decline participation. The subject has the option to end the experiment at any time.

4. Heart Rate Increase
Previous research has shown that rotation with G levels at the feet between 1 and 1.5 G causes increased heart rate of up to 1.75 times normal supine levels. While the increased

heart rate is no greater than that which would be experienced during aerobic exercise, medical heart conditions unknown to the subject may become evident. The heart rate of the subjects in the physiological studies will be continuously monitored. If heart rate becomes abnormally high, 1.75 times the subject's normal heart rate, the experiment will be stopped. Maximum heart rate for an individual is HR(max)= 220 - age. Subjects will also be monitored for complications for at least 15 minutes after each rotation session in the physiological studies.

5. Injury Related to Falling Off the AGS While Rotating
Serious injury could result from falling off the AGS while it is rotating. The following steps will be taken to prevent such an incident:
a. The subject will be loosely restrained at the legs and thorax, preventing him from making sudden motions or falling off the rotating bed. The restraints will be equipped with quick release latches making it possible for the subject to escape quickly if necessary.
b. Side railings similar to those on a hospital stretcher will be employed to contain the subject.
c. As mentioned previously, the subject will be equipped with an emergency stop switch which will stop the AGS from rotating within approximately 5 seconds.
d. The subject will be continuously monitored by at least one experimenter in the same room.
e. The subject will be equipped with a 2-way headset communication system connected to the observing experimenter.
f. Final human performance measurements will employ a video camera mounted on the AGS which may help the investigator understand the nature of any problems that arise.
g. Finally, subjects will experience a short test ride of several minutes duration after familiarization with the equipment.

6. Skin Irritation
Subjects in the human physiology study will have seven electrodes placed on their bodies. Sufficient electrical contact with the skin requires that electrode gel be placed between the leads and skin. Also, calf volume measurements require marking the leg with a washable marker to ensure consistency of measurements. The application of gel and marker to the skin may cause minor skin irritation. However, the irritation is unlikely to be lasting.

B. ***Detection and reporting of harmful effects:*** If applicable, please describe what follow-up efforts will be made to detect harm to subjects, and how this committee will be kept informed.

All AGS studies involve multiple sessions on different days. Detection of harmful effects during exposure will occur by asking the subjects how they feel after every 15 minutes of rotation and if they wish to continue. Subjects will also have the opportunity to report any harmful effects noticed since the last exposure before commencing the next trial. In addition, all physiological studies involve a 15-30 minute monitoring period after each trial, and the human performance studies involve post-rotation tests. In the event of harmful effects, COUHES will be informed verbally or through written communication, depending on the severity of the situation.

PART V.

INFORMED CONSENT MECHANISMS:
Please send the following attachment.

The committee is mandated by the DHHS and Institute regulations to require documented informed consent. The document should be retained as a permanent record. Under certain circumstances, the committee may waive documentation. The elements of such informed consent are:

1. Consent forms should start with a statement that participation is voluntary and that the subject is free to withdraw his/her consent and to discontinue participation in the project or activity at any time without prejudice to the subject.

2. A fair explanation of the procedures to be followed and their purposes, including identification of any procedures which are experimental.

3. A description of any attendant discomforts and risks reasonably to be expected.

4. A description of any benefits to the subject that are reasonably to be expected.

5. A disclosure of any appropriate alternative procedures that might be advantageous for the subject.

6. An offer on the part of the investigator to answer any inquiries concerning the procedures.

7. There shall be no exculpatory language making the subject waive or seem to waive any rights.

8. In addition, the following statement or a comparable one (in the case of cooperating institutions) shall appear on all informed consent documents, except that in certain cases in non-biomedical disciplines, COUHES may decide that it may be omitted:

"In the unlikely event of physical injury resulting from participation in this research, I understand that medical treatment will be available from the MIT Medical Department, including first aid emergency treatment and follow-up care as needed, and that my insurance carrier may be billed for the cost of such treatment. However, no compensation can be provided for medical care apart from the foregoing. I further understand that making such medical treatment available, or providing it, does not imply that such injury is the investigator's fault. I also understand that by my participation in this study I am not waiving any of my legal rights.*

"I understand that I may also contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, MIT 253-6787, if I feel I have been treated unfairly as a subject."

Consent forms used in cooperating institutions must assure that the rights of the subject are protected at least to the same degree.

*Further information may be obtained by calling the Institute's Insurance and Legal Affairs Office at 253-2822.

These elements should be clearly stated in a document to be signed by the subject or a legally authorized representative in the case of minors or incompetent individuals. The material presented in such as document must be in clear English, easily understandable to the least educated of subjects. Where minors are involved as subjects, due consideration should be given to their

capability to give consent. The informed consent document should be signed by both the subject and parent or guardian wherever possible.

In the case of Questionnaires or Interviews, the Committee may decide that a consent form is not required if the intent is merely to obtain the requested information. However, it must be made clear to the subject that:

- Participation is voluntary.
- The subject may decline to answer any questions.
- The subject may decline further participation at any time without prejudice.
- Confidentiality and/or anonymity are assured.

In addition:

- No coercion to participate will be involved. For example, handing out or collecting questionnaires personally may be so interpreted.
- The data collected will be reported in such a way that the identity of individuals is protected.
- Proper measures will be taken to safeguard the data.

Other examples of situations in which informed consent documentation is not required include use of discarded blood, certain psychological studies involving intentional deception, or record searches and use of stored data. In a case of any deception, debriefing mechanisms must be acceptable before approval of an application may be complete. The Committee expects the investigators will notify the Committee if any adverse side effects occur.

Signature of Principal Investigator _____Date_____

Print Full Name: Laurence Young

Signature of Department Head _____Date_____

Print Full Name: Earll Murman

Please return this application with 3 photocopies to:

H. Walter Jones, Jr. M.D.
COUHES Chairman
E23-389
253-6787

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MAN-VEHICLE LABORATORY

THE EFFECTS OF SHORT-ARM CENTRIFUGATION ON THE CARDIOVASCULAR SYSTEM

CONSENT FORM

I have been asked to participate in a study of the effects of short-arm centrifugation on the cardiovascular system. I understand that participation is voluntary and that I may withdraw consent and discontinue participation at any time for any reason. I have completed a selection questionnaire related to my medical history and understand that I should not participate in this study if I have any medical heart or respiratory conditions, if I have any medical conditions which would be triggered if I develop motion sickness, or if there is any possibility that I may be pregnant. I understand that participation in the investigation under any of the above circumstances may put me in danger. I agree to abstain from caffeine and alcohol intake 24 hours prior to each experimentation period since this may affect cardiovascular measurements. My participation as a subject on the AGS involves either testing of equipment or actual experimental trials.

Prior to rotation, I will be oriented to the MIT-Artificial Gravity Simulator (AGS) and all cardiovascular monitoring equipment. I understand that my height, weight, and certain characteristic lengths, such as location of my heart, may be measured. During rotation I may have several medical devices or leads attached to my body. These would consist of a blood pressure monitor, ECG leads, and/or an impedance plethysmograph around one of my calves. A description of how these devices will feel has been presented to me. I agree to participate in possible stationary monitoring periods before or after rotation.

Rotation on the AGS will not exceed the following parameters:
- onset rate no greater than 1 rpm/s
- G level at my feet no greater than 1.5 G
- time of rotation will not exceed 1 hour.

I understand that these are well within the safe limits for short-radius rotation. I can end rotation at my discretion by pressing the subject's stop button, the use of which has been demonstrated to me.

I understand the following risks and the listed steps investigators have taken to minimize those risks.

1. Headaches, Pressure in the Legs
These possible effects are caused by a fluid shift in the body due to centrifugation. On initial report of a headache from a subject, an investigator will suggest relaxation techniques to relieve the headache. If the headache persists for the longer than 5 minutes, the experiment will stop. The subject also has the option of ending the experiment at any time for any reason.

2. Nausea/Motion Sickness
Motion sickness is primarily due to sensory conflict. The subject tactually perceives himself as lying on a still bed after an initial period on the bed. Movements of the head and the resulting vestibular stimulation reveal the influence of Coriolis forces due to rotation. The canopy of the AGS is translucent and the subject sees a blurring of external objects during rotation. The consequent sensory conflict may cause nausea. For the physiological studies on the AGS, the subjects will be blindfolded and instructed not to move their head. If the subject reports intolerable motion sickness, the experiment will be stopped. The subject also has

the option ending the experiment at any time for any reason with an emergency switch.

3. Heart Rate Increase
Previous research has shown that rotation with G levels at the feet between 1 and 1.5 G causes increased heart rate of up to 1.75 times normal levels. While the increased heart rate is no greater than that which would be experienced during aerobic exercise, medical heart conditions unknown to the subject may become evident. The heart rate of the subjects in the physiological studies will be continuously monitored. If heart rate becomes abnormally high, 1.75 times the subject's normal heart rate, the experiment will be stopped. Maximum heart rate for an individual is HR(max)= 220 - age. Subjects will also be monitored for complications for at least 15 minutes after each rotation session in the physiological studies.

4. Injury Related to Falling Off the AGS While Rotating
Serious injury could result from falling off the AGS while it is rotating. The following steps will be taken to prevent such an incident:
a. The subject will be loosely restrained at the legs and thorax, preventing him from making sudden motions or falling off the rotating bed. The restraints will be equipped with quick release latches making it possible for the subject to escape quickly if necessary.
b. Side railing similar to those on a hospital stretcher will be employed to contain the subject.
c. As mentioned previously, the subject will be equipped with an emergency stop switch which will stop the AGS from rotating within approximately 5 seconds.
d. The subject will be continuously monitored by at least one experimenter in the same room.
e. The subject will be equipped with a 2-way headset communication system connected to the observing experimenter.
f. Final human performance measurements will employ a video camera mounted on the AGS which may help the investigator understand the nature of any problems that arise.
g. Finally, subjects will experience a short test ride of several minutes duration after familiarization with the equipment.

5. Skin Irritation
Subjects will have seven electrodes place on their bodies. Sufficient electrical contact with the skin requires that electrode gel be placed between the leads and skin. Also, calf volume measurements require marking the leg with a washable marker to ensure consistency of measurements. The application of gel and marker to the skin may cause minor skin irritation. However, the irritation is unlikely to be lasting.

If I am a participant in experimental trials, I tentatively agree to return for additional trails (at most 10) requested by the experimenter. However, I understand that I can withdraw from this study at any time for any reason. I understand that the likely protocol for the actual trials will consist of the following four sessions, the order of which will be determined by the experimenter:

1. control session: one hour of supine rest on the AGS, one half hour of standing, and a final half hour of supine rest on the AGS
2. one half hour of supine rest on the AGS, one hour of rotation resulting in 0.5 G's at my feet, and a final half hour of supine rest on the AGS
3. one half hour of supine rest on the AGS, one hour of rotation resulting in 1.0 G's at my feet, and a final half hour of supine rest on the AGS

4. one half hour of supine rest on the AGS, one hour of rotation resulting in 1.5 G's at my feet, and a final half hour of supine rest on the AGS.

In the unlikely event of physical injury resulting from participation in this research, I understand that medical treatment will be available from the MIT Medical Department, including first aid emergency treatment and follow-up care as needed, and that my insurance carrier may be billed for the cost of such treatment. However, no compensation can be provided for medical care apart from the foregoing. I further understand that making such medical treatment available, or providing it, does not imply that such injury is the investigator's fault. I also understand that by my participation in this study I am not waiving any of my legal rights. (Further information may be obtained by calling the Institute's Insurance and Legal Affairs Office at 253-2822.)

Monetary compensation for those who are not members of the Man-Vehicle Laboratory will be $10 per hour.

I understand that I may also contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, H. Walter Jones, Jr. M.D. (MIT E23-389, 253-6787), if I feel I have been treated unfairly as a subject.

I have been informed as to the nature and purpose of this experiment and the risks involved, and agree to participate in the experiment. I understand that participation in this experiment is voluntary, and I am free to withdraw my consent and to discontinue participation in the study at any time without prejudice.

Subject _____ Date _____
Subject Code No.: _____

Experimenter _____ Date _____

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MAN-VEHICLE LABORATORY

THE EFFECT OF CORIOLIS FORCES ON THE HUMAN PERFORMANCE OF TWO-HANDED TASKS WHILE IN A ROTATING ENVIRONMENT

CONSENT FORM

I have been asked to participate in a study of the effects of the forces produced by rotation on the performance of two-handed tasks. I understand that participation is voluntary and that I may withdraw consent and discontinue participation at any time for any reason. I have completed a selection questionnaire related to my medical history and understand that I should not participate in this study if I have any medical heart conditions, if I have any medical conditions which would be triggered if I develop motion sickness, or if there is any possibility that I could be pregnant.

Prior to rotation, I will undergo a static training session while lying on the platform in which I will be taught and have the chance to practice the manual task which I will be asked to perform while rotating. The manual task involves simultaneous use of both my hands. After I have learned the task, a prerotation test session will be conducted. During the next portion of the experiment I will be rotated at a speed of 10 RPM, a speed well within the established safety limits, while still lying on my back. During the first few minutes of rotation while the platform comes up to speed, I will probably feel some slight dizziness. If I do become dizzy I will close my eyes and relax until the sensation goes away. After the initial start-up phase, my balance system will adapt to the constant rotational rate, and sensation of spinning should be greatly reduced. At this point I will be asked to perform the manual tasks learned in the training session. During this portion of the experiment I may experience nausea or disorientation, especially if I move my head. To reduce the possibility of nausea, a padded headrest will be provided to help reduce the amount of head movement, and all objects I will have to interact with will be in my immediate line of sight.

I will be prevented from falling off the platform by two side rails and two quick-release safety belts, one at chest level and one at my legs. I should not try to sit up or make fast head movements while rotating; if I try to sit up the safety belt at my chest will be released and will stop the rotation of the platform. My hands will be free to move within the confines of the hand rails and wind canopy. In the case of an emergency, or if I have an immediate desire to stop rotation, there will be an easily accessible stop switch (the use of which has been demonstrated to me) within arms reach which will bring the platform to a halt within approximately 5 seconds. I will be in constant communication with the experimenter through headsets and will be monitored by a video camera. If I experience unacceptable symptoms, I am free to close my eyes, ask for a break, or withdraw entirely from the experiment at any time. I understand that rotation sessions will not exceed thirty minutes and that I may be asked to come back two more times in order to investigate adaptation to artificial gravity, once three days after the initial test session, and again five days after the second test session.

In the unlikely event of physical injury resulting from participation in this research, I understand that medical treatment will be available from the MIT Medical Department, including first aid emergency treatment and follow-up care as needed, and that my insurance carrier may be billed for the cost of such treatment. However, no compensation can be provided for medical care apart from the foregoing. I further understand that making such medical treatment available, or providing it, does not imply that such injury is the investigator's fault. I also understand that by my participation in this study I am not waiving any of my legal rights. (Further information may be obtained by calling the Institute's Insurance and Legal Affairs Office at 253-2822.)

Monetary compensation for those who are not members of the Man Vehicle Laboratory will be $10 per hour.

I understand that I may also contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, H. Walter Jones, Jr. M.D.(MIT E23-389, 253-6787), if I feel I have been treated unfairly as a subject.

I have been informed as to the nature and purpose of this experiment and the risks involved, and agree to participate in the experiment.

I understand that participation in this experiment is voluntary, and I am free to withdraw my consent and to discontinue participation in the study at any time without prejudice.

Subject _____ Date _____

Experimenter _____ Date _____

References

1. Boff, K. R. and Lincoln, J. E.: Environmental Stress, Fatigue, and Circadian Rhythms. Engineering Data Compendium: Human Perception and Performance, 3, 10.102, AAMRL, Wright-Patterson AFB, Ohio, 1988.

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SELECTION QUESTIONNAIRE

BIOGRAPHICAL INFORMATION:

Name: _____ Age: _____ Sex: _____

Address: _____ Telephone: _____

_____ Occupation: _____

PLEASE ANSWER ALL QUESTIONS TO THE BEST OF YOUR ABILITY:

1. Do you have a history of medical heart conditions (arrhythmia, heart attack, failure)? _____
2. Do you have a heart murmur that requires notification of dentist during a dental exam? _____
3. Do you have a history of seizures or epilepsy? _____
4. Do you have a history of black outs? _____
5. Do you have any breathing difficulties (asthma, bronchitis, emphysema)? _____
6. Is there any possibility you could be pregnant? _____
5. Do you have a history of claustrophobia? _____
   Do you get claustrophobic: ❑ Very easily ❑ Sometimes ❑ Almost never
6. Do you have any medical conditions which might be triggered if you develop motion sickness? _____ If yes, explain: _____
7. Have you ever had motion sickness? _____ If yes, about how many times? _____
   From which of the following: ❑ Car ❑ Plane ❑ Boat ❑ Game ride ❑ Other _____
   Do you become motion sick: ❑ Very easily ❑ Sometimes ❑ Almost never
   Approximately when did you last have motion sickness (Month/Year)? _____
8. Do you have any other chronic or acute medical problems which might place you in danger during this experiment? _____ If yes, explain: _____
9. Have you had extensive experience spinning (ice skating, dancing, game ride)? _____
   Did you: ❑ Like it ❑ Dislike it ❑ Feel indifferent
10. Do you have any conditions which would prevent you from having full use of both of your arms and hands? _____

SUBJECT'S ASSIGNED CODE: _____

APPENDIX C

Protocol Checklist

Things to Do Prior to Placing the Subject on the AGS
1. Calibrate the impedance cardiograph.
2. Weight the subject.
3. Measure subject height.
4. Draw circumference lines on the calf, 2 cm apart.
5. Place impedance electrodes on the calf.
6. Put the foot plate at the desired height.
7. Offer the subject food and water.
8. Place appropriate counterweights on the AGS while another experimenter counterbalances.

Things to Do in Transition
1. Allow subject to climb onto the AGS via a chair. Have him position himself with his feet firmly flat on the foot plate.
2. Attach the ECG leads to the ECG electrodes.
3. Attach the impedance cardiograph leads to the electrode tape.
4. Place the BP cuff around one arm.

Things to Do During 30-minute Pre-Stimulus Period
1. Measure the circumferences immediately.
2. Have the subject initiate an BP measurement every five minutes.
3. Fix the BP unit to the side of the AGS with a clamp.
4. Measure the distance between the impedance electrodes.
5. Make sure no loose objects are on the AGS or in the path or rotation.
6. Confirm balance of the AGS with a level. If necessary change the counterweights.
7. Move several chairs over to the wall where standing will take place. (if standing trial)
8. Connect the battery to the camera and turn the power on. (if rotation trial)
9. Turn on the video monitor and adjust camera focus. (if rotation trial)
10. Blindfold the subject. (if rotation trial)
11. Mount the headset on the subject. Check for proper function and any interference with the ECG readings. If interference persists, adjust the AGS ground lead. (if rotation trial)
12. Fasten the subject's seat belt and place the safety button near their hand. (if rotation trial)
13. Measure the circumferences after the BP reading at 20 minutes
14. After the circumference measurements at 20 minutes, attach the wind canopy. (if rotation trial)
15. Attach the linen sheets to both ends of the canopy and the AGS. (if rotation trial)
16. Plug in the emergency stop relay; turn the motor power on; briefly place the controller start/stop switch in the start position. (if rotation trial)

Things to Do During Rotation Period
1. Rotate the AGS up to the desired level over 30 s using the motor controller potentiometer.
2. Immediately initiate a BP measurement when steady-state rotation is reached. Take a BP reading every 5 minutes thereafter.
3. Check to make sure the computer system is recording data.
4. After 15 minutes of rotation, ask the subject if he wants to continue the experiment.
5. Ask the subject how he feels every 10 minutes
6. Confirm the rotation rate experimentally.

7. Monitor the heart rate and BP readings for any abnormal responses and indications that the subject is too relaxed.
8. Maintain verbal communication with the subject.

Things to Do During Standing Period
1. Allow the subject to sit up at least 15 s prior to the transition to standing.
2. Aid the subject in transition from supine on the AGS to standing with his back against the wall, being careful of all leads.
3. Initiate a blood pressure measurement after standing is achieved and verbal verification of the subject's well-being has been elicited. Take a BP reading every 5 minutes thereafter.
4. Offer the subject water.
5. An experimenter is required to stand next to the subject at all times and be prepared to catch the subject.
6. The subject is allowed to move his legs a bit.

Things to Do Post-Stimulus
1. Rotate the subject down to no movement over 30 s using the motor controller potentiometer; turn the motor controller power off.
2. Immediately initiate a BP measurement when rotation has stopped. Take a BP reading every 5 minutes thereafter.
3. Remove the wind canopy. (if rotation trial)
4. Measure the circumferences immediately after the first BP reading.
5. Remove the subject's blindfold and headset.

APPENDIX D

Heart Rate Computer Code

```
% program ecg
% overhead program for calculating peak times/heart rate from the ECG data
% all 4 trials for one subject

subject='E';
dayc=1104;
day05=1119;
day10=1108;
day15=1115;

% control
% load the original file
load -ascii /usr/tmp/dawn/EGE1104.PRN;
% down sample from 250Hz to 125Hz
signal=resample(EGE1104);
sr=125;      %sampling rate
min=120;     %approximate number of minutes covered
[tbp, peaktime, hrtime,heartrate]=overhead(signal,sr,min,subject,'Control');
new=[tbp 0.0];
save hrvEcont peaktime new -ascii;
save heartEcont hrtime heartrate -ascii;
figure(2)
print -dps hrEcont.ps
figure(3)
print -dps hrvEcont.ps
clear EGE1104;

% 0.5 G
load -ascii /usr/tmp/dawn/EGE1119.PRN;
signal=resample(EGE1119);
sr=125;
min=120;
[tbp, peaktime,hrtime, heartrate]=overhead(signal,sr,min,subject,'0.5 G');
new=[tbp 0.0];
save hrvE0.5 peaktime new -ascii;
save hrE0.5 hrtime heartrate -ascii;
figure(2)
print -dps hrE0.5.ps
figure(3)
print -dps hrvE0.5.ps
clear EGE1119;

% 1.0 G
load -ascii /usr/tmp/dawn/EGE1108.PRN;
signal=resample(EGE1108);
sr=125;
min=120;
[tbp, peaktime,hrtime, heartrate]=overhead(signal,sr,min,subject,'1.0 G');
new=[tbp 0.0];
save hrvE1.0 peaktime new -ascii;
save hrE1.0 hrtime heartrate -ascii;
```

```
figure(2)
print -dps hrE1.0.ps
figure(3)
print -dps hrvE1.0.ps
clear EGE1108;


% 1.5 G
load -ascii /usr/tmp/dawn/EGE1115.PRN;
signal=resample(EGE1115);
sr=125;
min=120;
[tbp, peaktime,hrtime, heartrate]=overhead(signal,sr,min,subject,'1.5 G');
new=[tbp 0.0];
save hrvE1.5 peaktime new -ascii;
save hrE1.5 hrtime heartrate -ascii;
figure(2)
print -dps hrE1.5.ps
figure(3)
print -dps hrvE1.5.ps
clear EGE1115



function [signal2]=resample(signal1)
% down-samples a file by 2
signal2=zeros(1,length(signal1)/2);
j=1;
      for i=1:length(signal2),
            signal2(i)=signal1(j);
            j=j+2;
      end;
end;



function [tbp, peaktime,hrtime, heartrate]=overhead(signal,sr,min,subject,
trial)
% overhead program for finding the peak times/heart rate from an ECG signal

% see if there is less than the specified number of minutes
min2=length(signal)/sr/60;
if min <= min2,
        signal=signal(1:sr*60*min);
        min2=min;
end;

[tbp, heartrate, peaktime]=process(signal,sr,min2);
avt=30;
hrtime=(avt:avt:min2*60)/60;
figure(2)
plot(hrtime,heartrate,'.')
xlabel('Time (min)');
ylabel('Heart Rate (bpm)');
title(sprintf('Heart Rate vs. Time for Subject %c During %s Trial',subject,
trial));
figure(3)
plot(peaktime(1:length(peaktime)-1),tbp,'.');
```

```
xlabel('Time (s)');
ylabel('R-R Interval Time (s)');
title(sprintf('R-R Intervals vs. Time for Subject %c During %s Trial',subject,
trial));
end;



function [tbp, heartrate,peaktime]=process(signal,sr,min2)
% filters the signal, finds the QRS peaks, and calculates heart rate

t=0:1/sr:min2*60-1/sr;  % time vector

figure(1)
xo=signal(1:10*sr);
subplot(221),plot(t(1:10*sr),xo)    % see the data
title('First Ten Seconds of ECG Signal');
xlabel('Time (s)');
ylabel('Voltage (V)');

% check to see what frequency range the data is in
fre=[1/4096:1/4096:1]*sr;
xfft=abs(fft(xo,4096));
subplot(222), plot(fre,xfft);
axis([0 75 0 800]);
title('FFT');
xlabel('Frequency (Hz)');

clear xo
clear xfft

% filter the signal with a matched filter
fmin=10;    % lower cutoff frequency in Hz
fmax=30;    % higher cutoff frequency in Hz
order=100;  % filter order
wn=[fmin*2/sr fmax*2/sr];
B=fir1(order,wn);
J=fftfilt(B,signal);

clear signal

% see what it looks like
subplot(223), plot(t(1:10*sr),J(1:10*sr));
title('ECG Voltage vs. Time, Filtered');
xlabel('Time (s)');
ylabel('Voltage (V)');

% see what filtered fft looks like
Y=abs(fft(J(1:10*sr),4096));
subplot(224), plot(fre,Y)
axis([0 75 0 800]);
title('FFT of Filtered Data');
xlabel('Frequency (Hz)')

%clear Y

print -dps filtering
```

```
% let's find the peaks
k=1;
peaktime=zeros(1, min2*100);
r=-1000;
for i=1:length(J),
      if i > 5*sr
            m=max(abs(J(i-5*sr:i)));
      else
            m=max(abs(J(1:5*sr)));
      end;  % FIND the local maximum.
      % lockout period assumes heart rate never exceeds 133 bpm
      if ((abs(J(i)) > .25*m) & ((i-r) > .45*sr))
            peaktime(k)=t(i);
            k=k+1;
            r=i;
      end;
end;
peaktime=peaktime(1:k-1);

%clear J

% find the time between peaks
tbp=zeros(1,length(peaktime)-1);
k=1;
for i=1:length(peaktime)-1,
      tbp(k)=peaktime(i+1)-peaktime(i);
      if tbp(k) > 1.5
            if k > 1
                  tbp(k)=tbp(k-1);
            else
                  tbp(k)=0;
            end;
      end;
      k=k+1;
end;

% let's find heartrate
avt=30; % number of seconds over which heart rate is averaged
hrtime=(avt:avt:min2*60)/60;
heartrate=zeros(size(hrtime));
for i=avt:avt:min2*60,
      q=find((peaktime <= i) & (peaktime >= (i-avt)));
      if length(q) > 1
            dummy=zeros(1,length(q)-1);
            k=1;
            j=0;
            for n=1:length(q)-1,
            % lockout period assumes heartrate is always greater than 40bpm
                  if (peaktime(q(n+1))-peaktime(q(n))) < 1.5
                      dummy(k)=(peaktime(q(n+1))-peaktime(q(n)))^(-1)*60;
                        k=k+1;
                  else
                        j=j+1;
                  end;
            end;
            dummy=dummy(1:length(dummy)-j);
            heartrate(i/avt)=mean(dummy);
      else
```

```
            heartrate(i/avt)=0;
      end;
end;

end
```

```
% heartc.m
% overhead program for calculated heart rate at different averaging intervals
% from a known set of peak times
% allows for noise rejection

figure(1)
min2=120;
subject='C';

load 'hrvCcont' -ascii;
hprocess(hrvCcont(1,:),min2,subject,'Control');
%[hrtratec5,hrtratec15,hrvarc]=hrover(hrvCcont(1,:),min2,subject,'Control');
[hrtratec5,hrtratec15,hrvarc]=hrover2(hrvCcont(1,:),min2,subject,'Control',[32
],[40],[1/(96/60)]);

load 'hrvC0.5' -ascii;
hprocess(hrvC0(1,:),min2,subject,'0.5 G');
%[hrtratef5,hrtratef15,hrvarf]=hrover(hrvC0(1,:),min2,subject,'0.5 G');
[hrtratef5,hrtratef15,hrvarf]=hrover2(hrvC0(1,:),min2,subject,'0.5
G',[0],[120],[.6]);

load 'hrvC1.0' -ascii;
hprocess(hrvC1(1,:),min2,subject,'1.0 G');
%[hrtrateo5,hrtrateo15,hrvaro]=hrover(hrvC1(1,:),min2,subject,'1.0 G');
[hrtrateo5,hrtrateo15,hrvaro]=hrover2(hrvC1(1,:),min2,subject,'1.0
G',[0],[120],[2/3]);

load 'hrvC1.5' -ascii;
hprocess(hrvC1(1,:),min2,subject,'1.5 G');
%[hrtrateft5,hrtrateft15,hrvarft]=hrover(hrvC1(1,:),min2,subject,'1.5 G');
[hrtrateft5,hrtrateft15,hrvarft]=hrover2(hrvC1(1,:),min2,subject,'1.5 G',[0
30.005 90.0001],[30 90 120],[.6 1/(110/60) .6]);

data1=[hrtratec5' hrtratef5' hrtrateo5' hrtrateft5'];
data2=[hrtratec15' hrtratef15' hrtrateo15' hrtrateft15'];
data3=[hrvarc' hrvarf' hrvaro' hrvarft'];
%save Chr5 data1 -ascii;
%save Chr15 data2 -ascii;
%save Chrv data3 -ascii;
save Chr52 data1 -ascii;
save Chr152 data2 -ascii;
save Chrv2 data3 -ascii;
```

```
% heartd.m
figure(1)
min2=120;
subject='D';
```

```
load 'hrvDcont' -ascii;
hprocess(hrvDcont(1,:),min2,subject,'Control');
[hrtratec5,hrtratec15,hrvarc]=hrover(hrvDcont(1,:),min2,subject,'Control');

load 'hrvD0.5' -ascii;
hprocess(hrvD0(1,:),min2,subject,'0.5 G');
%[hrtratef5,hrtratef15,hrvarf]=hrover(hrvD0(1,:),min2,subject,'0.5 G');
[hrtratef5,hrtratef15,hrvarf]=hrover2(hrvD0(1,:),min2,subject,'0.5
G',[0],[120],[2/3]);

load 'hrvD1.0' -ascii;
hprocess(hrvD1(1,:),min2,subject,'1.0 G');
%[hrtrateo5,hrtrateo15,hrvaro]=hrover(hrvD1(1,:),min2,subject,'1.0 G');
[hrtrateo5,hrtrateo15,hrvaro]=hrover2(hrvD1(1,:),min2,subject,'1.0 G',[0
30.0001 90.0001],[30 90 120],[.6 2/3 1/(11/6)]);

load 'hrvD1.5.1' -ascii;
peaktime1=hrvD1(1,:);
load 'hrvD1.5.2' -ascii;
peaktime2=hrvD1(1,:)+3600;
hprocess([peaktime1 peaktime2],min2,subject,'1.5 G');
[hrtrateft5,hrtrateft15,hrvarft]=hrover([peaktime1
peaktime2],min2,subject,'1.5 G');

data1=[hrtratec5' hrtratef5' hrtrateo5' hrtrateft5'];
data2=[hrtratec15' hrtratef15' hrtrateo15' hrtrateft15'];
data3=[hrvarc' hrvarf' hrvaro' hrvarft'];
%save Dhr5 data1 -ascii;
%save Dhr15 data2 -ascii;
%save Dhrv data3 -ascii;
save Dhr52 data1 -ascii;
save Dhr152 data2 -ascii;
save Dhrv2 data3 -ascii;



% hearte.m
figure(1)
min2=120;
subject='E';

load 'hrvEcont' -ascii;
hprocess(hrvEcont(1,:),min2,subject,'Control');
[hrtratec5,hrtratec15,hrvarc]=hrover(hrvEcont(1,:),min2,subject,'Control');

load 'hrvE0.5' -ascii;
hprocess(hrvE0(1,:),min2,subject,'0.5 G');
%[hrtratef5,hrtratef15,hrvarf]=hrover(hrvE0(1,:),min2,subject,'0.5 G');
[hrtratef5,hrtratef15,hrvarf]=hrover2(hrvE0(1,:),min2,subject,'0.5
G',[0],[120],[2/3]);

load 'hrvE1.0' -ascii;
hprocess(hrvE1(1,:),min2,subject,'1.0 G');
%[hrtrateo5,hrtrateo15,hrvaro]=hrover(hrvE1(1,:),min2,subject,'1.0 G');
[hrtrateo5,hrtrateo15,hrvaro]=hrover2(hrvE1(1,:),min2,subject,'1.0 G',[0 30
75.0001 82.0001],[27 75 82 120],[.75 .75 .6 .75]);

load 'hrvE1.5' -ascii;
```

```
hprocess(hrvE1(1,:),min2,subject,'1.5 G');
%[hrtrateft5,hrtrateft15,hrvarft]=hrover(hrvE1(1,:),min2,subject,'1.5 G');
[hrtrateft5,hrtrateft15,hrvarft]=hrover2(hrvE1(1,:),min2,subject,'1.5 G',[0
30],[28 120],[1/(11/6) .5]);

data1=[hrtratec5' hrtratef5' hrtrateo5' hrtrateft5'];
data2=[hrtratec15' hrtratef15' hrtrateo15' hrtrateft15'];
data3=[hrvarc' hrvarf' hrvaro' hrvarft'];
%save Ehr5 data1 -ascii;
%save Ehr15 data2 -ascii;
%save Ehrv data3 -ascii;
save Ehr52 data1 -ascii;
save Ehr152 data2 -ascii;
save Ehrv2 data3 -ascii;



% heartf.m
figure(1)
min2=120;
subject='F';

load 'hrvFcont' -ascii;
hprocess(hrvFcont(1,:),min2,subject,'Control');
%[hrtratec5,hrtratec15,hrvarc]=hrover(hrvFcont(1,:),min2,subject,'Control');
[hrtratec5,hrtratec15,hrvarc]=hrover2(hrvFcont(1,:),min2,subject,'Control',[0]
,[120],[.6]);

load 'hrvF0.5' -ascii;
hprocess(hrvF0(1,:),min2,subject,'0.5 G');
%[hrtratef5,hrtratef15,hrvarf]=hrover(hrvF0(1,:),min2,subject,'0.5 G');
[hrtratef5,hrtratef15,hrvarf]=hrover2(hrvF0(1,:),min2,subject,'0.5 G',[0
20.001 28.001 37.001],[20 28 37 120],[2/3 .6 2/3 .6]);

load 'hrvF1.0' -ascii;
hprocess(hrvF1(1,:),130,subject,'1.0 G');
%[hrtrateo5,hrtrateo15,hrvaro]=hrover(hrvF1(1,:),130,subject,'1.0 G');
[hrtrateo5,hrtrateo15,hrvaro]=hrover2(hrvF1(1,:),130,subject,'1.0 G',[0
40.001],[40 130],[60/95 .6]);

load 'hrvF1.5' -ascii;
hprocess(hrvF1(1,:),min2,subject,'1.5 G');
%[hrtrateft5,hrtrateft15,hrvarft]=hrover(hrvF1(1,:),min2,subject,'1.5 G');
[hrtrateft5,hrtrateft15,hrvarft]=hrover2(hrvF1(1,:),min2,subject,'1.5 G',[0
29.0001 60.0001 92.0001],[29 60 92 120],[2/3 .6 6/11 .6]);

diff1=length(hrtrateo5)-length(hrtrateft5);
diff2=length(hrtrateo15)-length(hrtrateft15);
hrtratec5=[hrtratec5 zeros(1,diff1)];
hrtratef5=[hrtratef5 zeros(1,diff1)];
hrtrateft5=[hrtrateft5 zeros(1,diff1)];
hrtratec15=[hrtratec15 zeros(1,diff2)];
hrtratef15=[hrtratef15 zeros(1,diff2)];
hrtrateft15=[hrtrateft15 zeros(1,diff2)];
hrvarc=[hrvarc zeros(1,diff1)];
hrvarf=[hrvarf zeros(1,diff1)];
hrvarft=[hrvarft zeros(1,diff1)];
data1=[hrtratec5' hrtratef5' hrtrateo5' hrtrateft5'];
```

```
data2=[hrtratec15' hrtratef15' hrtrateo15' hrtrateft15'];
data3=[hrvarc' hrvarf' hrvaro' hrvarft'];
%save Fhr5 data1 -ascii;
%save Fhr15 data2 -ascii;
%save Fhrv data3 -ascii;
save Fhr52 data1 -ascii;
save Fhr152 data2 -ascii;
save Fhrv2 data3 -ascii;



% heartg.m
figure(1)
min2=120;
subject='G';

load 'hrvGcont' -ascii;
hprocess(hrvGcont(1,:),min2,subject,'Control');
%[hrtratec5,hrtratec15,hrvarc]=hrover(hrvGcont(1,:),min2,subject,'Control');
[hrtratec5,hrtratec15,hrvarc]=hrover2(hrvGcont(1,:),min2,subject,'Control',[45
62 93],[59 85 120],[.6 60/115 60/95]);

load 'hrvG0.5' -ascii;
hprocess(hrvG0(1,:),min2,subject,'0.5 G');
[hrtratef5,hrtratef15,hrvarf]=hrover(hrvG0(1,:),min2,subject,'0.5 G');

load 'hrvG1.0' -ascii;
hprocess(hrvG1(1,:),min2,subject,'1.0 G');
%[hrtrateo5,hrtrateo15,hrvaro]=hrover(hrvG1(1,:),min2,subject,'1.0 G');
[hrtrateo5,hrtrateo15,hrvaro]=hrover2(hrvG1(1,:),min2,subject,'1.0
G',[0],[120],[.6]);

load 'hrvG1.5' -ascii;
hprocess(hrvG1(1,:),min2,subject,'1.5 G');
%[hrtrateft5,hrtrateft15,hrvarft]=hrover(hrvG1(1,:),min2,subject,'1.5 G');
[hrtrateft5,hrtrateft15,hrvarft]=hrover2(hrvG1(1,:),min2,subject,'1.5 G',[0
27.001 50.0001 90],[27 50 87 120],[.6 60/110 .5 .6]);

data1=[hrtratec5' hrtratef5' hrtrateo5' hrtrateft5'];
data2=[hrtratec15' hrtratef15' hrtrateo15' hrtrateft15'];
data3=[hrvarc' hrvarf' hrvaro' hrvarft'];
%save Ghr5 data1 -ascii;
%save Ghr15 data2 -ascii;
%save Ghrv data3 -ascii;
save Ghr52 data1 -ascii;
save Ghr152 data2 -ascii;
save Ghrv2 data3 -ascii;



% hearth.m
figure(1)
min2=120;
subject='H';

load 'hrvHcont' -ascii;
hprocess(hrvHcont(1,:),min2,subject,'Control');
[hrtratec5,hrtratec15,hrvarc]=hrover(hrvHcont(1,:),min2,subject,'Control');
```

```
load 'hrvH0.5' -ascii;
hprocess(hrvH0(1,:),min2,subject,'0.5 G');
%[hrtratef5,hrtratef15,hrvarf]=hrover(hrvH0(1,:),min2,subject,'0.5 G');
[hrtratef5,hrtratef15,hrvarf]=hrover2(hrvH0(1,:),min2,subject,'0.5
G',[0],[120],[6/11]);

load 'hrvH1.0' -ascii;
hprocess(hrvH1(1,:),min2,subject,'1.0 G');
%[hrtrateo5,hrtrateo15,hrvaro]=hrover(hrvH1(1,:),min2,subject,'1.0 G');
[hrtrateo5,hrtrateo15,hrvaro]=hrover2(hrvH1(1,:),min2,subject,'1.0 G',[0
32.0001 55.0001],[32 55 120],[6/11 .6 6/11]);

load 'hrvH1.5' -ascii;
hprocess(hrvH1(1,:),min2,subject,'1.5 G');
%[hrtrateft5,hrtrateft15,hrvarft]=hrover(hrvH1(1,:),min2,subject,'1.5 G');
[hrtrateft5,hrtrateft15,hrvarft]=hrover2(hrvH1(1,:),min2,subject,'1.5 G',[0
35.0001 90.001],[35 90 120],[.6 6/11 .6]);

data1=[hrtratec5' hrtratef5' hrtrateo5' hrtrateft5'];
data2=[hrtratec15' hrtratef15' hrtrateo15' hrtrateft15'];
data3=[hrvarc' hrvarf' hrvaro' hrvarft'];
%save Hhr5 data1 -ascii;
%save Hhr15 data2 -ascii;
%save Hhrv data3 -ascii;
save Hhr52 data1 -ascii;
save Hhr152 data2 -ascii;
save Hhrv2 data3 -ascii;



% hearti.m
figure(1)
min2=120;
subject='I';

load 'hrvIcont' -ascii;
hprocess(hrvIcont(1,:),min2,subject,'Control');
%[hrtratec5,hrtratec15,hrvarc]=hrover(hrvIcont(1,:),min2,subject,'Control');
[hrtratec5,hrtratec15,hrvarc]=hrover2(hrvIcont(1,:),min2,subject,'Control',[0
60 90],[57 87 120],[6/11 .5 .6]);

load 'hrvI0.5' -ascii;
hprocess(hrvI0(1,:),min2,subject,'0.5 G');
%[hrtratef5,hrtratef15,hrvarf]=hrover(hrvI0(1,:),min2,subject,'0.5 G');
[hrtratef5,hrtratef15,hrvarf]=hrover2(hrvI0(1,:),min2,subject,'0.5 G',[0 20.01
75.0001],[20 75 120],[6/11 .6 6/11]);

load 'hrvI1.0' -ascii;
hprocess(hrvI1(1,:),min2,subject,'1.0 G');
%[hrtrateo5,hrtrateo15,hrvaro]=hrover(hrvI1(1,:),min2,subject,'1.0 G');
[hrtrateo5,hrtrateo15,hrvaro]=hrover2(hrvI1(1,:),min2,subject,'1.0
G',[0],[120],[.6]);

load 'hrvI1.5' -ascii;
hprocess(hrvI1(1,:),min2,subject,'1.5 G');
%[hrtrateft5,hrtrateft15,hrvarft]=hrover(hrvI1(1,:),min2,subject,'1.5 G');
```

```
[hrtrateft5,hrtrateft15,hrvarft]=hrover2(hrvI1(1,:),min2,subject,'1.5 G',[0 32
60.001 90.0001],[28 60 90 120],[.6 6/11 60/105 .6]);

data1=[hrtratec5' hrtratef5' hrtrateo5' hrtrateft5'];
data2=[hrtratec15' hrtratef15' hrtrateo15' hrtrateft15'];
data3=[hrvarc' hrvarf' hrvaro' hrvarft'];
%save Ihr5 data1 -ascii;
%save Ihr15 data2 -ascii;
%save Ihrv data3 -ascii;
save Ihr52 data1 -ascii;
save Ihr152 data2 -ascii;
save Ihrv2 data3 -ascii;



% heartj.m
figure(1)
min2=120;
subject='J';

load 'hrvJcont' -ascii;
hprocess(hrvJcont(1,:),min2,subject,'Control');
%[hrtratec5,hrtratec15,hrvarc]=hrover(hrvJcont(1,:),min2,subject,'Control');
[hrtratec5,hrtratec15,hrvarc]=hrover2(hrvJcont(1,:),min2,subject,'Control',[0
61 92.0001],[58 92 120],[.6 .6 1.5]);

load 'hrvJ0.5' -ascii;
hprocess(hrvJ0(1,:),min2,subject,'0.5 G');
%[hrtratef5,hrtratef15,hrvarf]=hrover(hrvJ0(1,:),min2,subject,'0.5 G');
[hrtratef5,hrtratef15,hrvarf]=hrover2(hrvJ0(1,:),min2,subject,'0.5
G',[0],[120],[2/3]);

load 'hrvJ1.0' -ascii;
hprocess(hrvJ1(1,:),min2,subject,'1.0 G');
%[hrtrateo5,hrtrateo15,hrvaro]=hrover(hrvJ1(1,:),min2,subject,'1.0 G');
[hrtrateo5,hrtrateo15,hrvaro]=hrover2(hrvJ1(1,:),min2,subject,'1.0 G',[0
105.001 112.0001],[105 112 120],[2/3 6/11 2/3]);

load 'hrvJ1.5' -ascii;
hprocess(hrvJ1(1,:),min2,subject,'1.5 G');
%[hrtrateft5,hrtrateft15,hrvarft]=hrover(hrvJ1(1,:),min2,subject,'1.5 G');
[hrtrateft5,hrtrateft15,hrvarft]=hrover2(hrvJ1(1,:),min2,subject,'1.5 G',[0
30.001 90.001],[30 90 120],[.6 .5 .6]);

data1=[hrtratec5' hrtratef5' hrtrateo5' hrtrateft5'];
data2=[hrtratec15' hrtratef15' hrtrateo15' hrtrateft15'];
data3=[hrvarc' hrvarf' hrvaro' hrvarft'];
%save Jhr5 data1 -ascii;
%save Jhr15 data2 -ascii;
%save Jhrv data3 -ascii;
save Jhr52 data1 -ascii;
save Jhr152 data2 -ascii;
save Jhrv2 data3 -ascii;



function hprocess(peaktime,min2,subject, trial)
% finds the R-R intervals from the peak times and calculates instantaneous HR
```

```
tbp=zeros(1,length(peaktime)-1);
k=1;
for i=1:length(peaktime)-1,
        tbp(k)=peaktime(i+1)-peaktime(i);
        if tbp(k) > 1.5
                if k > 1
                        tbp(k)=tbp(k-1);
                else
                        tbp(k)=0;
                end;
        end;
        k=k+1;
end;

% do the plot

bp=.4:.01:1.6;
bp2=40:.1:150;
if (trial(1,1:5) == 'Contr')
      tl1=ones(size(bp))*60;
      tl12=ones(size(bp2))*60;
else
      tl1=ones(size(bp))*30;
      tl12=ones(size(bp2))*30;
end;
tl2=ones(size(bp))*90;
tl22=ones(size(bp2))*90;

figure(gcf+1)
subplot(211),plot(peaktime(1:length(peaktime)-1)/60,tbp,'.');
xlabel('Time (min)');
ylabel('R-R Interval Time (s)');
title(sprintf('R-R Intervals vs. Time for Subject %c During %s Trial',subject,
trial));
hold on
sy(.4,1.6);
axis(axis)
plot(tl1,bp);
plot(tl2,bp);
grid
subplot(212),plot(peaktime(1:length(peaktime)-1)/60,1./(tbp/60),'.');
xlabel('Time (min)');
ylabel('Instantaneous Heart Rate (bpm)');
title(sprintf('Instantaneous Heart Rate vs. Time for Subject %c During %s
Trial',subject, trial));
hold on
axis(axis)
plot(tl12,bp2);
plot(tl22,bp2);
grid



function [heartrate2,heartrate3,hstdev2]=hrover(peaktime,min,subject,trial)
% overhead program to plot HR due to different averaging intervals

% find average heartrates for 30s, 5 min, and 15 min. intervals
```

```
[hrtime1,heartrate1,hstdev1]=hrate(peaktime,min,30);
[hrtime2,heartrate2,hstdev2]=hrate(peaktime,min,300);
[hrtime3,heartrate3,hstdev3]=hrate(peaktime,min,900);

bp=40:.1:150;
if (trial(1,1:5) == 'Contr')
      tl1=ones(size(bp))*60;
else
      tl1=ones(size(bp))*30;
end;
tl2=ones(size(bp))*90;

figure(gcf+1)
subplot(311),plot(hrtime1,heartrate1,'.')
ylabel('Heart Rate (bpm)');
title(sprintf('Heart Rate vs. Time for Subject %c During %s Trial',subject,
trial));
cur=axis;
if cur(3) == 0,
      cur(3)=50;
end;
cur=[0 cur(2) cur(3) cur(4)];
axis(cur)
axis(axis)
hold on
plot(tl1,bp);
plot(tl2,bp);
grid
subplot(312),plot(hrtime2,heartrate2,'o')
ylabel('Heart Rate (bpm)');
hold on
axis(axis)
plot(tl1,bp);
plot(tl2,bp);
grid
axis(cur)
subplot(313),plot(hrtime3,heartrate3,'o')
xlabel('Time (min)');
ylabel('Heart Rate (bpm)');
hold on
axis(axis)
plot(tl1,bp);
plot(tl2,bp);
grid
axis(cur)



function [hrtime, heartrate,hstdev]=hrate(peaktime,min2,avt)
% let's find heartrate

% avt= number of seconds over which heart rate is averaged
hrtime=(avt:avt:min2*60)/60;
heartrate=zeros(1,length(hrtime));
hstdev=zeros(1,length(hrtime));
for i=avt:avt:min2*60,
      q=find((peaktime <= i) & (peaktime >= (i-avt)));
      if length(q) > 1
```

```
                dummy=zeros(1,length(q)-1);
                k=1;
                j=0;
                for n=1:length(q)-1,
                % lockout period assumes heartrate is always greater than 40bpm
                        if (peaktime(q(n+1))-peaktime(q(n))) < 1.5
                           dummy(k)=(peaktime(q(n+1))-peaktime(q(n)))^(-1)*60;
                           k=k+1;
                        else
                           j=j+1;
                        end;
                end;
                dummy=dummy(1:length(dummy)-j);
                heartrate(i/avt)=mean(dummy);
        else
                heartrate(i/avt)=0;
        end;
        hstdev(i/avt)=std(dummy);
end;



function [heartrate2,heartrate3,hstdev2]=hrover2(peaktime,min,subject,trial,
stb,ste,cutoff)
% overhead program to plot HR due to different averaging intervals
% allows for noise rejection

% stb=times when periods of elimination of noisy data begin
% ste= times when periods of elimination of noisy data begin
% cutoff = R-R interval values in periods below which data will be eliminated

% find average heartrates for 30s, 5 min, and 15 min. intervals
[hrtime1,heartrate1,hstdev1]=hrate2(peaktime,min,30,stb,ste,cutoff);
[hrtime2,heartrate2,hstdev2]=hrate2(peaktime,min,300,stb,ste,cutoff);
[hrtime3,heartrate3,hstdev3]=hrate2(peaktime,min,900,stb,ste,cutoff);

bp=40:.1:150;
if (trial(1,1:5) == 'Contr')
        tl1=ones(size(bp))*60;
else
        tl1=ones(size(bp))*30;
end;
tl2=ones(size(bp))*90;

figure(gcf+1)
subplot(311),plot(hrtime1,heartrate1,'.')
ylabel('Heart Rate (bpm)');
title(sprintf('Heart Rate vs. Time for Subject %c During %s Trial',subject,
trial));
cur=axis;
if cur(3) == 0,
        cur(3)=50;
end;
cur=[0 cur(2) cur(3) cur(4)];
axis(cur)
axis(axis)
hold on
plot(tl1,bp);
```

```
plot(tl2,bp);
grid
subplot(312),plot(hrtime2,heartrate2,'o')
ylabel('Heart Rate (bpm)');
hold on
axis(axis)
plot(tl1,bp);
plot(tl2,bp);
grid
axis(cur)
subplot(313),plot(hrtime3,heartrate3,'o')
xlabel('Time (min)');
ylabel('Heart Rate (bpm)');
hold on
axis(axis)
plot(tl1,bp);
plot(tl2,bp);
grid
axis(cur)



function [hrtime, heartrate,hstdev]=hrate2(peaktime,min2,avt,stb,ste,cutoff)
% let's find heartrate
% allows for noise rejection

% avt= number of seconds over which heart rate is averaged

count=length(stb);

hrtime=(avt:avt:min2*60)/60;
heartrate=zeros(1,length(hrtime));
hstdev=zeros(1,length(hrtime));
for i=avt:avt:min2*60,
       q=find((peaktime <= i) & (peaktime >= (i-avt)));
       if length(q) > 1
                dummy=zeros(1,length(q)-1);
                k=1;
                j=0;
                for n=1:length(q)-1,
                  % check to see if point is in noisy period
                  g=0;
                  for w=1:count,
                        if ((i >= stb(w)*60) & (i <= ste(w)*60))
                              g=w;
                        end;
                  end;
                  if (g == 0)
                        % lockout period assumes heartrate is always greater
than 40bpm
                        if (peaktime(q(n+1))-peaktime(q(n))) < 1.5
                           dummy(k)=(peaktime(q(n+1))-peaktime(q(n)))^(-1)*60;
                           k=k+1;
                        else
                           j=j+1;
                        end;
                  else
```

```
                        if (((peaktime(q(n+1))-peaktime(q(n))) < 1.5) &
((peaktime(q(n+1))-peaktime(q(n))) > cutoff(g)))
                           dummy(k)=(peaktime(q(n+1))-peaktime(q(n)))^(-1)*60;
                           k=k+1;
                        else
                           j=j+1;
                        end;
                  end;
               end;
               dummy=dummy(1:length(dummy)-j);
               heartrate(i/avt)=mean(dummy);
      else
               heartrate(i/avt)=0;
      end;
      hstdev(i/avt)=std(dummy);
end;
```

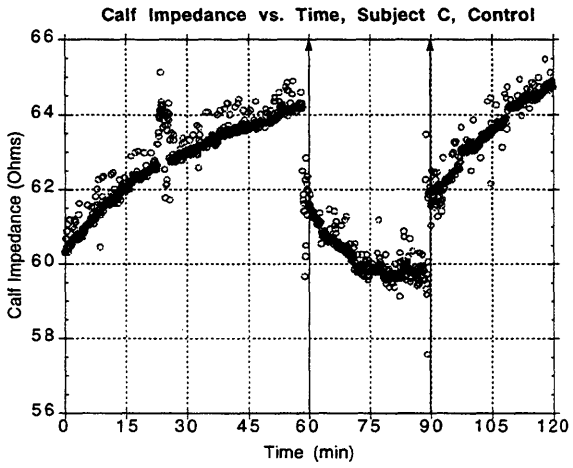
APPENDIX E

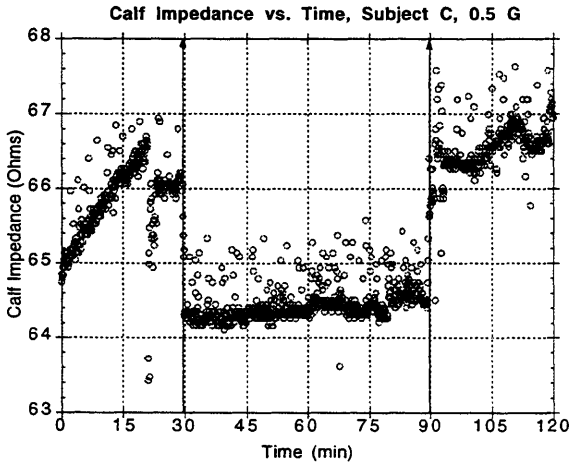
Calf Impedance Measurements

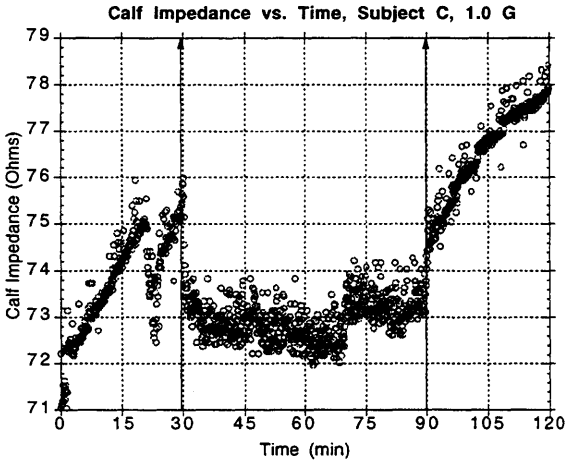
Measured Impedance Plots

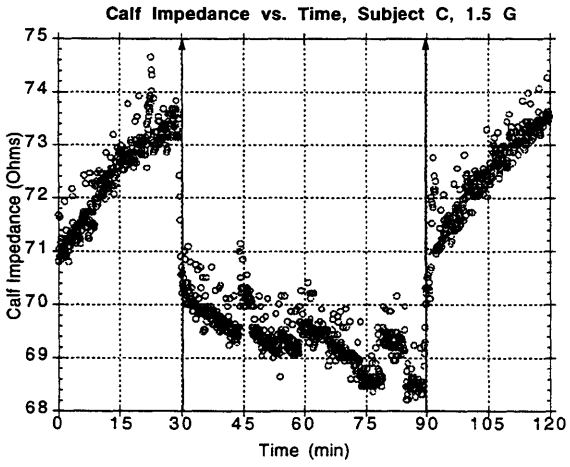
The vertical lines with arrows represent the onset or end of a stimulus.

Subject C

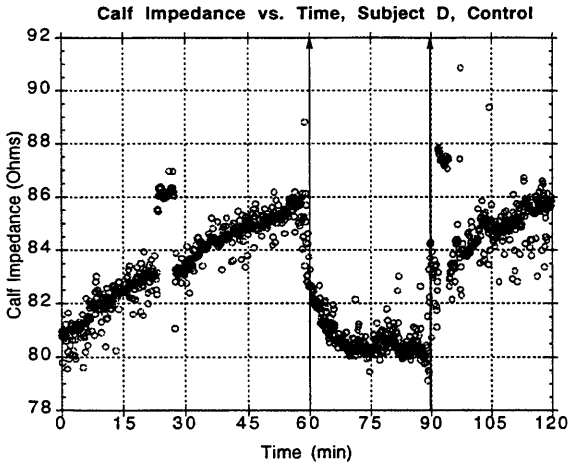


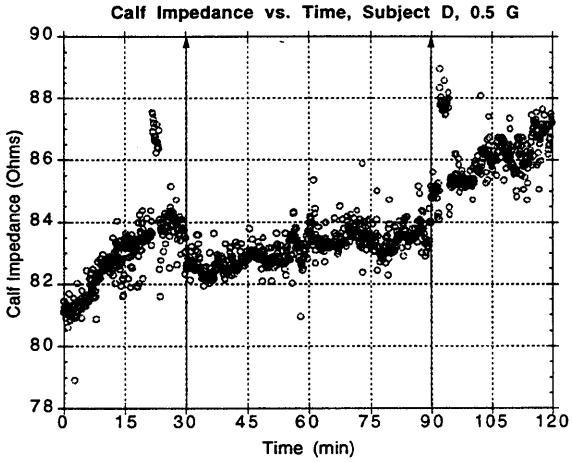


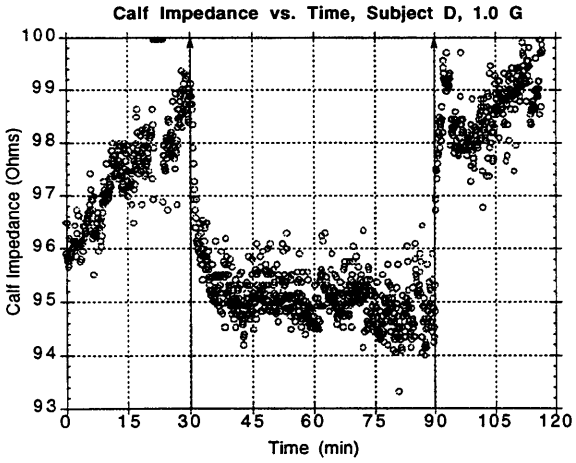


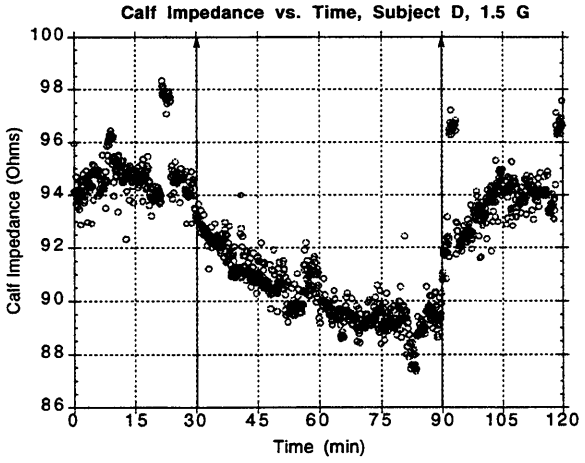


Subject D

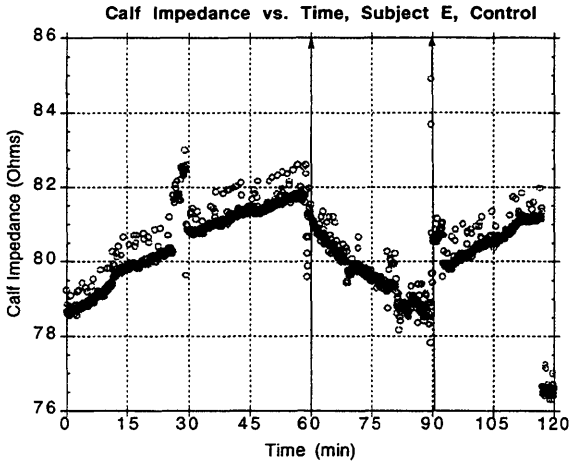

Calf Impedance vs. Time, Subject D, Control
Calf Impedance (Ohms)
92
90
88
86
84
82
80
78
0
15
30
45
60
75
90
105
120
Time (min)

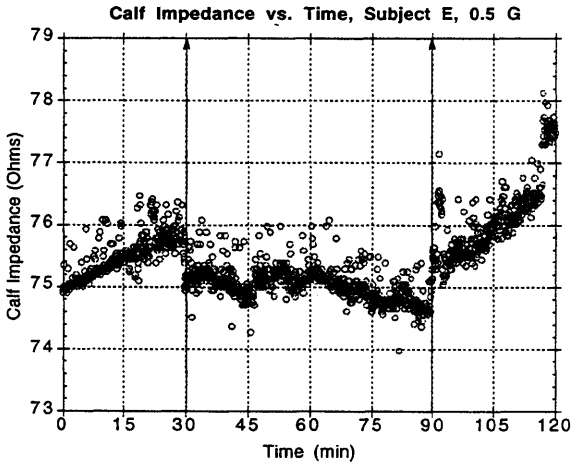

Calf Impedance vs. Time, Subject D, 0.5 G
Calf Impedance (Ohms)
90
88
86
84
82
80
78
0
15
30
45
60
75
90
105
120
Time (min)

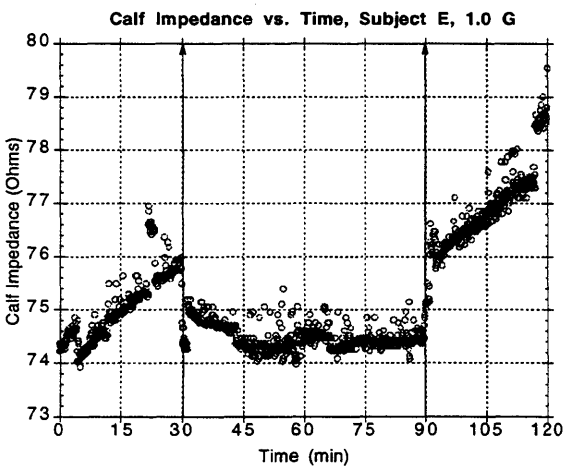

Calf Impedance vs. Time, Subject D, 1.0 G
Calf Impedance (Ohms)
100
99
98
97
96
95
94
93
0
15
30
45
60
75
90
105
120
Time (min)

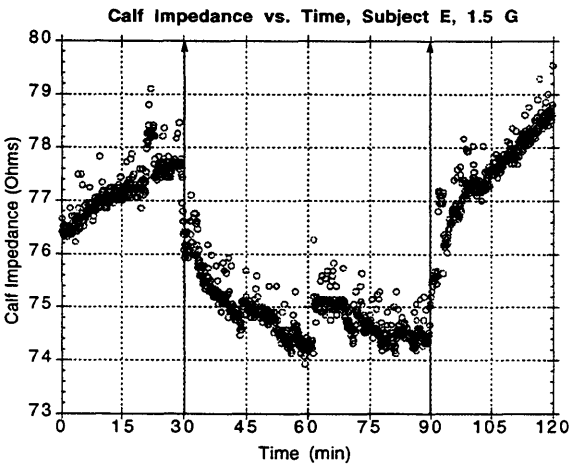

Calf Impedance vs. Time, Subject D, 1.5 G
Calf Impedance (Ohms)
100
98
96
94
92
90
88
86
0
15
30
45
60
75
90
105
120
Time (min)

Subject E

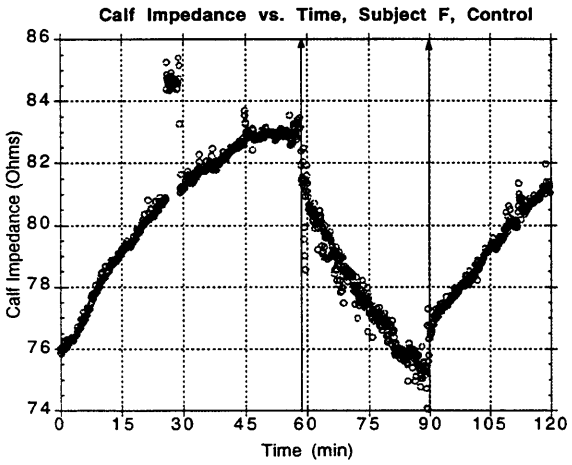

Calf Impedance vs. Time, Subject E, Control
Calf Impedance (Ohms)
86
84
82
80
78
76
0 15 30 45 60 75 90 105 120
Time (min)

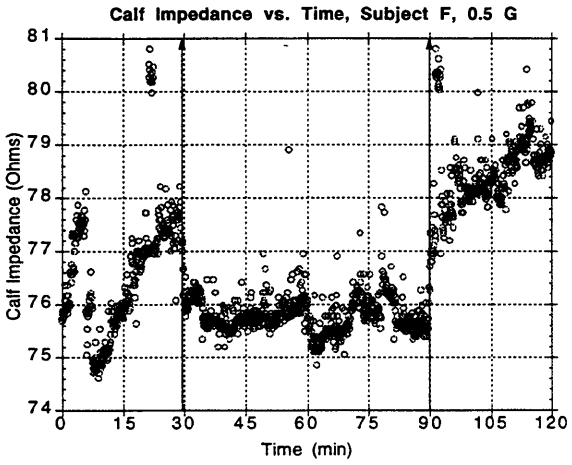

Calf Impedance vs. Time, Subject E, 0.5 G
Calf Impedance (Ohms)
79
78
77
76
75
74
73
0 15 30 45 60 75 90 105 120
Time (min)

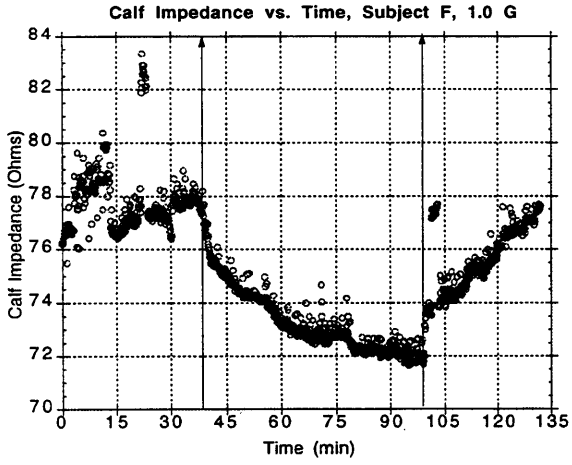

Calf Impedance vs. Time, Subject E, 1.0 G
Calf Impedance (Ohms)
80
79
78
77
76
75
74
73
0 15 30 45 60 75 90 105 120
Time (min)

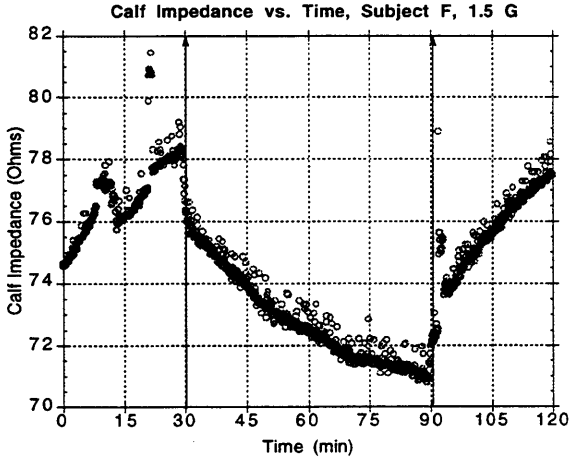

Calf Impedance vs. Time, Subject E, 1.5 G
Calf Impedance (Ohms)
80
79
78
77
76
75
74
73
0 15 30 45 60 75 90 105 120
Time (min)

Subject F

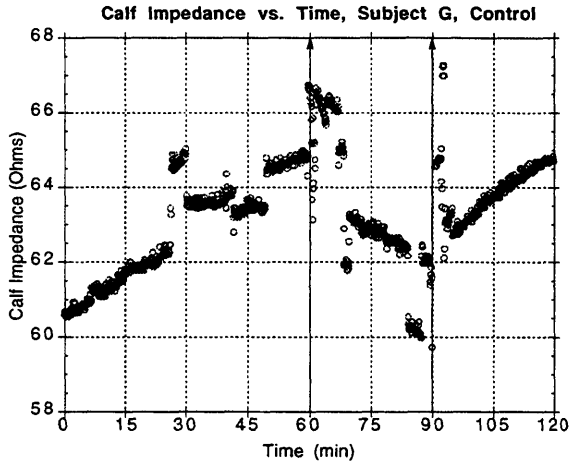

Calf Impedance vs. Time, Subject F, Control
Calf Impedance (Ohms)
86
84
82
80
78
76
74
0 15 30 45 60 75 90 105 120
Time (min)

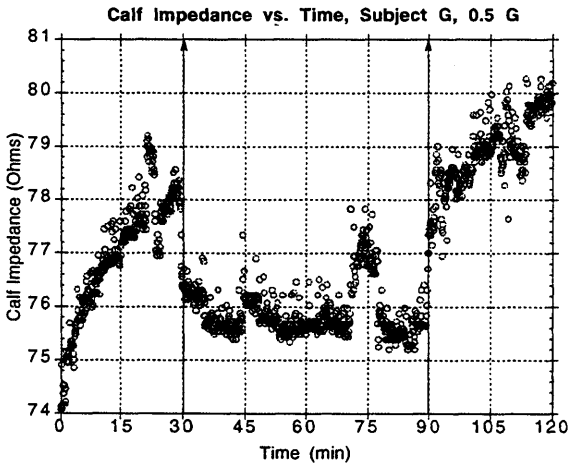

Calf Impedance vs. Time, Subject F, 0.5 G
Calf Impedance (Ohms)
81
80
79
78
77
76
75
74
0 15 30 45 60 75 90 105 120
Time (min)

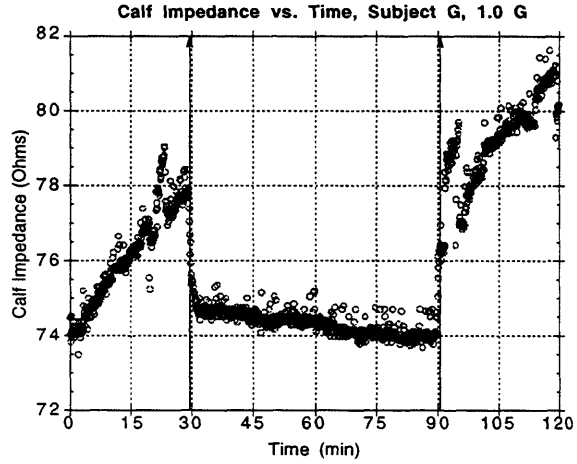

Calf Impedance vs. Time, Subject F, 1.0 G
Calf Impedance (Ohms)
84
82
80
78
76
74
72
70
0 15 30 45 60 75 90 105 120 135
Time (min)

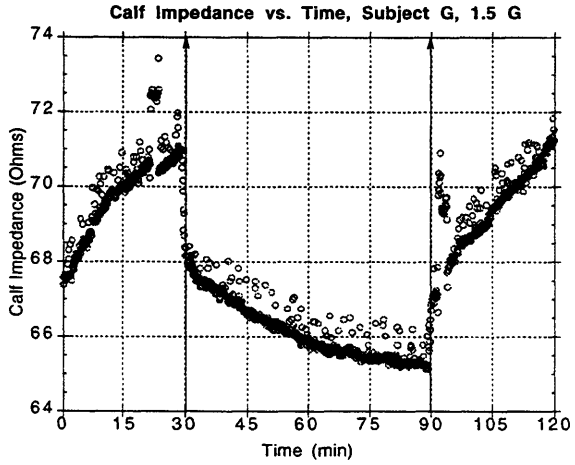

Calf Impedance vs. Time, Subject F, 1.5 G
Calf Impedance (Ohms)
82
80
78
76
74
72
70
0 15 30 45 60 75 90 105 120
Time (min)

Subject G

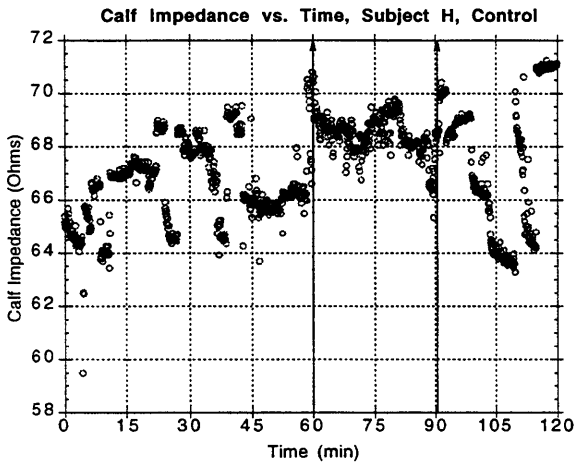

Calf Impedance vs. Time, Subject G, Control
Calf Impedance (Ohms)
Time (min)

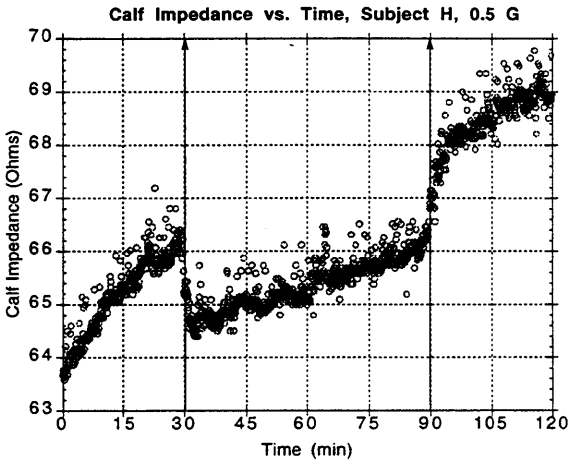

Calf Impedance vs. Time, Subject G, 0.5 G
Calf Impedance (Ohms)
Time (min)

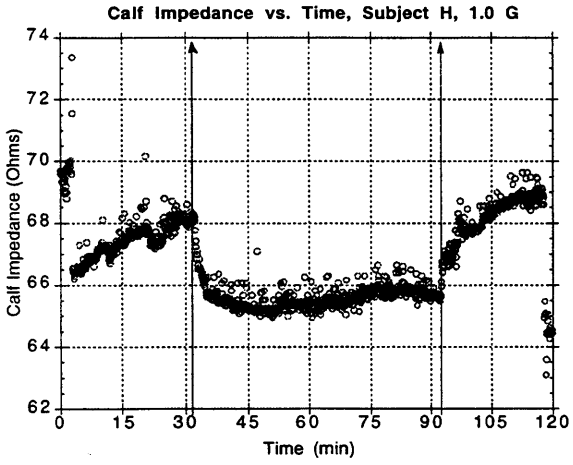

Calf Impedance vs. Time, Subject G, 1.0 G
Calf Impedance (Ohms)
Time (min)

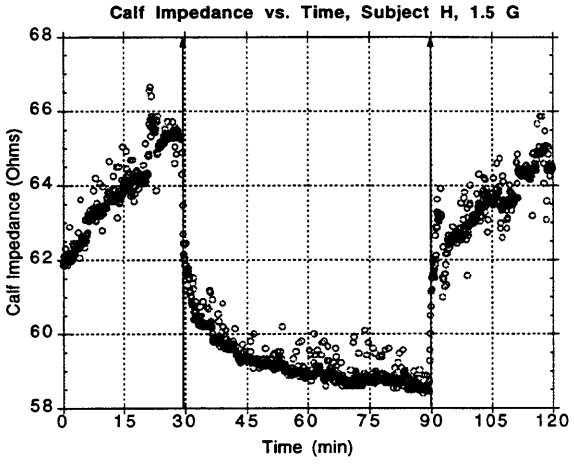

Calf Impedance vs. Time, Subject G, 1.5 G
Calf Impedance (Ohms)
Time (min)

Subject H

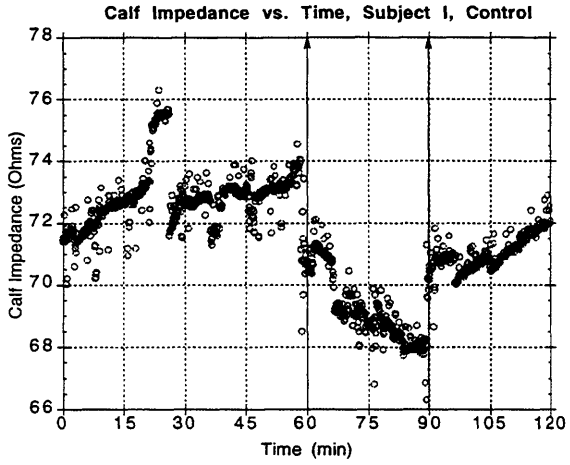

Calf Impedance vs. Time, Subject H, Control
Calf Impedance (Ohms)
72
70
68
66
64
62
60
58
0
15
30
45
60
75
90
105
120
Time (min)

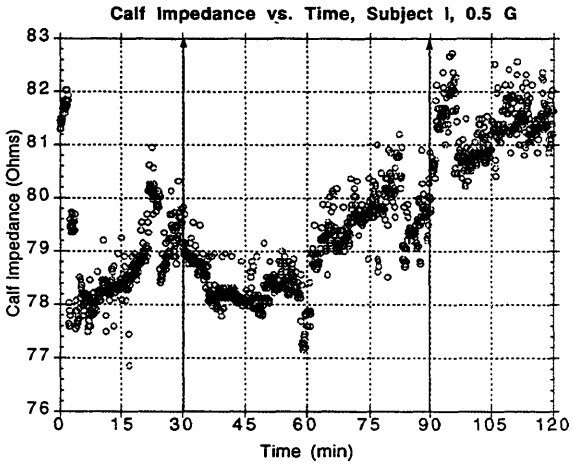

Calf Impedance vs. Time, Subject H, 0.5 G
Calf Impedance (Ohms)
70
69
68
67
66
65
64
63
0
15
30
45
60
75
90
105
120
Time (min)

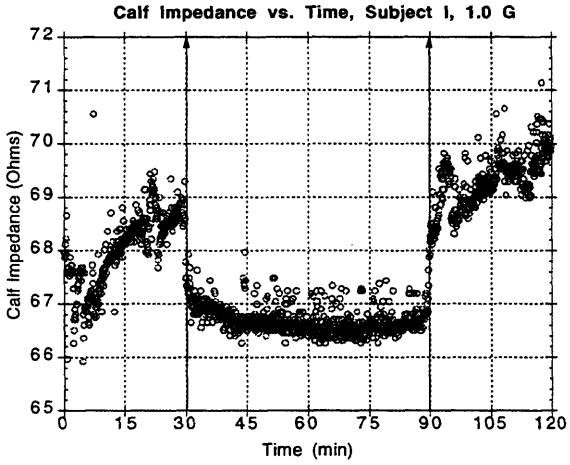

Calf Impedance vs. Time, Subject H, 1.0 G
Calf Impedance (Ohms)
74
72
70
68
66
64
62
0
15
30
45
60
75
90
105
120
Time (min)

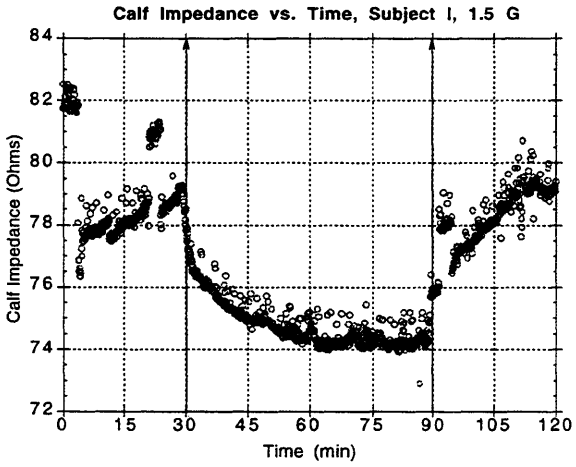

Calf Impedance vs. Time, Subject H, 1.5 G
Calf Impedance (Ohms)
68
66
64
62
60
58
0
15
30
45
60
75
90
105
120
Time (min)

Subject I

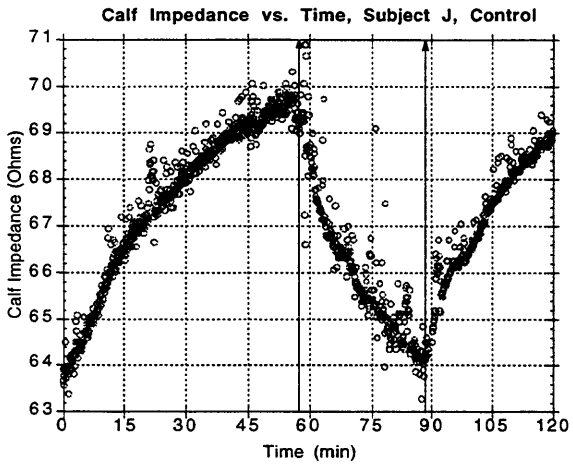

Calf Impedance vs. Time, Subject I, Control
Calf Impedance (Ohms)
78
76
74
72
70
68
66
0 15 30 45 60 75 90 105 120
Time (min)

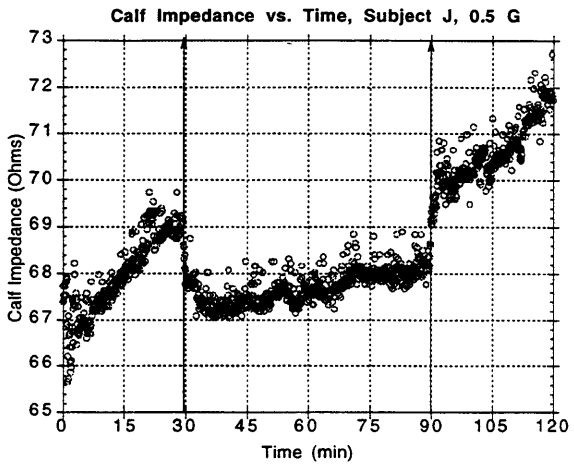

Calf Impedance vs. Time, Subject I, 0.5 G
Calf Impedance (Ohms)
83
82
81
80
79
78
77
76
0 15 30 45 60 75 90 105 120
Time (min)

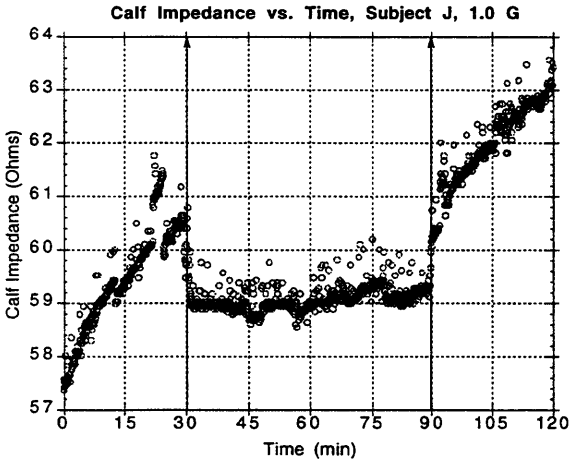

Calf Impedance vs. Time, Subject I, 1.0 G
Calf Impedance (Ohms)
72
71
70
69
68
67
66
65
0 15 30 45 60 75 90 105 120
Time (min)

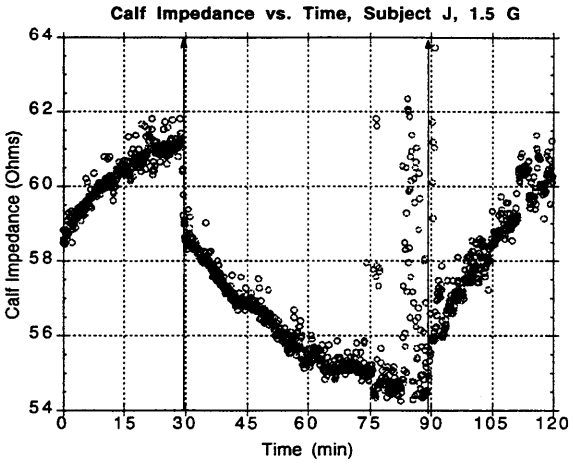

Calf Impedance vs. Time, Subject I, 1.5 G
Calf Impedance (Ohms)
84
82
80
78
76
74
72
0 15 30 45 60 75 90 105 120
Time (min)

Subject J


Calf Impedance vs. Time, Subject J, Control
Calf Impedance (Ohms)
71
70
69
68
67
66
65
64
63
0
15
30
45
60
75
90
105
120
Time (min)

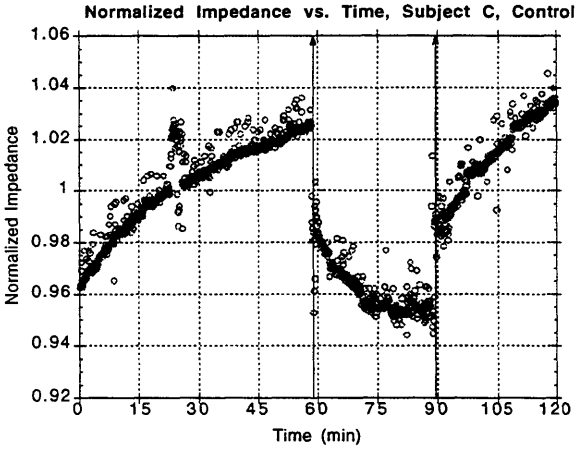

Calf Impedance vs. Time, Subject J, 0.5 G
Calf Impedance (Ohms)
73
72
71
70
69
68
67
66
65
0
15
30
45
60
75
90
105
120
Time (min)

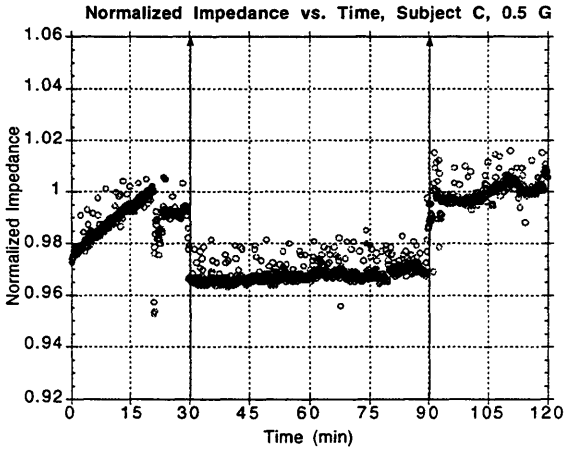

Calf Impedance vs. Time, Subject J, 1.0 G
Calf Impedance (Ohms)
64
63
62
61
60
59
58
57
0
15
30
45
60
75
90
105
120
Time (min)

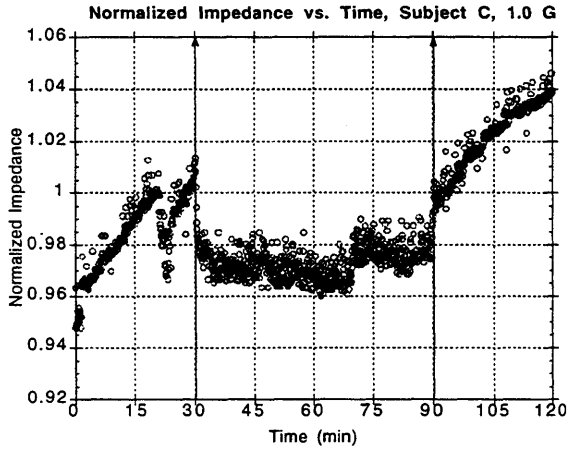

Calf Impedance vs. Time, Subject J, 1.5 G
Calf Impedance (Ohms)
64
62
60
58
56
54
0
15
30
45
60
75
90
105
120
Time (min)

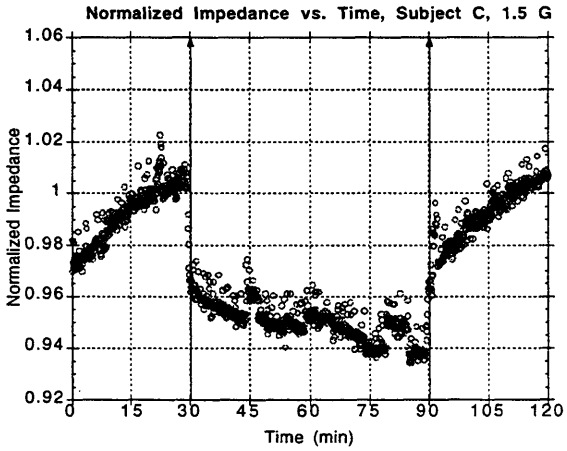
Normalized Volume Plots

Subject C

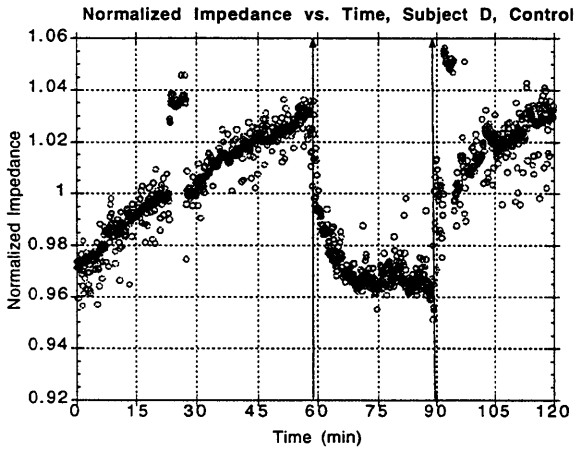


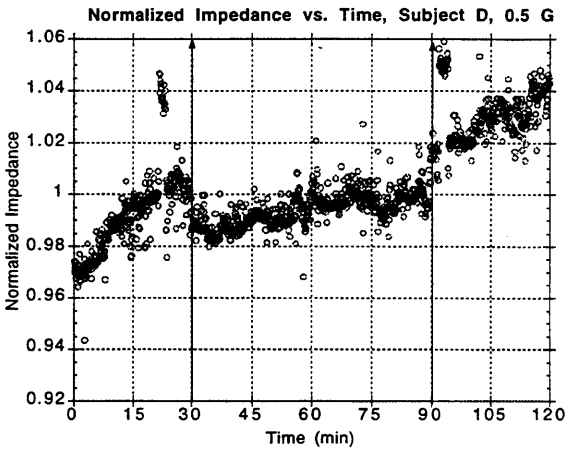


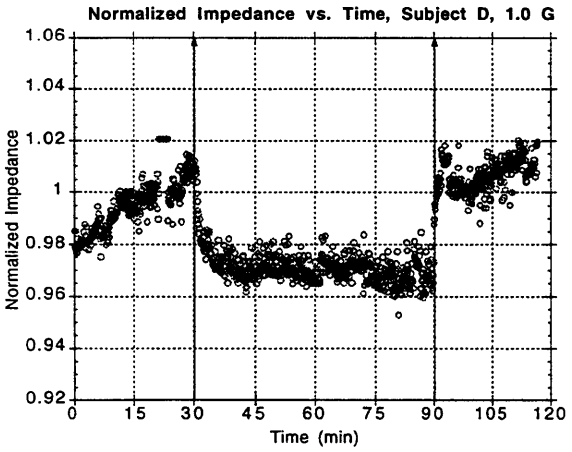


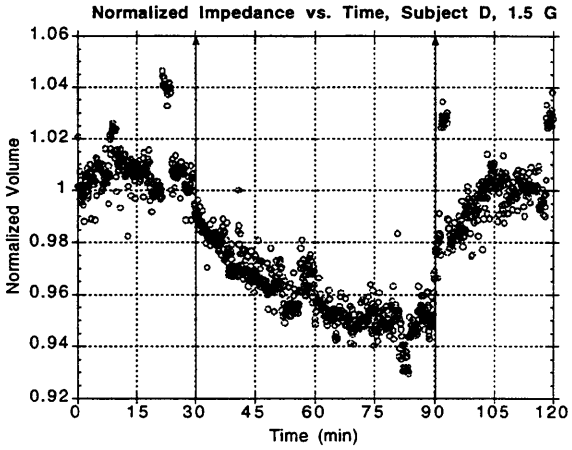


Subject D

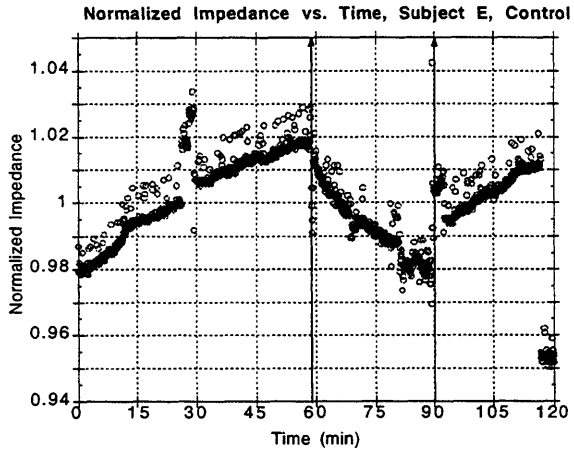

Normalized Impedance vs. Time, Subject D, Control
Normalized Impedance
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0
15
30
45
60
75
90
105
120
Time (min)

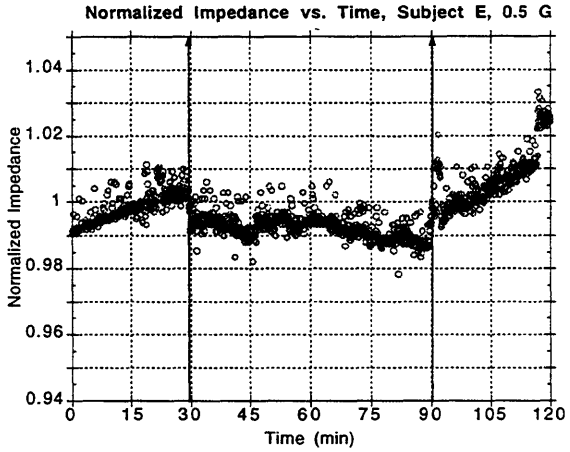

Normalized Impedance vs. Time, Subject D, 0.5 G
Normalized Impedance
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0
15
30
45
60
75
90
105
120
Time (min)

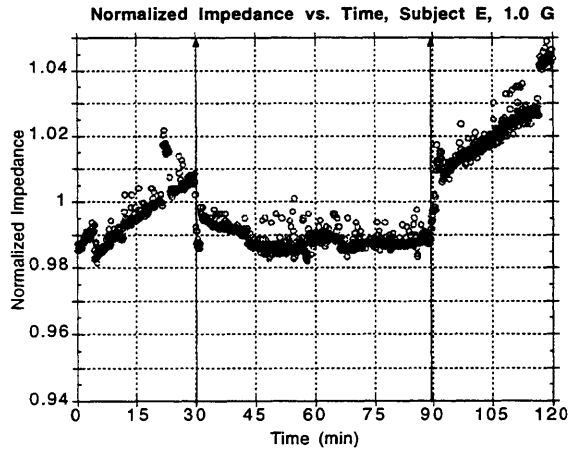

Normalized Impedance vs. Time, Subject D, 1.0 G
Normalized Impedance
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0
15
30
45
60
75
90
105
120
Time (min)

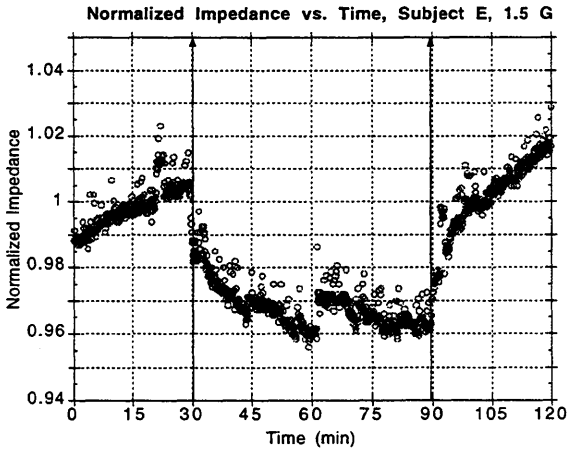

Normalized Impedance vs. Time, Subject D, 1.5 G
Normalized Volume
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0
15
30
45
60
75
90
105
120
Time (min)

Subject E

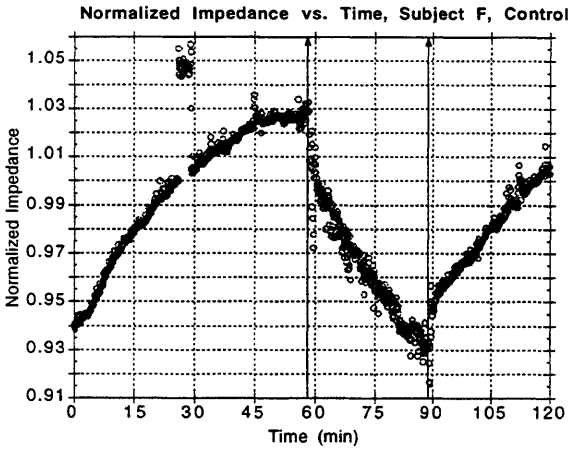

Normalized Impedance vs. Time, Subject E, Control
Normalized Impedance
1.04
1.02
1
0.98
0.96
0.94
0 15 30 45 60 75 90 105 120
Time (min)

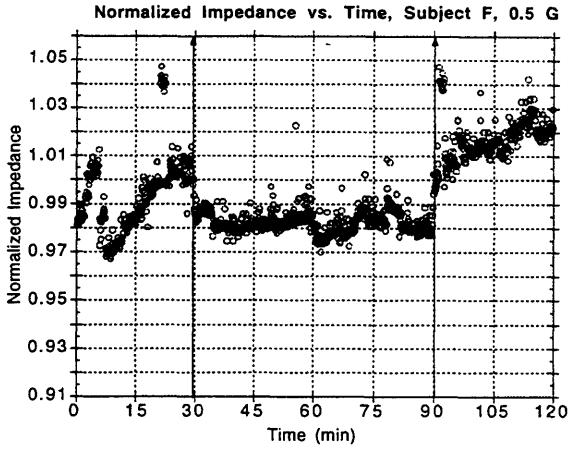

Normalized Impedance vs. Time, Subject E, 0.5 G
Normalized Impedance
1.04
1.02
1
0.98
0.96
0.94
0 15 30 45 60 75 90 105 120
Time (min)

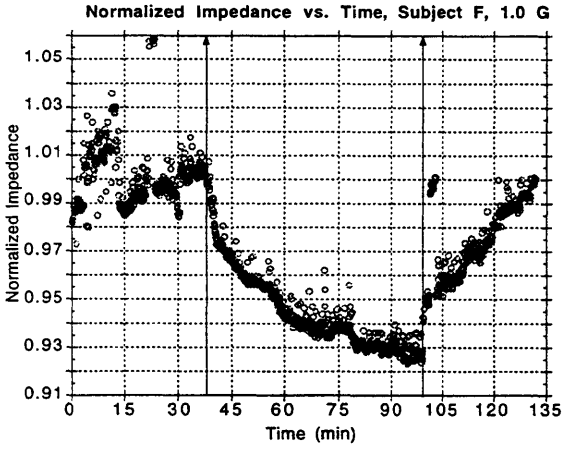

Normalized Impedance vs. Time, Subject E, 1.0 G
Normalized Impedance
1.04
1.02
1
0.98
0.96
0.94
0 15 30 45 60 75 90 105 120
Time (min)

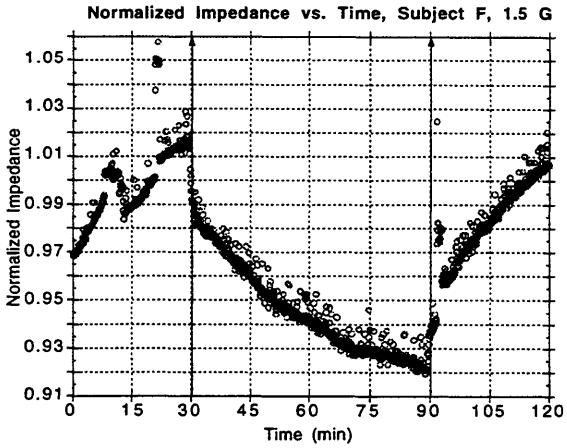

Normalized Impedance vs. Time, Subject E, 1.5 G
Normalized Impedance
1.04
1.02
1
0.98
0.96
0.94
0 15 30 45 60 75 90 105 120
Time (min)

Subject F

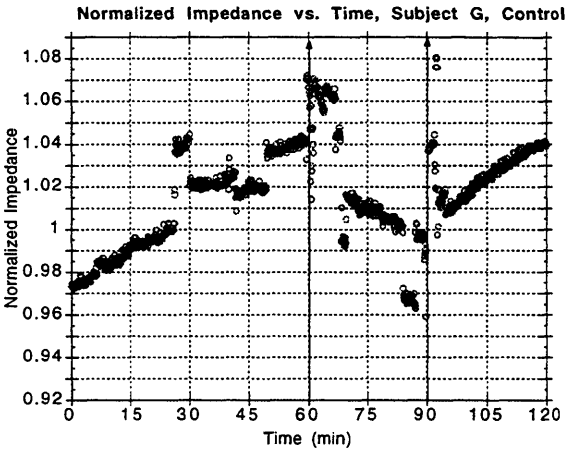

Normalized Impedance vs. Time, Subject F, Control
Normalized Impedance
1.05
1.03
1.01
0.99
0.97
0.95
0.93
0.91
0 15 30 45 60 75 90 105 120
Time (min)

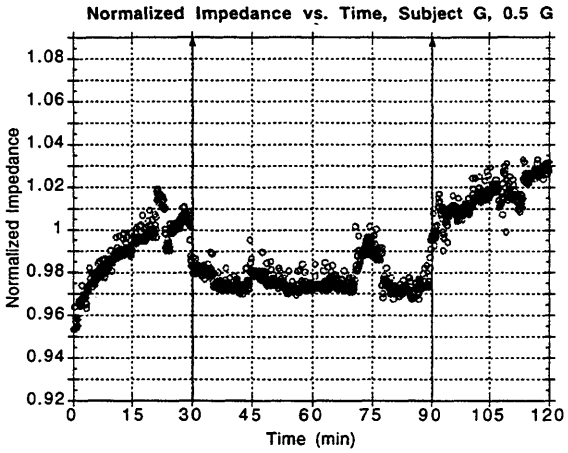

Normalized Impedance vs. Time, Subject F, 0.5 G
Normalized Impedance
1.05
1.03
1.01
0.99
0.97
0.95
0.93
0.91
0 15 30 45 60 75 90 105 120
Time (min)

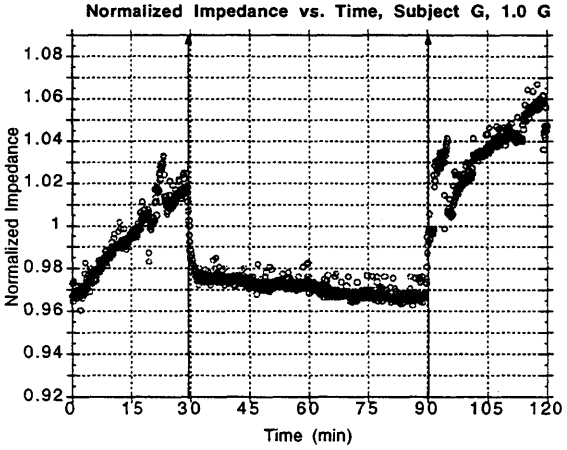

Normalized Impedance vs. Time, Subject F, 1.0 G
Normalized Impedance
1.05
1.03
1.01
0.99
0.97
0.95
0.93
0.91
0 15 30 45 60 75 90 105 120 135
Time (min)

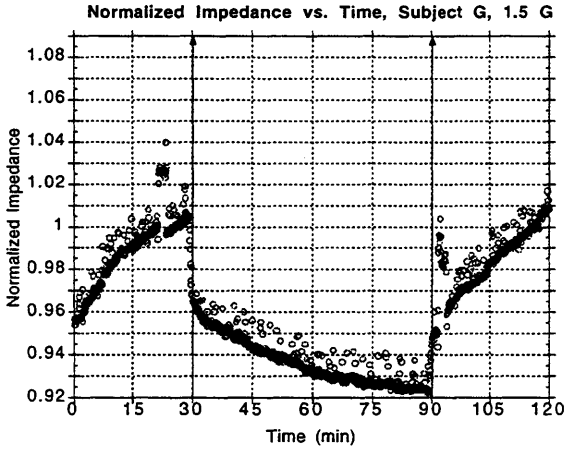

Normalized Impedance vs. Time, Subject F, 1.5 G
Normalized Impedance
1.05
1.03
1.01
0.99
0.97
0.95
0.93
0.91
0 15 30 45 60 75 90 105 120
Time (min)

Subject G

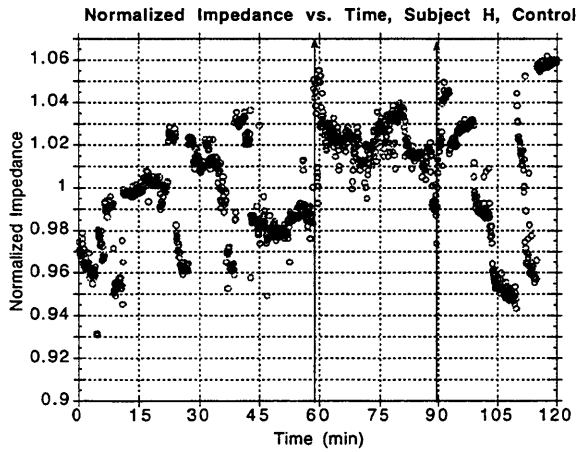

Normalized Impedance vs. Time, Subject G, Control
Normalized Impedance
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0 15 30 45 60 75 90 105 120
Time (min)

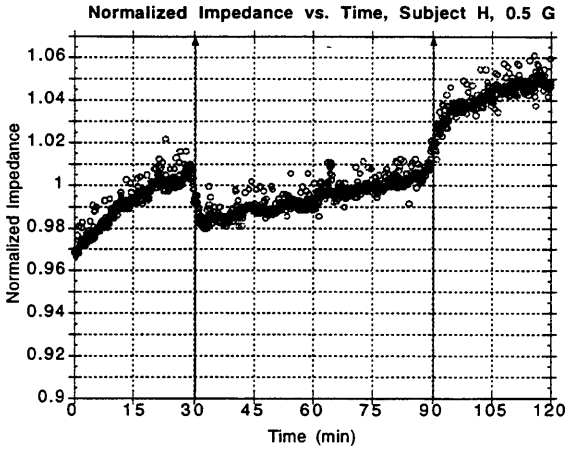

Normalized Impedance vs. Time, Subject G, 0.5 G
Normalized Impedance
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0 15 30 45 60 75 90 105 120
Time (min)

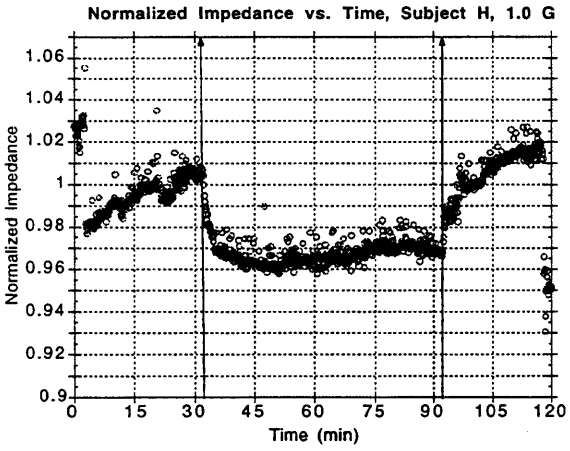

Normalized Impedance vs. Time, Subject G, 1.0 G
Normalized Impedance
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0 15 30 45 60 75 90 105 120
Time (min)

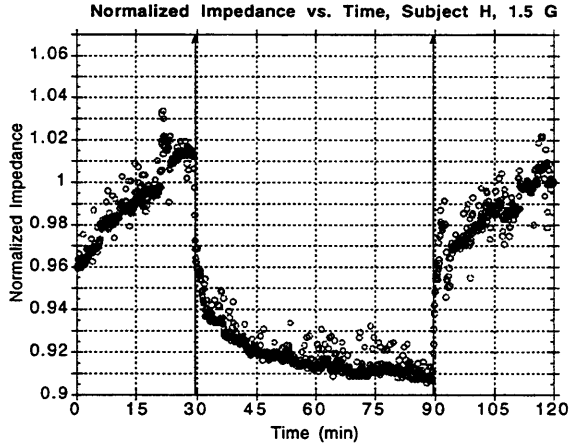

Normalized Impedance vs. Time, Subject G, 1.5 G
Normalized Impedance
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0 15 30 45 60 75 90 105 120
Time (min)

Subject H

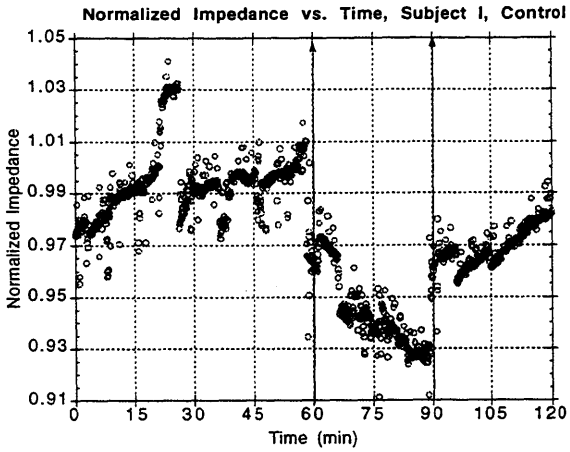

Normalized Impedance vs. Time, Subject H, Control
Normalized Impedance
Time (min)

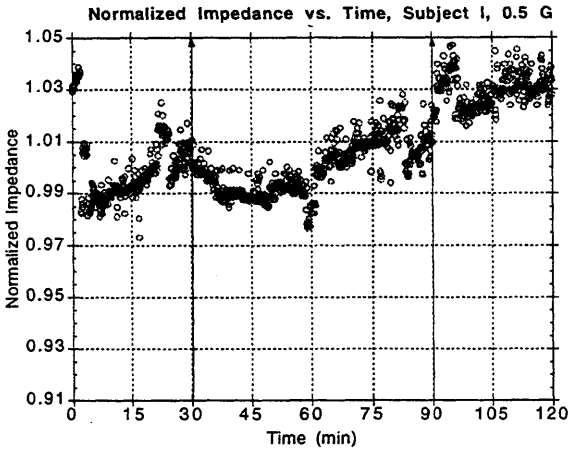

Normalized Impedance vs. Time, Subject H, 0.5 G
Normalized Impedance
Time (min)

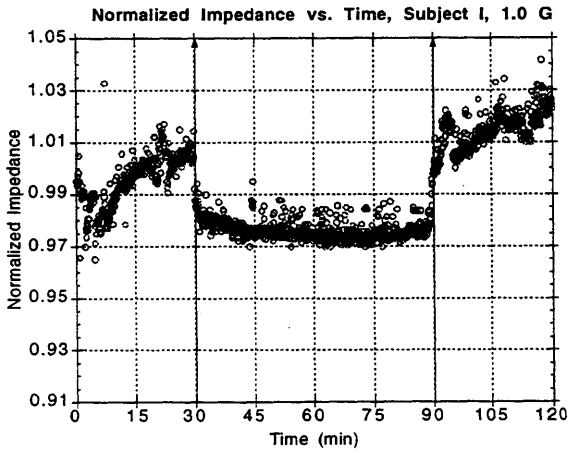

Normalized Impedance vs. Time, Subject H, 1.0 G
Normalized Impedance
Time (min)

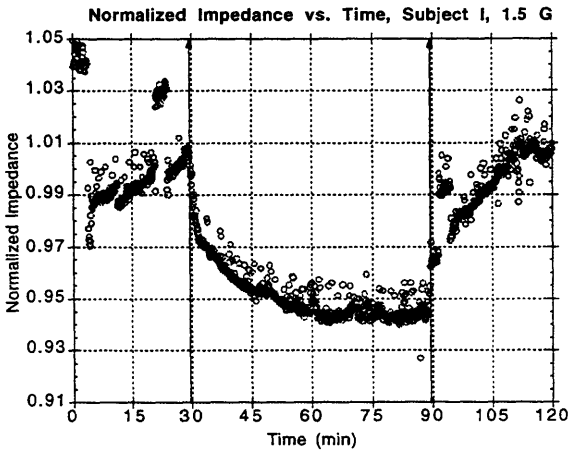

Normalized Impedance vs. Time, Subject H, 1.5 G
Normalized Impedance
Time (min)

Subject I

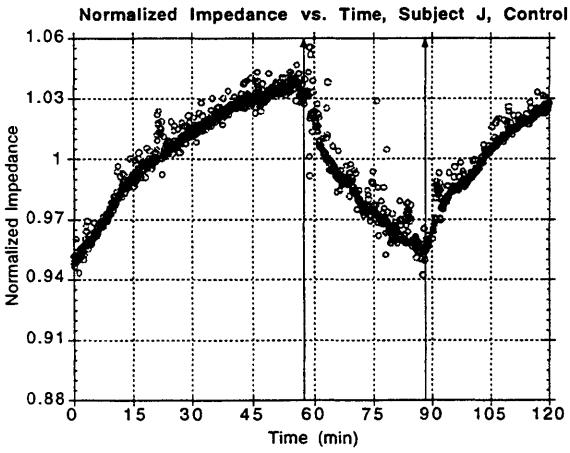

Normalized Impedance vs. Time, Subject I, Control
Normalized Impedance
1.05
1.03
1.01
0.99
0.97
0.95
0.93
0.91
0 15 30 45 60 75 90 105 120
Time (min)

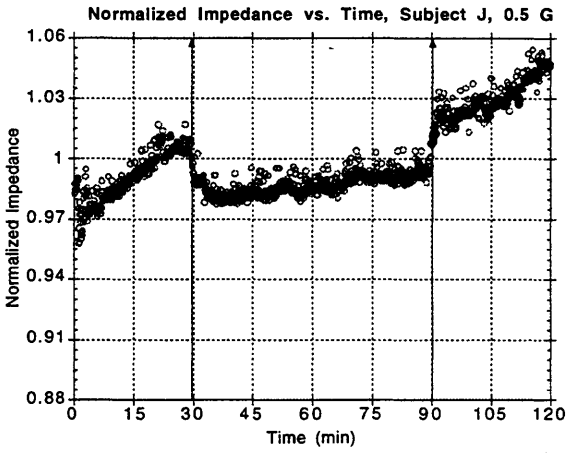

Normalized Impedance vs. Time, Subject I, 0.5 G
Normalized Impedance
1.05
1.03
1.01
0.99
0.97
0.95
0.93
0.91
0 15 30 45 60 75 90 105 120
Time (min)

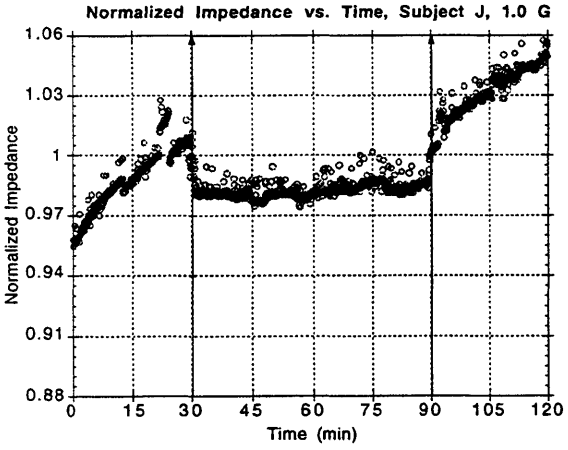

Normalized Impedance vs. Time, Subject I, 1.0 G
Normalized Impedance
1.05
1.03
1.01
0.99
0.97
0.95
0.93
0.91
0 15 30 45 60 75 90 105 120
Time (min)

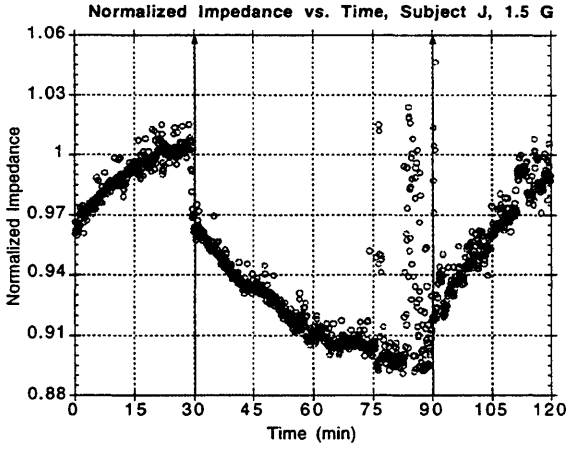

Normalized Impedance vs. Time, Subject I, 1.5 G
Normalized Impedance
1.05
1.03
1.01
0.99
0.97
0.95
0.93
0.91
0 15 30 45 60 75 90 105 120
Time (min)

Subject J


Normalized Impedance vs. Time, Subject J, Control
Normalized Impedance
1.06
1.03
1
0.97
0.94
0.91
0.88
0
15
30
45
60
75
90
105
120
Time (min)


Normalized Impedance vs. Time, Subject J, 0.5 G
Normalized Impedance
1.06
1.03
1
0.97
0.94
0.91
0.88
0
15
30
45
60
75
90
105
120
Time (min)


Normalized Impedance vs. Time, Subject J, 1.0 G
Normalized Impedance
1.06
1.03
1
0.97
0.94
0.91
0.88
0
15
30
45
60
75
90
105
120
Time (min)


Normalized Impedance vs. Time, Subject J, 1.5 G
Normalized Impedance
1.06
1.03
1
0.97
0.94
0.91
0.88
0
15
30
45
60
75
90
105
120
Time (min)

Data at Discrete Points

Subject C

t=0											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
60.303	64.746	72.217	70.801	60.44116667	64.89753939	71.346	71.1505	average (Ohms)			
60.303	64.844	71.043	71.48	0.1800200622	0.127437929	0.333689547	0.2763546634	stdev (Ohms)			
60.352	64.795	71.094	71.045	0.2978443985	0.196247346	0.4677040042	0.3885320612	conf. of variation (%)			
60.303	64.844	71.094	71.045	0.0519657477	0.03678816	0.0965327881	0.0797777204	std error (Ohms)			
60.352	64.844	71.191	71.631	0.9649853877	0.975489092	0.951590839	0.974196905	normalized value			
60.493	64.941	71.143	70.898								
60.889	65.039	71.191	71.143								
60.449	64.99	71.383	71.143								
60.449	65.137	71.398	70.996								
60.449	64.99	71.191	71.24								
60.303	64.941	71.631	70.85								
60.449	65.137	71.484	71.094								
t=20											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			average	stdev
62.646	66.455	74.951	72.998	62.69425	66.359	74.9735	73.0145	average (Ohms)		69.2603125	3.712541267
62.744	66.553	74.903	73.047	0.078100314	0.09613043	0.0532686616	0.1166248884	stdev (Ohms)			
62.598	66.602	74.951	73.096	0.1246972663	0.144437276	0.071048803	0.1597726349	conf. of variation (%)			
62.549	66.504	74.951	73.145	0.022543619	0.027734244	0.015377325	0.033666704	std error (Ohms)			
62.793	66.357	75	73.096	1	1	1	1	normalized value			
62.598	66.553	75.049	73.047								
62.646	66.65	74.951	72.803								
62.549	66.699	75.098	73.047								
62.695	66.65	74.951	72.9								
62.598	66.65	74.951	73.096								
62.549	66.602	74.951	72.803								
62.646	66.309	75	73.096								
t=30-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
62.999	66.113	73.098	73.584	63.01472727	66.15383333	73.24816667	73.38275	average (Ohms)			
63.086	66.162	73.146	73.389	0.055279455	0.045954406	0.174815821	0.235059809	stdev (Ohms)			
62.988	66.113	73.098	73.682	0.08772466	0.069435744	0.232324539	0.320276806	conf. of variation (%)			
63.097	66.162	73.293	73.828	0.016667383	0.013260121	0.050466135	0.067855922	std error (Ohms)			
63.097	66.162	73.146	73.143	1.006074388	0.999763963	1.009636744	1.005180478	normalized value			
62.988	66.211	73.049	73.193								
62.988	66.211	73.195	73.291								
	66.113	73.342	73.193								
63.086	66.162	73.146	73.584								
62.988	66.211	73.391	73.486								
62.999	66.162	73.439	73.145								
63.086	66.064	73.635	73.193								
t=30+											
	0.5 G	1.0 G	1.5 G		0.5 G	1.0 G	1.5 G				
	64.355	73.526	70.898		64.31075	73.50691667	70.47125	average (Ohms)			
	64.307	73.73	70.557		0.060355068	0.219724397	0.205002938	stdev (Ohms)			
	64.307	73.633	70.703		0.093842289	0.298916628	0.29090294	conf. of variation (%)			
	64.258	73.438	70.557		0.017421741	0.06342897	0.059179251	std error (Ohms)			
	64.355	73.438	70.215		0.966076552	0.98041249	0.965167878	normalized value			
	64.258	73.682	70.605								
	64.307	73.633	70.361								
	64.258	73.242	70.41								
	64.453	73.145	70.313								
	64.258	73.438	70.508								
	64.258	73.389	70.264								
	64.355	73.389	70.264								
t=60-											
Control				Control							
64.16				64.12966667				average (Ohms)			
64.307				0.325201318				stdev (Ohms)			
64.209				0.819044426				conf. of variation (%)			
64.307				0.131612961				std error (Ohms)			
64.16				1.023779588				normalized value			
64.307											
64.258											
64.6											
64.307											
64.16											
64.209											
63.5											
t=60+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
61.865	64.355	72.705	69.58	61.36416667	64.45708333	72.57491667	69.55363636	average (Ohms)			
61.719	64.551	72.51	69.531	0.205746831	0.195988617	0.230354438	0.110260599	stdev (Ohms)			
61.426	64.404	72.607	69.531	0.334199035	0.304060635	0.317402298	0.158398659	conf. of variation (%)			
61.621	64.453	72.461	69.531	0.0839958	0.05657704	0.066497609	0.033244888	std error (Ohms)			
	64.258	72.754	69.678	0.982915364	0.968274775	0.967981749	0.952555798	normalized value			
61.426	64.553	73.145	69.58								
	64.355	72.656	69.58								
	64.355	72.51	69.434								
	64.795	72.266	69.482								
	64.307	72.461									
	64.404	72.314	69.678								
61.328	64.893	72.51	69.287								
t=90-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
59.961	64.502	73.73	68.408	59.6337	64.47341667	73.34427273	68.43490909	average (Ohms)			
59.863	64.453	73.34		0.249951129	0.038855112	0.233375702	0.082750776	stdev (Ohms)			
59.814	64.453	73.242	68.457	0.419144089	0.060265321	0.318192127	0.120918953	conf. of variation (%)			
59.814	64.551	73.145	68.408	0.079041487	0.011216305	0.070363422	0.024950298	std error (Ohms)			
59.57	64.453	73.096	68.311	0.952094102	0.968520132	0.978243196	0.937278336	normalized value			
59.619	64.453	73.584	68.555								
	64.502	73.047	68.408								
59.326	64.453	73.535	68.408								
	64.502		68.311								
59.18	64.502	73.486	68.555								
59.717	64.404	73.486	68.457								
59.473	64.453	73.096	68.506								
t=90+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
61.67	63.623	74.17	70.508	61.82866667	63.86908333	74.71525	70.47125	average (Ohms)			
61.621	63.623	74.414	70.508	0.312366141	0.213472836	0.362907483	0.251630235	stdev (Ohms)			
62.5	63.674	74.854	70.508	0.505212481	0.334085816	0.485720763	0.357096313	conf. of variation (%)			
61.67	66.26	75.098	70.313	0.090172338	0.061624161	0.104762866	0.072643166	std error (Ohms)			
61.67	63.771	74.463	70.557	0.987158204	0.962485847	0.996528866	0.965167878	normalized value			
61.768	63.869	75.293	70.996								
61.768	63.82	74.463	70.41								
61.768	63.82	74.951	70.117								
61.816	63.869	74.463	70.264								
62.451	66.26	74.561	70.117								
61.523	66.016	74.609	70.654								
61.719	63.82	75.244	70.703								
t=120											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
64.746	67.285	78.418	73.34	64.50491667	67.02475	77.52166667	73.49458333	average (Ohms)			
64.893	67.188	77.59	73.438	0.102190071	0.139907787	0.161036361	0.085317011	stdev (Ohms)			
64.893	67.041	77.881	73.486	0.157443809	0.199788306	0.206690088	0.116086122	conf. of variation (%)			
64.844	67.061	77.93	73.438	0.029499732	0.038655848	0.046492967	0.0246289	std error (Ohms)			
64.844	67.139	77.832	73.438	1.036252796	1.00684628	1.039293059	1.006575178	normalized value			
64.844	67.09	77.832	73.438								
64.941	66.992	77.59	73.486								
63.088	66.943	77.832	73.584								
64.844	66.943	77.881	73.486								
63.039	66.943	77.832	73.584								
64.844	66.846	77.881	73.584								
63.039	66.846	77.881	73.633								

Subject D

t=0										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
80.713	81.443	95.752	94.141	80.85525	81.185	95.83366667	94.05525	average (Ohms)		
80.762	81.104	95.801	94.141	0.172263606	0.172002214	0.141799688	0.287104708	stdev (Ohms)		
80.713	81.25	95.801	94.092	0.21305183	0.211864401	0.147955304	0.305251125	coef. of variation (%)		
80.859	81.443	95.654	94.043	0.04972822	0.049652738	0.040934044	0.08287999	std error (Ohms)		
80.713	81.299	95.709	94.141	0.972257059	0.970806644	0.978687017	1.000089511	normalized value		
81.006	81.152	96.191	94.678							
80.957	81.055	95.947	93.652							
80.859	80.908	95.85	94.189							
80.957	81.104	95.947	93.848							
81.201	81.348	95.801	94.189							
80.957	81.104	95.947	93.555							
80.366	81.006	95.85	93.994							
t=20										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G		average	stdev
83.203	83.447	97.656	94.287	83.16241667	83.42833333	97.94108333	93.98991667	average (Ohms)	89.6799373	7.437442484
82.91	83.496	97.9	94.189	0.222030184	0.248423148	0.28961273	0.209438826	stdev (Ohms)		
83.105	83.496	97.705	94.092	0.270379179	0.297063905	0.295785073	0.216447302	coef. of variation (%)		
83.301	83.643	97.461	94.092	0.064957732	0.071713586	0.0847587	0.058727731	std error (Ohms)		
83.203	83.496	97.461	93.994	1	1	1	1	normalized value		
83.203	83.643	98.096	94.189							
83.057	83.545	98.145	93.652							
83.008	83.496	98.096	93.896							
83.789	83.691	98.145	93.701							
83.105	83.643	98.242	94.043							
83.057	83.545	98.193	93.994							
83.008	84.375	98.193	93.75							
t=30-										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
83.154	82.959	98.585	93.945	83.44727273	83.76866667	98.77108333	94.38954545	average (Ohms)		
83.252	84.082	98.438	94.092	0.269294896	0.28927193	0.22588994	0.2600932	stdev (Ohms)		
83.496	83.838	98.389	94.189	0.322715036	0.330097406	0.228700479	0.275541298	coef. of variation (%)		
83.447	83.74	99.023	94.238	0.081196049	0.084460514	0.065208809	0.07842103	std error (Ohms)		
	83.838	98.877	94.873	1.003425288	1.001702016	1.008474483	1.004294384	normalized value		
84.131	84.082	98.926								
83.643	83.984	98.73	94.434							
83.545	83.838	98.73	94.482							
83.398	83.74	99.121	94.58							
83.301	83.789	98.877	94.482							
83.301	83.74	98.877	94.434							
83.252	83.594	98.73	94.58							
t=30+										
	0.5 G	1.0 G	1.5 G		0.5 G	1.0 G	1.5 G			
	82.52	96.729	93.506		82.60525	96.29733333	93.282	average (Ohms)		
	82.617	96.387	93.457		0.112304072	0.312289008	0.194782896	stdev (Ohms)		
	82.52	96.387	93.457		0.135953705	0.324296631	0.20881027	coef. of variation (%)		
	82.471	96.582	93.164		0.032419595	0.090150071	0.056228834	std error (Ohms)		
	82.813	96.924	93.262		0.987789931	0.983214851	0.992468164	normalized value		
	82.52	96.143	93.311							
	82.52	96.143	93.115							
	82.715	96.094	93.066							
	82.52	95.996	93.066							
	82.764	95.996	93.115							
	82.666	95.947	93.213							
	82.617	96.24	93.652							
t=60-										
Control				Control						
85.693				85.616				average (Ohms)		
83.01				0.356640894				stdev (Ohms)		
83.84				0.416358097				coef. of variation (%)		
83.742				0.102953938				std error (Ohms)		
83.958				1.029503512				normalized value		
84.912										
83.84										
85.693										
85.693										
85.254										
85.791										
85.986										
t=60+										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
83.008	83.643	94.58	89.355	83.17883333	83.728	94.47734545	89.807	average (Ohms)		
82.813	83.984		89.16	0.668018686	0.284043531	0.22904164	0.290679926	stdev (Ohms)		
82.764	84.18	95.068	89.6	0.803111151	0.33924357	0.241917794	0.323003693	coef. of variation (%)		
83.057	83.789	94.482	89.99	0.192840526	0.081996304	0.069058635	0.083738862	std error (Ohms)		
84.619	83.691	94.531	89.99	1.000197405	1.001215726	0.986678561	0.955496113	normalized value		
84.229	84.082	94.58	89.99							
83.74	83.643	94.482	89.99							
82.617	83.594	94.531	90.039							
82.715	83.496	94.922	89.941							
82.617	83.984	95.068	89.795							
82.715	83.398	94.531	89.795							
83.252	83.252	94.678	90.039							
t=90-										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
79.932	82.91	94.434	89.063	79.80172727	83.24375	94.76643455	89.47758333	average (Ohms)		
80.029	83.008	94.531	89.111	0.411201189	0.166319575	0.389328489	0.414055018	stdev (Ohms)		
80.029	83.447		89.16	0.514698084	0.199791063	0.410820435	0.462744973	coef. of variation (%)		
80.078	83.447	95.41	89.063	0.123981824	0.048010595	0.117386936	0.119526811	std error (Ohms)		
80.42	83.35	94.873	90.137	0.960671064	0.995425085	0.967386342	0.951591304	normalized value		
79.785	83.203	95.068	89.453							
80.322	83.301	94.873	89.404							
	83.203	94.238	89.307							
79.102	83.154	94.336	89.355							
79.492	83.203	94.531	89.502							
80.225	83.301	94.824	89.893							
79.395	83.398	95.313	90.283							
t=90+										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
83.154	85.01	97.803	91.748	82.47416667	84.84291667	98.06725	91.59558333	average (Ohms)		
81.982	85.156	97.607	91.846	0.819578146	0.419186758	0.286610523	0.211224281	stdev (Ohms)		
83.594	85.107	97.754	91.797	0.991355234	0.49407396	0.292258938	0.229733103	coef. of variation (%)		
83.398	85.156	98.096	91.748	0.236591831	0.121008794	0.082737224	0.060975198	std error (Ohms)		
83.35	85.01	98.193	91.699	0.994128938	1.01454785	1.001288189	0.978140986	normalized value		
83.447	84.766	97.803	92.041							
81.885	85.107	98.389	92.041							
81.738	84.18	98.486	91.846							
81.104	84.277	98.143	91.797							
82.813	85.254	97.9	92.09							
82.471	84.082	98.291	92.188							
83.154	85.01	98.34	92.383							
t=120										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
85.986	87.207	99.17	93.506	85.95758333	87.30475	99.19058333	93.63241667	average (Ohms)		
83.84	87.207	99.17	94.043	0.187283129	0.108238898	0.43499637	0.370863724	stdev (Ohms)		
85.596	87.109	99.023	93.555	0.217931576	0.123978247	0.438710597	0.396000164	coef. of variation (%)		
86.182	87.256	98.535	93.652	0.05406436	0.031245879	0.131346196	0.107059135	std error (Ohms)		
86.133	87.207	98.877	93.115	1.033370643	1.043986344	1.012733117	0.996409189	normalized value		
86.084	87.402	99.707	93.604							
86.084	87.451	98.877	93.799							
85.986	87.451	98.682	93.848							
86.035	87.354	98.926	93.066							
85.645	87.305	99.707	93.408							
85.84	87.354	99.834	93.848							
83.84	87.354	99.736	94.385							

Subject E

t=0											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
78.662	74.951	74.219	76.416	78.67825	74.95583333	74.30816667	76.42008333	average (Ohms)			
78.857	74.951	74.365	76.416	0.0892279037	0.0987419355	0.0341182911	0.037060308	stdev (Ohms)			
78.613	75	74.316	76.514	0.113473618	0.131663228	0.072016496	0.0746669	coef. of variation (%)			
78.662	74.951	74.219	76.367	0.0257726444	0.0285043411	0.0136641239	0.01647195	std error (Ohms)			
78.613	75	74.268	76.416	0.979831315	0.991815241	0.986546539	0.988263279	normalized value			
78.711	75	74.365	76.416								
78.613	74.951	74.316	76.416								
78.364	74.951	74.268	76.318								
78.662	75	74.316	76.367								
78.613	74.902	74.316	76.416								
78.809	73.299	74.365	76.514								
78.76	75	74.365	76.463								
t=20											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			average	stdev
80.322	75.586	75.342	77.393	80.28775	75.61441667	75.3215	77.3275	average (Ohms)		77.14028167	2.283937904
80.225	75.879	75.342	77.588	0.0532892902	0.135623459	0.064020959	0.135527907	stdev (Ohms)			
80.225	75.488	75.293	77.1	0.0634870964	0.179364351	0.08499644	0.198342442	coef. of variation (%)			
80.322	75.781	75.391	77.246	0.015268866	0.039151698	0.018481139	0.044312689	std error (Ohms)			
80.371	75.391	75.293	77.344	1	1	1	1	normalized value			
80.322	75.537	75.488	77.393								
80.371	75.635	75.293	77.197								
80.322	75.635	75.293	77.197								
80.322	75.586	75.293	77.148								
80.273	75.488	75.293	77.344								
80.225	75.732	75.244	77.441								
80.273	75.635	75.293	77.393								
t=30-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
80.859	75.684	75.732	77.686	80.93716667	75.87483333	75.83	77.64109091	average (Ohms)			
80.811	76.367	75.928	77.734	0.248889475	0.219710438	0.083574681	0.122516492	stdev (Ohms)			
80.811	76.074	75.879	77.686	0.307493327	0.281661828	0.110213213	0.15779832	coef. of variation (%)			
80.811	75.684	75.879	77.588	0.071848302	0.06169289	0.024125932	0.036940112	std error (Ohms)			
80.811	75.684	75.928		1.008212144	1.009444008	1.00675106	1.004053961	normalized value			
81.299	76.123	75.732	77.637								
80.811	75.83	75.781	77.734								
80.762	75.732	75.781	77.783								
81.348	75.83	75.781	77.783								
80.859	75.83	75.781	77.49								
80.859	75.928	75.781	77.49								
81.443	75.732	75.977	77.441								
t=30+											
	0.5 G	1.0 G	1.5 G		0.5 G	1.0 G	1.5 G				
	75.098	75.195	76.034		75.11545455	75.01616667	76.13116667	average (Ohms)			
	75.049	75.098	75.928		0.277280595	0.102749527	0.142424994	stdev (Ohms)			
	75.586	75.049	76.172		0.369152519	0.136969578	0.187078439	coef. of variation (%)			
	75.049	75.049	75.977		0.083604259	0.029661176	0.041114554	std error (Ohms)			
		74.951	76.123		0.99940129	0.995946266	0.984528003	normalized value			
	75.195	74.951	76.416								
	75.391	74.951	76.367								
	75.195	75.195	76.172								
	74.512	74.902	76.123								
	75.299	75	76.123								
	74.951	74.902	76.074								
	74.951	74.951	76.025								
t=60-											
Control				Control							
81.836				81.81958333				average (Ohms)			
81.836				0.248298009				stdev (Ohms)			
81.787				0.303470147				coef. of variation (%)			
81.641				0.071677461				std error (Ohms)			
81.689				1.018952978				normalized value			
81.836											
82.368											
81.738											
81.787											
81.738											
81.592											
81.787											
t=60+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
81.443	75.146	74.361	74.268	81.20125	75.31945455	74.52816667	74.27991667	average (Ohms)			
81.25	75.146	74.414	74.219	0.176585351	0.217845066	0.093913662	0.05127902	stdev (Ohms)			
81.25	75.195	74.609	74.365	0.217466297	0.289228151	0.126013648	0.069034838	coef. of variation (%)			
81.348	75.146	74.512	74.268	0.0509738	0.065682739	0.027111116	0.014802978	std error (Ohms)			
81.201		74.512	74.219	1.011251872	0.996099129	0.989467372	0.960388522	normalized value			
81.543	75.293	74.512	74.316								
81.152	75.781	74.361	74.268								
81.104	75.684	74.414	74.219								
81.104	75.342	74.361	74.316								
81.006	75.195	74.463	74.268								
81.055	75.244	74.463	74.365								
80.957	75.342	74.736	74.268								
t=90-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
78.809	74.736	74.361	74.463	78.7435	74.69075	74.43883333	74.41836364	average (Ohms)			
79.15	74.707	74.365	74.316	0.242188694	0.140244679	0.070351532	0.10590021	stdev (Ohms)			
78.76	74.658	74.414		0.307366586	0.187767125	0.09472354	0.142303868	coef. of variation (%)			
79.102	74.561	74.609	74.365	0.069913834	0.04048315	0.020360699	0.031930115	std error (Ohms)			
78.516	74.658	74.365	74.365	0.980643916	0.987784516	0.988346874	0.96237902	normalized value			
78.662	74.658	74.463	74.316								
78.857	74.561	74.414	74.463								
78.711	74.658	74.463	74.365								
78.906	75.098	74.463	74.316								
78.32	74.658	74.463	74.512								
78.613	74.609	74.463	74.463								
78.516	74.707	74.463	74.658								
t=90+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
79.688	75.586	76.025	75.488	79.60633333	75.5045	76.24108333	75.50866667	average (Ohms)			
79.688	75.488	76.611	75.391	0.141450816	0.185603928	0.178494949	0.08940646	stdev (Ohms)			
79.443	75.439	76.27	75.391	0.177687892	0.245818366	0.234119115	0.118403561	coef. of variation (%)			
	75.635	76.172	75.391	0.081666667	0.053579259	0.051527034	0.025809422	std error (Ohms)			
	75.635	76.221	75.537	0.991389539	0.998544353	1.012208776	0.976478829	normalized value			
	75.439	76.221	75.488								
	75.977	76.172	75.488								
	75.342	76.221	75.586								
	75.342	76.074	75.684								
	75.293	76.025	75.537								
	75.439	76.416	75.586								
	75.439	76.465	75.537								
t=120											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
81.201	76.367	77.734	78.662	81.2805	76.52591667	77.57975	78.74758333	average (Ohms)			
81.152	76.465	77.588	78.662	0.235369922	0.138180026	0.080295032	0.083608893	stdev (Ohms)			
81.152	76.514	77.637	78.711	0.289541732	0.180566315	0.103500014	0.106173281	coef. of variation (%)			
81.201	76.514	77.539	78.662	0.067945444	0.039889138	0.023179185	0.024135808	std error (Ohms)			
81.25	76.514	77.588	78.857	1.01236396	1.01205458	1.029951479	1.018364532	normalized value			
81.982	76.611	77.441	78.662								
81.152	76.904	77.49	78.711								
81.25	76.465	77.588	78.809								
81.152	76.611	77.686	78.906								
81.201	76.416	77.539	78.76								
81.443	76.465	77.539	78.809								
81.348	76.465	77.588	78.76								

Subject F

t=0											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
73.879		76.221	74.561	73.98483333		76.42083333	74.63775	average (Ohms)			
76.025		76.172	74.658	0.107888691		0.185545551	0.043777312	stdev (Ohms)			
73.83		76.221	74.609	0.141987159		0.24279605	0.05867984	coef. of variation (%)			
73.977		76.27	74.561	0.031144782		0.05362987	0.012643195	std error (Ohms)			
73.928		76.27	74.658	0.940328748		0.98484676	0.96430479	normalized value			
73.928		76.367	74.658								
73.977		76.709	74.658								
73.977		76.363	74.658								
76.025		76.363	74.658								
76.025		76.611	74.609								
76.27		76.363	74.658								
73.977		76.514	74.707								
t=30											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			average	stddev
80.664	77.734	77.051	76.855	80.80666667	77.16058333	77.59616667	76.98975	average (Ohms)		78.13820167	1.797144606
80.713	77.051	77.051	76.953	0.063963531	0.280830411	0.339967601	0.07364512	stdev (Ohms)			
80.811	77.734	77.588	76.855	0.079154255	0.36395379	0.438124221	0.095831764	coef. of variation (%)			
80.811	77.246	77.686	76.953	0.018464681	0.081068757	0.098140159	0.021851129	std error (Ohms)			
80.811	76.953	77.881	77.051	1	1	1	1	normalized value			
80.839	77.051	77.393	77.002								
80.811	77.002	77.539	77.002								
80.811	77.051	77.393	77.051								
80.908	77.148	78.271	77.051								
80.811	76.953	77.881	77.002								
80.811	76.953	77.437	77.002								
80.839	77.051	77.437	77.1								
t=30-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
81.201	77.783	78.32	78.32	81.2825	77.74666667	77.89716667	78.29334545	average (Ohms)			
81.152	77.588	77.783	78.809	0.118481683	0.171851592	0.157519811	0.212262745	stdev (Ohms)			
81.201	77.734	77.881	78.271	0.145776308	0.221040463	0.202224429	0.271111422	coef. of variation (%)			
81.201	77.734	77.881		0.034202716	0.049609281	0.045471908	0.063999536	std error (Ohms)			
81.25	77.686	77.832	78.418	1.005888341	1.007583631	1.003879038	1.016934663	normalized value			
81.201	77.588	77.881	78.369								
81.201	77.637	77.783	78.076								
81.299	77.686	77.881	78.32								
81.445	77.637	77.93	78.174								
81.543	77.832	77.686	78.125								
81.348	77.832	77.881	78.32								
81.348	78.223	78.027	78.027								
	77.93										
t=30+											
	0.5 G	1.0 G	1.5 G		0.5 G	1.0 G	1.5 G				
	76.65	76.758	76.367		76.09866667	76.73341667	76.297	average (Ohms)			
	76.172	76.904	76.27		0.262087851	0.203319926	0.222479008	stdev (Ohms)			
	76.123	76.855	76.318		0.345575714	0.264969208	0.291825902	coef. of variation (%)			
	76.221	76.758	76.27		0.079915957	0.058697407	0.064224138	std error (Ohms)			
	76.025	76.611	76.611		0.986287776	0.988881558	0.990222724	normalized value			
	73.879	77.002	73.977								
	73.781	76.959	76.025								
	76.514	76.563	76.074								
	73.928	76.514	76.172								
	73.977	76.416	76.221								
	73.879	76.959	73.928								
	76.025	76.514	76.611								
t=60-											
Control				Control							
82.764				83.15816667				average (Ohms)			
82.861				0.19573998				stdev (Ohms)			
83.398				0.235406801				coef. of variation (%)			
83.301				0.056511059				std error (Ohms)			
83.203				1.029100922				normalized value			
83.252											
83.105											
83.105											
83.154											
83.447											
83.154											
83.154											
t=60+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
81.594	73.732	72.559	72.51	81.47725	73.52475	72.84741667	72.48133939	average (Ohms)			
81.494	73.732	72.998	72.359	0.430970189	0.20415285	0.192399428	0.159563932	stdev (Ohms)			
81.445	73.537	72.705	72.412	0.528915622	0.270512514	0.264112897	0.211866042	coef. of variation (%)			
81.543	73.488	72.705	72.9	0.15215884	0.058933852	0.055540729	0.044532916	std error (Ohms)			
81.299	73.586	72.734	72.461	1.010773637	0.978799625	0.938801745	0.941441339	normalized value			
82.471	73.781	72.607	72.51								
82.001	73.586	73.242	72.412								
	73.684	72.9	72.266								
	73.195	72.852	72.412								
81.201	73.488	72.949	72.461								
	73.195	72.998	72.51								
	73.389	72.9	72.363								
t=90-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
73.049	73.586	71.973	70.596	73.3235	73.40425	72.03408333	70.88825	average (Ohms)			
73.049	73.635	72.656	70.898	0.174572463	0.172070848	0.261951924	0.063667378	stdev (Ohms)			
73.391	73.488	72.119	70.898	0.231757439	0.227387463	0.363549034	0.092622001	coef. of variation (%)			
73.439	76.025	71.875	70.801	0.05039473	0.049672431	0.073619007	0.018956339	std error (Ohms)			
73.537	73.391	71.973	70.947	0.932169975	0.979855863	0.928577872	0.920879078	normalized value			
73.586	73.391	71.924	70.801								
73.293	73.586	71.924	70.801								
73.293	73.537	71.777	70.898								
73.146	73.635	71.924	70.947								
73.293	73.732	71.973	70.898								
73.439	73.537	72.51	70.947								
73.391	73.732	72.021	70.947								
t=90+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
76.318	76.709	73.73	73.047	76.59108333	77.03458333	73.73075	72.4895	average (Ohms)			
76.709	77.344	73.682	72.363	0.185659247	0.235981141	0.127469872	0.219826998	stdev (Ohms)			
76.318	76.807	73.828	72.217	0.242403215	0.305735194	0.172838746	0.303253572	coef. of variation (%)			
76.514	77.344	73.73	72.266	0.053593208	0.067344597	0.036797382	0.063458588	std error (Ohms)			
76.465	76.953	73.975	72.363	0.947831245	0.998367042	0.950443213	0.941547414	normalized value			
76.363	77.051	73.828	72.51								
76.465	76.807	73.584	72.705								
76.563	76.904	73.633	72.412								
76.709	77.441	73.779	72.51								
76.807	77.002	73.828	72.412								
76.807	76.959	73.393	72.559								
76.855	77.1	73.877	72.51								
t=120											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
81.152	78.857	77.49		81.18083333	78.98758333	77.38491667	77.55236364	average (Ohms)			
81.104	78.662	77.389	77.588	0.102781174	0.376739229	0.084763262	0.054081924	stdev (Ohms)			
81.104	78.809	77.441	77.539	0.126607685	0.476960066	0.109522697	0.06973801	coef. of variation (%)			
81.152	78.662	77.441	77.49	0.029670949	0.108755248	0.024469046	0.016306314	std error (Ohms)			
81.201	79.834	77.441	77.539	1.004650994	1.023677893	0.997210657	1.007307643	normalized value			
81.152	78.809	77.686	77.539								
81.396	78.955	77.441	77.49								
81.25	78.857	77.539	77.539								
81.25	78.711	77.588	77.589								
81.299	79.15	77.588	77.589								
81.055	78.906	77.637	77.588								
81.055	79.639	77.588	77.686								

Subject G

t=0											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
60.596	74.072	74.463	67.578	60.6	74.29191667	74.19325	67.5455	average (Ohms)			
60.596	74.121	74.025	67.383	0.04849677	0.2320192284	0.2125131355	0.089112953	stdev (Ohms)			
60.693	74.072	74.025	67.578	0.0802653495	0.3397228406	0.286605375	0.131954949	coef. of variation (%)			
60.645	74.902	73.828	67.383	0.0140041063	0.0727731701	0.061347264	0.025772908	std error (Ohms)			
60.547	74.072	74.512	67.627	0.9732753087	0.93601591	0.9687328049	0.956276835	normalized value			
60.547	74.17	73.975	67.627								
60.547	74.365	74.121	67.578								
60.596	74.512	74.121	67.48								
60.596	74.365	74.072	67.529								
60.645	74.17	74.365	67.529								
60.547	74.17	74.17	67.627								
60.645	74.512	73.926	67.627								
t=30											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			average	stdev
62.207	77.399	76.363	70.459	62.264	77.70991667	76.326	70.63383333	average (Ohms)		71.7834375	7.06040277
62.207	77.441	76.463	70.654	0.09268223	0.271077801	0.100133519	0.150777279	stdev (Ohms)			
62.207	77.686	76.463	70.605	0.1488539676	0.3488332958	0.130873152	0.213463234	coef. of variation (%)			
62.207	77.637	76.367	70.459	0.0267355062	0.0782593421	0.02891183	0.0435323631	std error (Ohms)			
62.207	77.49	76.367	70.605	1	1	1	1	normalized value			
62.207	77.637	76.514	70.357								
62.207	78.271	76.611	70.801								
62.305	77.881	76.514	70.654								
62.256	77.588	76.363	70.308								
62.256	78.174	76.363	70.556								
62.431	77.734	76.709	70.703								
62.431	77.441	76.611	70.605								
t=30-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
	78.125	78.223		63.61863636	78.2145	77.88916667	71.01818182	average (Ohms)			
63.525	78.564	77.93	71.582	0.0800202584	0.140865248	0.224057961	0.201797339	stdev (Ohms)			
63.77	78.174	77.832	71.094	0.126067731	0.180098636	0.287662547	0.28414883	coef. of variation (%)			
63.672	78.027	77.686	71.045	0.0241811989	0.040663717	0.0644679962	0.060844185	std error (Ohms)			
63.672	78.32	77.734	70.996	1.021736334	1.006493165	1.017813118	1.005441422	normalized value			
63.623	78.223	77.686	70.947								
63.623	78.174	77.832	70.801								
63.477	78.32	78.418	70.898								
63.574	78.076	77.832	70.947								
63.574	78.125	77.881	70.947								
63.623	78.223	77.93	70.947								
63.672	78.223	77.686	70.996								
	78.369										
t=30+											
	0.5 G	1.0 G	1.5 G		0.5 G	1.0 G	1.5 G				
	76.758	75.195	68.164		76.45258333	74.95583333	68.11958333	average (Ohms)			
	76.611	75.293	68.164		0.178132465	0.179534682	0.120236796	stdev (Ohms)			
	76.563	75.146	68.164		0.23299731	0.239409061	0.176358422	coef. of variation (%)			
	76.416	75.146	68.164		0.051422415	0.051830702	0.034715147	std error (Ohms)			
	76.367	75.098	68.164		0.983820169	0.980004617	0.964400913	normalized value			
	76.367	74.951	68.115								
	76.416	74.951	67.969								
	76.709	74.902	68.018								
	76.318	74.805	68.115								
	76.123	74.951	68.018								
	76.416	74.707	68.408								
	76.367	74.805	67.969								
t=60-											
Control				Control							
64.795				64.83166667				average (Ohms)			
64.795				0.0515158811				stdev (Ohms)			
64.844				0.079460877				coef. of variation (%)			
64.844				0.014871334				std error (Ohms)			
64.941				1.041258383				normalized value			
64.844											
64.746											
64.893											
64.795											
64.844											
64.795											
64.844											
t=60+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
	75.488	74.316	65.967		75.73241667	74.31216667	65.812	average (Ohms)			
	75.635	74.121	65.869		0.263800834	0.086955645	0.077443294	stdev (Ohms)			
	75.586	74.414	65.82		0.350973659	0.117015092	0.117673425	coef. of variation (%)			
	75.586	74.316	65.771		0.076730092	0.025102163	0.022355936	std error (Ohms)			
	75.586	74.316	65.723		0.974552797	0.971070834	0.931734732	normalized value			
	75.635	74.316	65.771								
	75.684	74.219	65.674								
	75.732	74.316	65.82								
	76.465	74.365	65.869								
	76.025	74.268	65.869								
	75.635	74.463	65.82								
	75.732	74.316	65.771								
t=90-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
62.109	75.635		65.283	62.06875	75.66154545	74.00990909	65.21654545	average (Ohms)			
61.963	75.684	74.025	65.254	0.058084775	0.099833571	0.097814574	0.038636786	stdev (Ohms)			
62.061	75.684	73.779	65.283	0.093581349	0.032649695	0.132164159	0.089910905	coef. of variation (%)			
62.109	75.633	73.926	65.283	0.01676763	0.012010877	0.029492204	0.017679636	std error (Ohms)			
62.109	75.635	74.072	65.254	0.996864159	0.9736408	0.967121097	0.923304531	normalized value			
62.061		73.926	65.254								
62.051	75.635	74.072	65.137								
62.158	75.635	74.023	65.137								
62.109	75.732	74.023									
62.051	75.635	74.072	65.186								
61.963	75.732	74.121	65.254								
62.051	75.635	74.072	65.137								
t=90+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
62.109	77.393	75.83	66.846	62.2315	77.3065	76.297	67.04116667	average (Ohms)			
62.354	77.344	75.977	66.943	0.173241161	0.172208383	0.192299935	0.1082798	stdev (Ohms)			
	77.399	76.27	66.992	0.278381786	0.222185731	0.252239667	0.161512605	coef. of variation (%)			
	77.148	76.367	67.041	0.1225	0.049712278	0.055512215	0.031257686	std error (Ohms)			
	77.399	76.416	67.09	0.999478029	0.997982559	0.996223306	0.949136745	normalized value			
	77.49	76.416	67.041								
	77.832	76.318	67.139								
	77.588	76.025	67.041								
	77.686	76.221	66.895								
	77.441	76.318	67.188								
	77.49	76.416	67.09								
	77.588	76.27	67.188								
t=120											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
64.844	80.078	80.127	71.338	64.88875	79.85053333	80.3263	71.30953333	average (Ohms)			
64.795	80.127	80.176	71.338	0.06722841	0.162949704	0.199203185	0.107282408	stdev (Ohms)			
64.844	79.736	80.176	71.338	0.103605648	0.204068909	0.247991863	0.150446317	coef. of variation (%)			
64.893	79.688	80.322	71.191	0.01940717	0.047059528	0.037505006	0.030969764	std error (Ohms)			
65.039	79.932	80.176	71.533	1.042155178	1.027543673	1.049865286	1.009363406	normalized value			
64.844	79.688	80.518	71.191								
64.893	79.98	80.225	71.24								
64.893	79.59	80.322	71.191								
64.893	79.834	80.322	71.289								
64.893	79.883	80.518	71.436								
64.99	79.785	80.225	71.387								
64.844	79.883	80.811	71.24								

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t=0										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
63.381	63.672	66.339	61.863	63.12041667	63.76358333	66.447	62.00258333	average (Ohms)		
63.137	63.672	66.455	61.963	0.207640186	0.189193651	0.10919805	0.134738679	stdev (Ohms)		
64.59	63.672	66.455	61.863	0.31885574	0.286077732	0.163424783	0.217340146	coef. of variation (%)		
63.088	63.77	66.357	62.109	0.059940539	0.054398182	0.031721115	0.03890146	std error (Ohms)		
63.088	63.574	66.211	61.963	0.97064508	0.96749784	0.980134599	0.961690979	normalized value		
64.941	63.77	66.309	61.865							
63.039	63.623	66.333	62.305							
64.59	63.721	66.455	61.963							
64.59	63.623	66.455	62.061							
63.039	64.209	66.455	61.914							
63.088	64.063	66.504	62.158							
63.474	63.818	66.602	63.012							
t=20										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G		average	stddev
67.199	65.576	67.725	65.137	67.08583333	65.73508333	67.79575	64.4735	average (Ohms)	66.27804167	1.47040057
67.041	65.723	67.822	64.209	0.106264837	0.091416587	0.096341368	0.328290735	stdev (Ohms)		
67.199	65.869	67.627	64.111	0.158362083	0.139025886	0.142109512	0.509187112	coef. of variation (%)		
66.992	65.674	67.676	64.209	0.030470248	0.026389696	0.027811357	0.094769977	std error (Ohms)		
66.943	65.625	67.822	64.258	1	1	1	1	normalized value		
66.943	65.82	67.822	64.355							
67.041	65.723	67.822	64.307							
67.09	65.82	67.822	64.355							
67.09	65.82	67.676	64.795							
67.286	65.771	67.92	64.307							
67.199	65.82	67.92	64.795							
67.383	65.82	67.871	64.844							
t=30-										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
67.627	66.113	68.066	65.381	67.70425	66.18283333	68.16408333	65.34016667	average (Ohms)		
67.627	66.113	68.262	65.479	0.096387399	0.12996304	0.102227428	0.077710228	stdev (Ohms)		
67.773	66.113	68.262	65.479	0.142363647	0.18730834	0.14997257	0.11893178	coef. of variation (%)		
· 67.578	66.211	68.311	65.283	0.027824702	0.037578627	0.029510516	0.022433009	std error (Ohms)		
67.627	66.162	68.213	65.381	1.009158119	1.006497597	1.005452647	1.015442215	normalized value		
67.627	66.357	68.262	65.332							
67.725	66.406	68.213	65.283							
67.725	65.957	68.066	65.283							
67.773	66.309	68.018	65.283							
67.773	66.113	68.066	65.332							
67.676	66.211	68.066	65.332							
67.92	66.113	68.164	65.234							
t=30+										
	0.5 G	1.0 G	1.5 G		0.5 G	1.0 G	1.5 G			
	64.551	67.773	62.695		64.64025	67.00441667	62.05866667	average (Ohms)		
	64.746	67.432	62.451		0.10368947	0.407466931	0.307869906	stdev (Ohms)		
	64.648	67.432	62.158		0.160409072	0.608118615	0.496015014	coef. of variation (%)		
	64.746	67.286	62.061		0.029931266	0.117625998	0.088874586	std error (Ohms)		
	64.697	66.992	62.012		0.983043671	0.988338842	0.962700438	normalized value		
	64.448	66.846	61.865							
	64.795	67.09	61.865							
	64.6	66.992	62.451							
	64.697	66.504	61.865							
	64.502	66.65	61.865							
	64.6	66.553	61.768							
	64.453	66.553	61.768							
t=60-										
Control				Control						
70.215				70.12266667				average (Ohms)		
70.508				0.376062495				stdev (Ohms)		
70.508				0.536282947				coef. of variation (%)		
70.361				0.125354165				std error (Ohms)		
69.922				1.045320558				normalized value		
70.117										
69.678										
69.434										
70.361										
t=60+										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
69.092	65.039	65.332	58.887	69.2894	65.18554545	65.31890909	58.8576	average (Ohms)		
68.994	65.137	65.186	58.936	0.211483228	0.155836044	0.181738326	0.052673417	stdev (Ohms)		
	65.137	65.479	58.838	0.305464166	0.239065938	0.278232637	0.089492973	coef. of variation (%)		
69.336		65.479	58.838	0.066876869	0.046986335	0.054794227	0.016656797	std error (Ohms)		
69.629	65.039	65.479		1.031590693	0.991538497	0.963494557	0.912893996	normalized value		
	65.137	65.088	58.887							
68.994	65.284		58.887							
69.238	65.039	65.283	58.838							
69.482	65.088	64.941								
69.336	65.332	65.479	58.74							
69.092	65.332	65.43	58.887							
69.141	65.527	65.332	58.838							
t=90-										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
67.871	66.162	63.625	58.545	68.208	66.30858333	63.6495	58.56116667	average (Ohms)		
67.92	66.211	63.723	58.594	0.186228653	0.097545735	0.127399159	0.129099695	stdev (Ohms)		
68.066	66.357	63.723	58.447	0.275030314	0.14710879	0.194364232	0.220450277	coef. of variation (%)		
68.311	66.455	63.527	58.496	0.058890671	0.028159034	0.036834704	0.037250531	std error (Ohms)		
68.359	66.357	63.576	58.496	1.016666708	1.0084176	0.948370978	0.908268241	normalized value		
68.359	66.309	63.576	58.887							
68.359	66.26	63.576	58.447							
68.262	66.455	63.723	58.643							
68.262	66.311	63.479	58.545							
68.311	66.26	63.625	58.691							
68.262	66.26	63.674	58.496							
68.311	66.406	63.967	58.447							
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
68.164	66.895	66.748	61.133	68.449	67.01666667	66.74808333	61.5885	average (Ohms)		
68.262	67.199	66.602	61.182	0.140926157	0.087099058	0.216395034	0.244859529	stdev (Ohms)		
68.311	67.041	66.406	61.523	0.205884903	0.129966234	0.324198525	0.397573133	coef. of variation (%)		
68.457	66.992	66.455	61.523	0.040681877	0.025143327	0.062467865	0.0706848	std error (Ohms)		
68.457	66.846	66.797	61.572	1.020258907	1.019186096	0.984575766	0.955252933	normalized value		
68.457	67.199	66.748	61.963							
68.457	66.992	66.65	61.621							
68.555	66.992	66.602	61.719							
68.506	66.992	66.992	61.67							
68.604	67.041	67.09	61.768							
68.506	67.041	66.895	61.523							
68.652	67.09	66.992	61.865							
t=120										
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			
71.094	68.945	69.043	64.99	71.16291667	68.96358333	68.90058333	64.55733333	average (Ohms)		
71.143	68.848	68.994	64.99	0.081687273	0.084509772	0.174636785	0.335921347	stdev (Ohms)		
71.045	69.043	68.945	64.941	0.114789102	0.122539053	0.25349101	0.517300804	coef. of variation (%)		
71.094	68.945	68.994	63.039	0.023581083	0.02439587	0.050415071	0.09697214	std error (Ohms)		
71.045	68.848	69.141	64.6	1.060710888	1.048825129	1.01632648	1.00719417	normalized value		
71.191	68.896	68.604	64.063							
71.143	69.092	69.092	65.039							
71.289	68.994	68.896	64.941							
71.24	68.896	68.896	65.479							
71.24	68.994	68.75	65.039							
71.24	69.092	68.848	65.039							
71.191	68.994	68.604	65.088							

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t=0											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
71.387	77.599			71.59441667	77.75883333			average (Ohms)			
71.436	78.076			0.259347795	0.157843901			stdev (Ohms)			
71.533	77.881			0.362243537	0.202991601			coef. of variation (%)			
71.387	77.881			0.074867201	0.045565609			std error (Ohms)			
72.266	77.637			0.976635761	0.984492574			normalized value			
71.484	77.588										
71.436	77.686										
71.387	77.637										
71.533	77.783										
71.729	77.734										
71.826	77.734										
71.729	77.93										
t=30											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G			average	stddev
73.193	79.004	69.141	78.467	73.30733333	78.98366667	68.31591667	78.64983333	average (Ohms)		74.8149375	3.05139864
73.193	79.15	68.604	78.32	0.137182913	0.104974744	0.446082638	0.188715139	stdev (Ohms)			
73.242	78.955	69.141	78.418	0.187133936	0.132906903	0.652941615	0.239943539	coef. of variation (%)			
73.145	79.004	68.164	78.564	0.039601286	0.030303598	0.128772965	0.054477384	std error (Ohms)			
73.291	79.004	68.164	78.662	1	1	1	1	normalized value			
73.291	78.906	67.969	78.662								
73.291	78.809	68.604	78.662								
73.34	78.955	68.115	79.004								
73.291	79.053	67.969	78.711								
73.682	78.809	68.018	78.711								
73.34	79.053	67.92	78.76								
73.389	79.102	68.018	78.857								
t=30-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
72.705	79.248	68.555	79.199	72.6904	79.541	68.7215	79.1545	average (Ohms)			
72.559	79.297	68.848	79.102	0.083268241	0.182619824	0.187832572	0.079051064	stdev (Ohms)			
		68.994	79.102	0.11455191	0.229592064	0.273324028	0.099864057	coef. of variation (%)			
72.734	79.736	68.701	79.102	0.02633173	0.055061949	0.054222935	0.022814305	std error (Ohms)			
	79.639	68.945	79.199	0.991584289	1.007034311	1.005972707	1.006416627	normalized value			
72.607	79.736	68.945	79.248								
72.607	79.541	68.652	79.004								
72.636	79.395	68.457	79.102								
72.705	79.492	68.848	79.297								
72.803	79.443	68.652	79.199								
72.705	79.639	68.555	79.15								
72.803	79.785	68.506	79.15								
t=30+											
	0.5 G	1.0 G	1.5 G		0.5 G	1.0 G	1.5 G				
	79.004	67.285	78.174		78.96308333	67.28484364	77.66316667	average (Ohms)			
	79.15	67.188	78.027		0.071636022	0.260266125	0.444903224	stdev (Ohms)			
	78.955		77.832		0.090720905	0.387091513	0.572847835	coef. of variation (%)			
	78.955	67.188	78.516		0.020679538	0.078473189	0.128432498	std error (Ohms)			
	78.955	67.285	77.588		0.999799998	0.984154418	0.987480372	normalized value			
	78.906	67.48	77.49								
	79.004	67.383	77.881								
	78.906	67.676	77.734								
	78.955	67.285	77.197								
	78.955	67.041	77.246								
	78.955	66.65	77.246								
	78.857	67.139	77.051								
t=60-											
Control				Control							
				73.9012				average (Ohms)			
73.779				0.154733519				stdev (Ohms)			
				0.209578628				coef. of variation (%)			
73.828				0.048930973				std error (Ohms)			
73.779				1.008101054				normalized value			
73.633											
73.828											
73.926											
74.072											
74.072											
74.072											
74.023											
t=60+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
71.191		66.504	75.195	70.68075		66.504	74.71108333	average (Ohms)			
70.801		66.504	74.658	0.230066858		0.061980642	0.228398621	stdev (Ohms)			
70.654		66.455	74.638	0.325453965		0.093198367	0.305696543	coef. of variation (%)			
70.361		66.504	74.707	0.066414575		0.018087867	0.065973417	std error (Ohms)			
70.654		66.602	74.854	0.964304663		0.973434639	0.949920428	normalized value			
70.947		66.553	74.561								
70.732		66.455	74.609								
70.732		66.455	74.609								
70.654			74.609								
70.654		66.504	73.098								
70.41		66.602	74.561								
70.459		66.406	74.414								
t=90-											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
67.871		66.797	74.072	68.06190909		66.87433333	74.30309091	average (Ohms)			
68.213		66.797	74.17	0.176828988		0.152349081	0.157350281	stdev (Ohms)			
68.066		66.748	74.414	0.259806094		0.227813981	0.212037317	coef. of variation (%)			
67.92		66.699	74.316	0.053315946		0.043979991	0.047303197	std error (Ohms)			
68.262		67.139	74.17	0.928446118		0.978835295	0.944732973	normalized value			
67.871		66.797	74.609								
67.773		67.188	74.219								
68.213		66.846									
		66.846	74.316								
68.262		66.797	74.268								
68.164		66.992	74.268								
68.066		66.846	74.512								
t=90+											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
69.629	80.762	68.164	75.781	70.2555	80.59491667	68.34316667	75.94408333	average (Ohms)			
70.215	80.518	68.164	75.83	0.424582469	0.111047438	0.263480051	0.12026067	stdev (Ohms)			
69.58	80.664	68.262	75.977	0.604340541	0.137784692	0.385826304	0.158354232	coef. of variation (%)			
69.824	80.469	68.506	75.928	0.122566401	0.03205664	0.076119606	0.034716263	std error (Ohms)			
70.166	80.664	68.457	75.928	0.958369531	1.020399787	1.000354933	0.965597511	normalized value			
70.605	80.615	68.115	75.928								
70.459	80.518	68.359	75.83								
70.166	80.566	69.092	75.83								
70.361	80.615	68.262	75.977								
71.045	80.664	68.213	76.172								
70.459	80.713	68.213	76.123								
70.557	80.371	68.311	76.025								
t=120											
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				
72.021	81.543	70.117	79.346	72.12716667	81.48591667	70.05616667	79.33758333	average (Ohms)			
72.168	81.396	69.873	79.346	0.152821747	0.142367935	0.205051583	0.095014227	stdev (Ohms)			
72.266	81.445	69.971	79.297	0.21201683	0.174714773	0.292693979	0.119761937	coef. of variation (%)			
72.168	81.445	69.824	79.248	0.044144706	0.041098083	0.059193295	0.027428822	std error (Ohms)			
72.021	81.348	70.068	79.199	0.98390111	1.031680601	1.025428536	1.008744436	normalized value			
72.168	81.689	70.215	79.297								
72.119	81.543	70.605	79.443								
72.461	81.543	69.922	79.443								
72.07	81.738	70.117	79.395								
72.07	81.543	70.02	79.492								
72.168	81.348	69.971	79.346								
71.826	81.25	69.971	79.199								

Subject J

t=0												
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G					
63.672	66.63	37.368	38.496	63.82638333	66.44411111	37.5075	38.67308333	average (Ohms)				
63.916	66.846	37.373	38.838	0.131400469	0.338202997	0.08516577	0.130384322	stdev (Ohms)				
63.574	66.406	37.52	38.594	0.205871069	0.509002816	0.115055897	0.222354983	coef. of variation (%)				
63.77	66.699	37.422	38.545	0.037932048	0.112734132	0.019100412	0.037696447	std error (Ohms)				
63.867		37.471	38.789	0.950264638	0.968867286	0.936616846	0.963379458	normalized value				
63.963	66.064	37.52	38.447									
63.721	63.967	37.368	38.74									
63.965	66.113	37.52	38.838									
63.721	66.846	37.52	38.643									
63.965	66.406	37.471	38.691									
63.916		37.617	38.74									
63.867		37.52	38.74									
t=20												
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G				average	stdev
66.963	68.213	60.059	60.84	67.16716667	68.57916667	60.1135	60.89283333	average (Ohms)			64.18866667	4.305080586
67.09	68.408	60.059	60.791	0.111057588	0.320099135	0.080212785	0.306286307	stdev (Ohms)				
67.09	69.189	60.059	61.621	0.165345034	0.466671105	0.13343112	0.5029927	coef. of variation (%)				
67.286	68.408	60.107	60.791	0.032059364	0.092387546	0.023155437	0.088417299	std error (Ohms)				
67.139	68.457	60.107	60.449	1	1	1	1	normalized value				
67.188	68.553	60.107	60.742									
67.286	68.262	60.352	61.328									
67.286	69.238	60.107	60.84									
67.383	68.506	60.059	60.645									
67.286	68.604	60.107	60.889									
67.139	68.506	60.107	60.84									
67.09	68.604	60.156	60.938									
t=30-												
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G					
67.969	68.848	60.4	61.28	68.14583333	69.07341667	60.52918182	61.195	average (Ohms)				
68.213	68.945	60.498	61.133	0.165885411	0.135222012	0.08839773	0.115723557	stdev (Ohms)				
68.018	69.189	60.4	61.182	0.243434228	0.195759965	0.146041555	0.189109463	coef. of variation (%)				
68.164	68.848	60.498	61.084	0.047886995	0.039035232	0.026652927	0.034892562	std error (Ohms)				
68.353	69.189		61.084	1.014540835	1.007286165	1.00688143	1.00496227	normalized value				
68.164	69.043	60.645										
68.164	69.238	60.596	61.328									
68.115	69.189	60.547	61.426									
68.311	69.043	60.449	61.182									
68.018	69.189	60.547	61.182									
67.969	69.092	60.645	61.279									
68.066	69.092	60.596	61.035									
t=30+												
	0.5 G	1.0 G	1.5 G		0.5 G	1.0 G	1.5 G					
	67.773	39.131	38.643		67.78366667	39.03325	38.64658333	average (Ohms)				
	67.773	39.033	38.545		0.086058999	0.126365919	0.26207024	stdev (Ohms)				
	67.725	39.18	38.643		0.126927126	0.324397681	0.446863611	coef. of variation (%)				
	67.871	39.082	38.691		0.024837146	0.036396434	0.073653162	std error (Ohms)				
	67.725	38.936	38.594		0.988420431	0.981597133	0.963111429	normalized value				
	67.92	38.984	38.691									
	67.725	38.936	38.301									
	67.676	39.326	38.398									
	67.676	38.984	38.496									
	67.822	38.936	39.375									
	67.92	38.887	38.691									
	67.822	38.984	38.691									
t=60-												
Control				Control								
69.727				69.48944444				average (Ohms)				
69.629				0.091657121				stdev (Ohms)				
				0.131503573				coef. of variation (%)				
				0.030552974				std error (Ohms)				
69.775				1.037701125				normalized value				
69.775												
69.629												
69.727												
69.678												
69.381												
69.824												
t=60+												
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G					
69.336	67.725	38.936	55.318	69.36272727	67.68408333	39.02825	55.3936	average (Ohms)				
	67.676	38.936	55.42	0.07034515	0.126318831	0.160366115	0.144206025	stdev (Ohms)				
69.336	67.432	39.033	55.664	0.101704695	0.186630038	0.272011105	0.260320036	coef. of variation (%)				
69.287	67.676	38.887	55.371	0.021270163	0.036465105	0.046331445	0.045601949	std error (Ohms)				
69.434	67.676	38.984	55.42	1.032688004	0.986948174	0.981930617	0.909772819	normalized value				
69.434	67.676	38.984	55.176									
69.434	67.627	38.936	55.42									
69.383	67.627	39.082	55.469									
69.385	67.627	38.936	55.225									
69.287	67.969	39.473	55.273									
69.434	67.676	39.18										
69.238	67.822	38.984										
t=90-												
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G					
64.209	68.164	39.277	34.834	64.17	68.20390909	39.26516667	34.35716667	average (Ohms)				
64.16		39.277		0.085329722	0.130798666	0.073297994	0.140489739	stdev (Ohms)				
64.063	68.164	39.229		0.133286149	0.191775907	0.127052699	0.257309228	coef. of variation (%)				
	68.066	39.18		0.027046873	0.039437282	0.021736659	0.057354696	std error (Ohms)				
64.16	68.213	39.326		0.955377303	0.994528111	0.985835007	0.895955821	normalized value				
64.307	68.262	39.229	34.443									
64.16	68.359	39.229										
64.16	68.306	39.424	34.341									
	68.164	39.277										
64.307	68.066	39.277	34.341									
64.063	68.115	39.131	34.492									
64.111	68.164	39.326	34.492									
t=90+												
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G					
64.502	69.092	59.961	35.957	64.91527273	69.29933333	60.24183333	36.189	average (Ohms)				
64.746	69.141	60.059	35.859	0.21558622	0.193160006	0.130253576	0.344263905	stdev (Ohms)				
64.746	69.043	60.156	36.104	0.332083541	0.278732849	0.216221136	0.612689148	coef. of variation (%)				
64.795	69.336	60.4	35.908	0.065001691	0.055760491	0.037601546	0.099380429	std error (Ohms)				
64.844	69.238	60.254	35.957	0.986592846	1.010501246	1.00210151	0.922773267	normalized value				
64.941	69.434	60.205	36.641									
64.99	69.629	60.254	36.201									
65.039	69.189	60.303	35.908									
65.186	69.531	60.352	36.006									
65.186	69.141	60.352	36.25									
65.137	69.531	60.254	36.543									
	69.287	60.352	36.594									
t=120												
Control	0.5 G	1.0 G	1.5 G	Control	0.5 G	1.0 G	1.5 G					
68.799	71.875	63.184	60.547	68.94516667	71.80991667	63.15516667	60.27816667	average (Ohms)				
68.848	71.777	63.379	60.498	0.068973402	0.063482937	0.149292777	0.17621827	stdev (Ohms)				
68.896	71.826	63.525	60.254	0.100043854	0.088404157	0.236390441	0.292341788	coef. of variation (%)				
68.994	71.826	63.086	60.107	0.019911483	0.018325945	0.043097115	0.050869835	std error (Ohms)				
69.043	71.729	63.086	60.107	1.026471267	1.047109788	1.050363776	0.989905763	normalized value				
68.994	71.826	63.086	60.254									
68.945	71.826	63.086	60.156									
68.994	71.924	63.135	60.254									
68.945	71.875	63.086	60.4									
68.945	71.729	63.135	60.107									
68.994	71.777	63.086	60.107									
68.945	71.729	62.988	60.547									

Data for Average, Normalized Plot

Time (min)	Normalized Volume, Control	Standard Error of Normalized Volume, Control	Normalized Volume, 0.5 G	Standard Error of Normalized Volume, 0.5 G	Normalized Volume, 1.0 G	Standard Error of Normalized Volume, 1.0 G	Normalized Volume, 1.5 G	Standard Error of Normalized Volume, 1.5 G
0	0.96602	0.00486	0.97389	0.00438	0.97245	0.00523	0.97345	0.00599
20	1.0000	0.00000	1.00000	0.00000	1.00000	0.00000	1.00000	0.00000
30^-	1.00758	0.00307	1.00422	0.00166	1.00735	0.00159	1.00759	0.00170
30^+			0.98606	0.00344	0.98537	0.00190	0.97626	0.00476
60^-	1.02920	0.00433						
60^+	1.00487	0.00942	0.98531	0.00451	0.96954	0.00531	0.94462	0.00800
90^-	0.96536	0.01087	0.98688	0.00525	0.97039	0.00664	0.93060	0.00797
90^+	0.98314	0.00843	1.00605	0.00408	0.99296	0.00665	0.95675	0.00660
120	1.02498	0.00848	1.03022	0.00558	1.02790	0.00642	1.00551	0.00306

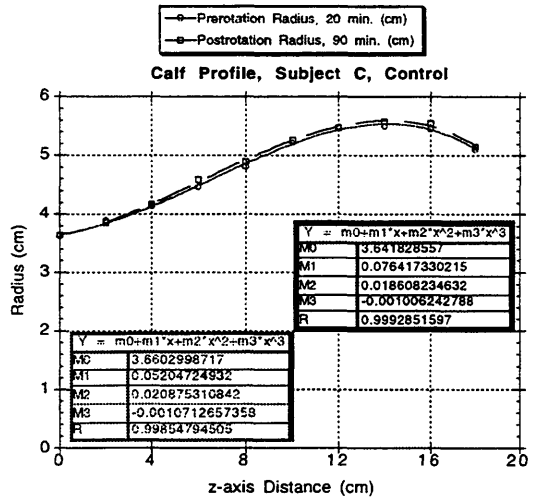
APPENDIX F

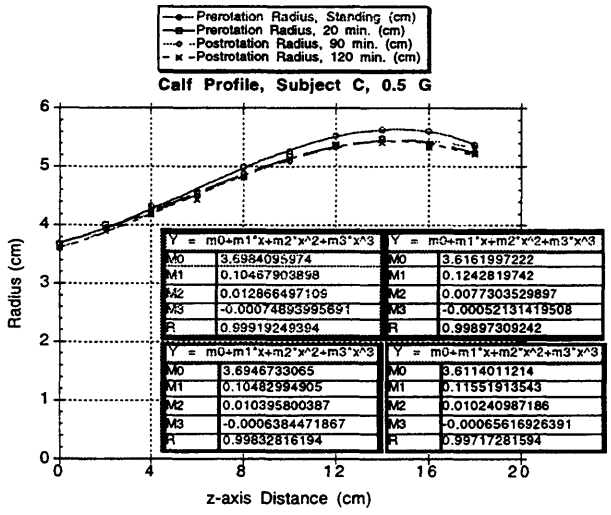
Calf Circumference Profiles, Volume Data, and Volume Plots

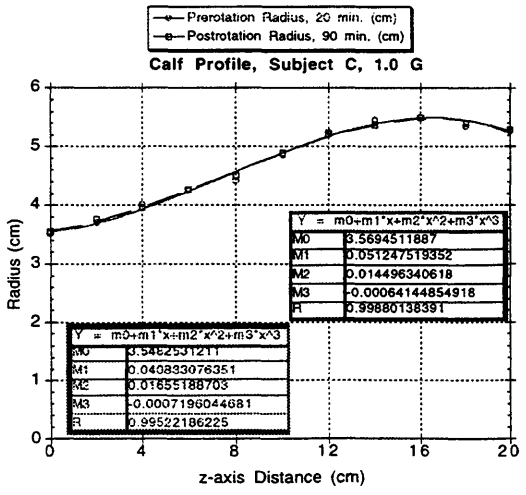
Calf Circumference Profiles

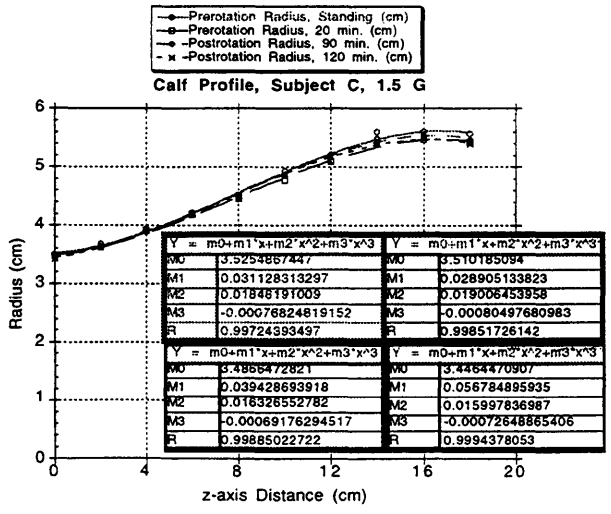
Postrotation in the control implies post-standing. The $t = 0$ measurements were made in the erect position. The equation coefficients are arranged so that $t = 0$ and 20 are in the first column and $t =$ 90 and 120 are in the second column. As mentioned previously, not every subject had calf circumferences measured at $t = 0$ and 120 for every trial.

Subject C

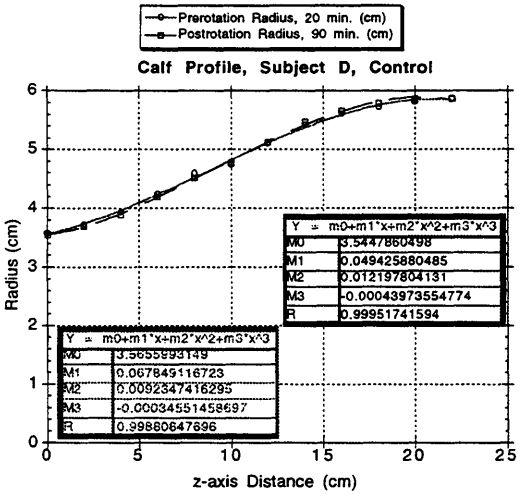


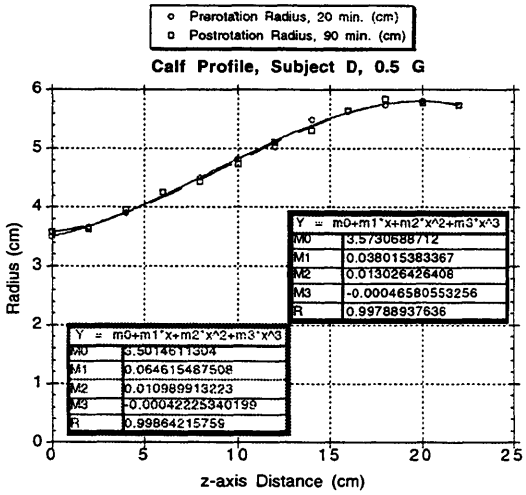


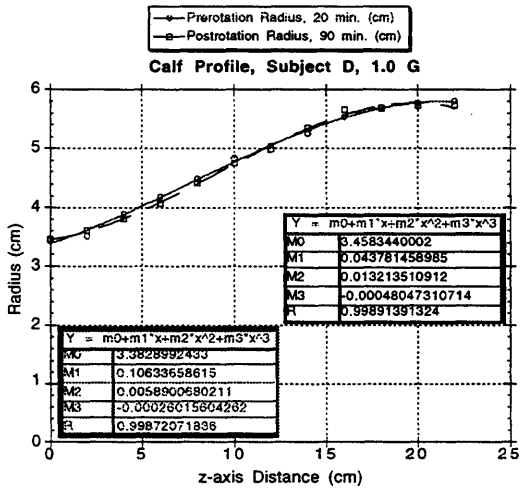


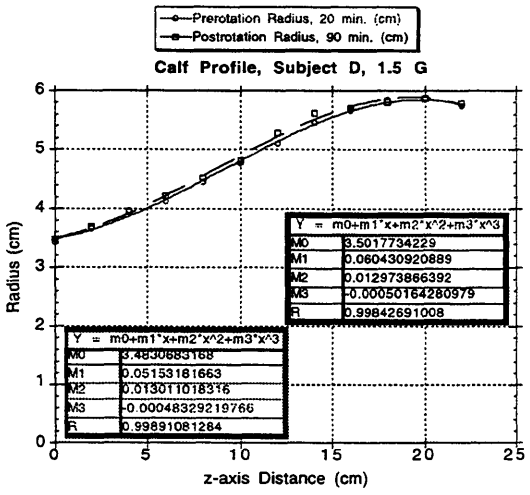


Subject D

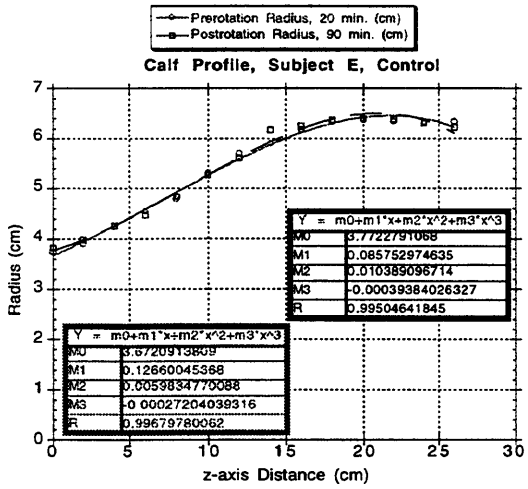

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Calf Profile, Subject D, Control
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.5447860498
M1 0.049425880485
M2 0.012197804131
M3 -0.00043973554774
R 0.99951741594
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.5655993149
M1 0.067849116723
M2 0.0092347416295
M3 -0.00034551458697
R 0.99880647696

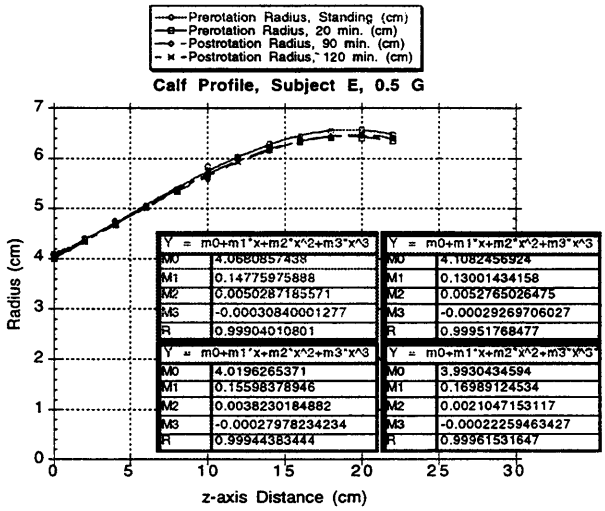

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Calf Profile, Subject D, 0.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.5730688712
M1 0.038015383367
M2 0.013026426408
M3 -0.00046580553256
R 0.99788937636
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.5014611304
M1 0.064615487508
M2 0.010989913223
M3 -0.00042225340199
R 0.99864215759

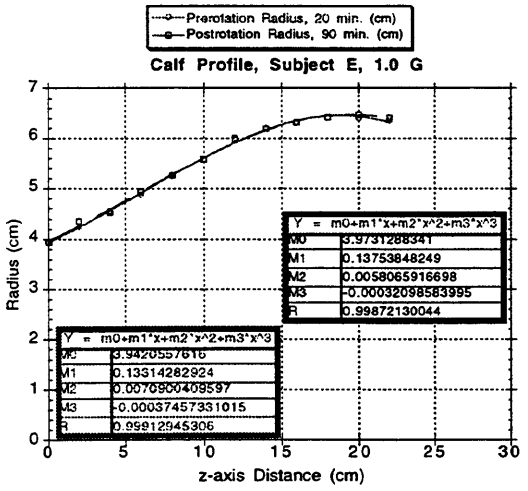

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Calf Profile, Subject D, 1.0 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.4583440002
M1 0.043781458985
M2 0.013213510912
M3 -0.00048047310714
R 0.99891391324
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.3828992433
M1 0.10633658615
M2 0.0058900580211
M3 -0.00026015604282
R 0.99872071836

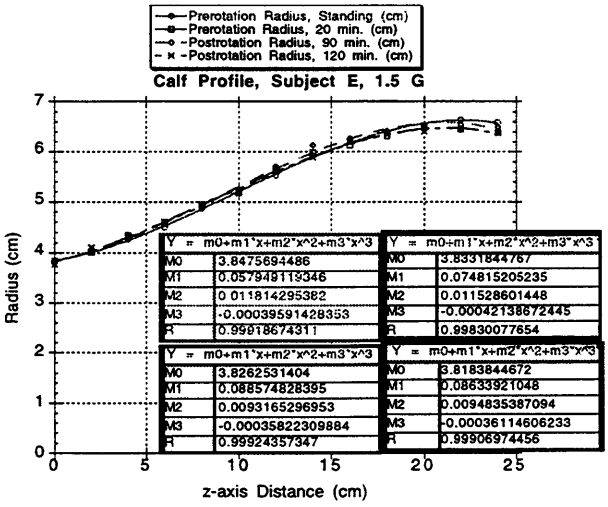

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Calf Profile, Subject D, 1.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.5017734229
M1 0.060430920889
M2 0.012973866392
M3 -0.00050164280979
R 0.99842691008
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.4830683168
M1 0.05153181663
M2 0.013011018316
M3 -0.00048329219766
R 0.99891081284

Subject E

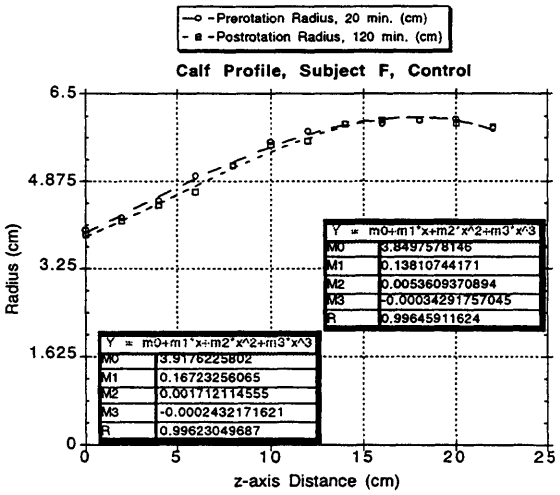

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Calf Profile, Subject E, Control
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.7722791068
M1 0.085752974635
M2 0.010389096714
M3 -0.00039384026327
R 0.99504641845
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.6720913809
M1 0.12660045368
M2 0.0059834770088
M3 -0.00027204039316
R 0.99679780062

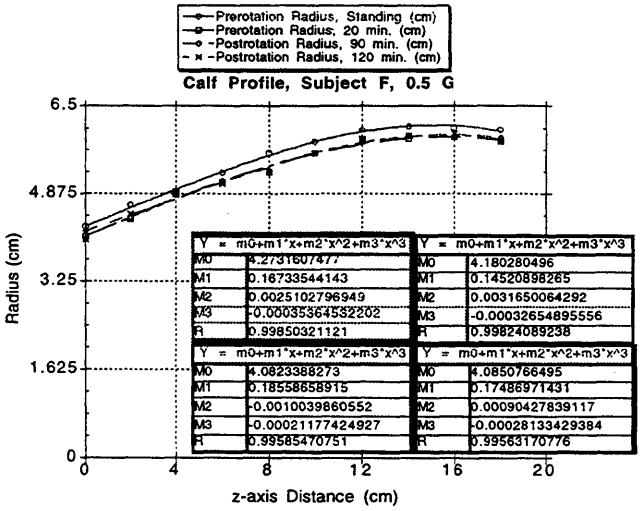

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject E, 0.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 4.0680857438
M1 0.14775975888
M2 0.0050287185571
M3 -0.00030840001277
R 0.99904010801
Y = m0+m1*x+m2*x^2+m3*x^3
M0 4.1082456924
M1 0.13001434158
M2 0.0052765026475
M3 -0.00029269706027
R 0.99951768477
Y = m0+m1*x+m2*x^2+m3*x^3
M0 4.0196265371
M1 0.15598378946
M2 0.0038230184882
M3 -0.00027978234234
R 0.99944383444
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9930434594
M1 0.16989124534
M2 0.0021047153117
M3 -0.00022259463427
R 0.99961531647

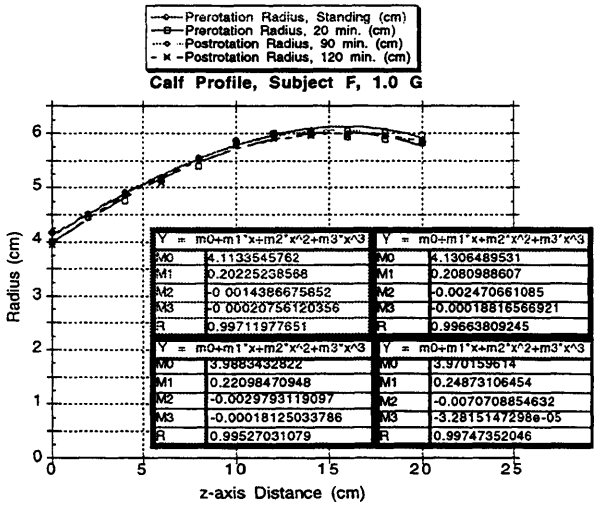

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Calf Profile, Subject E, 1.0 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9731288341
M1 0.13753848249
M2 0.0058065916698
M3 -0.00032098583995
R 0.99872130044
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9420557616
M1 0.13314282924
M2 0.0070900409597
M3 -0.00037457331015
R 0.99912945306

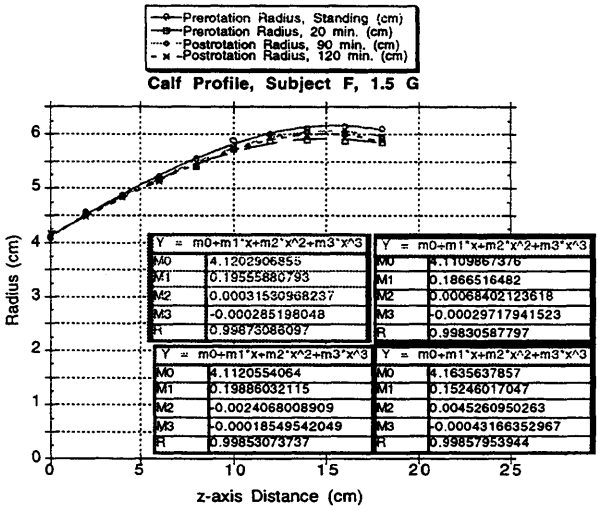

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject E, 1.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8475694486
M1 0.057949113346
M2 0.011814295382
M3 -0.00039591428353
R 0.99918674311
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8331844767
M1 0.074815205235
M2 0.011528601448
M3 -0.00042138672445
R 0.99830077654
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8262531404
M1 0.088574828395
M2 0.0093165296953
M3 -0.00035822309884
R 0.99924357347
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8183844672
M1 0.08633921048
M2 0.0094835387094
M3 -0.00036114606233
R 0.99906974456

Subject F

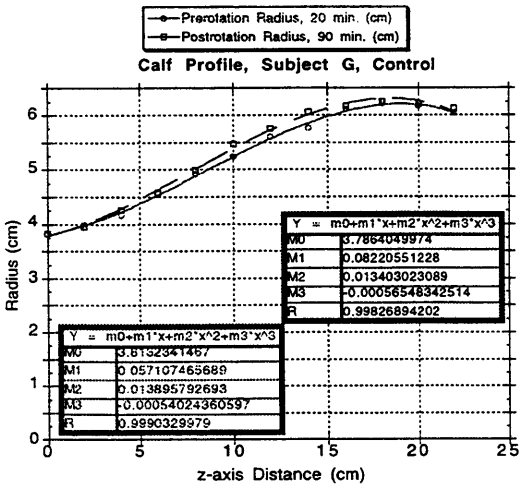

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject F, Control
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8497578146
M1 0.13810744171
M2 0.0053609370894
M3 -0.00034291757045
R 0.99645911624
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9176225802
M1 0.16723256065
M2 0.001712114555
M3 -0.0002432171621
R 0.99623049687

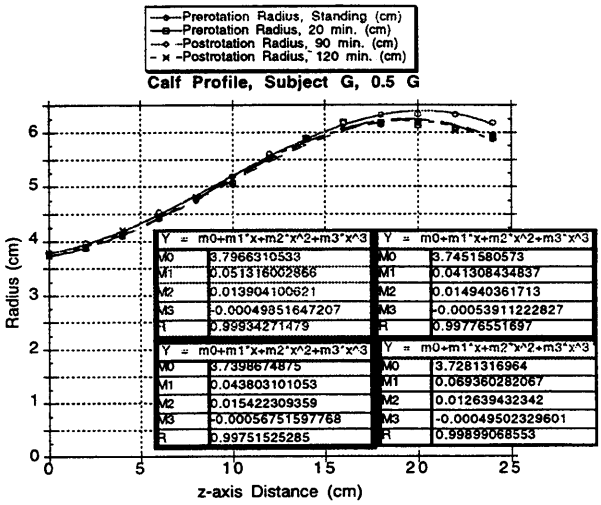

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject F, 0.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 4.180280496
M1 0.14520898265
M2 0.0031650064292
M3 -0.00032654895556
R 0.99824089238
Y = m0+m1*x+m2*x^2+m3*x^3
M0 4.0850766495
M1 0.17486971431
M2 0.00090427839117
M3 -0.00028133429384
R 0.99563170776

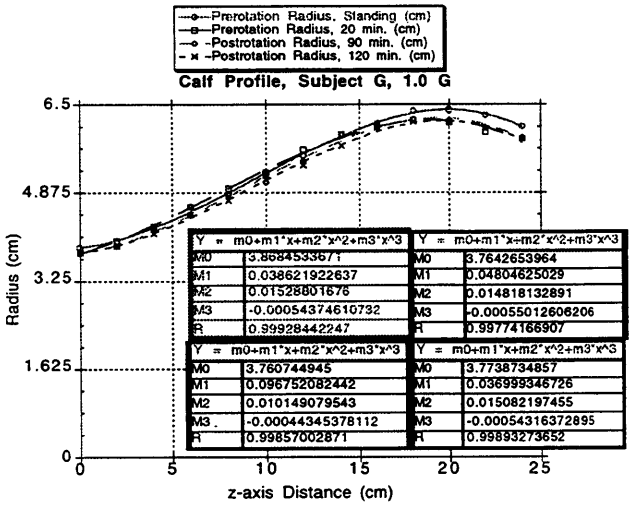

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject F, 1.0 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 4.1306489531
M1 0.2080988607
M2 -0.002470661085
M3 -0.00018816566921
R 0.99663809245
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9701596 14
M1 0.24873106454
M2 -0.0070708854632
M3 -3.2815147298e-05
R 0.99747352046

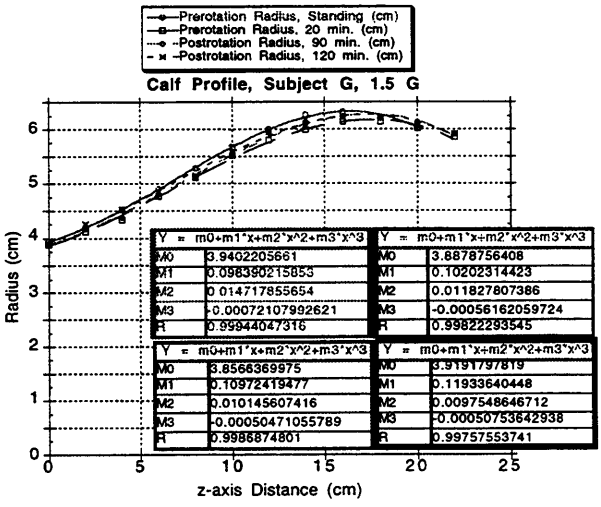

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject F, 1.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 4.1109867376
M1 0.1866516482
M2 0.00068402123618
M3 -0.00029717941523
R 0.99830587797
Y = m0+m1*x+m2*x^2+m3*x^3
M0 4.1635637857
M1 0.15246017047
M2 0.0045260950263
M3 -0.00043166352967
R 0.99857953944

Subject G

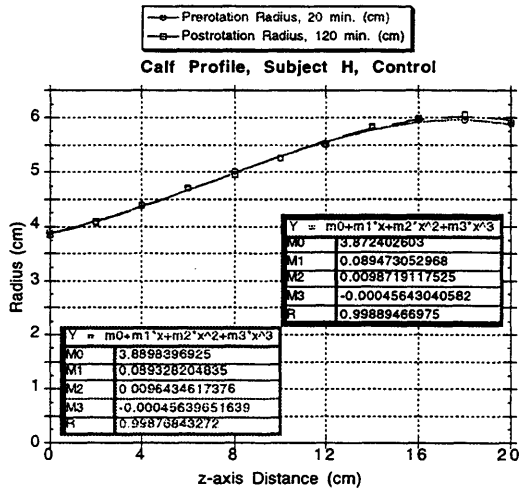

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Calf Profile, Subject G, Control
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.7864049974
M1 0.08220551228
M2 0.013403023089
M3 -0.00056548342514
R 0.99826894202
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8132341467
M1 0.057107465689
M2 0.013895792693
M3 -0.00054024360597
R 0.9990329979

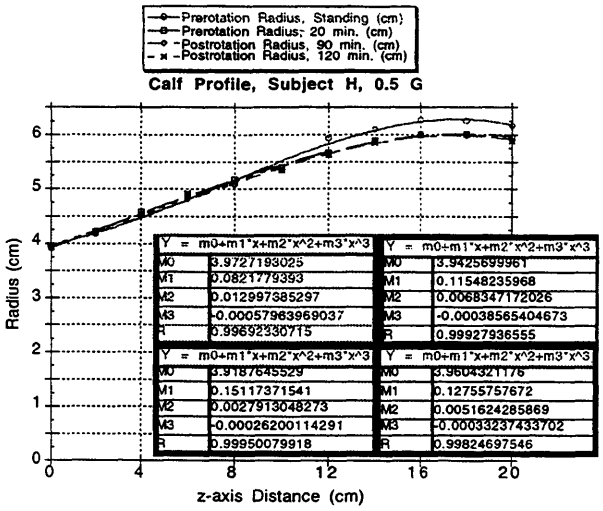

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
-Postrotation Radius, 90 min. (cm)
-Postrotation Radius, 120 min. (cm)
Calf Profile, Subject G, 0.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.7966310533
M1 0.051316002856
M2 0.013904100621
M3 -0.00049851647207
R 0.99934271479
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.7451580573
M1 0.041308434837
M2 0.014940361713
M3 -0.00053911222827
R 0.99776551697
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.7398674875
M1 0.043803101053
M2 0.015422309359
M3 -0.00056751597768
R 0.99751525285
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.7281316964
M1 0.069360282067
M2 0.012639432342
M3 -0.00049502329601
R 0.99899068553

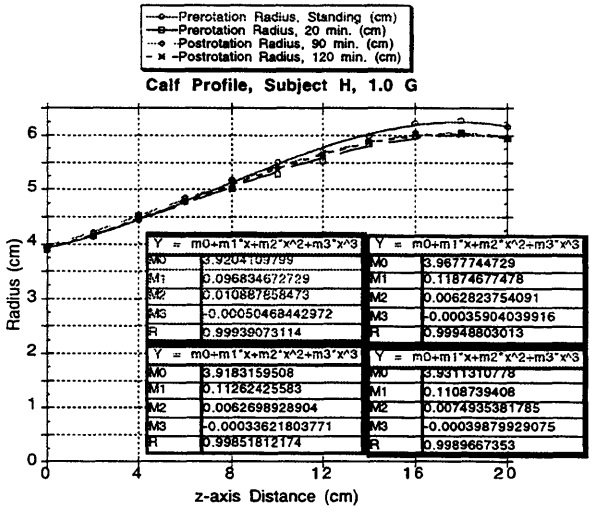

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
-Postrotation Radius, 90 min. (cm)
-Postrotation Radius, 120 min. (cm)
Calf Profile, Subject G, 1.0 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.868453367
M1 0.038621922637
M2 0.01528801676
M3 -0.00054374610732
R 0.99928442247
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.7642653964
M1 0.04804625029
M2 0.014818132891
M3 -0.00055012606206
R 0.99774166907
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.760744945
M1 0.096752082442
M2 0.010149079543
M3 -0.00044345378112
R 0.99857002871
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.7738734857
M1 0.036999346726
M2 0.015082197455
M3 -0.00054316372895
R 0.99893273652

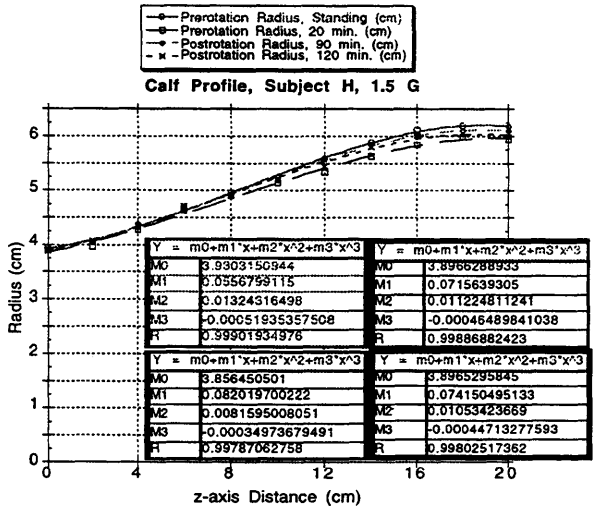

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
-Postrotation Radius, 90 min. (cm)
-Postrotation Radius, 120 min. (cm)
Calf Profile, Subject G, 1.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9402205661
M1 0.098390215853
M2 0.014717855654
M3 -0.00072107992621
R 0.99944047316
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8878756408
M1 0.10202314423
M2 0.011827807386
M3 -0.00056162059724
R 0.99822293545
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8566369975
M1 0.10972419477
M2 0.010145607416
M3 -0.00050471055789
R 0.9986874801
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9191797819
M1 0.11933640448
M2 0.0097548646712
M3 -0.00050753642938
R 0.99757553741

Subject H

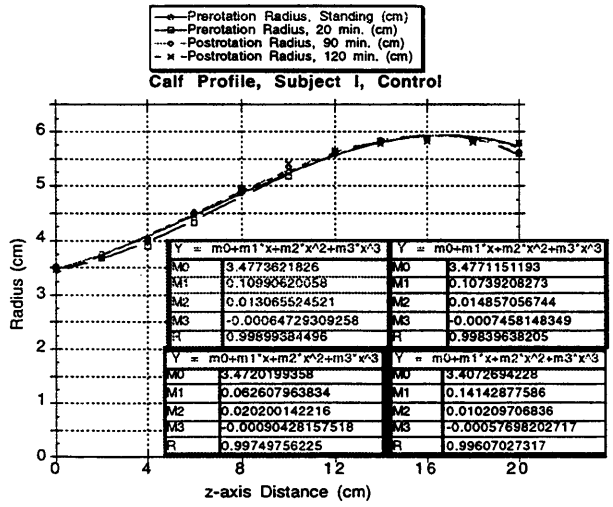

Prerotation Radius, 20 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject H, Control
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.872402603
M1 0.089473052968
M2 0.0098719117525
M3 -0.00045643040582
R 0.99889466975
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8898396925
M1 0.089328204835
M2 0.0096434617376
M3 -0.00045639651639
R 0.99873643272


Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject H, 0.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9727193025
M1 0.0821779393
M2 0.012997385297
M3 -0.00057963969037
R 0.99692330715
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9425699961
M1 0.11548235968
M2 0.0068347172026
M3 -0.00038565404673
R 0.99927936555
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9187645529
M1 0.15117371541
M2 0.0027913048273
M3 -0.00026200114291
R 0.99950079918
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9604321176
M1 0.12755757672
M2 0.0051624285869
M3 -0.00033237433702
R 0.99824697546

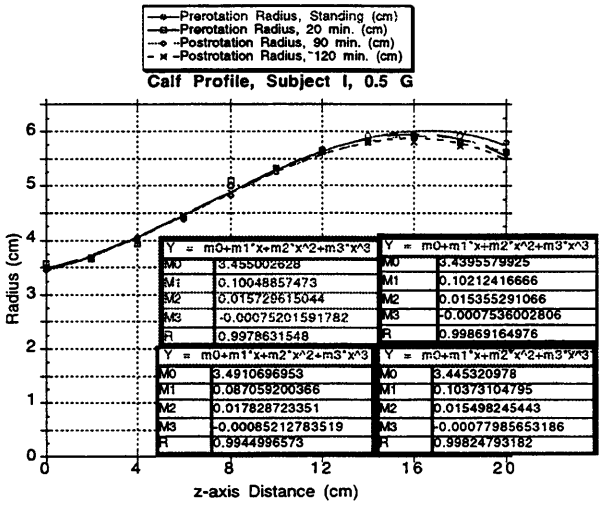

Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject H, 1.0 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9204109799
M1 0.096834672729
M2 0.010887658473
M3 -0.00050468442972
R 0.99939073114
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9677744729
M1 0.11874677478
M2 0.0062823754091
M3 -0.00035904039916
R 0.99948803013
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9183159508
M1 0.11262425583
M2 0.0062698928904
M3 -0.00033621803771
R 0.99851812174
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9311310778
M1 0.1108739408
M2 0.0074935381785
M3 -0.00039879929075
R 0.9989667353


Prerotation Radius, Standing (cm)
Prerotation Radius, 20 min. (cm)
Postrotation Radius, 90 min. (cm)
Postrotation Radius, 120 min. (cm)
Calf Profile, Subject H, 1.5 G
Radius (cm)
z-axis Distance (cm)
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.9303150944
M1 0.0556759115
M2 0.01324316498
M3 -0.00051935357508
R 0.99901934976
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8966288933
M1 0.0715639305
M2 0.011224811241
M3 -0.00046489841038
R 0.99886882423
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.856450501
M1 0.082019700222
M2 0.0081595008051
M3 -0.00034973679491
R 0.99787062758
Y = m0+m1*x+m2*x^2+m3*x^3
M0 3.8965295845
M1 0.074150495133
M2 0.01053423669
M3 -0.00044713277593
R 0.99802517362

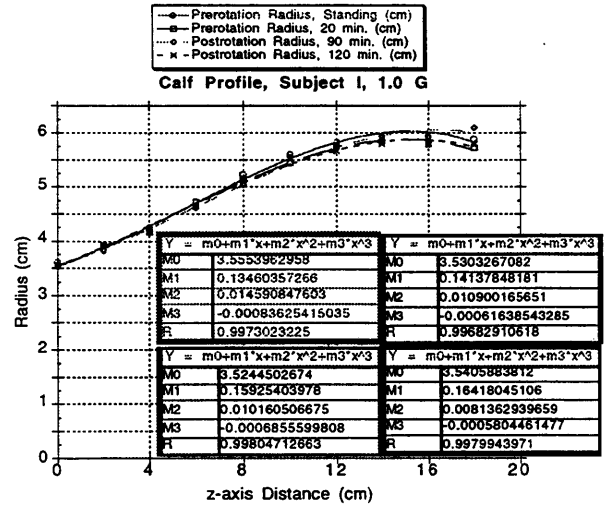
Subject I



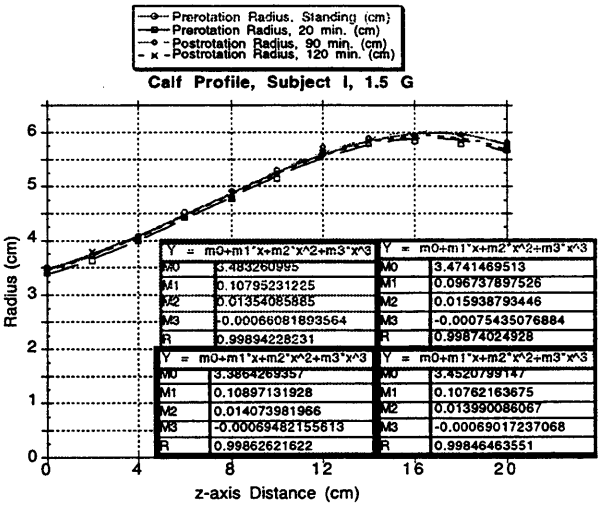
Y = m0+m1*x+m2*x^2+m3*x^3		Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.4773621826	M0	3.4771151193
M1	0.10990620058	M1	0.10739208273
M2	0.013065524521	M2	0.01485705674
M3	-0.00064729309258	M3	-0.0007458148349
R	0.99899384496	R	0.99839638205
Y = m0+m1*x+m2*x^2+m3*x^3		Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.4720199358	M0	3.4072694228
M1	0.062607963834	M1	0.14142877586
M2	0.020200142216	M2	0.010209706836
M3	-0.00090428157518	M3	-0.00057698202717
R	0.99749756225	R	0.99607027317



Y = m0+m1*x+m2*x^2+m3*x^3		Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.455002628	M0	3.4395579925
M1	0.10048857473	M1	0.10212416666
M2	0.015729515044	M2	0.015355291066
M3	-0.00075201591782	M3	-0.0007536002806
R	0.9978631548	R	0.99869164976
Y = m0+m1*x+m2*x^2+m3*x^3		Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.4910696953	M0	3.445320978
M1	0.087059200366	M1	0.10373104795
M2	0.017828723351	M2	0.015498245443
M3	-0.00085212783519	M3	-0.00077985653186
R	0.9944996573	R	0.99824793182

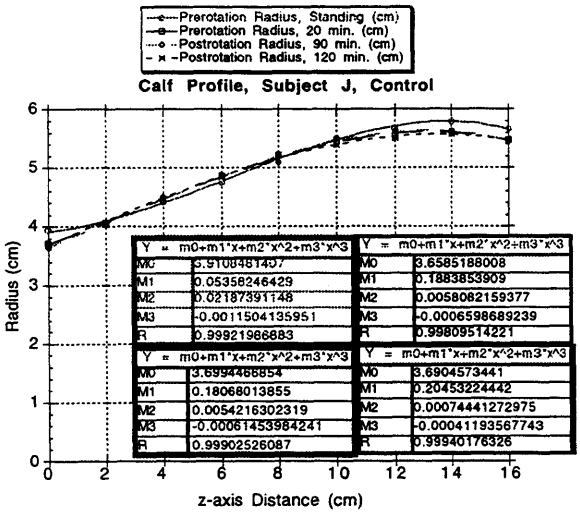


Y = m0+m1*x+m2*x^2+m3*x^3		Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.5553962958	M0	3.5303267082
M1	0.13460357266	M1	0.14137848181
M2	0.014590847603	M2	0.010900165651
M3	-0.00083625415035	M3	-0.00061638543285
R	0.9973023225	R	0.99682910618
Y = m0+m1*x+m2*x^2+m3*x^3		Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.5244502674	M0	3.5405883812
M1	0.15925403978	M1	0.16418045106
M2	0.010160506675	M2	0.0081362939659
M3	-0.0006855599808	M3	-0.0005804461477
R	0.99804712663	R	0.9979943971



Y = m0+m1*x+m2*x^2+m3*x^3		Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.483260995	M0	3.4741469513
M1	0.10795231225	M1	0.096737897526
M2	0.01354085885	M2	0.015938793446
M3	-0.00066081893564	M3	-0.00075435076884
R	0.9984228231	R	0.99874024928
Y = m0+m1*x+m2*x^2+m3*x^3		Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.3864269357	M0	3.4520799147
M1	0.10897131928	M1	0.10762163675
M2	0.014073981966	M2	0.013990086067
M3	-0.00069482155613	M3	-0.00069017237068
R	0.99862621622	R	0.99846463551

Subject J

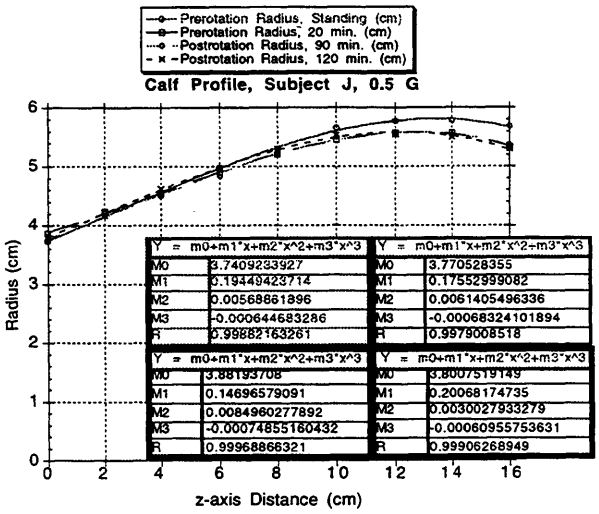


Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.9108481407
M1	0.05358246429
M2	0.02187391148
M3	-0.0011504135951
R	0.99921986883

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.6585188008
M1	0.1883853909
M2	0.0058082159377
M3	-0.0006598689239
R	0.99809514221

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.6994468854
M1	0.18068013855
M2	0.0054216302319
M3	-0.00061453984241
R	0.99902526087

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.6904573441
M1	0.20453224442
M2	0.00074441272975
M3	-0.00041193567743
R	0.99940176326

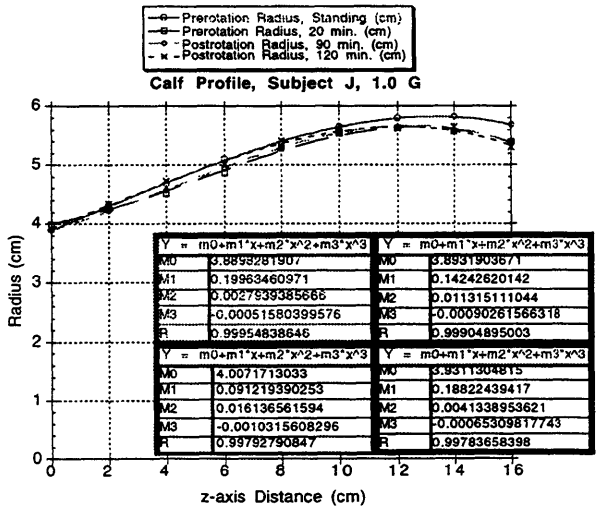


Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.7409233927
M1	0.19449423714
M2	0.00568861896
M3	-0.000644683286
R	0.99882163261

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.770528355
M1	0.17552999082
M2	0.0061405496336
M3	-0.00068324101894
R	0.9979008518

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.88193708
M1	0.14696579091
M2	0.0084960277892
M3	-0.00074855160432
R	0.99968866321

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.8007519149
M1	0.20068174735
M2	0.0030027933279
M3	-0.00060955753631
R	0.99906268949

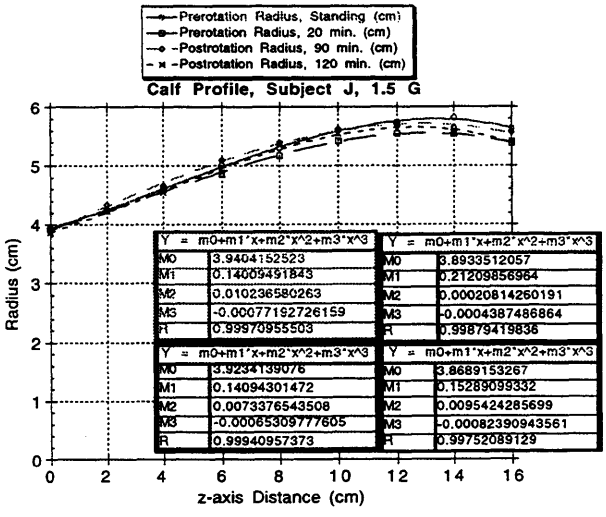


Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.8893281907
M1	0.19963460971
M2	0.0027939385666
M3	-0.00051580399576
R	0.99954838646

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.8931903671
M1	0.14242620142
M2	0.011315111044
M3	-0.00090261566318
R	0.99904895003

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	4.0071713033
M1	0.091219390253
M2	0.016136561594
M3	-0.0010315608296
R	0.99792790847

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.9311304815
M1	0.18822439417
M2	0.0041338953621
M3	-0.00065309817743
R	0.99783658398



Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.9404152523
M1	0.14009491843
M2	0.010236580263
M3	-0.00077192726159
R	0.99970955503

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.8933512057
M1	0.21209856964
M2	0.00020814260191
M3	-0.0004387486864
R	0.99879419836

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.9234139076
M1	0.14094301472
M2	0.0073376543508
M3	-0.00065309777605
R	0.99940957373

Y = m0+m1*x+m2*x^2+m3*x^3	
M0	3.8689153267
M1	0.15289099332
M2	0.0095424285699
M3	-0.00082390943561
R	0.99752089129

Volume Data

Volumes are in cm^3.

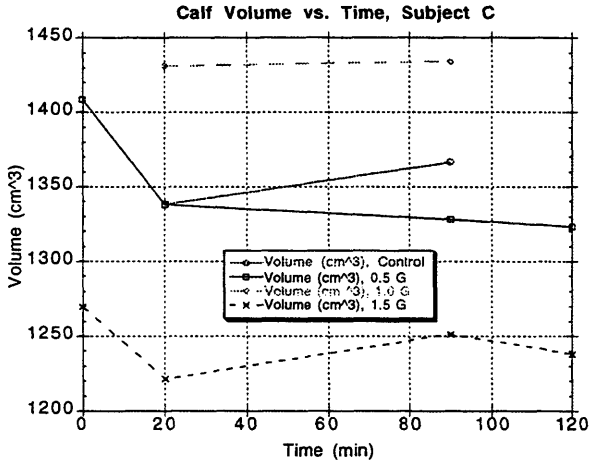
Subject/Time, Trial	0,C	20,C	90,C	120,C	0,0.5	20,0.5	90,0.5	120,0.5	0,1.0	20,1.0	90,1.0	120,1.0	0,1.5	20,1.5	90,1.5	120,1.5
C		1337.8	1366.7		1408.5	1338.2	1328.2	1323.2		1431.2	1434.2		1269.8	1221.5	1251.4	1237.9
D		1688.6	1695.3			1676.4	1670.1			1642	1632.5			1680.7	1723	
E		2512.5	2537.4		2276.6	2215	2216.8	2216.6		2178.6	2189.3		2302.6	2291.6	2337.8	2281.3
F		2036		1992.1	1752.2	1628.4	1638.9	1636.1	1944.5	1881.7	1925.8	1888.3	1732.8	1649.1	1689.3	1665.6
G		1949	2027.6		2227	2147.3	2131.9	2152.9	2248.3	2198.1	2161.5	2121.6	2124.2	2023.5	2076.3	2097
H		1700.8	1712.4		1849.5	1778.9	1751.9	1765.5	1824.1	1733.9	1777.3	1756.2	1746.3	1642.3	1720.8	1659.7
I	1628.7	1605.6	1682.8	1632.1	1651.4	1636.2	1615	1605.5	1522.9	1478.8	1499.4	1474.8	1644.6	1592.1	1654.2	1622.8
J	1292.4	1264.4	1269.3	1258.2	1340.8	1279.7	1272.8	1291.1	1376.3	1300.8	1310.6	1332.3	1348.7	1274.8	1353.7	1304.8

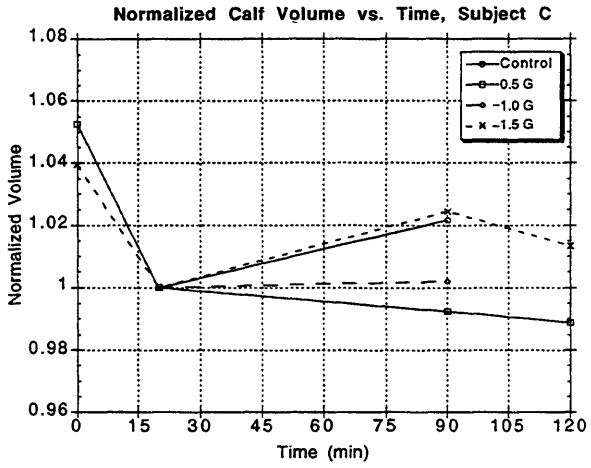
Normalized

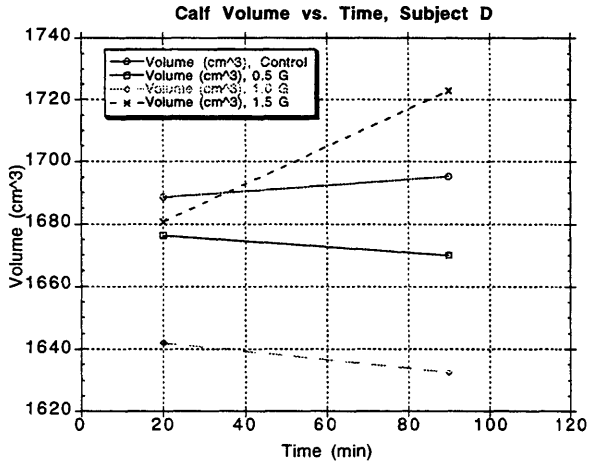
Subject/Time, Trial	0,C	20,C	90,C	120,C	0,05	20,05	90,05	120,05	0,10	20,10	90,10	120,10	0,15	20,15	90,15	120,15
C		1	1.0216		1.0526	1	0.9925	0.9888		1	1.0021		1.0395	1	1.0245	1.0134
D		1	1.004			1	0.9962			1	0.9942			1	1.0251	
E		1	1.0099		1.0278	1	1.0008	1.0007		1	1.0049		1.0048	1	1.0202	0.9955
F		1		0.9784	1.0761	1	1.0065	1.0047	1.0333	1	1.0234	1.0035	1.0508	1	1.0244	1.01
G		1	1.0403		1.0371	1	0.9928	1.0026	1.0228	1	0.9834	0.9652	1.0497	1	1.0261	1.0363
H		1	1.0068		1.0397	1	0.9848	0.9924	1.052	1	1.025	1.0129	1.0634	1	1.0478	1.0106
I	1.0144	1	1.0481	1.0165	1.0093	1	0.987	0.9812	1.0298	1	1.014	0.9973	1.033	1	1.039	1.0193
J	1.0221	1	1.0038	0.9951	1.0478	1	0.9946	1.0089	1.058	1	1.0075	1.0242	1.058	1	1.0619	1.0236
Average:	1.0182	1	1.0192	0.9967	1.0415	1	0.9944	0.9971	1.0392	1	1.0068	1.0006	1.0427	1	1.0336	1.0155
Std. Dev.	0.0054	0	0.0182	0.0191	0.0208	0	0.007	0.0099	0.0151	0	0.0141	0.0222	0.0196	0	0.0147	0.0127
Number:	2	8	7	3	7	8	8	7	5	8	8	5	7	8	8	7
Std. Error:	0.0039	0	0.0069	0.011	0.0079	0	0.0025	0.0037	0.0067	0	0.005	0.0099	0.0074	0	0.0052	0.0048

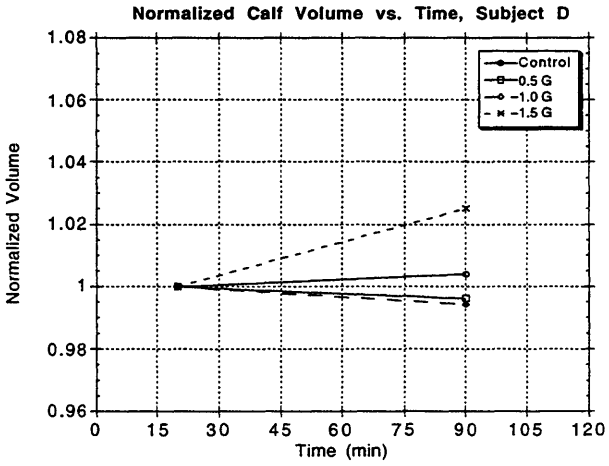
Subject	Average at t = 20	Std. Dev. at t = 20	Coef. of Var. at t = 20
C	1332.15	85.84	6.44
D	1671.92	20.57	1.23
E	2299.41	149.62	6.51
F	1798.79	195.44	10.87
G	2079.48	113.77	5.47
H	1713.96	57.53	3.36
I	1578.19	68.78	4.36
J	1279.91	15.32	1.20
total average and std:	1719.23	345.94	
men average and std.:	1941.19	300.88	
women average and std.:	1497.26	239.42	

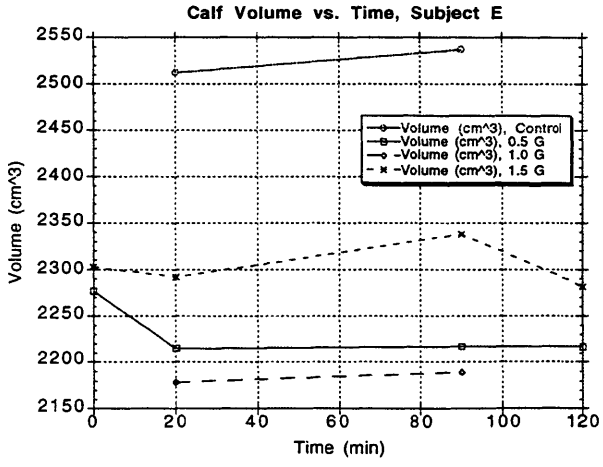
Volume Plots

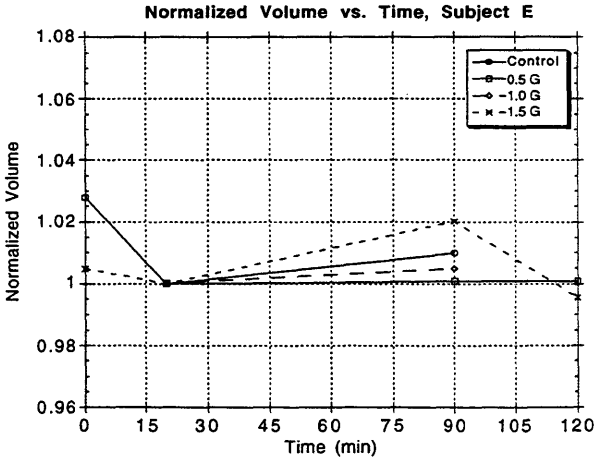


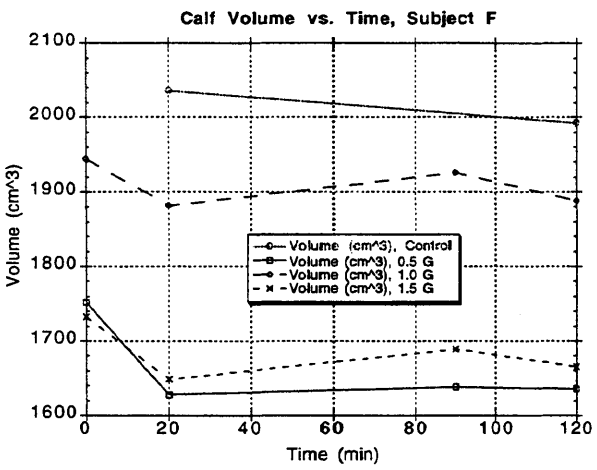


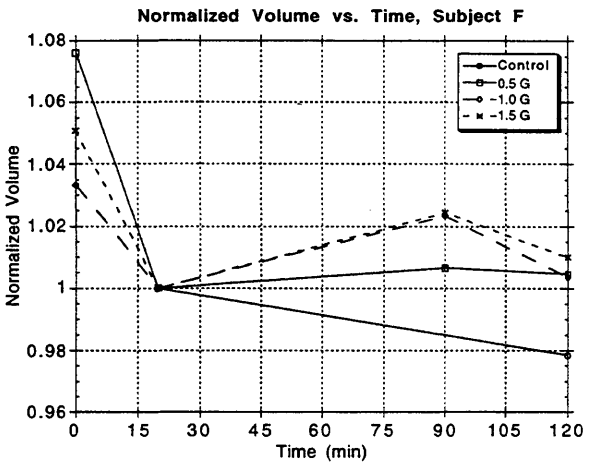


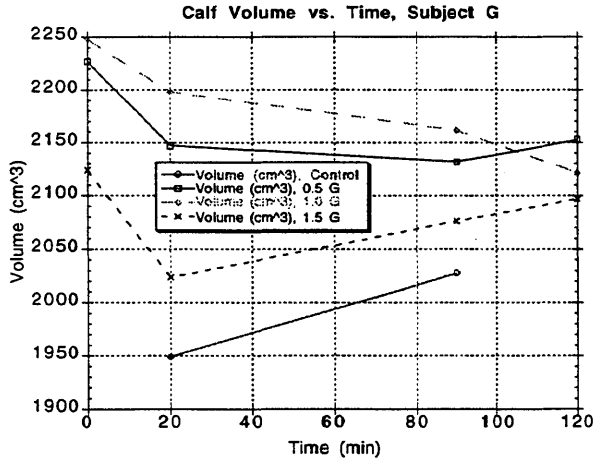


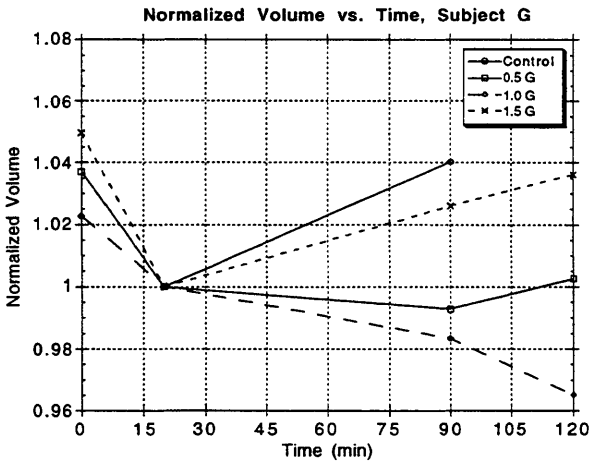


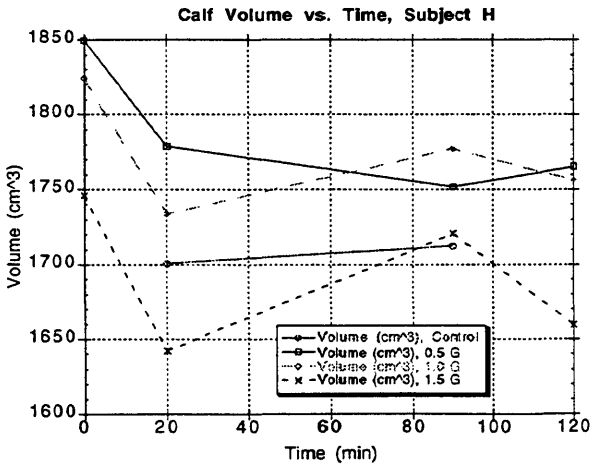


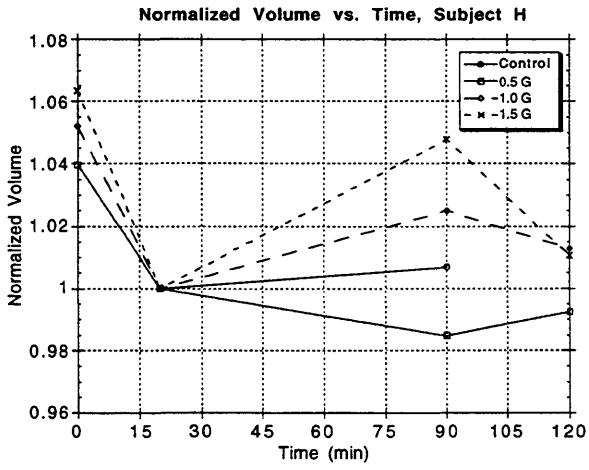

Calf Volume vs. Time, Subject F
Volume (cm^3)
Time (min)
Volume (cm^3), Control
Volume (cm^3), 0.5 G
Volume (cm^3), 1.0 G
Volume (cm^3), 1.5 G

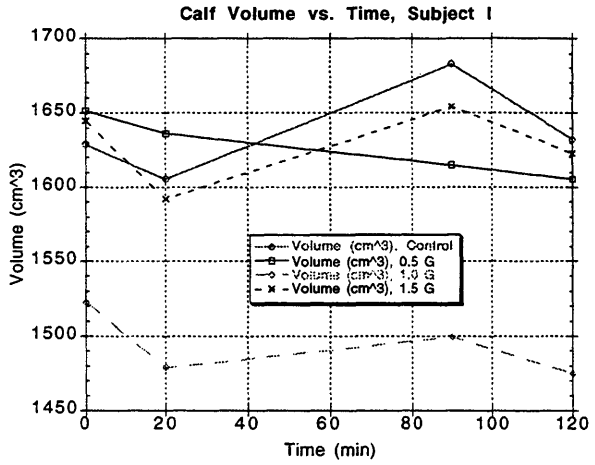

Normalized Volume vs. Time, Subject F
Normalized Volume
Time (min)
Control
0.5 G
-1.0 G
-1.5 G

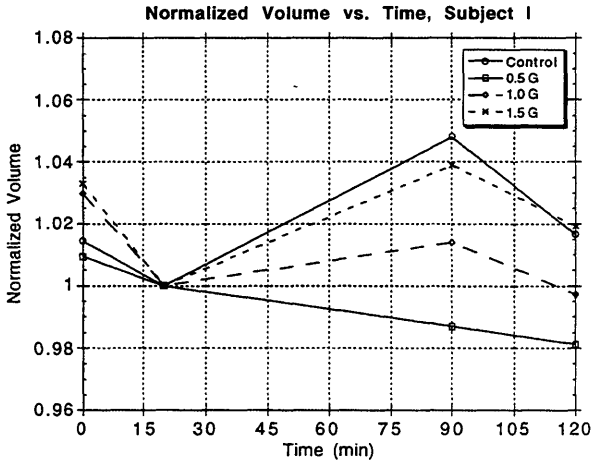

Calf Volume vs. Time, Subject G
Volume (cm^3)
Time (min)
Volume (cm^3), Control
Volume (cm^3), 0.5 G
Volume (cm^3), 1.5 G

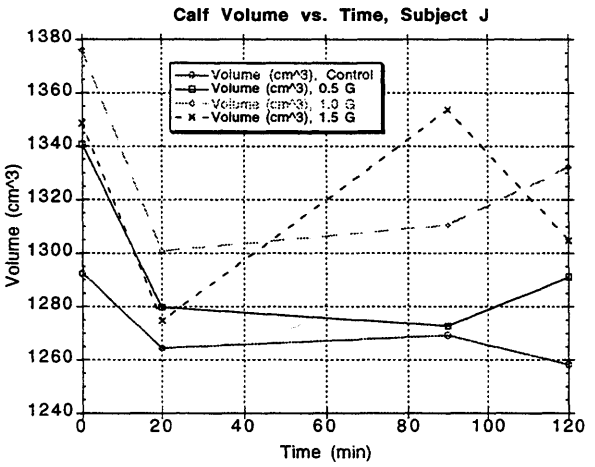

Normalized Volume vs. Time, Subject G
Normalized Volume
Time (min)
Control
0.5 G
-1.0 G
-1.5 G

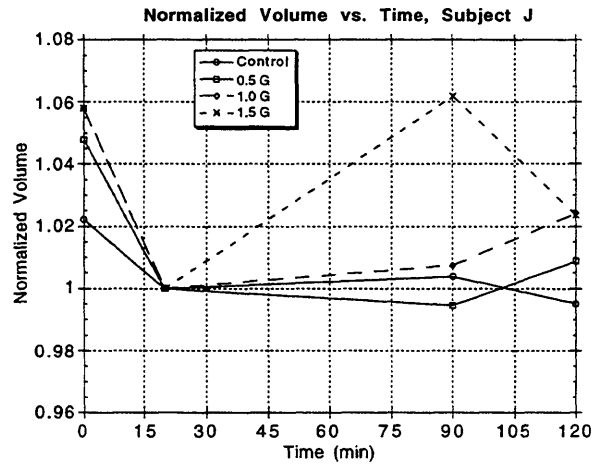

Calf Volume vs. Time, Subject H
Volume (cm^3)
Time (min)
Volume (cm^3), Control
Volume (cm^3), 0.5 G
Volume (cm^3), 1.5 G


Normalized Volume vs. Time, Subject H
Normalized Volume
Time (min)
Control
0.5 G
-1.0 G
-1.5 G


Calf Volume vs. Time, Subject I
Volume (cm^3)
Time (min)
Volume (cm^3), Control
Volume (cm^3), 0.5 G
Volume (cm^3), 1.0 G
Volume (cm^3), 1.5 G


Normalized Volume vs. Time, Subject I
Normalized Volume
Time (min)
Control
0.5 G
1.0 G
1.5 G


Calf Volume vs. Time, Subject J
Volume (cm^3)
Time (min)
Volume (cm^3), Control
Volume (cm^3), 0.5 G
Volume (cm^3), 1.0 G
Volume (cm^3), 1.5 G


Normalized Volume vs. Time, Subject J
Normalized Volume
Time (min)
Control
0.5 G
1.0 G
1.5 G

APPENDIX G

Data and Plots for Calf Impedance-Volume Relationship

Data for Calf Impedance-Volume Relationship

Subject C

Time (min.)	Volume (cm^3)	ΔV (cm^3)	Normalized V	Normalized ΔV	Impedance (Ohms)	ΔI (Ohms)	Normalized Impedance	Normalized ΔI
Control								
0					60.4412		0.9650	
20	1337.36		1.0000		62.6343	2.1931	1.0000	0.0350
90	1366.71	29.35	1.0219	0.0219	61.8287	-0.8056	0.9871	-0.0129
120					64.9049	3.0762	1.0363	0.0491
0.5 G								
0	1408.52		1.0526		64.9373		0.9755	
20	1338.15	-70.37	1.0000	-0.0526	66.5690	1.6317	1.0000	0.0245
90	1328.15	-10	0.9925	-0.0075	65.8691	-0.6999	0.9895	-0.0105
120	1323.22	-4.93	0.9888	-0.0037	67.0248	1.1557	1.0068	0.0174
1.0 G								
0					71.3460		0.9516	
20	1431.16		1.0000		74.9755	3.6295	1.0000	0.0484
90	1434.15	2.99	1.0021	0.0021	74.7153	-0.2602	0.9965	-0.0035
120					77.9217	3.2064	1.0393	0.0428
1.5 G								
0	1269.8		1.0395		71.1305		0.9742	
20	1221.53	-48.27	1.0000	-0.0395	73.0145	1.8840	1.0000	0.0258
90	1251.44	29.91	1.0245	0.0245	70.4713	-2.5433	0.9652	-0.0348
120	1237.93	-13.51	1.0134	-0.0111	73.4946	3.0233	1.0066	0.0414

Subject D

Time (min.)	Volume (cm^3)	ΔV (cm^3)	Normalized V	Normalized ΔV	Impedance (Ohms)	ΔI (Ohms)	Normalized Impedance	Normalized ΔI
Control								
0					80.8553		0.9723	
20	1688.56		1.0000		83.1624	2.3072	1.0000	0.0277
90	1695.29	6.73	1.0040	0.0040	82.6742	-0.4883	0.9941	-0.0059
120					85.9376	3.2634	1.0334	0.0392
0.5 G								
0					81.1850		0.9708	
20	1676.38		1.0000		83.6263	2.4413	1.0000	0.0292
90	1670.06	-6.32	0.9962	-0.0038	84.8429	1.2166	1.0145	0.0145
120					87.3048	2.4618	1.0440	0.0294
1.0 G								
0					95.8537		0.9787	
20	1642.01		1.0000		97.9411	2.0874	1.0000	0.0213
90	1632.53	-9.48	0.9942	-0.0058	98.0673	0.1262	1.0013	0.0013
120					99.1903	1.1231	1.0128	0.0115
1.5 G								
0					94.0553		1.0007	
20	1680.72		1.0000		93.9899	-0.0653	1.0000	-0.0007
90	1722.98	42.26	1.0251	0.0251	91.9353	-2.0546	0.9781	-0.0219
120					93.6524	1.7171	0.9964	0.0183

Subject E

Time (min.)	Volume (cm^3)	ΔV (cm^3)	Normalized V	Normalized ΔV	Impedance (Ohms)	ΔI (Ohms)	Normalized Impedance	Normalized ΔI
Control								
0					78.6783		0.9798	
20	2512.45		1.0000		80.2978	1.6195	1.0000	0.0202
90	2537.37	24.92	1.0099	0.0099	79.6063	-0.6914	0.9914	-0.0086
120					81.2905	1.6842	1.0124	0.0210
0.5 G								
0	2276.64		1.0278		74.9958		0.9918	
20	2215.03	-61.61	1.0000		75.6144	0.6186	1.0000	0.0082
90	2216.78	1.75	1.0008	0.0008	75.5045	-0.1099	0.9985	-0.0015
120	2216.55	-0.23	1.0007		76.5259	1.0214	1.0121	0.0135
1.0 G								
0					74.3082		0.9865	
20	2178.62		1.0000		75.3215	1.0133	1.0000	0.0135
90	2189.27	10.65	1.0049	0.0049	76.2411	0.9196	1.0122	0.0122
120					77.5798	1.3387	1.0300	0.0178
1.5 G								
0	2302.6		1.0048		76.4201		0.9883	
20	2291.55	-11.05	1.0000	-0.0048	77.3275	0.9074	1.0000	0.0117
90	2337.8	46.25	1.0202	0.0202	75.5087	-1.8188	0.9765	-0.0235
120	2281.31	-56.49	0.9955	-0.0247	78.7476	3.2389	1.0184	0.0419

Subject F

Time (min.)	Volume (cm^3)	ΔV (cm^3)	Normalized V	Normalized ΔV	Impedance (Ohms)	ΔI (Ohms)	Normalized Impedance	Normalized ΔI
Control								
0					75.9848		0.9403	
20	2035.97		1.0000		80.8067	4.8218	1.0000	0.0597
90					76.5911	-4.2156	0.9478	-0.0522
120	1992.09		0.9784		81.1808	4.5898	1.0046	0.0568
0.5 G								
0	1752.23		1.0761					
20	1628.35	-123.88	1.0000	-0.0761	77.1606		1.0000	
90	1638.9	10.55	1.0065	0.0065	77.0346	-0.1260	0.9984	-0.0016
120	1636.08	-2.82	1.0047	-0.0017	78.9876	1.9530	1.0237	0.0253
1.0 G								
0	1944.48		1.0333		76.4203		0.9848	
20	1881.73	-62.75	1.0000	-0.0333	77.5962	1.1758	1.0000	0.0152
90	1925.79	44.06	1.0234	0.0234	73.7508	-3.8454	0.9504	-0.0496
120	1888.34	-37.45	1.0035	-0.0199	77.5349	3.7842	0.9992	0.0488
1.5 G								
0	1732.84		1.0508		74.6378		0.9695	
20	1649.1	-83.74	1.0000	-0.0508	76.9898	2.3520	1.0000	0.0305
90	1689.31	40.21	1.0244	0.0244	72.4895	-4.5002	0.9415	-0.0585
120	1665.63	-23.68	1.0100	-0.0144	77.5524	5.0629	1.0073	0.0658

Subject G

Time (min.)	Volume (cm^3)	ΔV (cm^3)	Normalized V	Normalized ΔV	Impedance (Ohms)	ΔI (Ohms)	Normalized Impedance	Normalized ΔI
Control								
0					60.6000		0.9733	
20	1949		1.0000		62.2640	1.6640	1.0000	0.0267
90	2027.58	78.58	1.0403	0.0403	62.2315	-0.0325	0.9995	-0.0005
120					64.8888	2.6573	1.0422	0.0427
0.5 G								
0	2227		1.0371		74.2919		0.9560	
20	2147.29	-79.71	1.0000	-0.0371	77.7099	3.4180	1.0000	0.0440
90	2131.92	-15.37	0.9928	-0.0072	77.5065	-0.2034	0.9974	-0.0026
120	2152.9	20.98	1.0026	0.0098	79.8503	2.3438	1.0275	0.0302
1.0 G								
0	2248.29		1.0228		74.1333		0.9687	
20	2198.12	-50.17	1.0000	-0.0228	76.5260	2.3928	1.0000	0.0313
90	2161.53	-36.59	0.9834	-0.0166	76.2370	-0.2890	0.9962	-0.0038
120	2121.64	-39.89	0.9652	-0.0181	80.3265	4.0895	1.0497	0.0534
1.5 G								
0	2124.15		1.0497		67.5455		0.9563	
20	2023.51	-100.64	1.0000	-0.0497	70.6338	3.0883	1.0000	0.0437
90	2076.31	52.8	1.0261	0.0261	67.0412	-3.5927	0.9491	-0.0509
120	2096.99	20.68	1.0363	0.0102	71.3093	4.2682	1.0096	0.0604

Subject H

Time (min.)	Volume (cm^3)	ΔV (cm^3)	Normalized V	Normalized ΔV	Impedance (Ohms)	ΔI (Ohms)	Normalized Impedance	Normalized ΔI
Control								
0					65.1204		0.9706	
20	1700.75		1.0000		67.0898	1.9694	1.0000	0.0294
90	1712.36	11.61	1.0068	0.0068	68.4490	1.3592	1.0203	0.0203
120					71.1629	2.7139	1.0607	0.0405
0.5 G								
0	1849.53		1.0397		63.7656		0.9697	
20	1778.9	-70.63	1.0000	-0.0397	65.7551	1.9895	1.0000	0.0303
90	1751.86	-27.04	0.9848	-0.0152	67.0167	1.2616	1.0192	0.0192
120	1765.46	13.6	0.9924	0.0076	68.9656	1.9489	1.0488	0.0296
1.0 G								
0	1824.09		1.0520		66.4470		0.9801	
20	1733.91	-90.18	1.0000	-0.0520	67.7938	1.3467	1.0000	0.0199
90	1777.29	43.38	1.0250	0.0250	66.7481	-1.0457	0.9846	-0.0154
120	1756.24	-21.05	1.0129	-0.0121	68.9006	2.1525	1.0163	0.0318
1.5 G								
0	1746.3		1.0634		62.0036		0.9617	
20	1642.26	-104.04	1.0000	-0.0634	64.4735	2.4699	1.0000	0.0383
90	1720.77	78.51	1.0478	0.0478	61.5885	-2.8850	0.9553	-0.0447
120	1659.67	-61.1	1.0106	-0.0372	64.9373	3.3488	1.0072	0.0519

Subject I

Time (min.)	Volume (cm^3)	ΔV (cm^3)	Normalized V	Normalized ΔV	Impedance (Ohms)	ΔI (Ohms)	Normalized Impedance	Normalized ΔI
Control								
0	1628.71		1.0144		71.5944		0.9766	
20	1605.6	-23.11	1.0000	-0.0144	73.3073	1.7129	1.0000	0.0234
90	1682.82	77.22	1.0481	0.0481	70.2555	-3.0518	0.9584	-0.0416
120	1632.13	-50.69	1.0165	-0.0316	72.1272	1.8717	0.9839	0.0255
0.5 G								
0	1651.42		1.0093		77.7588		0.9845	
20	1636.21	-15.21	1.0000	-0.0093	78.9837	1.2248	1.0000	0.0155
90	1615.01	-21.2	0.9870	-0.0130	80.5949	1.6113	1.0204	0.0204
120	1605.49	-9.52	0.9812	-0.0058	81.4859	0.8910	1.0317	0.0113
1.0 G								
0	1522.86		1.0298					
20	1478.8	-44.06	1.0000	-0.0298	68.3189		1.0000	
90	1499.43	20.63	1.0140	0.0140	68.3432	0.0243	1.0004	0.0004
120	1474.82	-24.61	0.9973	-0.0166	70.0562	1.7130	1.0254	0.0251
1.5 G								
0	1644.61		1.0330					
20	1592.14	-52.47	1.0000	-0.0330	78.6498		1.0000	
90	1654.16	62.02	1.0390	0.0390	75.9441	-2.7058	0.9656	-0.0344
120	1622.81	-31.35	1.0193	-0.0197	79.3376	3.3935	1.0087	0.0431

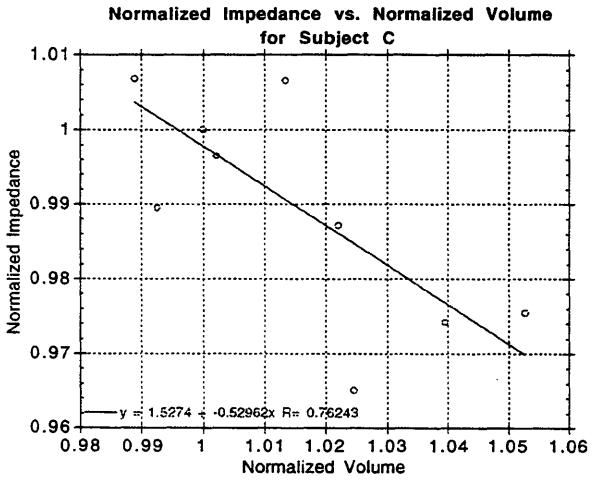
Subject J

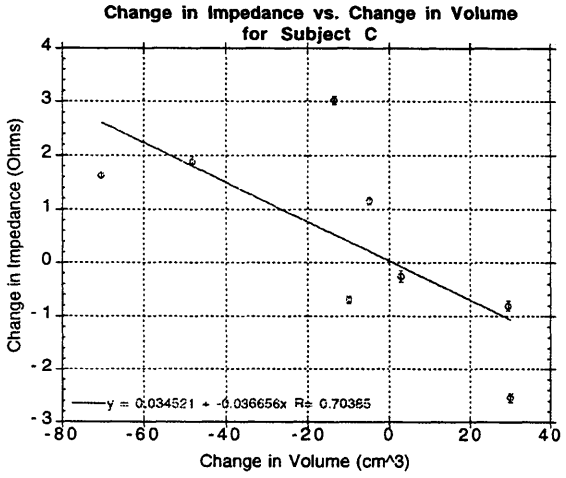
Time (min.)	Volume (cm^3)	ΔV (cm^3)	Normalized V	Normalized ΔV	Impedance (Ohms)	ΔI (Ohms)	Normalized Impedance	Normalized ΔI
Control								
0	1292.35		1.0221		63.8266		0.9503	
20	1264.41	-27.94	1.0000	-0.0221	67.1672	3.3406	1.0000	0.0497
90	1269.27	4.86	1.0038	0.0038	64.9193	-2.2479	0.9665	-0.0335
120	1258.23	-11.04	0.9951	-0.0087	68.9452	4.0259	1.0265	0.0599
0.5 G								
0	1340.78		1.0478		66.4441		0.9689	
20	1279.65	-61.13	1.0000	-0.0478	68.5792	2.1351	1.0000	0.0311
90	1272.78	-6.87	0.9946	-0.0054	69.2993	0.7202	1.0105	0.0105
120	1291.1	18.32	1.0089	0.0143	71.8099	2.5106	1.0471	0.0366
1.0 G								
0	1376.33		1.0580		57.5075		0.9566	
20	1300.82	-75.51	1.0000	-0.0580	60.1155	2.6080	1.0000	0.0434
90	1310.56	9.74	1.0075	0.0075	60.2418	0.1263	1.0021	0.0021
120	1332.29	21.73	1.0242	0.0167	63.1552	2.9133	1.0506	0.0485
1.5 G								
0	1348.66		1.0580		58.6751		0.9636	
20	1274.76	-73.9	1.0000	-0.0580	60.8928	2.2178	1.0000	0.0364
90	1353.66	78.9	1.0619	0.0619	56.1890	-4.7038	0.9228	-0.0772
120	1304.81	-48.85	1.0236	-0.0383	60.2782	4.0892	0.9899	0.0672

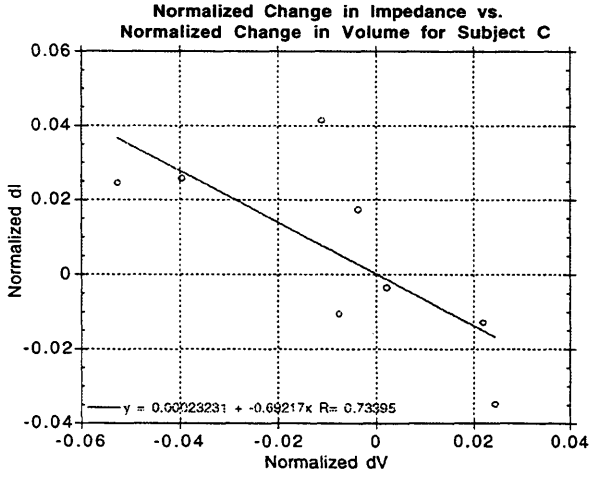
Plots for Calf Impedance-Volume Relationship

Error bars represent standard deviations.

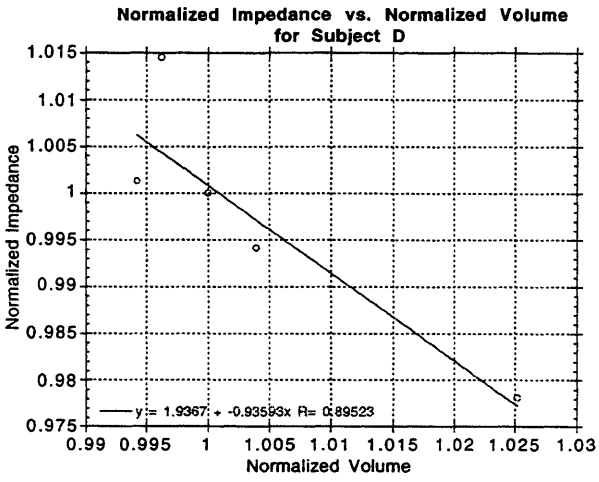
Subject C

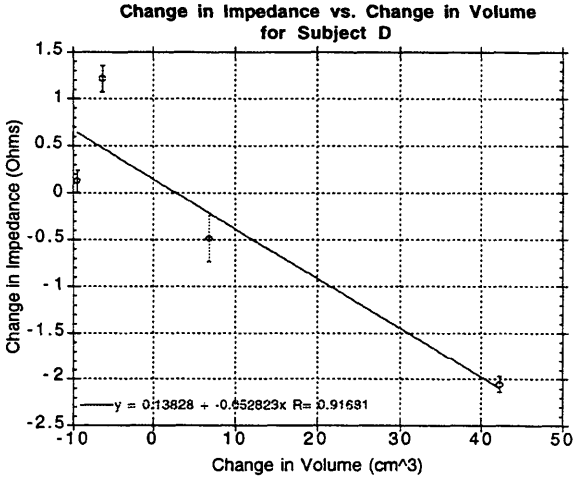


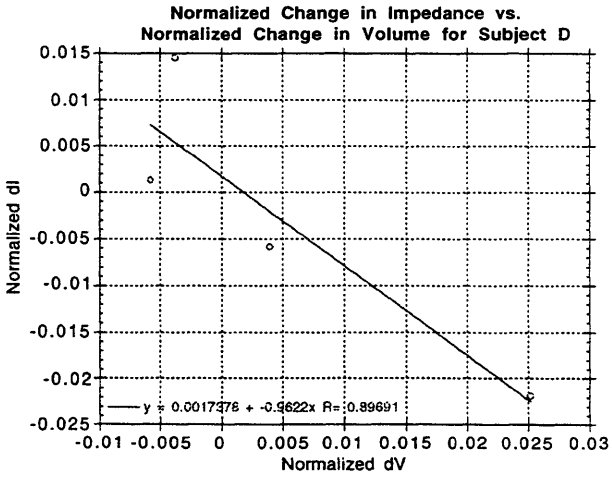




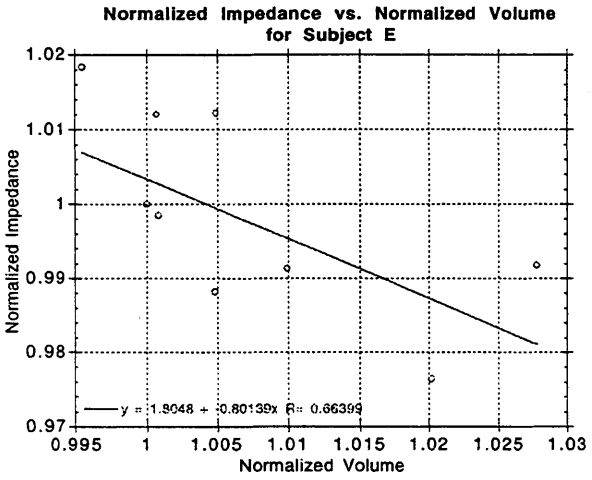
Subject D

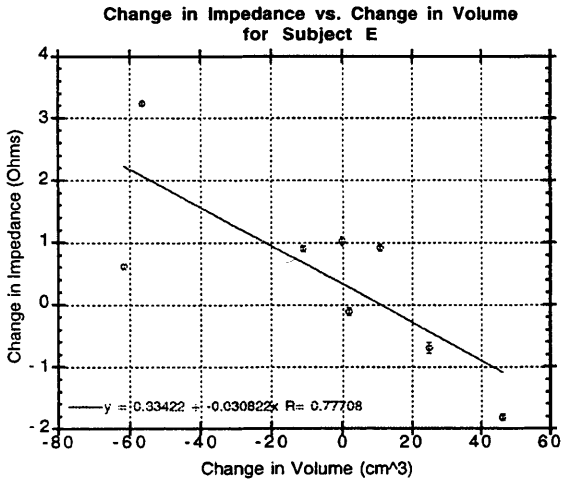


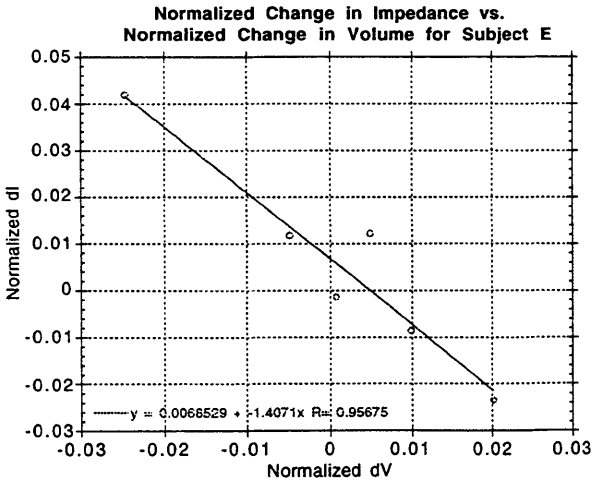




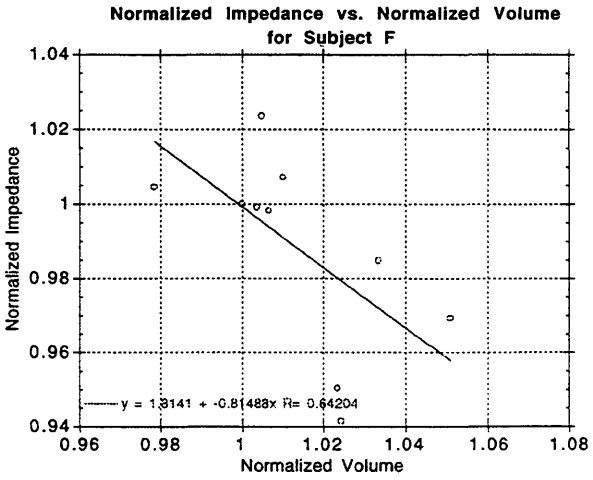
Subject E

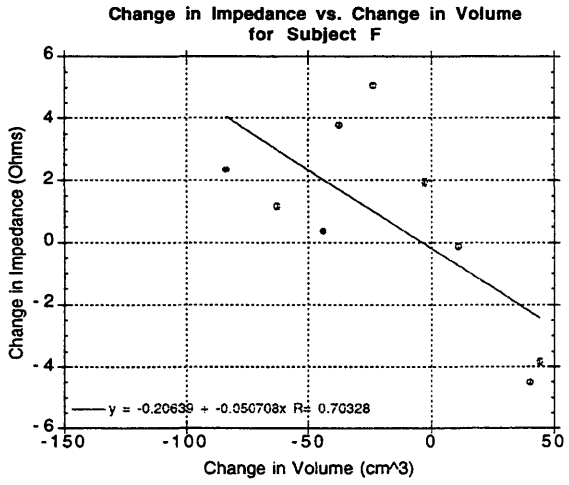


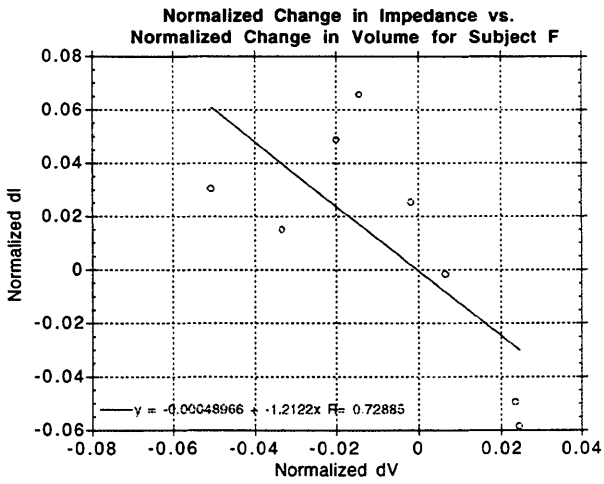




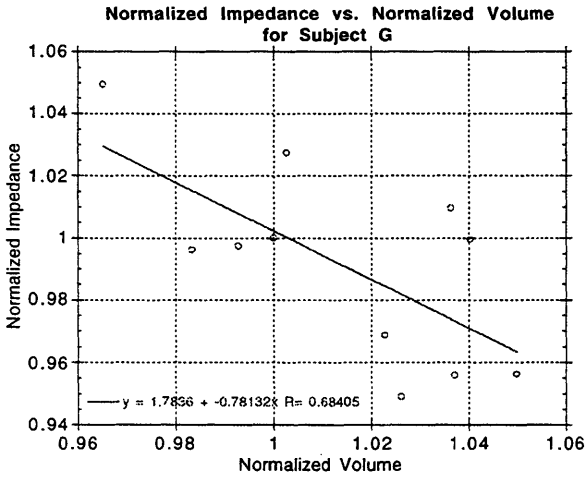
Subject F

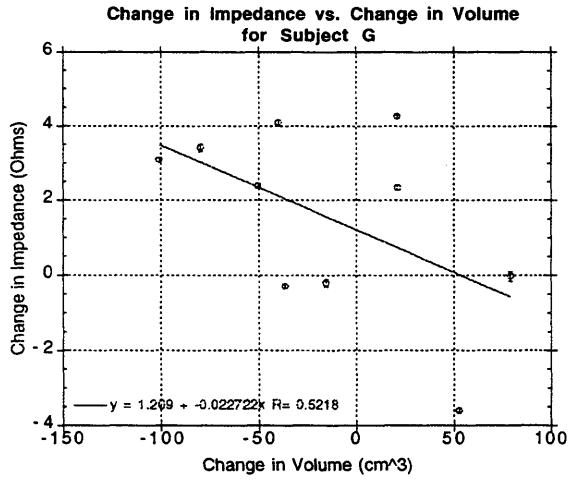


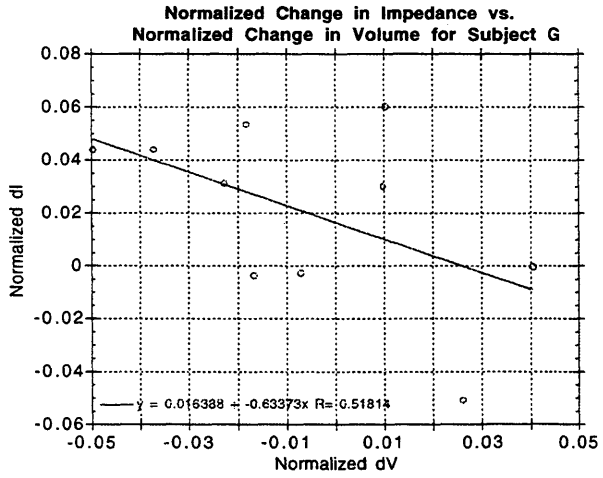




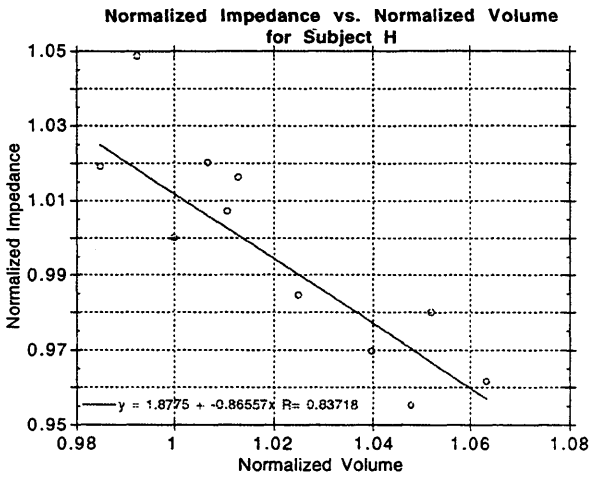
Subject G

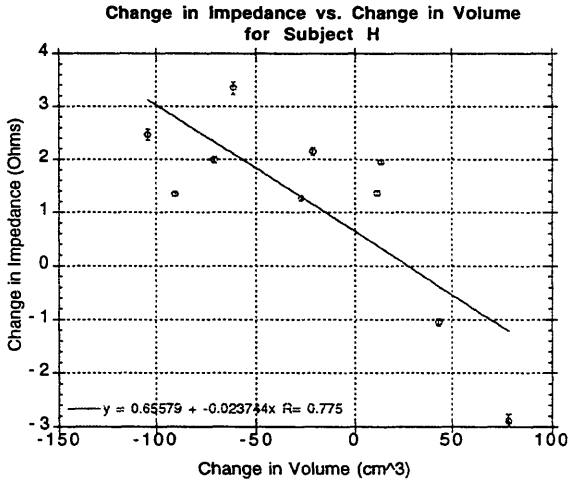


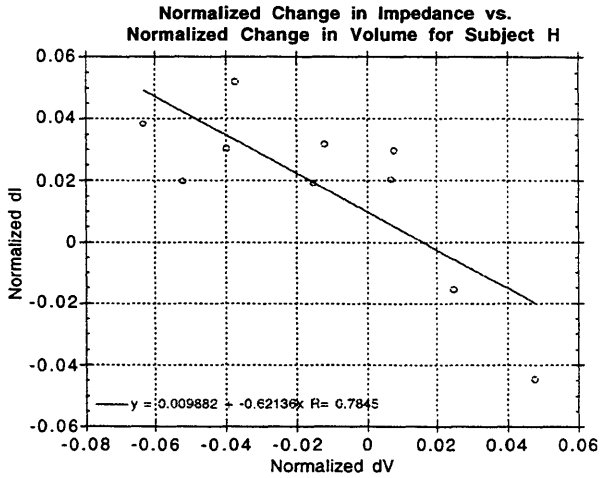




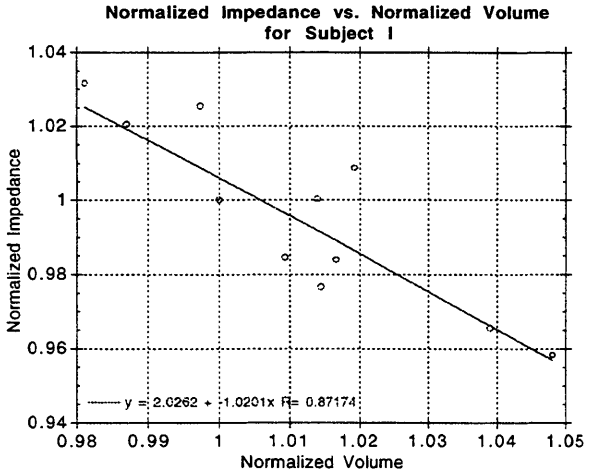
Subject H

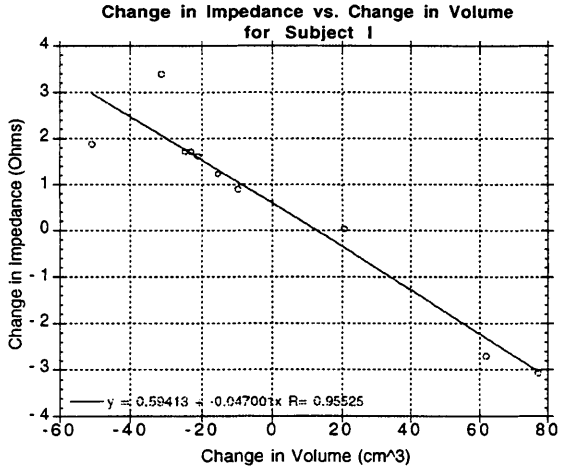


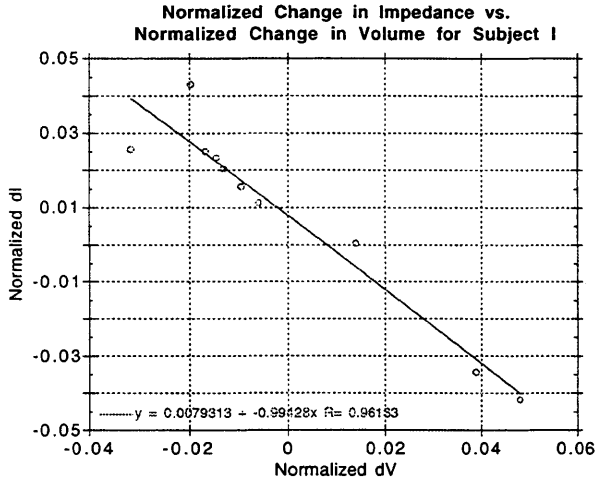




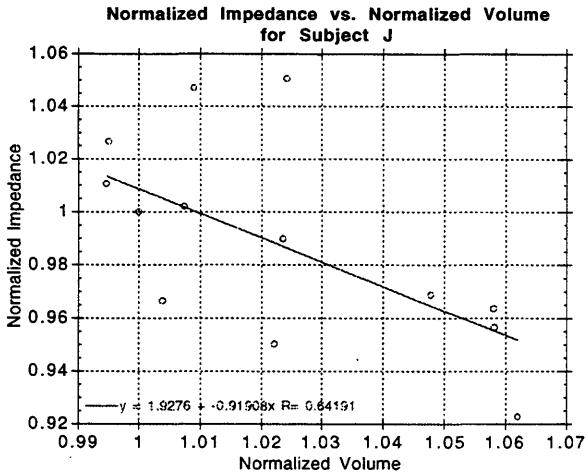
Subject I

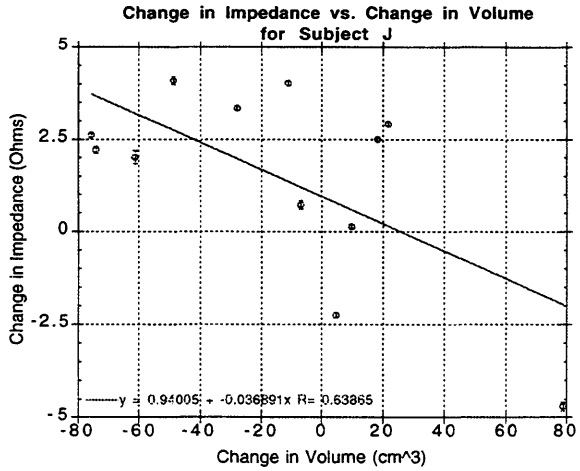


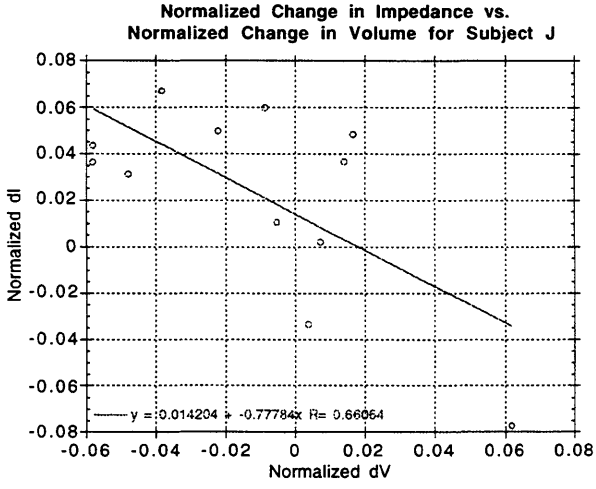




Subject J







APPENDIX H

Blood Pressure Data and Plots

Measured Blood Pressure Data

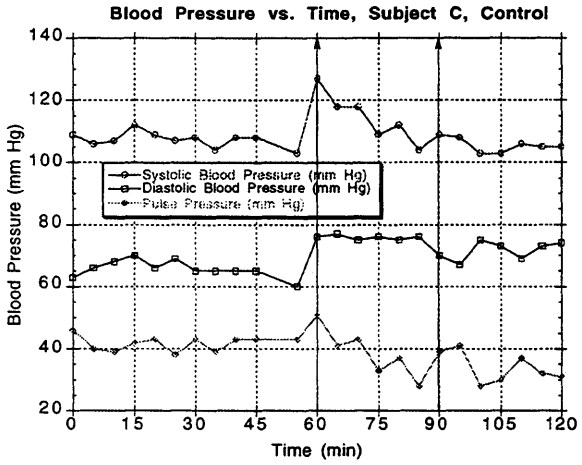
Results are presented with the subject's code letter followed by an "S" or a "D" indicating systolic or diastolic BP, respectively.

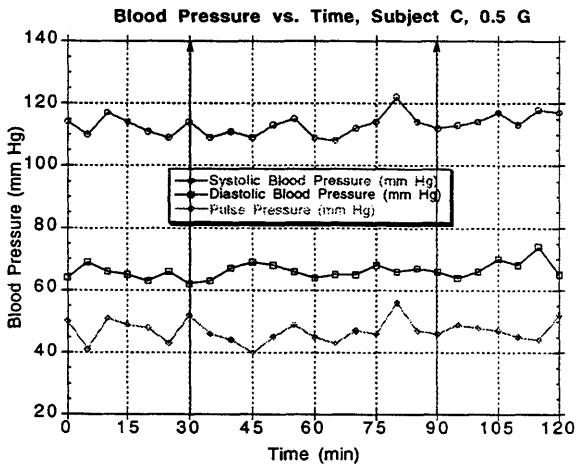
	BP During Control (bpm)															
Time (min)	CS	CD	DS	DD	ES	ED	FS	FD	GS	GD	HS	HD	IS	ID	JS	JD
0	109	63	136	58	143	75	119	74	113	71	127	73	132	66	106	67
5	106	66	121	65	136	76	121	72	117	62	126	70	133	68	108	61
10	107	68	136		136	83	117	68	113	62	127	70	127	68		
15	112	70	119	74	143	77	115	72	115	60	122	67	128	72	106	64
20	109	66	127	65	146	76	115	71	114	61	124	67	124	65	103	67
25	107	69	123	69	138	84	115	74	117	66	116	68	130	72	103	72
30	108	65			138	80	121	76	112	58	119	68	128	70	110	71
35	104	65	119	74	140	76	117	74	108	60	124	68	130	69	103	66
40	108	65	127	75	143	89	118	72	111	61	119	72	126	68	106	59
45	108	65		77	139	81	119	74	108	63	131	76	130	72	100	64
50			124	74	150	76	116	74	101	61	125	69	122	71	100	64
55	103	60	135	85	140	81	117	73	118	67	121	68	127	72	104	65
60	127	76	134	86	150	84	107	71			131	78	125	87	121	75
65	118	77	129	82	152	93	109	76	138	91	123	83	121	81	111	67
70	118	75	126	77	146	94	108	71	127	88	121	77			104	69
75	109	76	120	88			107	76	132	82	121	85	110	82	104	76
80	112	75	137	94	155	89	117	76	117	75	133	81	112	79	102	65
85	104	76	128	83	149	95	118	79	135	76	119	77	114	82	107	75
90	109	70	130	82	150	88	117	79	143	71			126	76	107	71
95	108	67	124	71	143	78	116	79	123	69	122	75	125	72	101	69
100	103	75	126	70	143	81	118	76	124	69	115	76	118	75	101	67
105	103	73	124	68	143	78	113	76	126	67	125	84	122	73	99	66
110	106	69	119	67	141	74	115	82	132	64	131	69	121	76	102	65
115	105	73	119	67	144	84	119	74	127	70	122	75	122	72	103	70
120	105	74	123	69	147	87	114	75	127	66	125	76	121	73	112	69
	BP During 0.5 G (bpm)															
Time (min)	CS	CD	DS	DD	ES	ED	FS	FD	GS	GD	HS	HD	IS	ID	JS	JD
0	114	64	112	60	140	66	115	68	117	68	125	66	138	73	121	66
5	110	69	111	57	132	65	111	72	107	61	116	60	139	72	110	60
10	117	66	110	56	127	73	113	70	108	65	113	62	137	75	112	59
15	114	65	111	62	130	65	113	71	108	58	115	62	135	71	104	58
20	111	63	109	58	132	66	108	72	122	66	115	61	129	73	106	59
25	109	66	106	59	131	85	107	70	115	63	115	62	131	72	107	59
30	114	62	107	59	133	72	110	74	112	64	113	62	130	69	108	57
35	109	63	106	61	132	80	111	70	127	63	116	67	130	71	102	54
40	111	67	103	63	131	78	107	70	107	60			133	75	104	58
45	109	69	108	61	133	73	112	76	108	61	122	74	130	73	106	56
50	113	68	106	65	134	66	109	70	111	72	116	71	127	72	104	61
55	115	66	104	63	135	72	104	75	115	63	122	71	130	72	106	62
60	109	64	111	67	133	79	113	70	118	67	115	67	133	69	102	58
65	108	65	112	66	134	73	110	76	116	64	116	70	129	76	103	59
70	112	65	113	63	135	77	107	76	110	69	114	70	126	72	100	63
75	114	68	116	73	138	72	111	77	106	71	117	67	125	73	107	62
80	122	66	112	69	139	80	103	71	112	67	118	71	125	80	102	61
85	114	67	111	72	135	72	105	71	119	67	121	73	122	74	105	61
90	112	66	116	64	133	72	111	74	113	63	116	69	125	70	104	63
95	113	64	120	69	139	83	115	73	105	59	117	71	126	73	105	65
100	114	66	113	68	136	78	108	79	107	58	116	70	121	74	104	67
105	117	70	113	69	135	80	111	76	109	60	116	64			106	62
110	113	68	102	61	140	79	111	75	113	58	113	71	126	77	103	61
115	118	74	128	72	143	70	111	76	113	60	115	70	122	72	103	64
120	117	65	120	74	132	79			106	60			126	71	109	67
	BP During 1.0 G (bpm)															
Time (min)	CS	CD	DS	DD	ES	ED	FS	FD	GS	GD	HS	HD	IS	ID	JS	JD
0	96	68	134	64	140	73	115	72	127	63	128	64	140	71	115	68
5	101	67	121	62	140	80	111	72	116	65	107	67	134	69	107	62
10	108	71	119	69	138	74	107	68	123	66	111	66	129	70	105	57
15	105	70	113	62	135	71	108	68	122	64	110	65	122	69	110	62
20	107	70	119	68	134	78	112	68	118	64	112	65	128	72	109	61
25			116	69	135	74	106	67	121	69	111	66	126	73	107	63
30	106	68	117	76	134	83			119	63	109	68	123	76	108	66
35	103	73	121	74	135	79	106	69	120	67	112	71	124	71	105	68
40	107	77	124	81	134	82	106	75	116	68	102	65	121	73	110	66
45	117	78	125	80	134	76	106	69	116	76	111	67	121	77	110	66
50	117	72	121	71	131	75	110	73	120	67	107	66	117	75	108	62
55	103	77	125	79	125	76	110	76	116	65			112	81	111	57
60	106	75	122	74	132	77	104	70	121	66	104	69	137	66	105	69
65	99	72	124	74	129	81	108	73	115	71	108	72	123	74	104	70
70	100	76	126	78			103	70	124	67	120	76	120	73	104	63
75	106	69	127	79	133	80	106	74	122	76	112	75	121	77	112	69
80	107	72			126	77	109	72	113	72	120	76	116	74	108	67
85	107	72	119	75			108	70	121	74	112	73	120	72	102	63
90	109	69	120	74	135	79	107	73	118	65	118	73	125	72	103	64
95	109	73	122	72	135	86	105	71	126	67	119	75	121	73	106	62
100	106	72	119	74	135	83	109	70	129	64	114	71	124	74	105	63
105	107	74	123	77	144	86	106	72	122	63	122	73	121	72	105	66
110	105	73	122	72	141	89	110	74	124	67	113	68	118	79	109	74
115	106	70	119	75	146	89	106	73	124	65	117	70	124	81	99	63
120	108	74			146	88			122	67	122	70	124	81	111	66
125																
130							108	76								
	BP During 1.5 G (bpm)															
Time (min)	CS	CD	DS	DD	ES	ED	FS	FD	GS	GD	HS	HD	IS	ID	JS	JD
0	112	68	132	71	169	77	113	70	124	71	127	66	137	73	105	71
5	115	66	118	64	161	77	104	68	113	66	118	62	131	68	102	60
10	115	70			154	74	106	76	119	68	121	65	130	68	101	59
15	113	73	121	80	152	79	104	69	121	64	119	64	129	67	104	63
20	113	73	115	67			103	72	108	59	111	82	122	68	107	64
25	113	68	126	63	155	79	102	71			114	61	128	64	105	62
30	109	74	121	75	158	77	102	76	104	70	117	68	124	75	99	61
35	108	73	118	73	151	81	102	77	101	67	118	72	119	75	106	65
40	108	70	122	74	152	79	111	75	100	69	105	82	123	77	104	63
45	107	66	125	76	156	85	107	75	105	70	112	69	126	81	99	63
50	105	70	126	77	156	80	106	75	102	68	109	75	126	80	105	65
55	107	70	125	76	157	86	100	73	109	71	118	75	121	80	118	75
60	108	72	125	80	157	88	109	76	102	71	113	75	118	82	109	69
65	109	70	125	78	160	87	105	87	105	71	112	80	121	79	111	70
70	108	72	126	77	156	86	96	76	100	74	113	76	118	83	110	71
75	106	73	122	75	165	92	106	79	106	72	117	73	116	74	100	67
80	105	73	120	86	154	91	107	80	100	74	126	66	120	86	112	72
85	107	73	123	82	167	89	104	79	101	77	128	99	116	81	106	68
90	111	68	130	76	158	72	107	76	113	70	120	76	118	71	103	69
95			121	74	157	73	112	78	107	70	121	78	115	73		
100	110	66	128	74	149	82	111	77	103	63	121	74	113	74	102	66
105	111	70	131	78	149	73	108	73	112	66	117	74	115	72	106	67
110	109	72	122	71	158	77	113	80	103	65	123	78	121	73	108	63
115	108	75	130	78	157	77	111	77	106	66	129	75	115	73	105	65
120	113	74	130	68	157	73	113	73	110	66	126	71	113	74	108	67

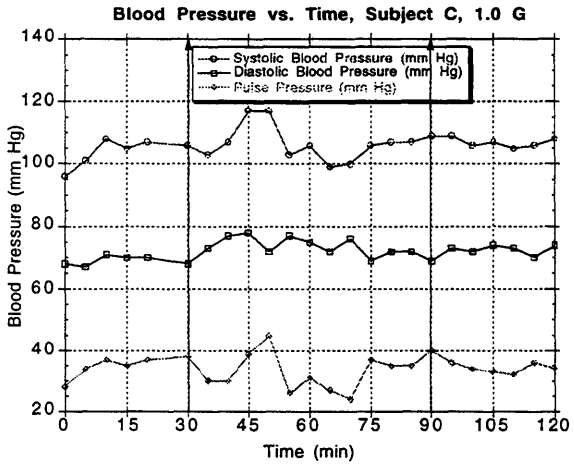
Measured Blood Pressure Plots

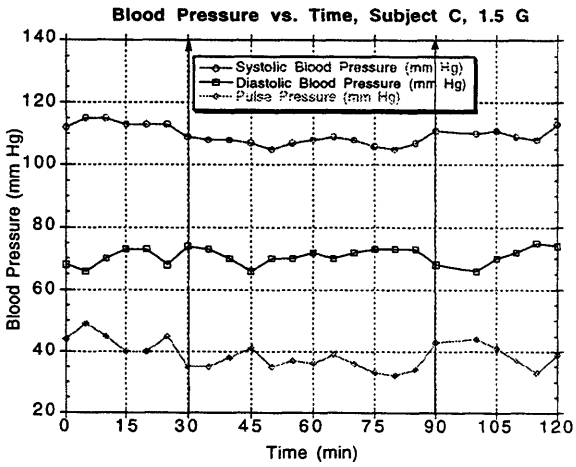
The vertical bars with arrows represent initiation or cessation of a stimulus.

Subject C

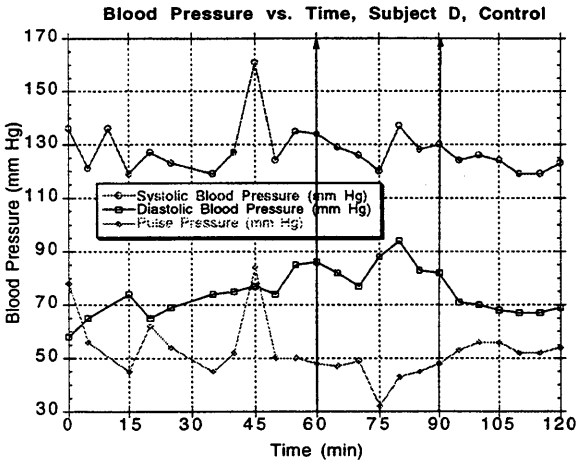


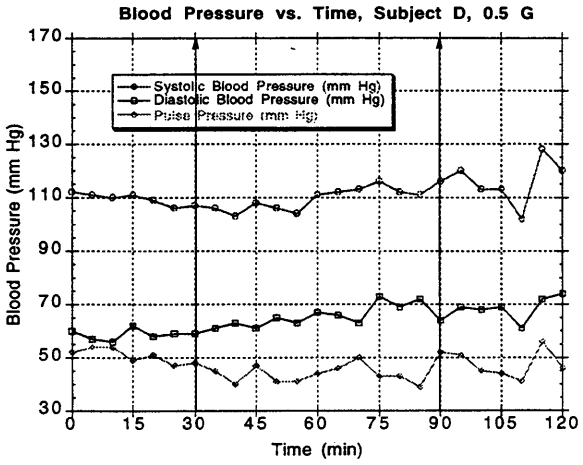


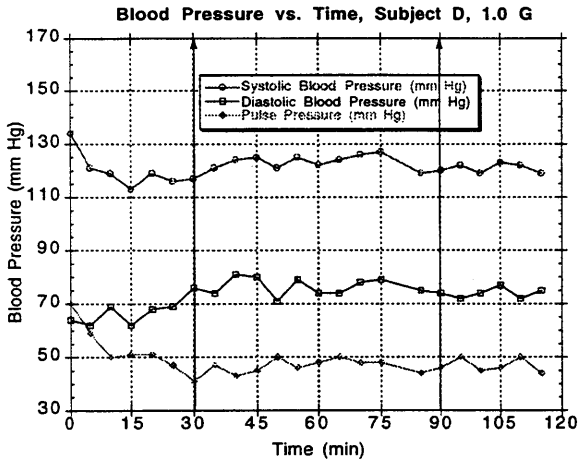


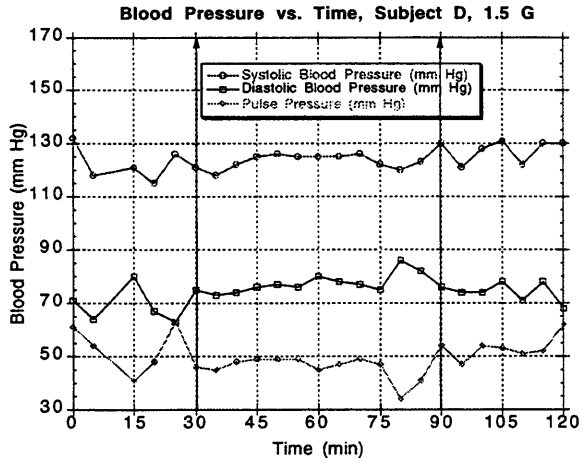


Subject D

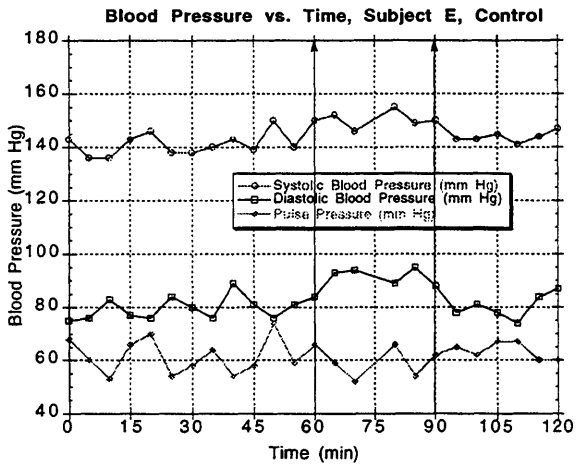

Blood Pressure vs. Time, Subject D, Control
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

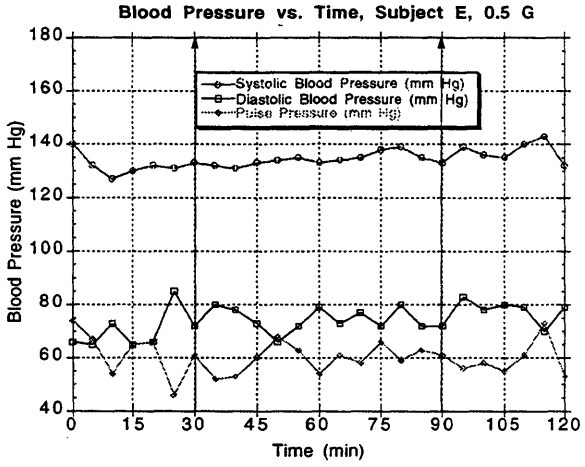

Blood Pressure vs. Time, Subject D, 0.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

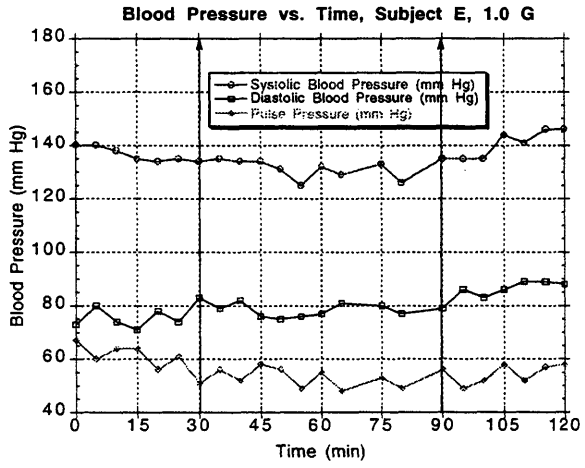

Blood Pressure vs. Time, Subject D, 1.0 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

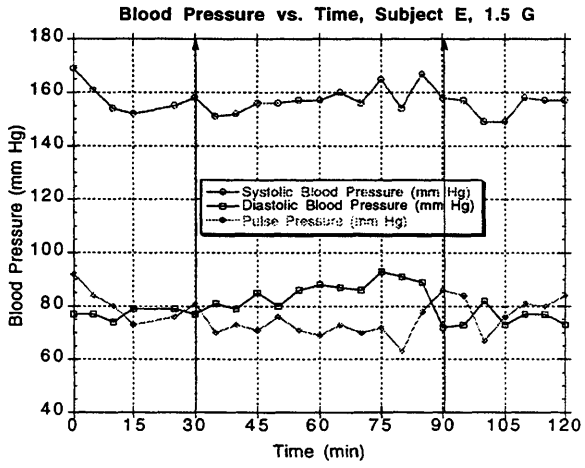

Blood Pressure vs. Time, Subject D, 1.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

Subject E

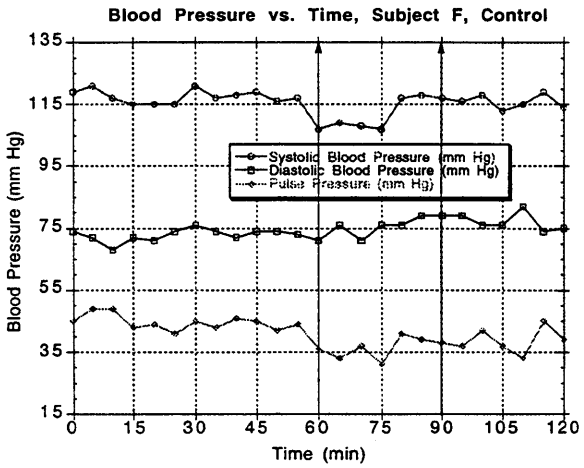

Blood Pressure vs. Time, Subject E, Control
Blood Pressure (mm Hg)
Time (min)
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)

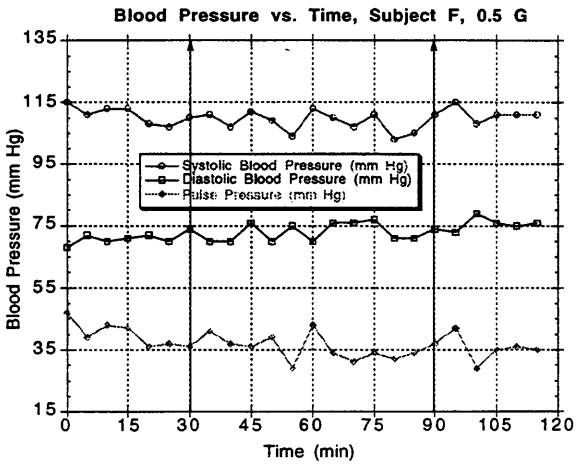

Blood Pressure vs. Time, Subject E, 0.5 G
Blood Pressure (mm Hg)
Time (min)
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)

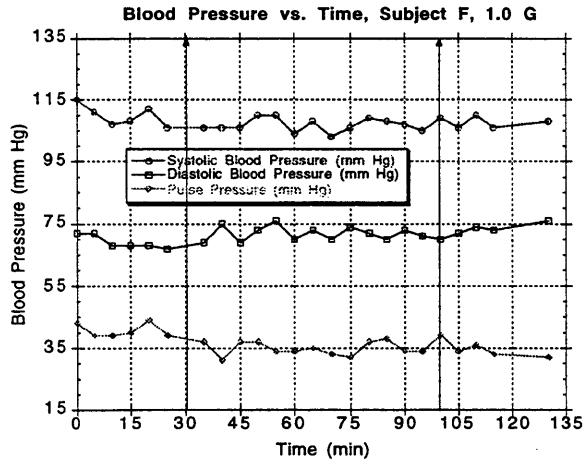

Blood Pressure vs. Time, Subject E, 1.0 G
Blood Pressure (mm Hg)
Time (min)
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)

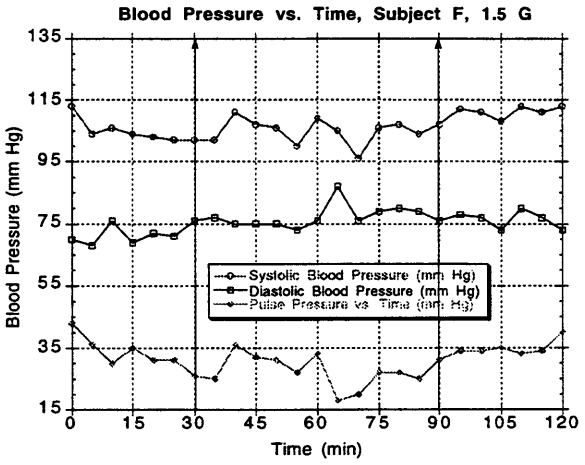

Blood Pressure vs. Time, Subject E, 1.5 G
Blood Pressure (mm Hg)
Time (min)
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)

Subject F

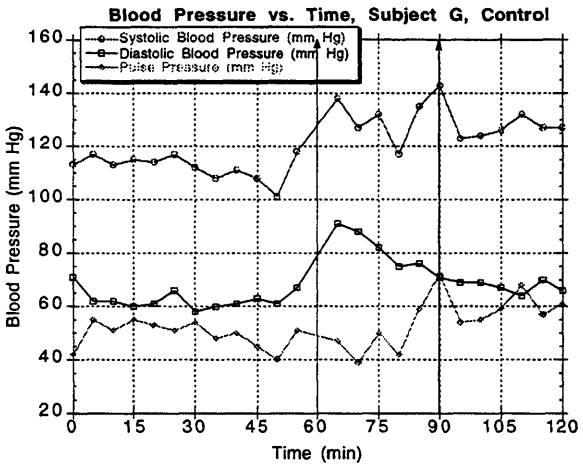

Blood Pressure vs. Time, Subject F, Control
Blood Pressure (mm Hg)
135
115
95
75
55
35
15
0 15 30 45 60 75 90 105 120
Time (min)
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)

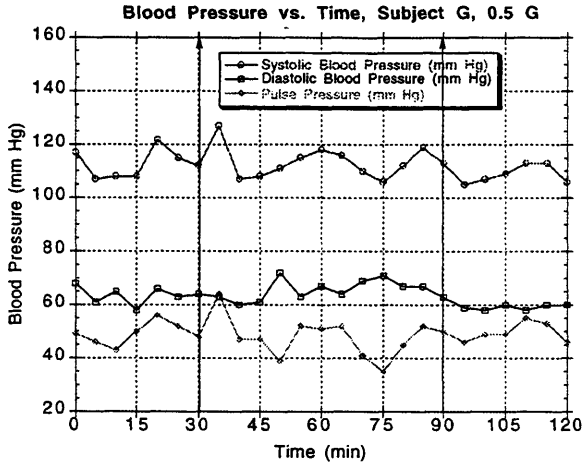

Blood Pressure vs. Time, Subject F, 0.5 G
Blood Pressure (mm Hg)
135
115
95
75
55
35
15
0 15 30 45 60 75 90 105 120
Time (min)
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)

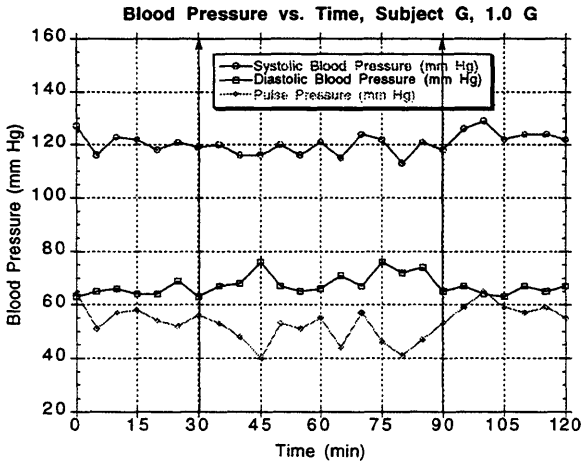

Blood Pressure vs. Time, Subject F, 1.0 G
Blood Pressure (mm Hg)
135
115
95
75
55
35
15
0 15 30 45 60 75 90 105 120 135
Time (min)
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)

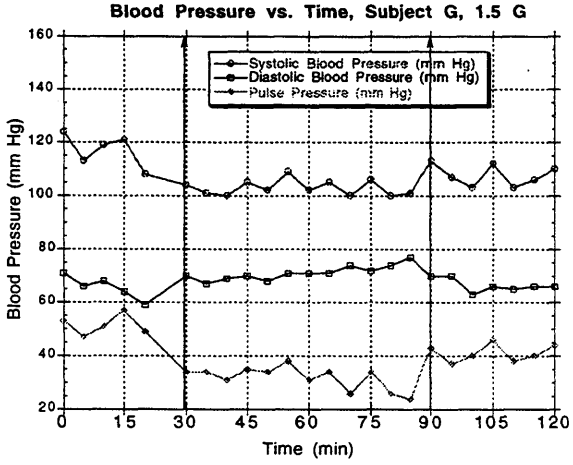

Blood Pressure vs. Time, Subject F, 1.5 G
Blood Pressure (mm Hg)
135
115
95
75
55
35
15
0 15 30 45 60 75 90 105 120
Time (min)
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure vs Time (mm Hg)

Subject G

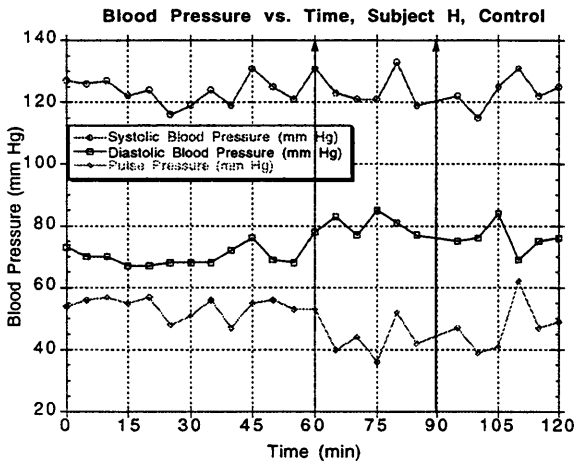

Blood Pressure vs. Time, Subject G, Control
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

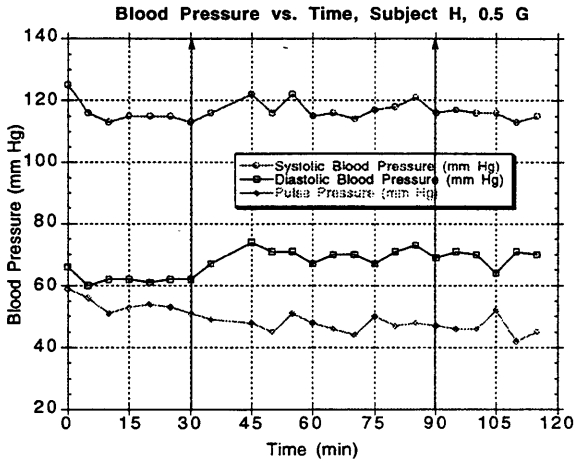

Blood Pressure vs. Time, Subject G, 0.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

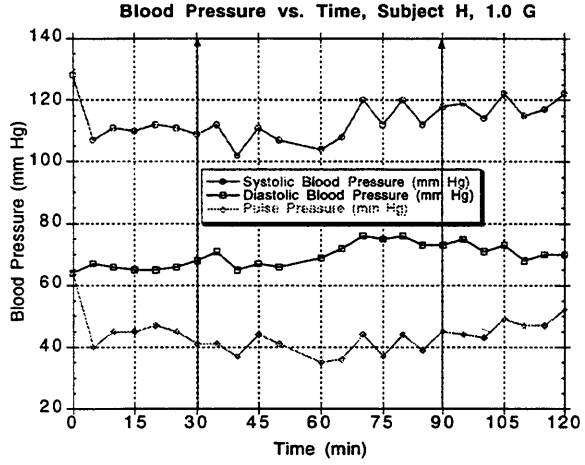

Blood Pressure vs. Time, Subject G, 1.0 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

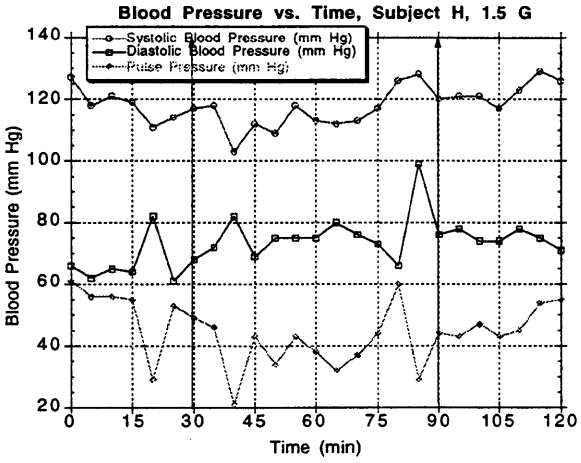

Blood Pressure vs. Time, Subject G, 1.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

Subject H

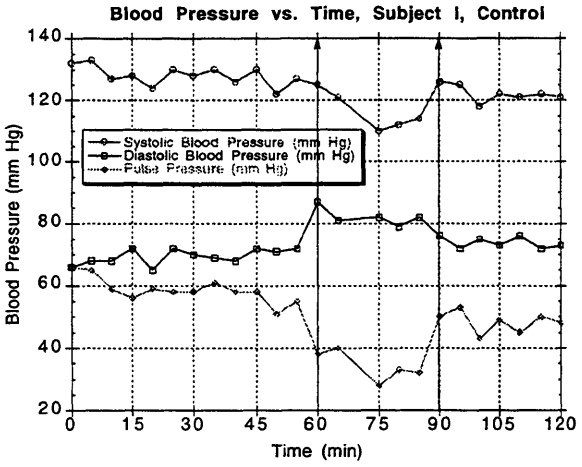

Blood Pressure vs. Time, Subject H, Control
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

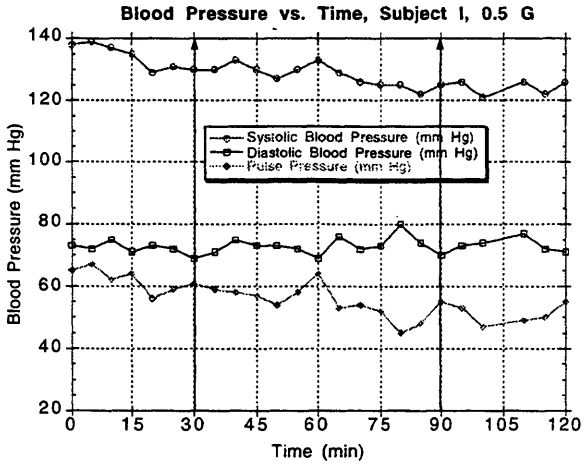

Blood Pressure vs. Time, Subject H, 0.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

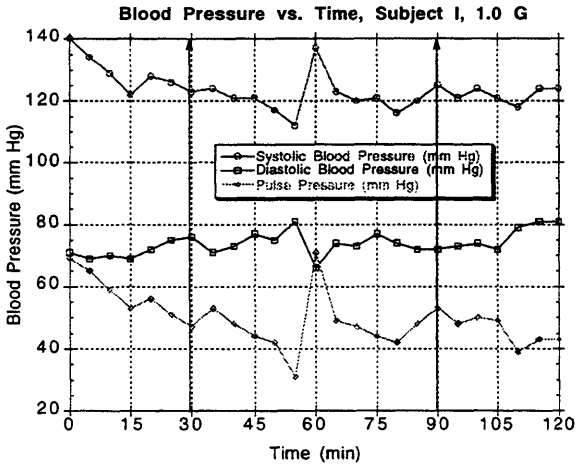

Blood Pressure vs. Time, Subject H, 1.0 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

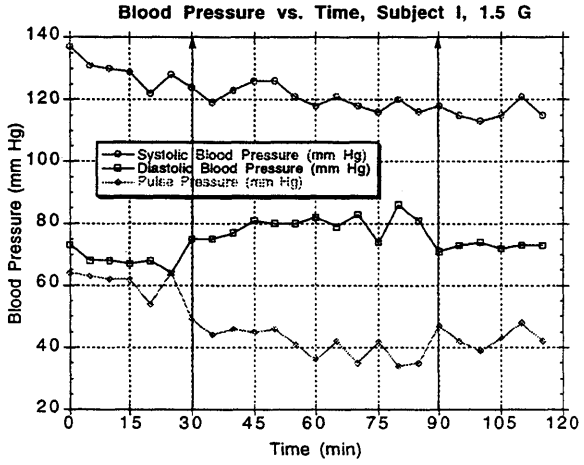

Blood Pressure vs. Time, Subject H, 1.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

Subject I

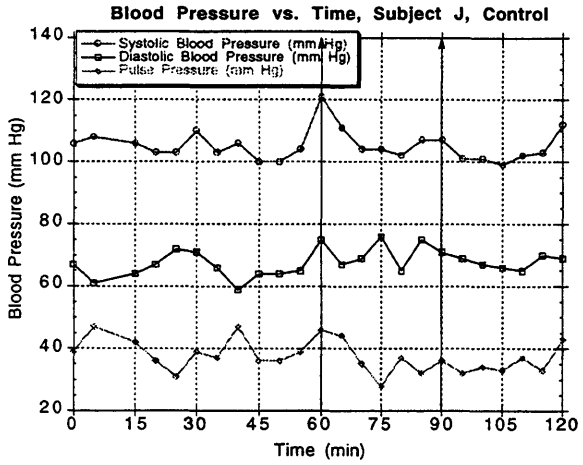

Blood Pressure vs. Time, Subject I, Control
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

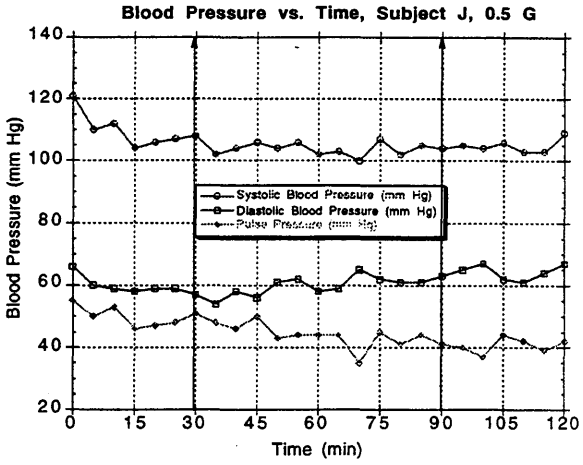

Blood Pressure vs. Time, Subject I, 0.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

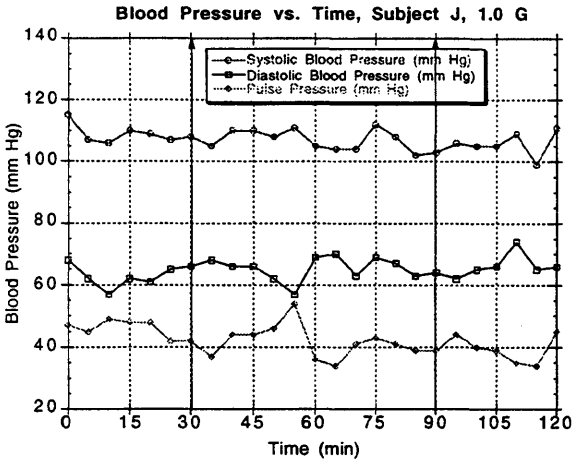

Blood Pressure vs. Time, Subject I, 1.0 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

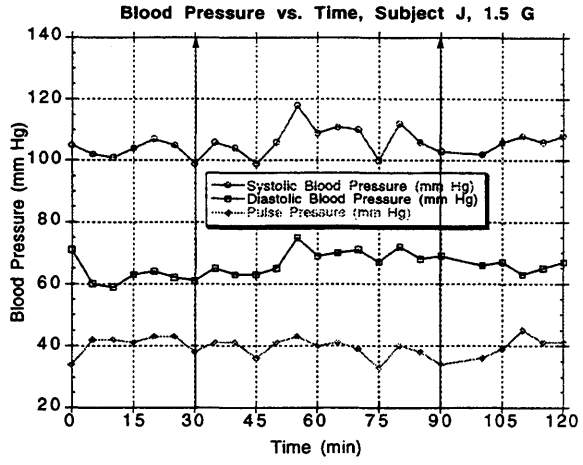

Blood Pressure vs. Time, Subject I, 1.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

Subject J


Blood Pressure vs. Time, Subject J, Control
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)


Blood Pressure vs. Time, Subject J, 0.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)


Blood Pressure vs. Time, Subject J, 1.0 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)


Blood Pressure vs. Time, Subject J, 1.5 G
Systolic Blood Pressure (mm Hg)
Diastolic Blood Pressure (mm Hg)
Pulse Pressure (mm Hg)
Blood Pressure (mm Hg)
Time (min)

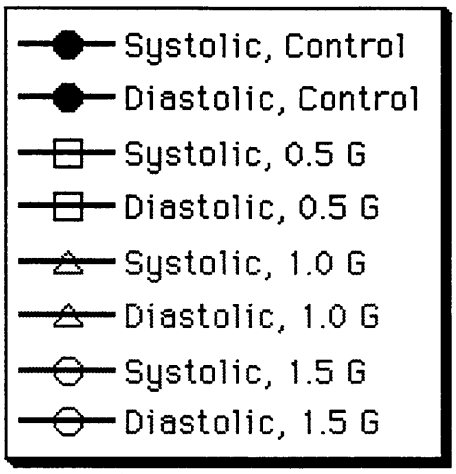
Normalized Blood Pressure Data

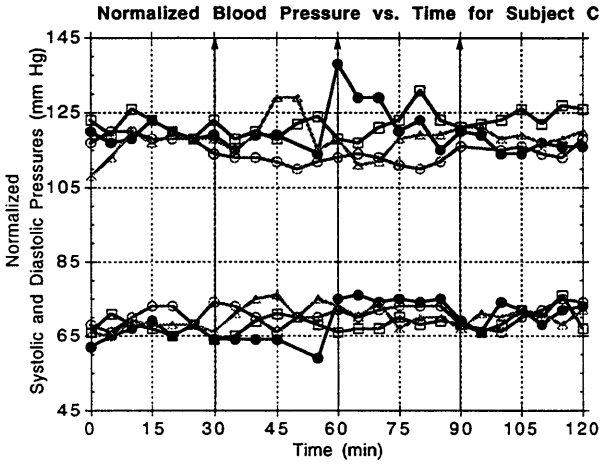
Results are presented with the subject's code letter followed by an "S" or a "D" indicating systolic or diastolic BP, respectively.

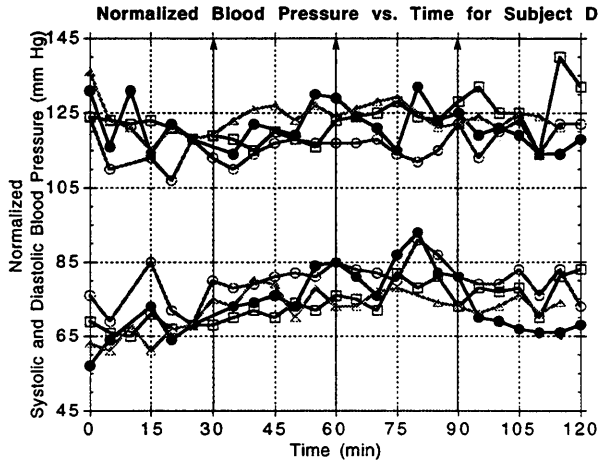
	BP During Control (0 ppm)																					
Time (min)	CS	CD	DS	DD	ES	ED	FS	FD	GS	GD	HS	HD	IS	JD	JS	JD	Number S	Number D	Average S	Std. Error S	Average D	Std. Error D
0	120	62	131	57	123	59	122	68	114	73	129	73	120	62	121	63	8	8	122.50	1.90	64.63	2.15
5	117	65	116	64	116	60	124	66	118	64	128	70	121	64	123	57	8	8	120.38	1.55	63.75	1.37
10	118	67	131		116	67	120	62	114	64	129	70	115	64			7	6	120.43	2.29	65.67	1.17
15	123	68	114	73	123	61	118	66	116	62	124	67	116	68	121	60	8	8	119.38	1.36	65.75	1.58
20	120	65	122	64	126	60	118	65	115	63	126	67	112	61	118	63	8	8	119.63	1.75	63.50	0.80
25	118	68	118	68	118	68	118	68	118	68	118	68	118	68	118	68	8	8	118.00	0.00	68.00	0.00
30	119	64			118	64	124	70	113	60	121	68	116	66	125	67	7	7	119.43	1.62	65.57	1.23
35	115	64	114	73	120	60	120	68	109	62	126	68	118	65	118	62	8	8	117.50	1.77	65.25	1.50
40	119	64	122	74	123	73	121	66	112	63	121	72	114	64	121	55	8	8	119.13	1.41	66.38	2.26
45	119	64		76	119	65	122	68	109	65	133	76	118	68	115	60	7	8	119.29	2.77	67.75	2.01
50			119	73	130	60	119	68	102	63	127	69	110	67	115	60	7	7	117.43	3.63	65.71	1.85
55	114	59	130	84	120	65	120	67	119	69	123	68	115	68	119	61	8	8	120.00	1.75	67.63	2.66
60	138	75	129	85	130	68	110	65			133	78	113	83	126	71	7	7	127.00	4.19	75.00	2.84
65	129	76	124	81	132	77	112	70	139	93	125	83	109	77	126	63	8	8	124.50	3.50	77.50	3.14
70	128	74	121	76	126	78	111	65	128	90	123	77			119	65	7	7	122.43	2.35	75.00	3.24
75	120	75	115	87			110	70	133	84	123	85	98	78	119	72	7	7	116.86	4.14	78.71	2.54
80	123	74	132	93	135	73	120	70	118	77	135	81	100	75	117	61	8	8	122.50	4.15	75.50	3.24
85	115	75	123	82	129	79	121	73	136	78	121	77	102	78	122	71	8	8	121.13	3.51	76.63	1.24
90	120	69	125	81	130	72	120	73	144	73			114	72	122	67	7	7	125.00	3.67	72.43	1.66
95	119	66	119	70	123	62	119	73	124	71	124	75	113	68	116	65	8	8	119.63	1.39	68.75	1.53
100	114	74	121	69	122	65	121	70	125	71	117	76	106	71	116	63	8	8	117.88	2.14	69.88	1.32
105	114	72	119	67	125	62	116	70	127	69	127	84	110	69	114	62	8	8	119.00	2.33	69.38	2.45
110	117	68	114	66	121	58	118	76	133	66	133	69	109	72	117	61	8	8	120.25	3.04	67.00	2.03
115	116	72	114	66	124	68	122	68	128	72	124	75	110	68	118	66	8	8	119.50	2.13	69.38	1.15
120	116	73	118	68	127	71	117	69	128	68	127	76	109	69	127	65	8	8	121.13	2.50	69.88	1.20
	BP During 0.5 G (0 ppm)																					
Time (min)	CS	CD	DS	DD	ES	ED	FS	FD	GS	GD	HS	HD	IS	JD	JS	JD	Number S	Number D	Average S	Std. Error S	Average D	Std. Error D
0	123	66	124	69	127	69	126	66	120	73	128	72	125	69	132	75	8	8	125.63	1.27	67.38	2.86
5	119	71	123	66	119	48	122	70	110	66	119	66	126	68	121	69	8	8	119.88	1.65	65.50	2.59
10	126	68	122	65	114	56	124	68	111	70	116	68	124	71	123	68	8	8	120.00	1.95	66.75	1.66
15	123	67	123	71	117	48	124	69	111	63	118	68	122	67	115	67	8	8	119.13	1.64	65.00	2.56
20	120	65	121	67	119	49	119	70	125	71	118	67	116	69	117	68	8	8	119.38	0.98	65.75	2.48
25	118	68	118	68	118	68	118	68	118	68	118	68	118	68	118	68	8	8	118.00	0.00	68.00	0.00
30	123	64	119	68	120	55	121	72	115	69	116	68	117	65	119	66	8	8	118.75	0.94	65.88	1.79
35	118	65	118	70	119	63	122	68	130	68	119	73	117	67	113	63	8	8	119.50	1.74	67.13	1.22
40	120	69	115	72	118	61	118	68	110	65			120	71	115	67	7	7	116.57	1.34	67.57	1.41
45	118	71	120	70	120	56	123	74	111	66	125	80	117	69	117	65	8	8	118.88	1.51	68.88	2.48
50	122	70	118	74	121	49	120	68	114	77	119	77	114	69	115	70	8	8	117.88	1.13	69.25	3.15
55	124	68	116	72	122	55	115	73	118	68	125	77	117	68	117	71	8	8	119.25	1.36	69.00	2.28
60	118	66	123	76	120	62	124	68	121	72	118	73	120	65	113	67	8	8	119.63	1.21	68.63	1.65
65	117	67	124	73	121	56	121	74	119	69	119	76	116	72	114	68	8	8	118.88	1.13	69.63	2.28
70	121	67	125	72	122	60	118	74	113	74	117	76	113	68	111	74	8	8	117.50	1.75	70.63	1.88
75	123	70	128	82	125	55	122	75	109	76	120	73	112	69	118	71	8	8	119.63	2.28	71.38	2.76
80	131	68	124	78	126	63	114	69	115	72	121	77	112	76	113	70	8	8	119.50	2.49	71.63	1.82
85	123	69	123	81	122	55	116	69	122	72	124	79	109	70	116	70	8	8	119.38	1.85	70.63	2.77
90	121	68	128	73	120	55	122	72	116	68	119	75	112	66	115	72	8	8	119.13	1.74	68.63	2.22
95	122	66	132	78	126	66	126	71	108	64	120	77	113	69	116	74	8	8	120.38	2.76	70.63	1.87
100	123	68	125	77	123	61	119	77	110	63	119	76	108	70	115	76	8	8	117.75	2.21	71.00	2.30
105	126	72	125	78	122	63	122	74	112	65	119	70			117	71	7	7	120.43	1.84	70.43	1.94
110	122	70	114	70	127	62	122	73	116	63	116	77	113	73	114	70	8	8	118.00	1.78	69.75	1.79
115	127	76	140	81	130	53	122	74	116	65	118	76	109	68	114	73	8	8	122.00	3.53	70.75	3.08
120	126	67	132	83	119	62			109	65			113	67	120	76	6	6	119.83	3.42	70.00	3.22
	BP During 1.0 G (0 ppm)																					
Time (min)	CS	CD	DS	DD	ES	ED	FS	FD	GS	GD	HS	HD	IS	JD	JS	JD	Number S	Number D	Average S	Std. Error S	Average D	Std. Error D
0	108	66	136	63	123	67	119	67	124	62	135	66	122	64	126	71	8	8	125.38	3.27	65.75	1.00
5	113	65	125	61	123	74	120	67	115	64	114	69	126	62	118	65	8	8	118.75	1.79	65.88	1.47
10	120	69	121	68	121	68	124	67	120	65	118	68	121	63	117	60	8	8	120.25	0.75	66.00	1.10
15	117	68	115	61	118	65	118	66	119	63	117	67	114	62	121	65	8	8	117.38	0.78	64.63	0.86
20	119	68	121	67	117	72			115	63	119	67	120	65	120	64	7	7	118.71	0.78	66.57	1.13
25	118	68	118	68	118	68	118	68	118	68	118	68	118	68	118	68	8	8	118.00	0.00	68.00	0.00
30	118	66	119	75	117	77	118	74	116	62	116	70	115	69	119	69	8	8	117.25	0.53	70.25	1.75
35	115	71	123	73	118	73	118	68	117	66	119	73	116	64	116	71	8	8	117.75	0.88	69.88	1.23
40	119	75	126	80	117	76	122	72	113	67	109	67	113	66	121	69	8	8	117.50	1.98	71.50	1.80
45	128	76	127	79	117	70	122	75	113	75	118	69	113	70	121	69	8	8	120.00	2.10	72.88	1.36
50	128	70	123	70	114	69	116	69	117	66	114	68	109	68	119	65	8	8	117.63	2.17	68.13	0.64
55	115	75	127	78	108	70	120	72	113	64			104	74	122	60	7	7	115.57	3.05	70.43	2.41
60	118	73	124	73	115	71	115	69	118	65	111	71	120	59	116	72	8	8	118.25	2.02	69.13	1.72
65	111	70	126	73	112	75	118	73	112	70	115	74	115	67	115	73	8	8	115.50	1.70	71.88	0.93
70	112	74	128	77			121	71	121	66	127	78	112	66	115	66	7	7	119.43	2.22	71.14	2.01
75	118	67	129	78	116	74	120	69	119	75	119	77	113	70	123	72	8	8	119.63	1.69	72.75	1.39
80	119	70			109	71	119	72	110	71	127	78	108	67	119	70	7	7	115.86	2.66	71.29	1.27
85	119	70	121	74			117	70	118	73	119	75	112	65	113	66	7	7	117.00	1.25	70.43	1.46
90	121	67	122	73	118	73	121	69	115	64	125	75	117	65	114	67	8	8	119.13	1.33	69.13	1.44
95	121	71	124	71	118	80	118	71	123	66	126	77	113	66	117	65	8	8	120.00	1.51	70.88	1.90
100	118	70	121	73	118	77	122	73	126	63	121	73	116	67	116	68	8	8	119.75	1.21	70.50	1.56
105	119	72	125	76	127	80	118	72	119	62	129	75	113	65	116	69	8	8	120.75	1.99	71.38	2.09
110	117	71	124	71	124	83			121	66	122	70	110	72	120	77	7	7	119.71	1.86	72.86	2.09
115	118	68	121	74	129	83			121	64	124	72	116	74	110	68	7	7	119.86	2.28	71.86	2.31
120	120	72			129	82	120	75	119	66	129	72	116	74	122	69	7	7	122.14	1.90	72.86	1.91
	BP During 1.5 G (0 ppm)																					
Time (min)	CS	CD	DS	DD	ES	ED	FS	FD	GS	GD	HS	HD	IS	JD	JS	JD	Number S	Number D	Average S	Std. Error S	Average D	Std. Error D
0	117	68	124	76	132	66	129	67	134	79	131	65	127	77	118	77	8	8	126.50	2.24	71.88	2.07
5	120	66	110	68	124	66	120	65	123	74	122	61	121	72	115	66	8	8	119.38	1.65	67.38	1.46
10	120	70			117	63	122	73	129	76	125	64	120	72	114	65	7	7	121.00	1.88	69.00	1.90
15	118	73	113	85	115	68	120	66	131	72	123	63	119	71	117	69	8	8	119.50	1.96	70.88	2.33
20	118	73	107	72			119	69	118	67	115		112	72	120	70	7	6	115.57	1.76	70.50	0.92
25	118	68	118	68	118	68	118	68	118	68	118	68	118	68	118	68	8	8	118.00	0.00	68.00	0.00
30	114	74	113	80	121	66	118	73	114	78	121	67	114	79	112	67	8	8	115.88	1.27	73.00	2.04
35	113	73	110	78	114	70	118	74	111	75	122	71	109	79	119	71	8	8	114.50	1.66	73.88	1.17
40	113	70	114	79	115	68	127	72	110	77	107	81	113	81	117	69	8	8	114.50	2.09	74.63	1.84
45	112	66	117	81	119	74	123	72	115	78	116	68	116	85	112	69	8	8	116.25	1.28	74.13	2.37
50	110	70	118	82	119	69	122	72	112	76	113	74	116	84	119	71	8	8	116.13	1.46	74.75	1.97
55	112	70	117	81	120	75	116	70	119	79	122	74	111	84	131	81	8	8	118.50	2.23	76.75	1.87
60	113	72	117	85	120	77	125	73	112	79	117	74	108	86	122	75	8	8	116.75	1.98	77.63	1.89
65	114	70	117	83	123	76	121	84	115	79	116	79	111	83	124	76	8	8	117.63	1.63	78.75	1.67
70	113	72	118	82	119	75	112	73	110	82	117	75	108	87	123	77	8	8	115.00	1.79	77.88	1.86
75	111	73	114	80	128	82	122	76	116	80	121	72	106	78	113	73	8	8	116.38	2.47	76.75	1.35
80	110	73	112	91	117	80	123	77	110	82	120	65	110	90	125	78	8	8	117.13	2.81	79.50	3.02
85	112	73	115	87	130	78	120	76	111	85	132	98	106	85	119	74	8	8	118.13	3.23	82.00	2.98
90	116	68	122	81	121	61	123	73	123	78	124	75	108	75	116	75	8	8	119.13	1.93	73.25	2.19
95			113	79	120	62	128	75	117	78	125	77	105	77			6	6	118.00	3.41	74.67	2.59
100	115	66	120	79	112	71	127	74	113	71	125	73	103	78	115	72	8	8	116.25	2.72	73.00	1.46
105	116	70	123	83	112	62	124	70	122	74	121	73	105	76	119	73	8	8	117.75	2.30	72.63	2.10
110	114	72	114	76	121	66	129	77	113	73	127	77	111	77	121	69	8	8	118.75	2.40	73.38	1.48
115	113	75	122	83	120	66	127	74	116	74	133	74	105	77	119	71	8	8	119.38	3.02	74.25	1.71
120	118	74	122	73	120	62	129	70	120	74	130	70	103	78	121	73	8	8	120.38	2.92	71.75	1.66

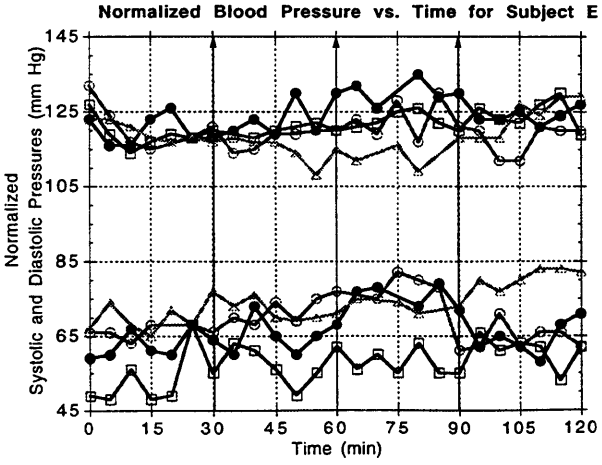
Normalized Blood Pressure Plots

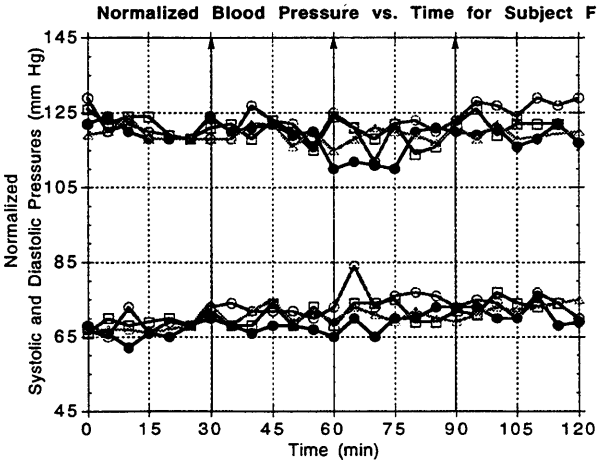
The vertical lines in the plots represent the onset or end of a stimulus. The following is the key for all of the plots.

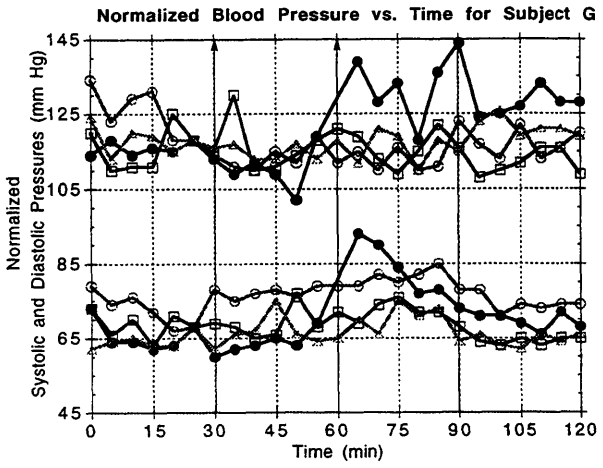


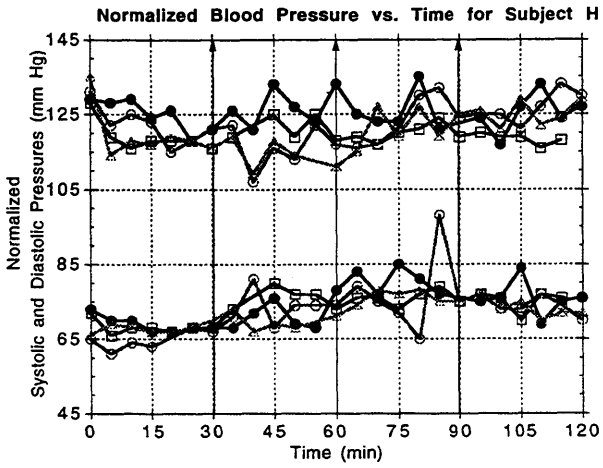


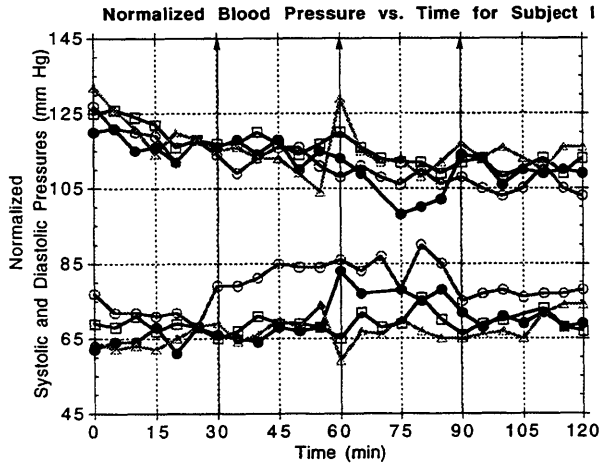


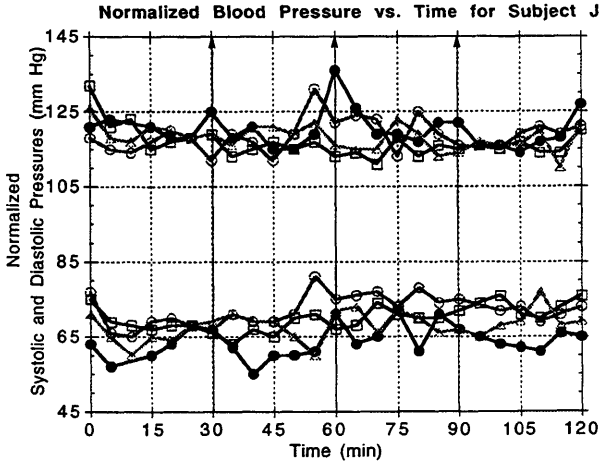





Normalized Blood Pressure vs. Time for Subject G
Normalized Systolic and Diastolic Pressures (mm Hg)
145
125
105
85
65
45
0 15 30 45 60 75 90 105 120
Time (min)


Normalized Blood Pressure vs. Time for Subject H
Normalized Systolic and Diastolic Pressures (mm Hg)
145
125
105
85
65
45
0 15 30 45 60 75 90 105 120
Time (min)


Normalized Blood Pressure vs. Time for Subject I
Normalized Systolic and Diastolic Pressures (mm Hg)
145
125
105
85
65
45
0 15 30 45 60 75 90 105 120
Time (min)


Normalized Blood Pressure vs. Time for Subject J
Normalized Systolic and Diastolic Pressures (mm Hg)
145
125
105
85
65
45
0 15 30 45 60 75 90 105 120
Time (min)

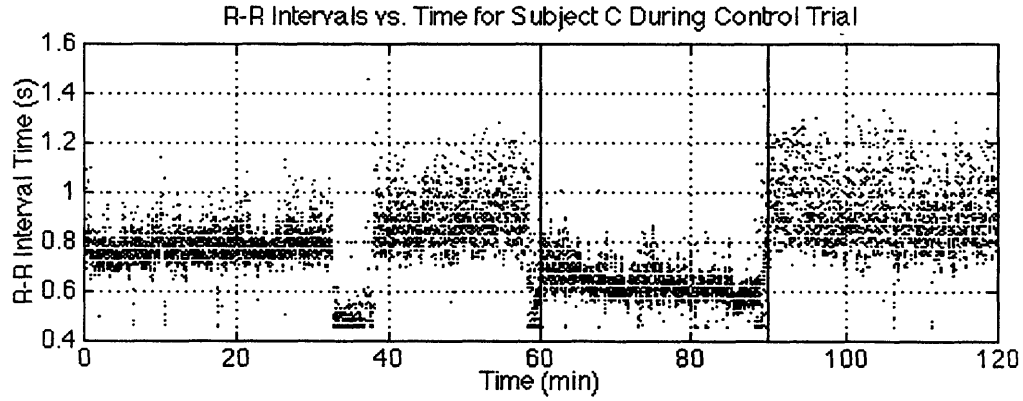
APPENDIX I

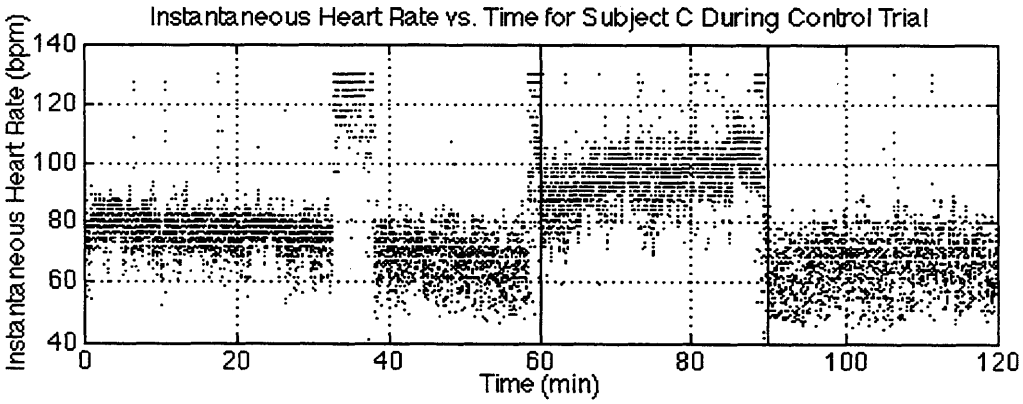
Heart Rate Data and Plots

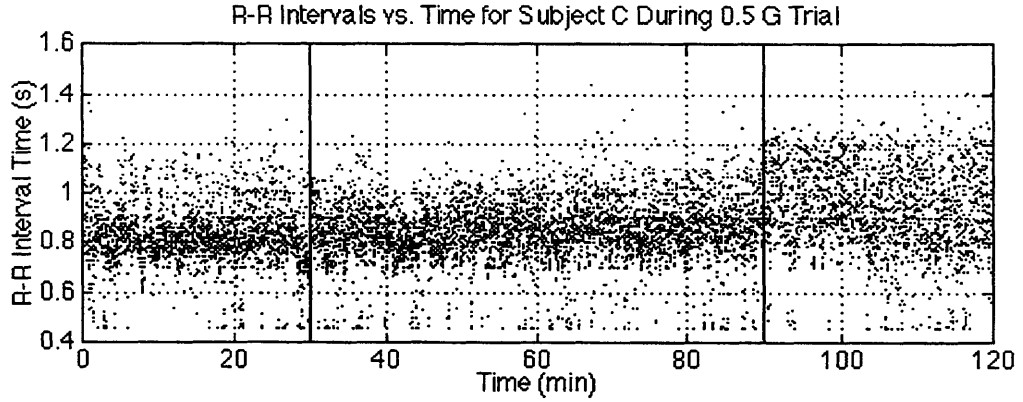
Plots of R-R Intervals and Instantaneous Heart Rate

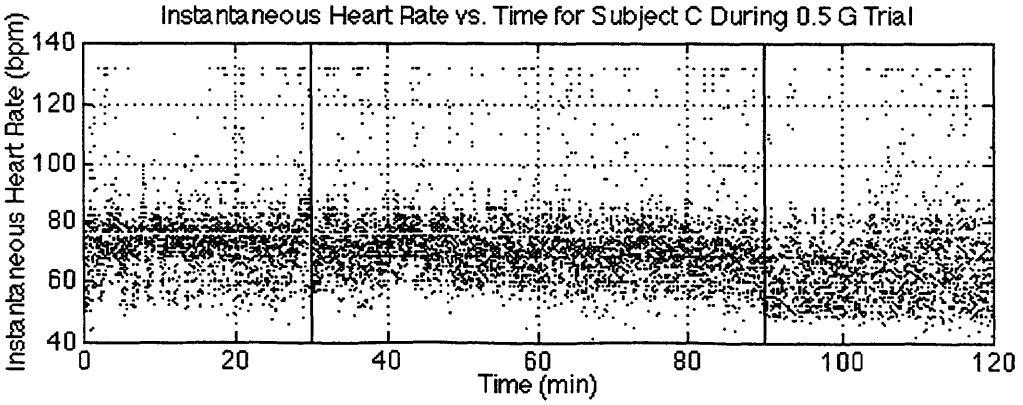
The vertical lines in the plots represent the onset or end of a stimulus.

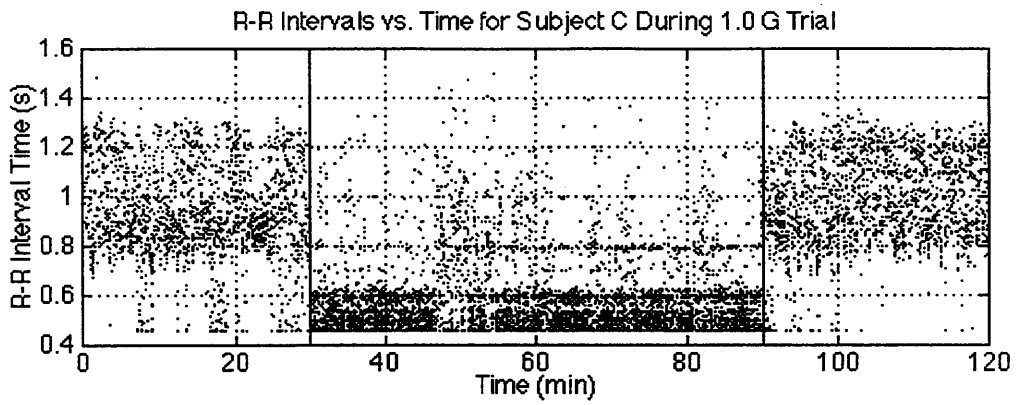
Subject C

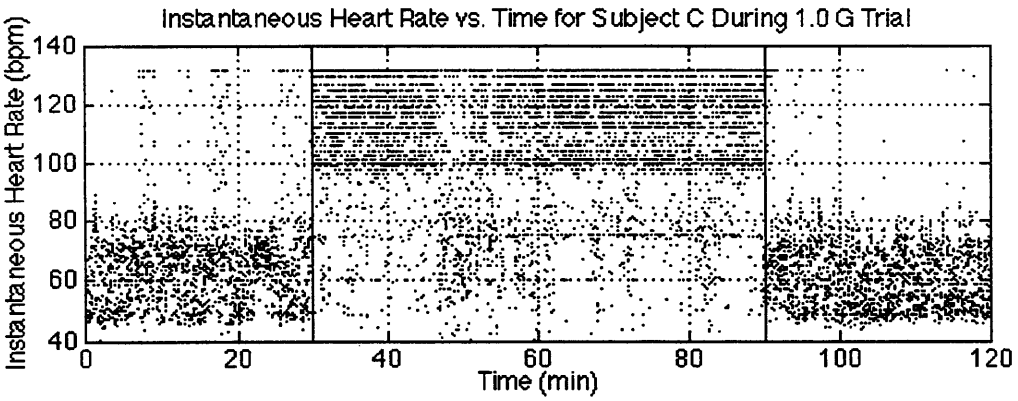

R-R Intervals vs. Time for Subject C During Control Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

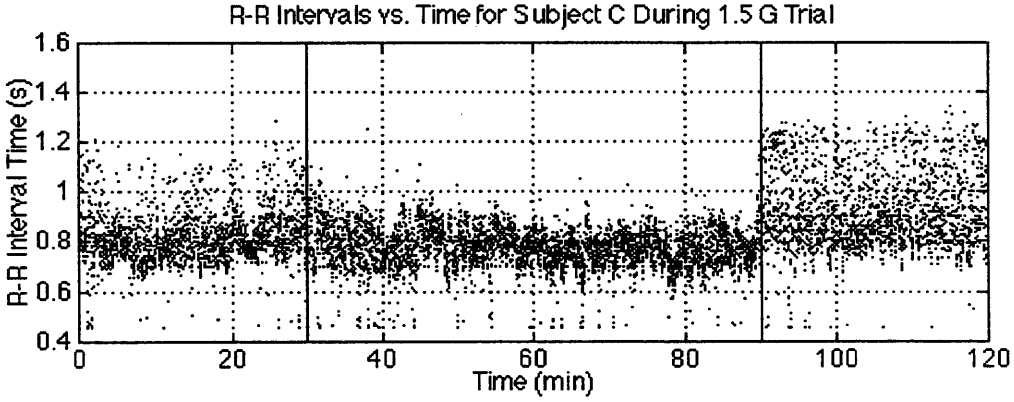

Instantaneous Heart Rate vs. Time for Subject C During Control Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

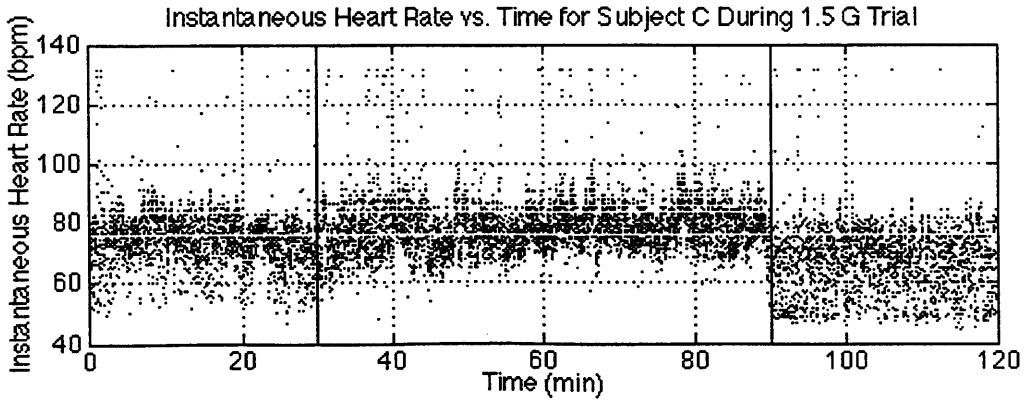

R-R Intervals vs. Time for Subject C During 0.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject C During 0.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

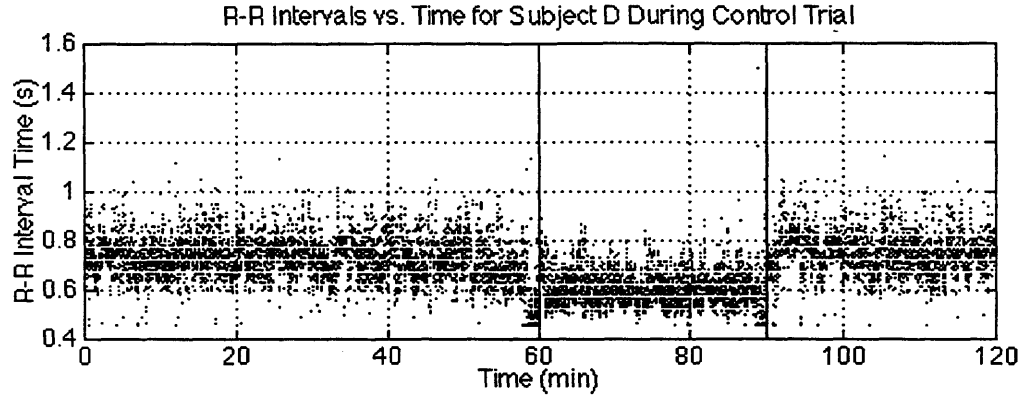

R-R Intervals vs. Time for Subject C During 1.0 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

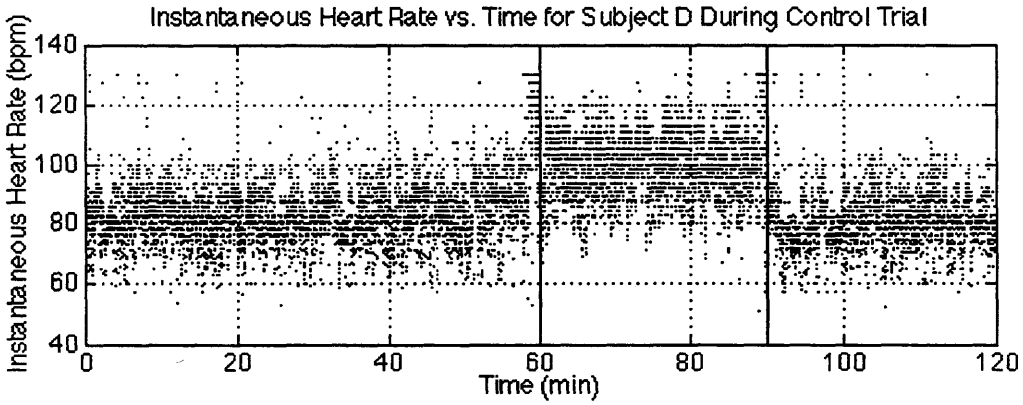

Instantaneous Heart Rate vs. Time for Subject C During 1.0 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

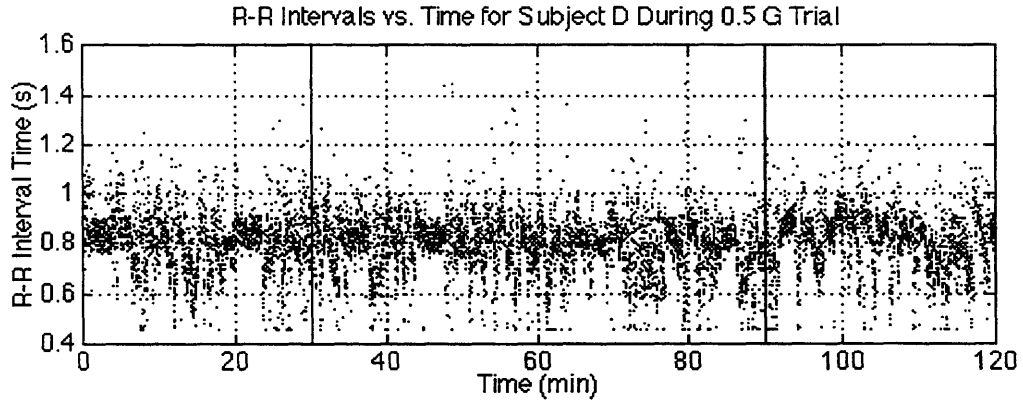

R-R Intervals vs. Time for Subject C During 1.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

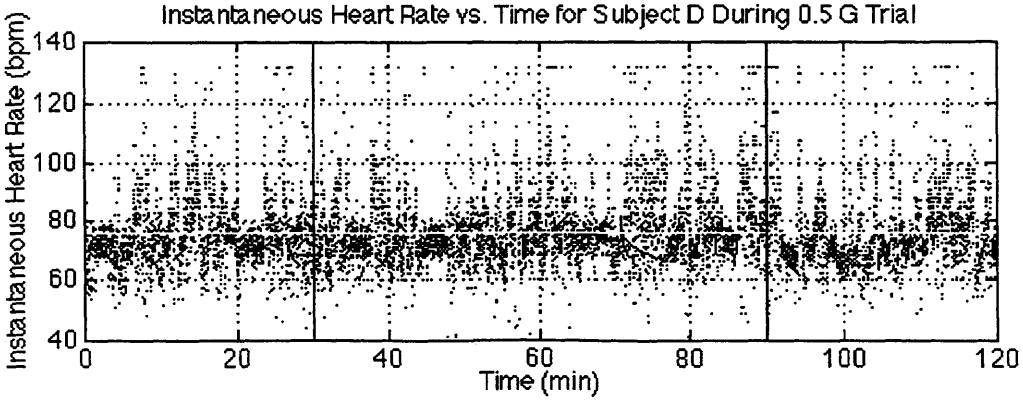

Instantaneous Heart Rate vs. Time for Subject C During 1.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

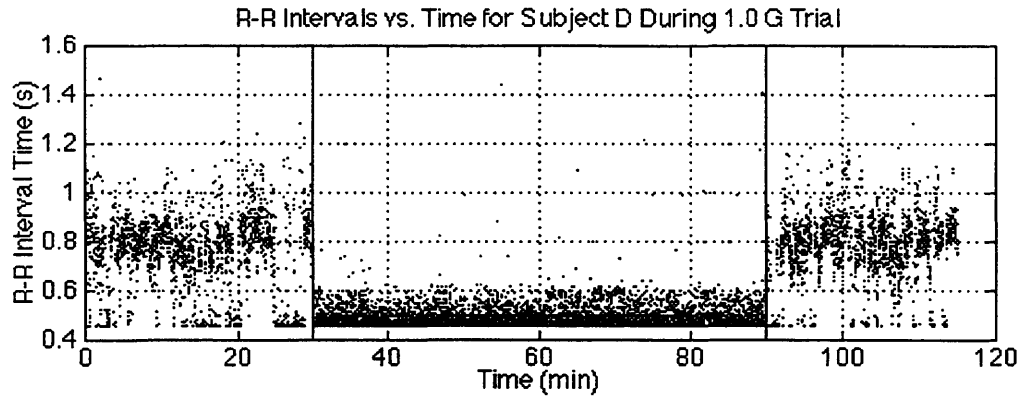
Subject D

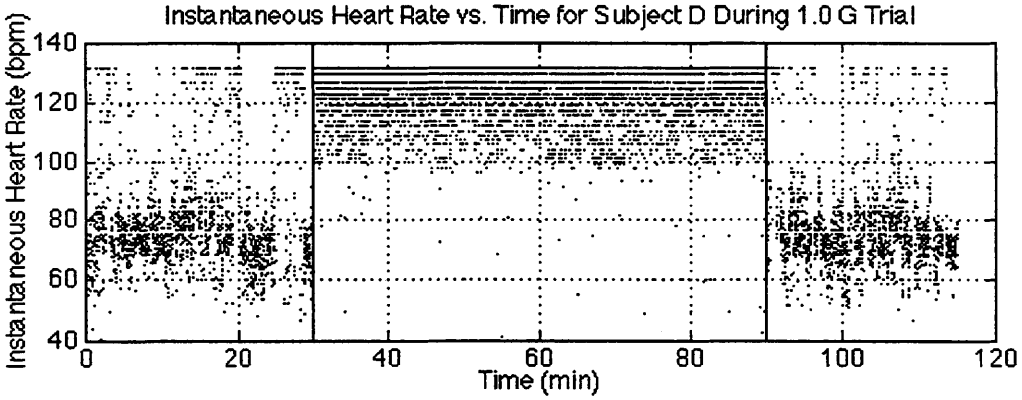

R-R Intervals vs. Time for Subject D During Control Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

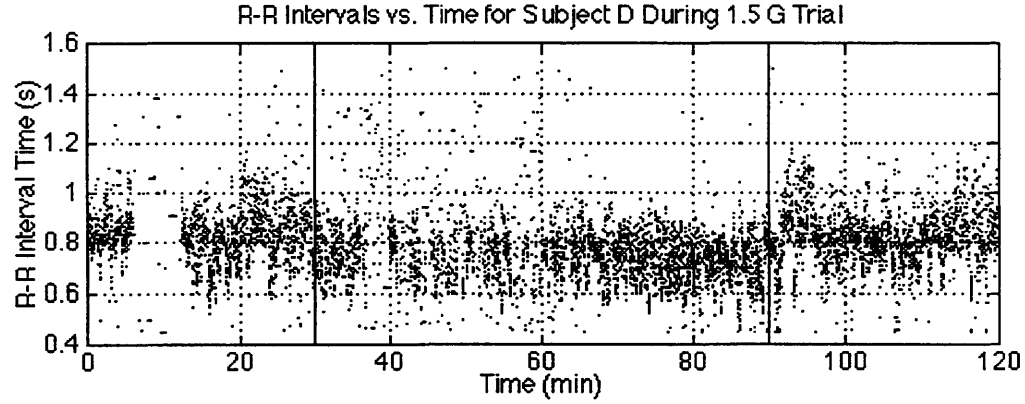

Instantaneous Heart Rate vs. Time for Subject D During Control Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

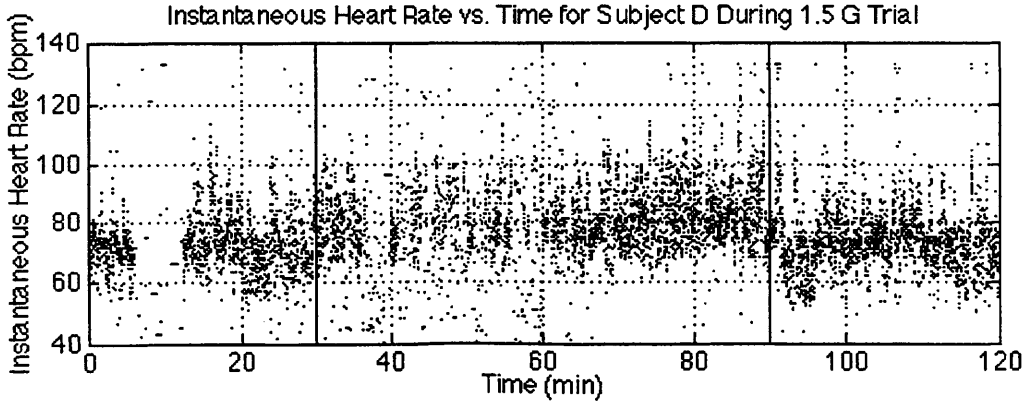

R-R Intervals vs. Time for Subject D During 0.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject D During 0.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

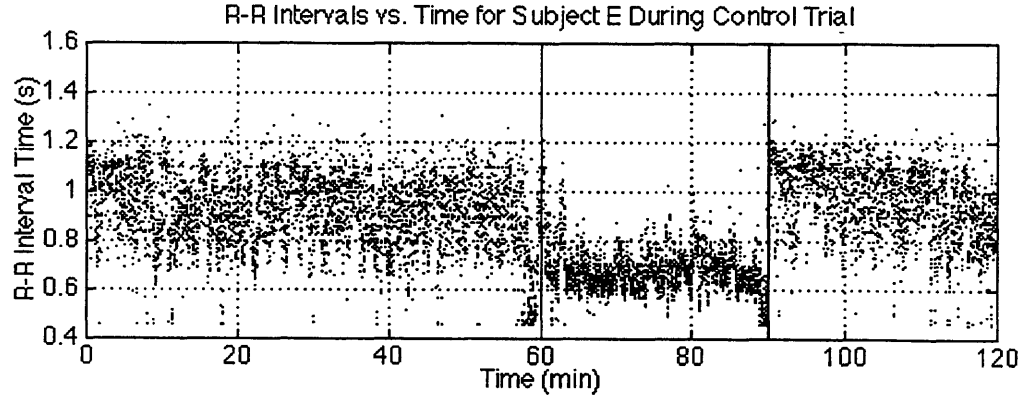

R-R Intervals vs. Time for Subject D During 1.0 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

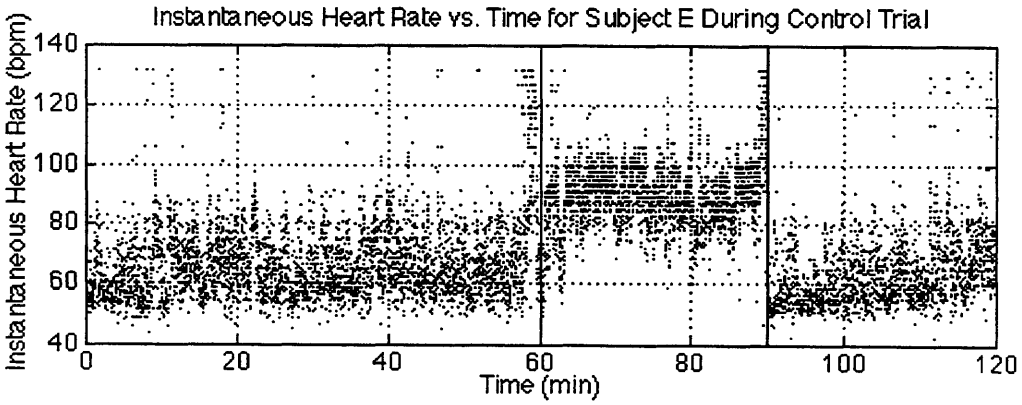

Instantaneous Heart Rate vs. Time for Subject D During 1.0 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

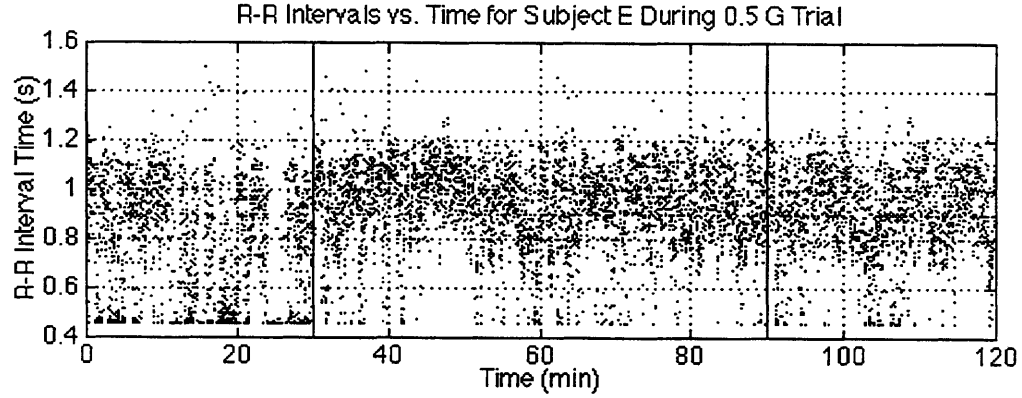

R-R Intervals vs. Time for Subject D During 1.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

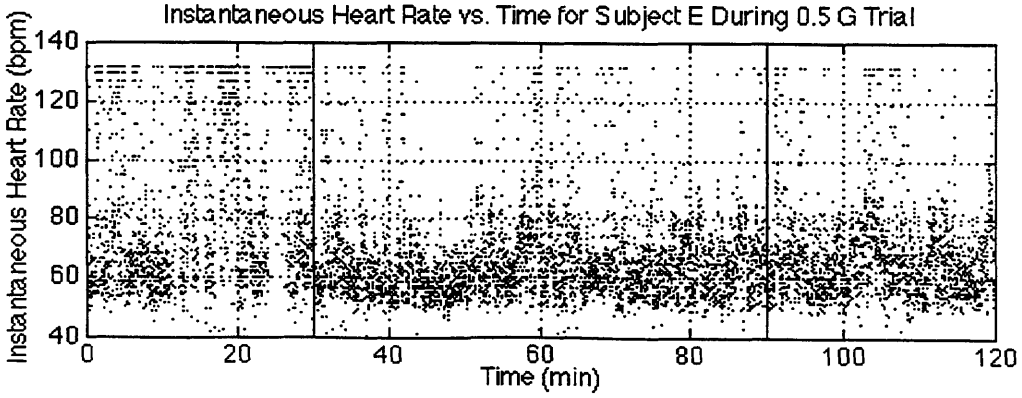

Instantaneous Heart Rate vs. Time for Subject D During 1.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

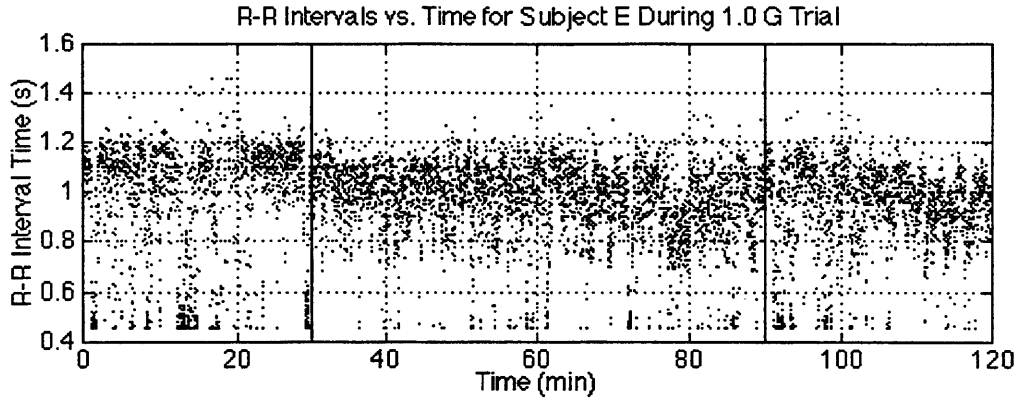
Subject E

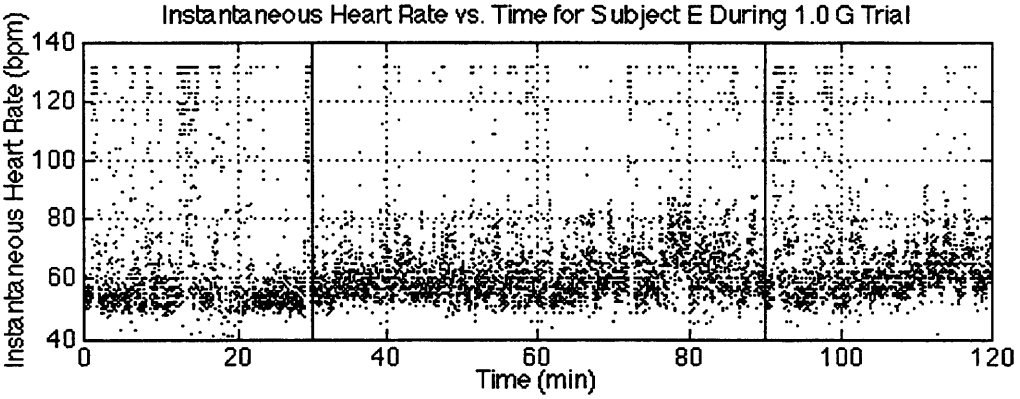

R-R Intervals vs. Time for Subject E During Control Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

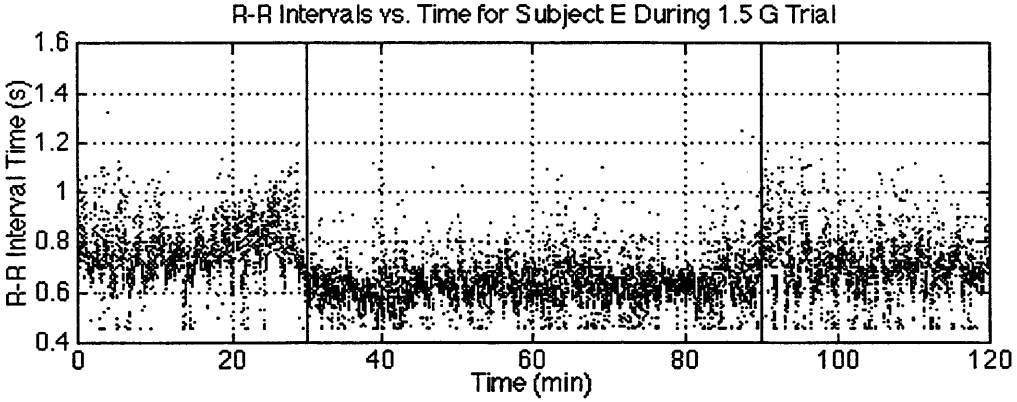

Instantaneous Heart Rate vs. Time for Subject E During Control Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

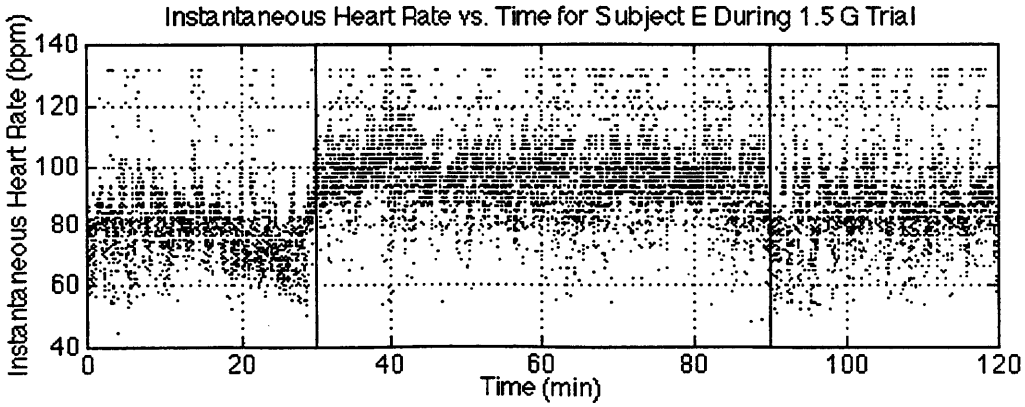

R-R Intervals vs. Time for Subject E During 0.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject E During 0.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

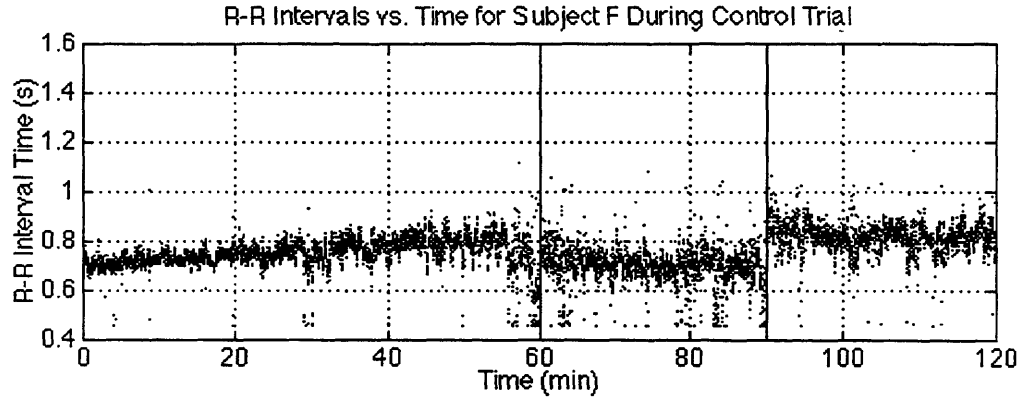

R-R Intervals vs. Time for Subject E During 1.0 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

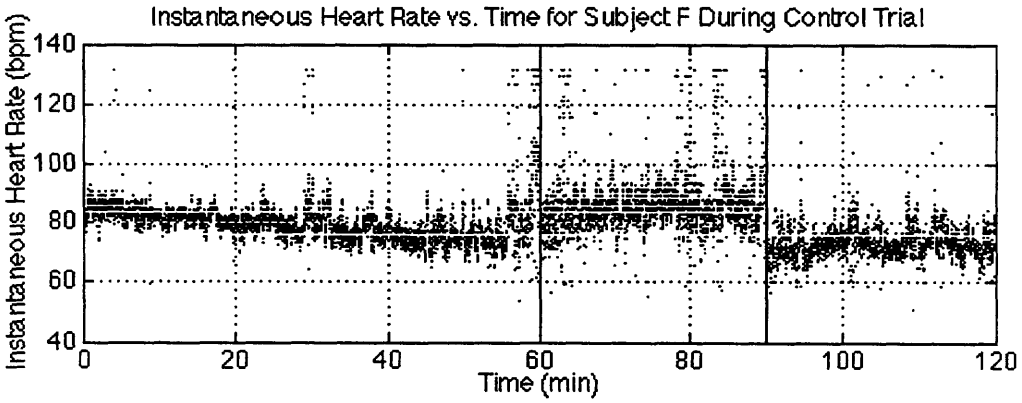

Instantaneous Heart Rate vs. Time for Subject E During 1.0 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

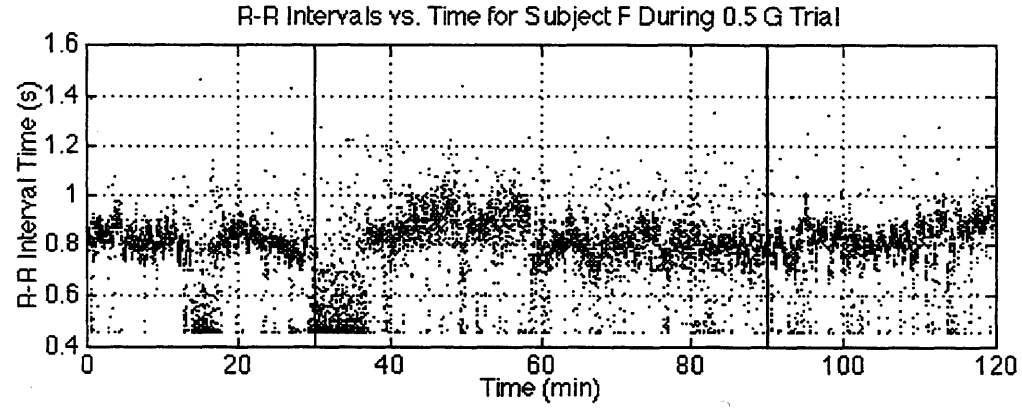

R-R Intervals vs. Time for Subject E During 1.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

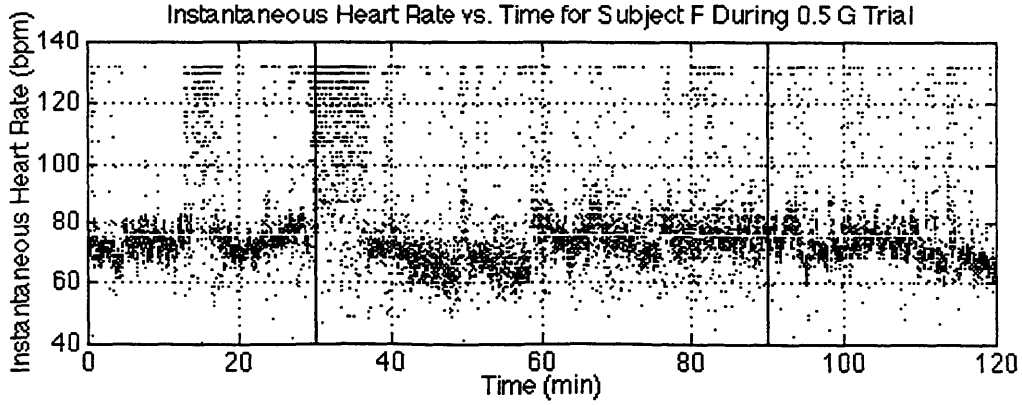

Instantaneous Heart Rate vs. Time for Subject E During 1.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

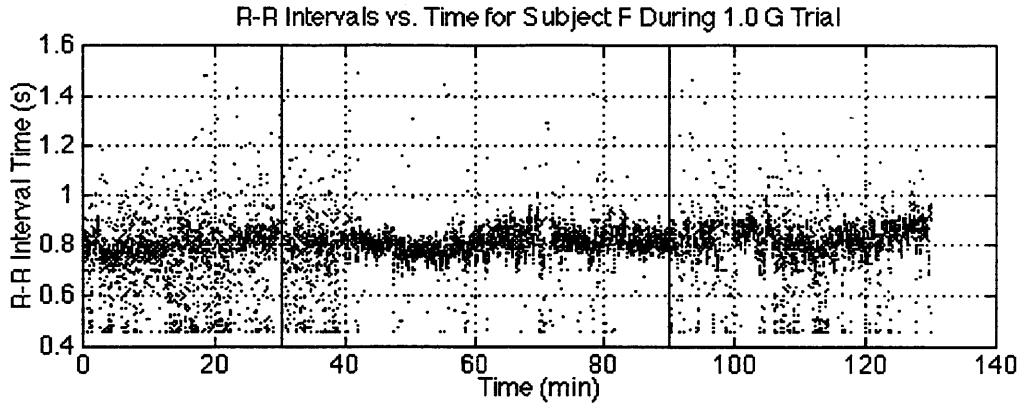
Subject F

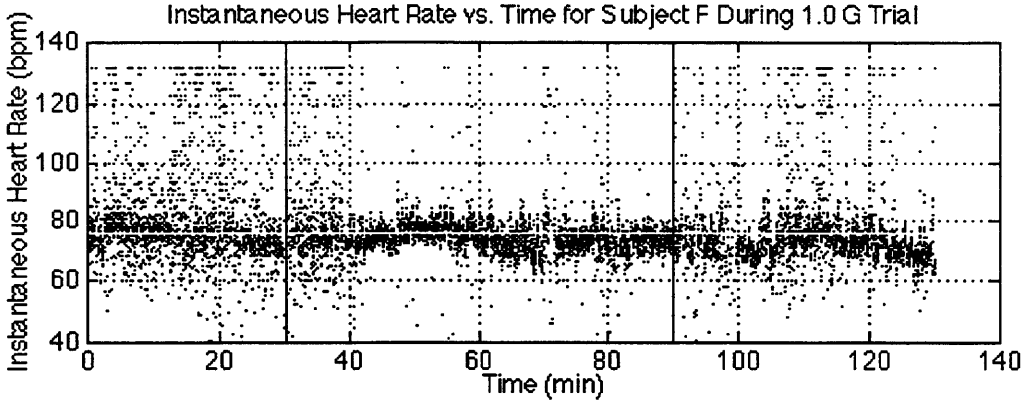

R-R Intervals vs. Time for Subject F During Control Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

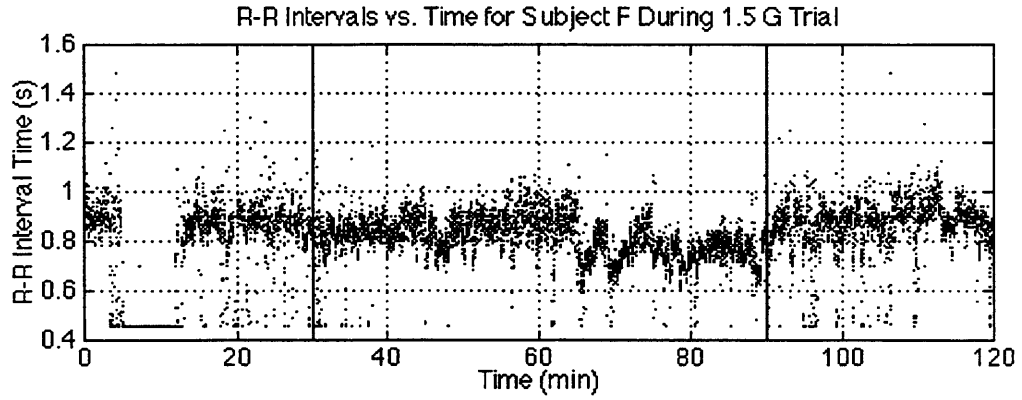

Instantaneous Heart Rate vs. Time for Subject F During Control Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

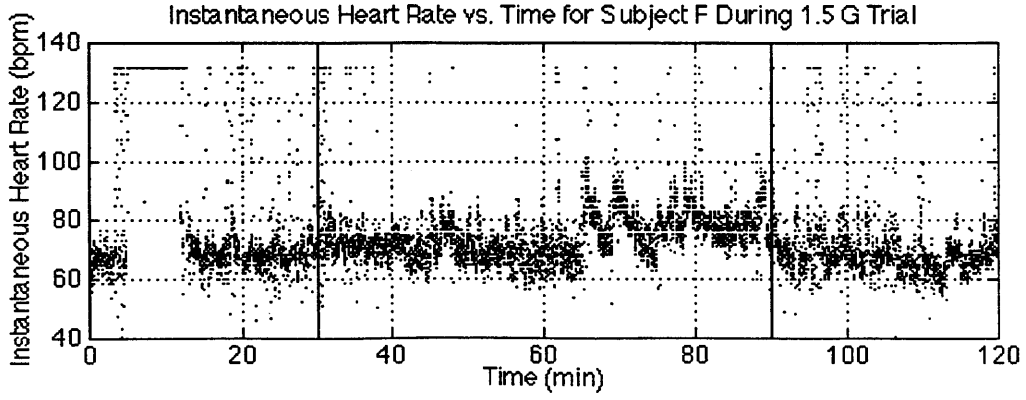

R-R Intervals vs. Time for Subject F During 0.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject F During 0.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

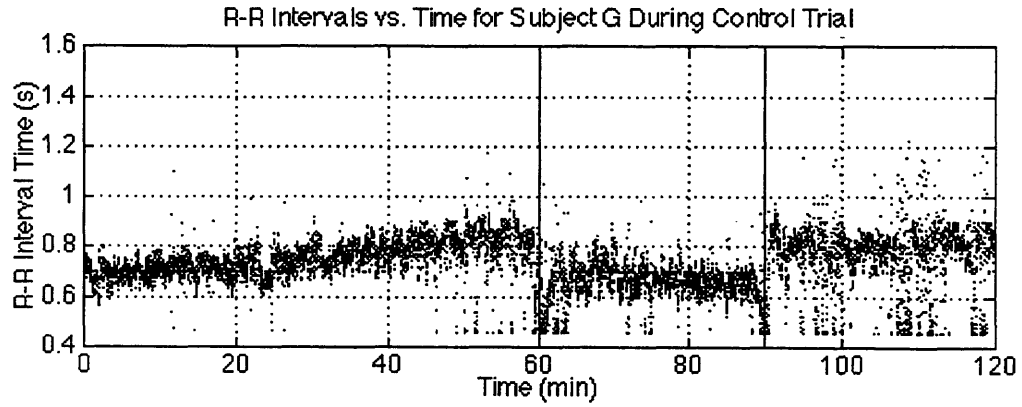

R-R Intervals vs. Time for Subject F During 1.0 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
140
Time (min)

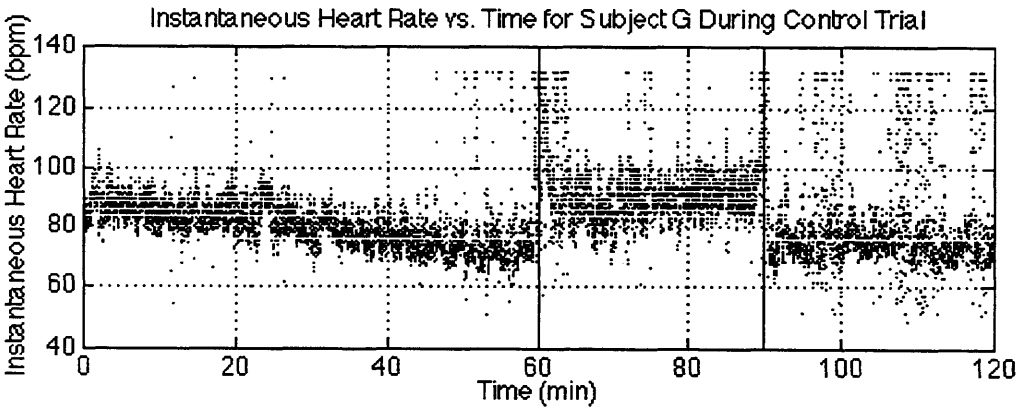

Instantaneous Heart Rate vs. Time for Subject F During 1.0 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
140
Time (min)

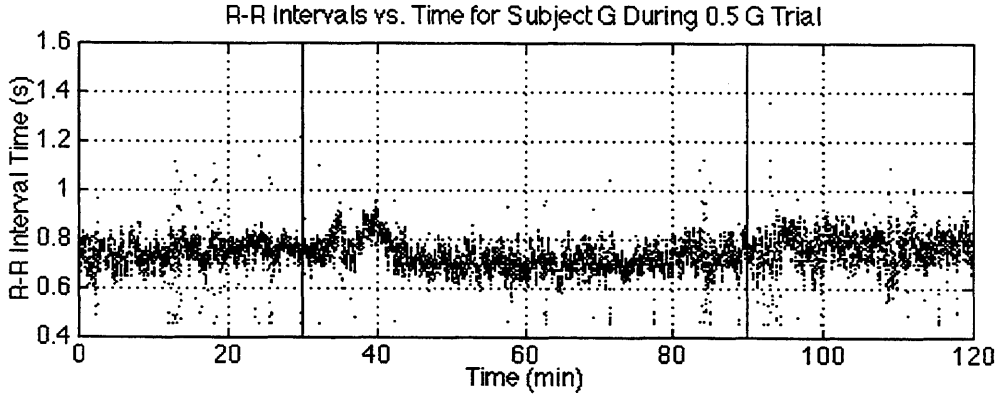

R-R Intervals vs. Time for Subject F During 1.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

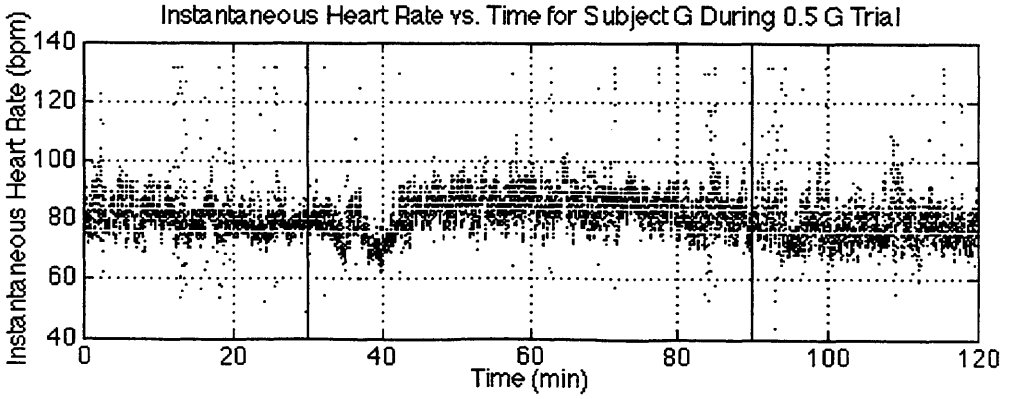

Instantaneous Heart Rate vs. Time for Subject F During 1.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

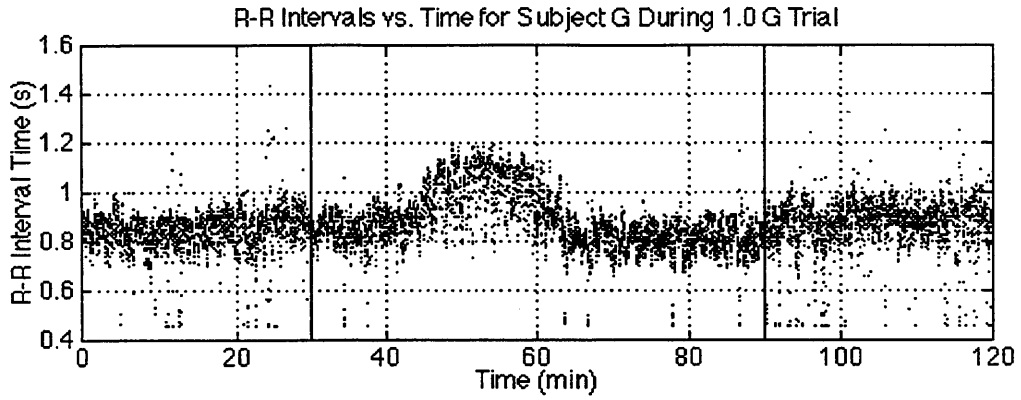
Subject G

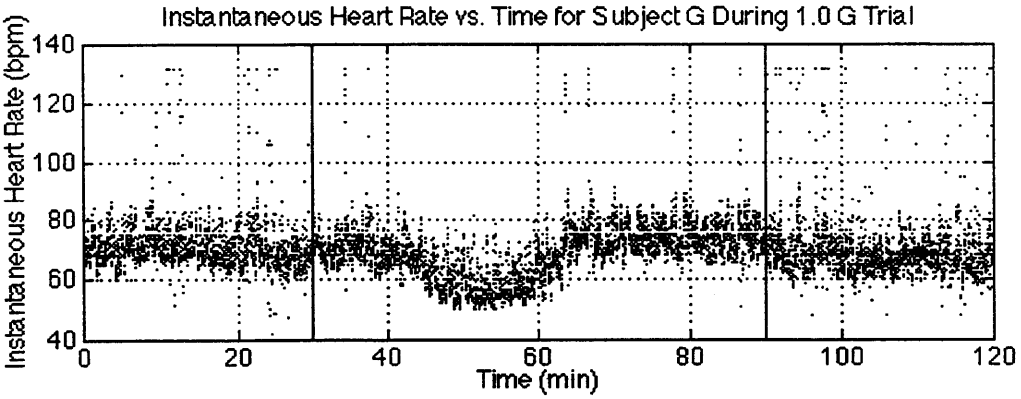

R-R Intervals vs. Time for Subject G During Control Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

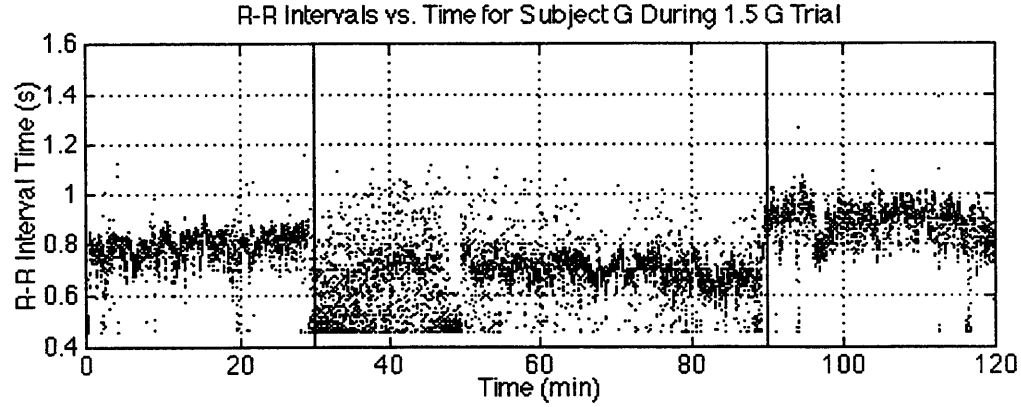

Instantaneous Heart Rate vs. Time for Subject G During Control Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

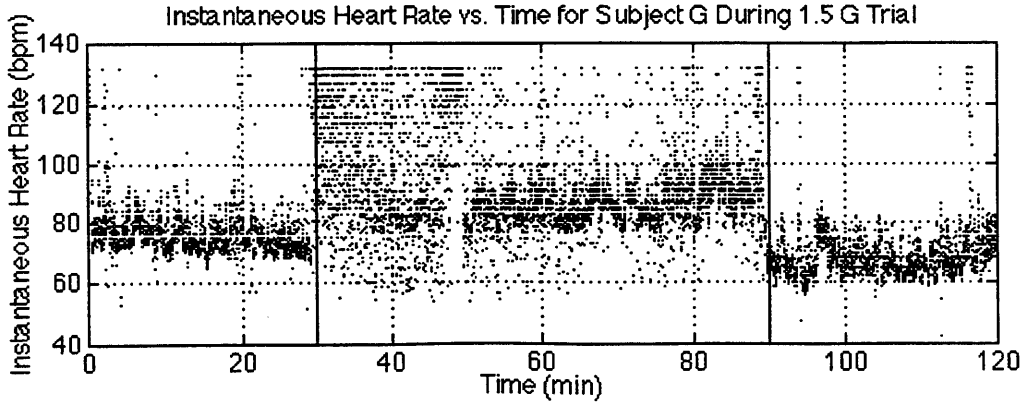

R-R Intervals vs. Time for Subject G During 0.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject G During 0.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

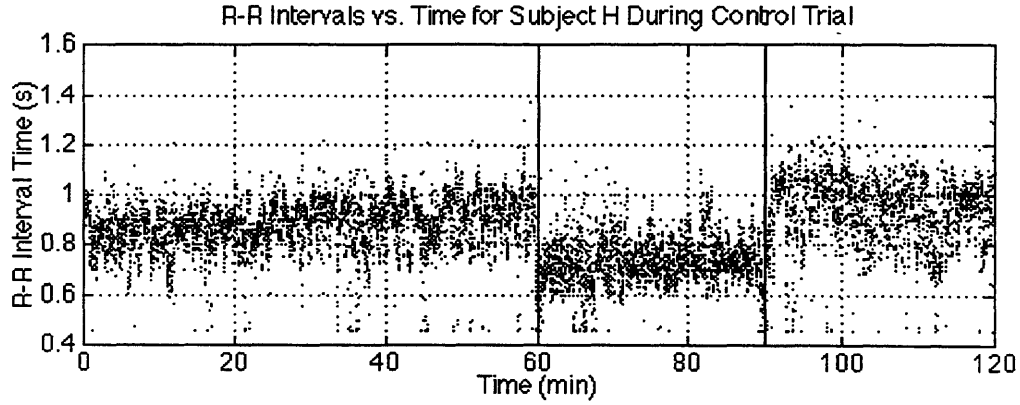

R-R Intervals vs. Time for Subject G During 1.0 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

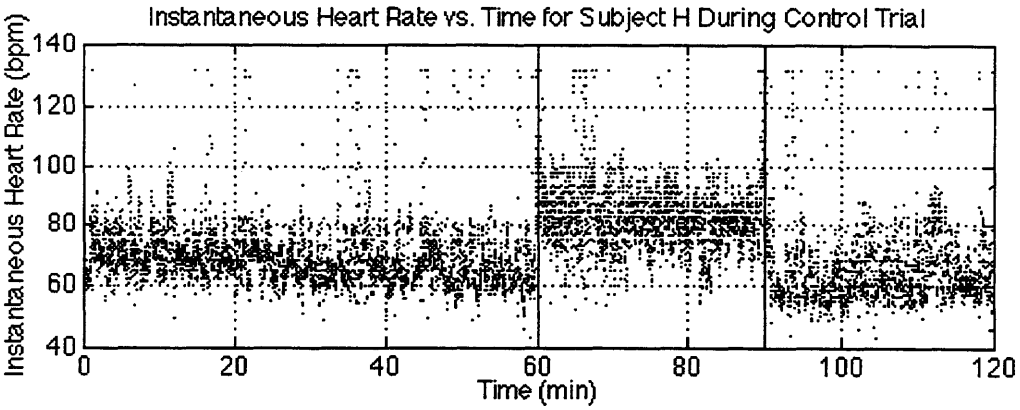

Instantaneous Heart Rate vs. Time for Subject G During 1.0 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

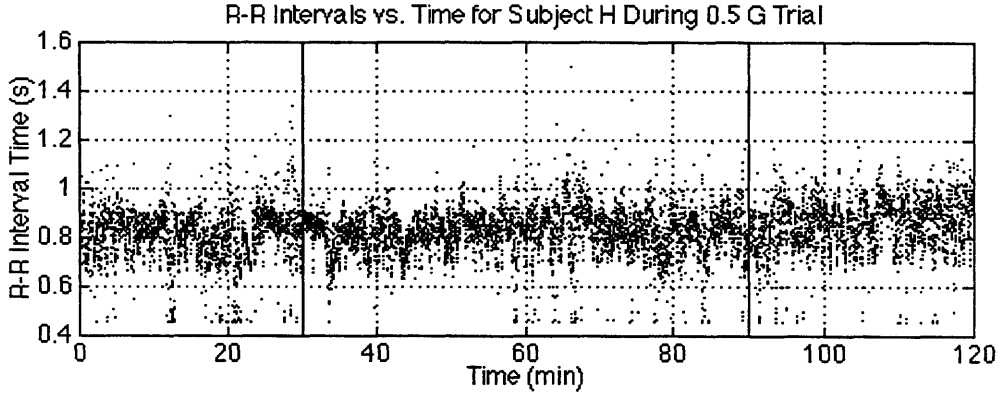

R-R Intervals vs. Time for Subject G During 1.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

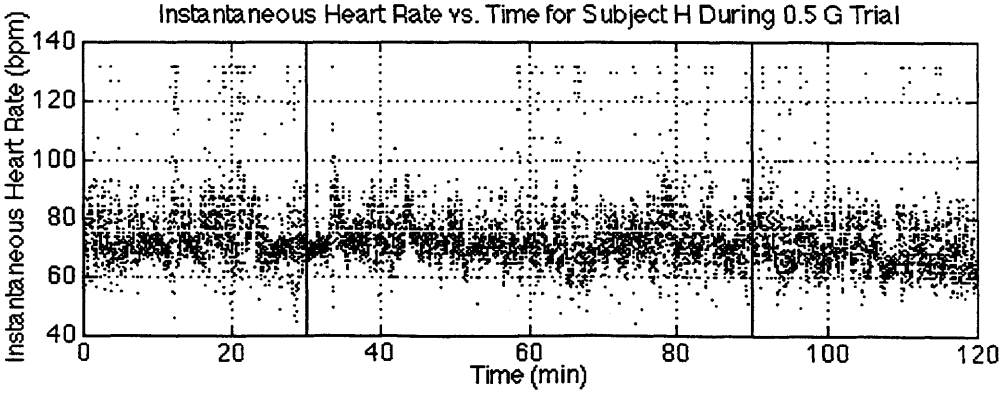

Instantaneous Heart Rate vs. Time for Subject G During 1.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

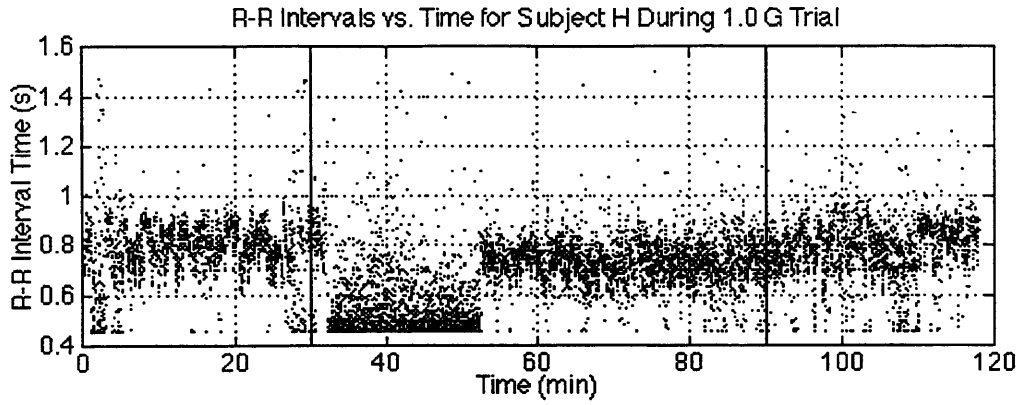
Subject H

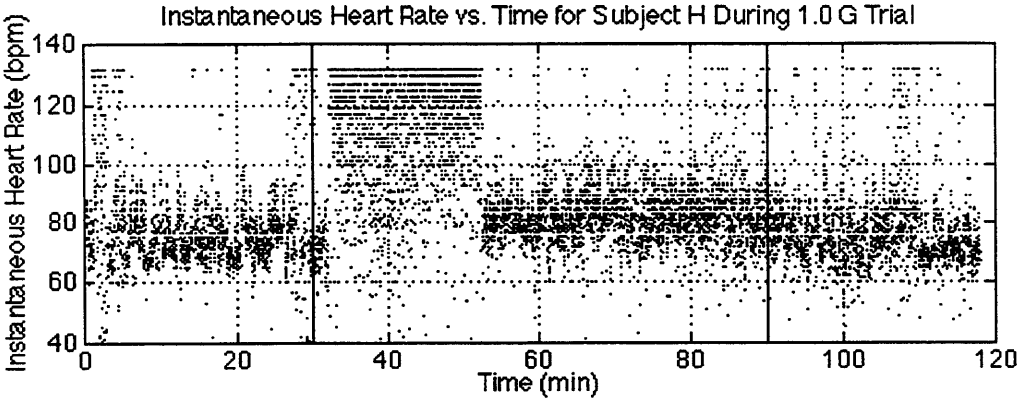

R-R Intervals vs. Time for Subject H During Control Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

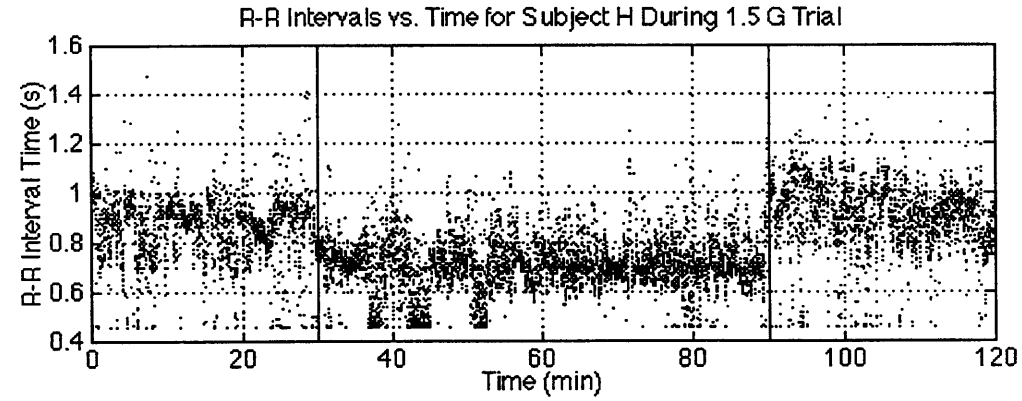

Instantaneous Heart Rate vs. Time for Subject H During Control Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

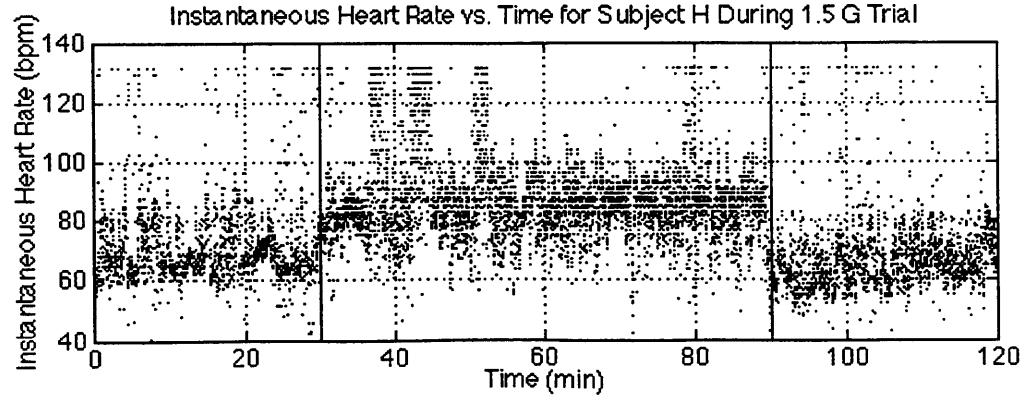

R-R Intervals vs. Time for Subject H During 0.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject H During 0.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

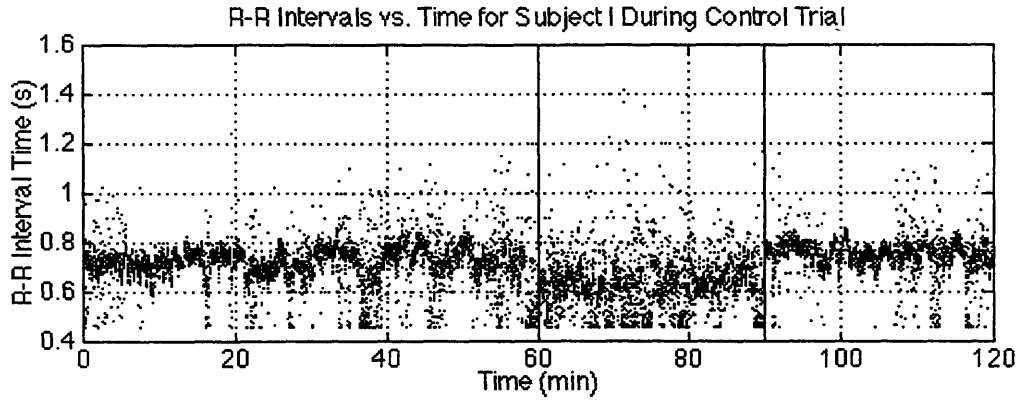

R-R Intervals vs. Time for Subject H During 1.0 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

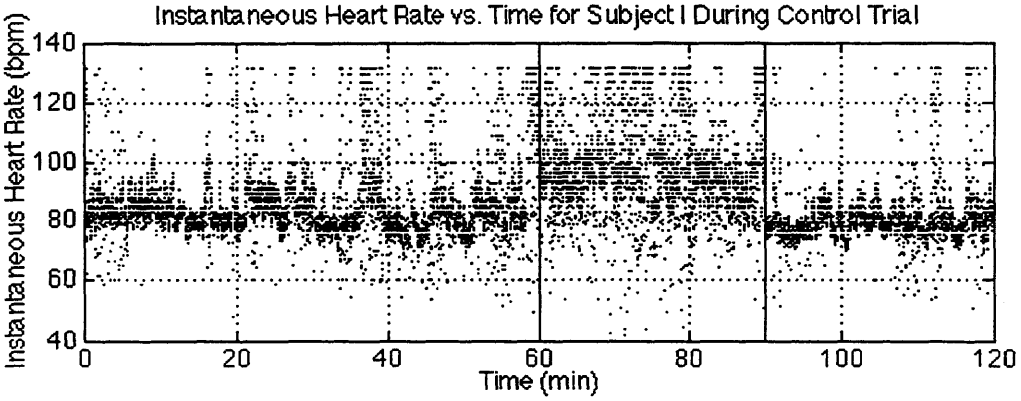

Instantaneous Heart Rate vs. Time for Subject H During 1.0 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

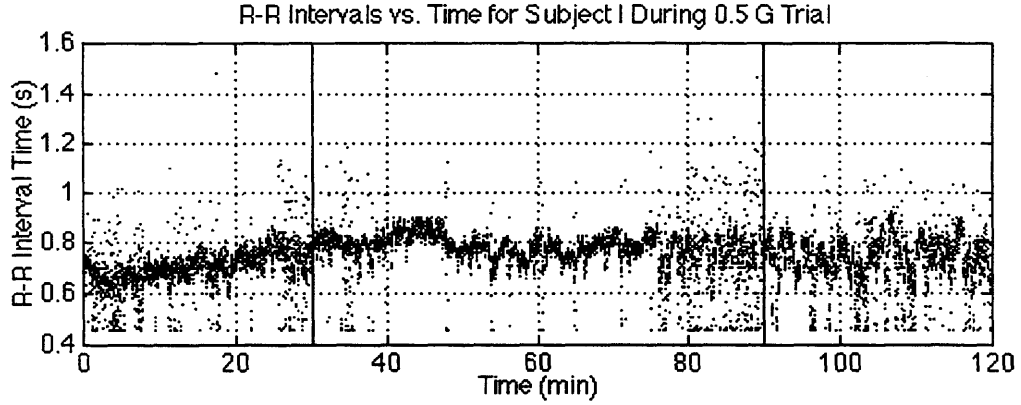

R-R Intervals vs. Time for Subject H During 1.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

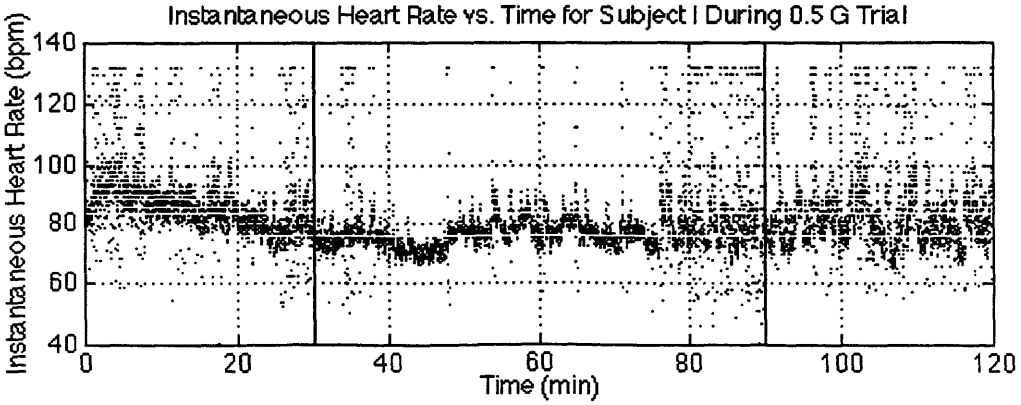

Instantaneous Heart Rate vs. Time for Subject H During 1.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

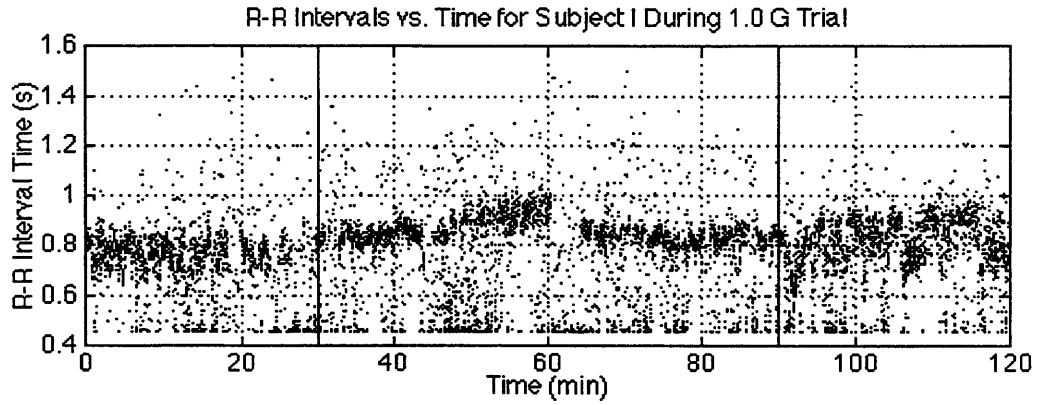
Subject I

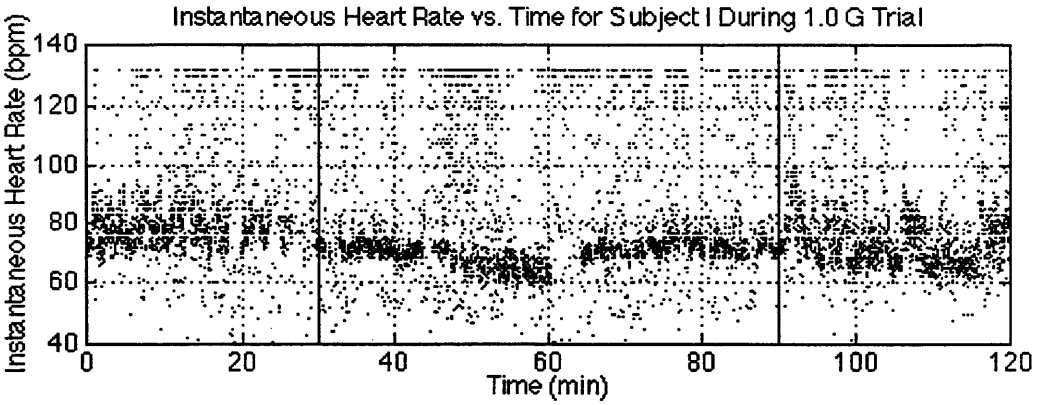

R-R Intervals vs. Time for Subject I During Control Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

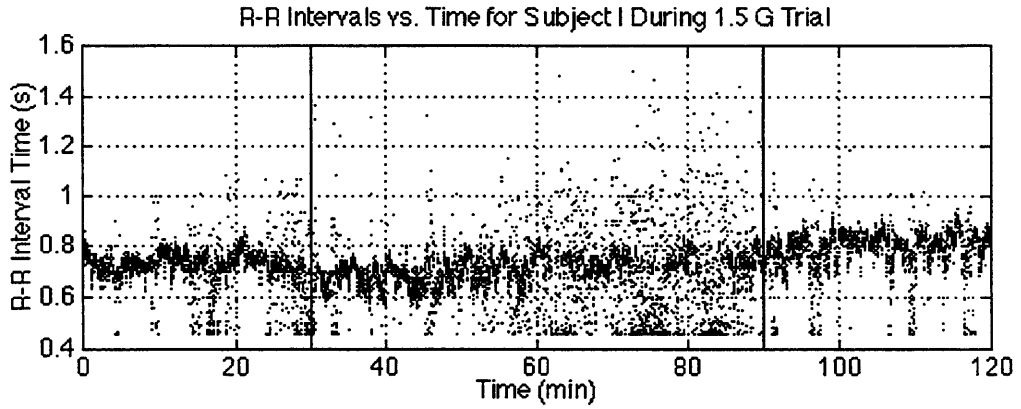

Instantaneous Heart Rate vs. Time for Subject I During Control Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

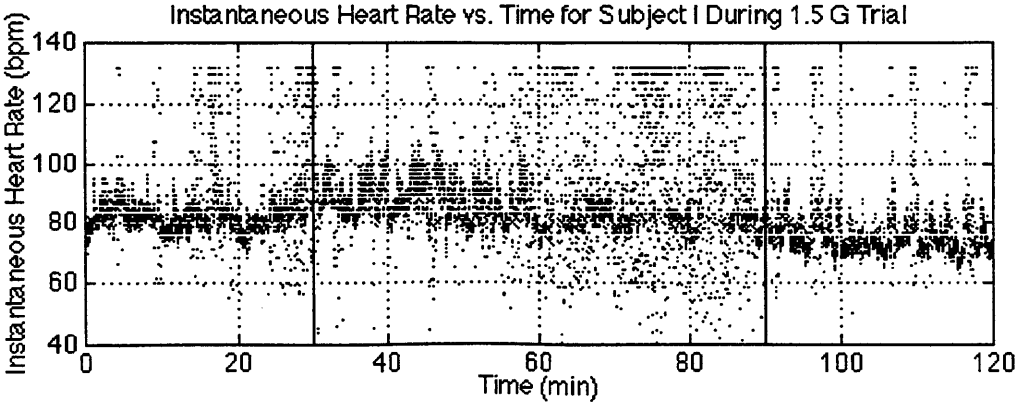

R-R Intervals vs. Time for Subject I During 0.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject I During 0.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

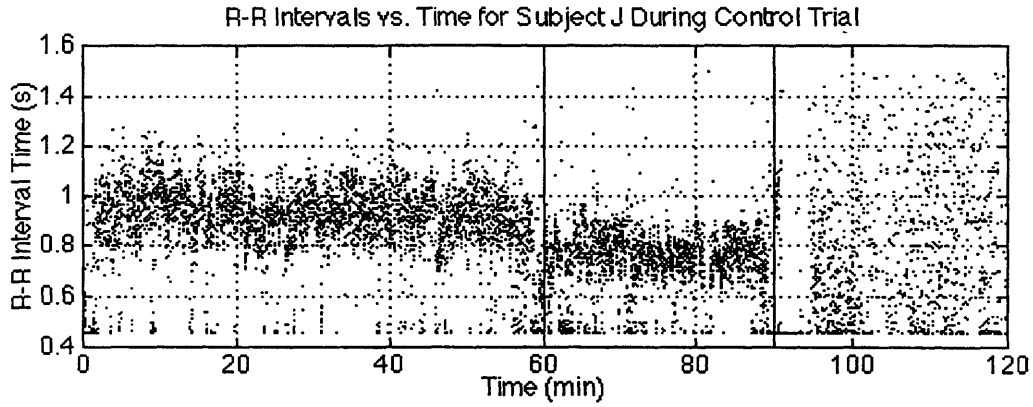

R-R Intervals vs. Time for Subject I During 1.0 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

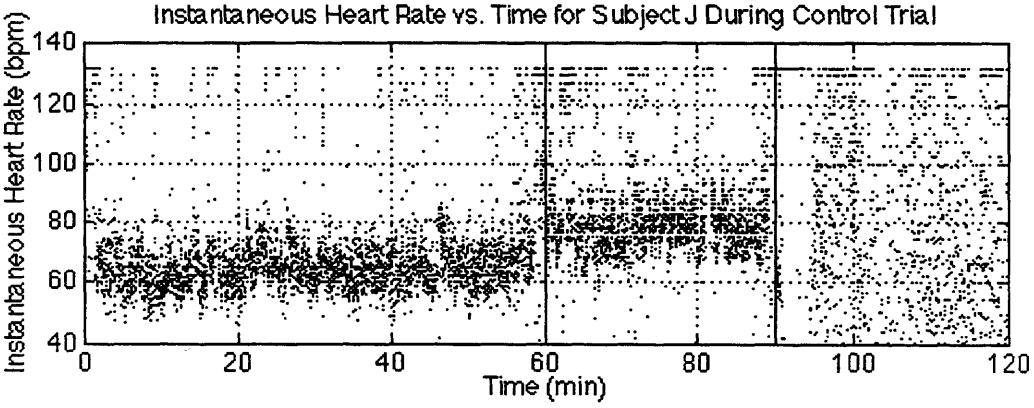

Instantaneous Heart Rate vs. Time for Subject I During 1.0 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

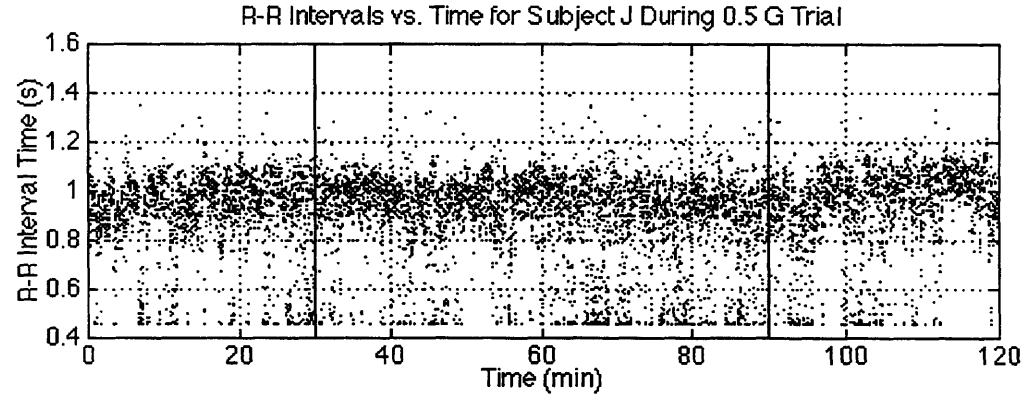

R-R Intervals vs. Time for Subject I During 1.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

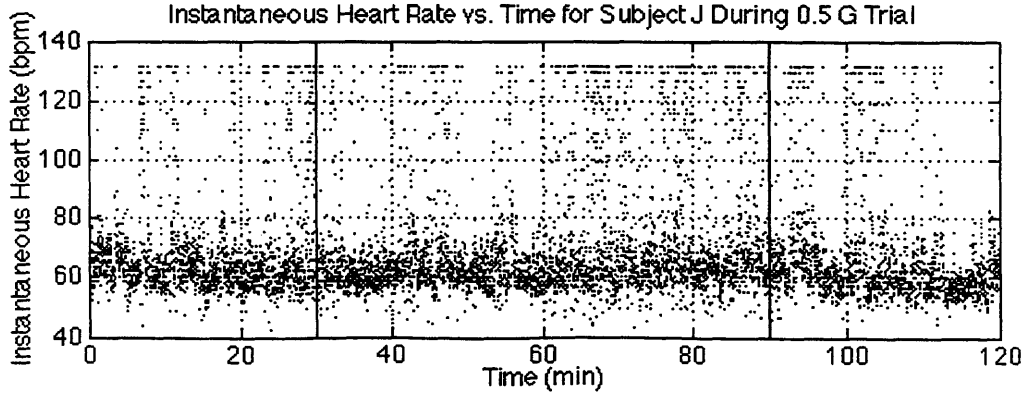

Instantaneous Heart Rate vs. Time for Subject I During 1.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

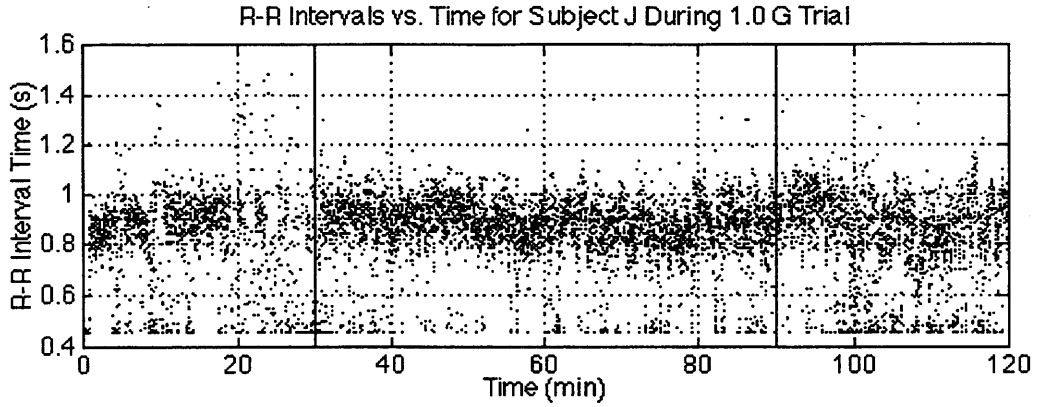
Subject J

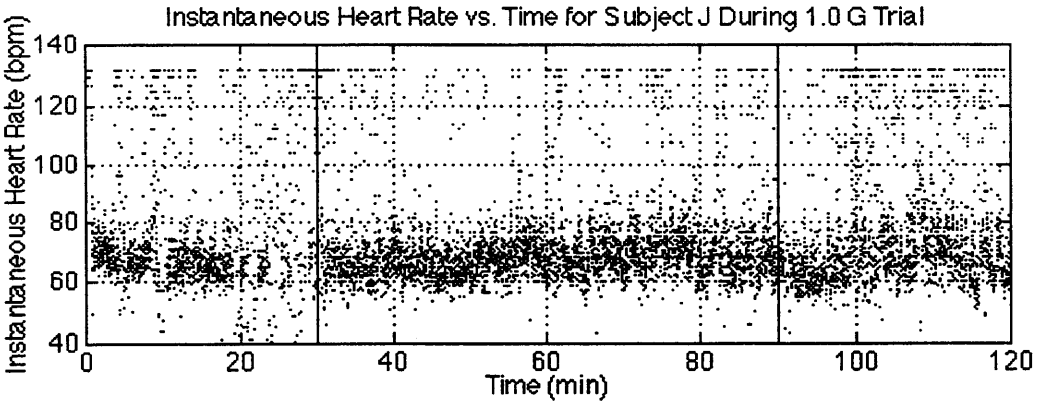

R-R Intervals vs. Time for Subject J During Control Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

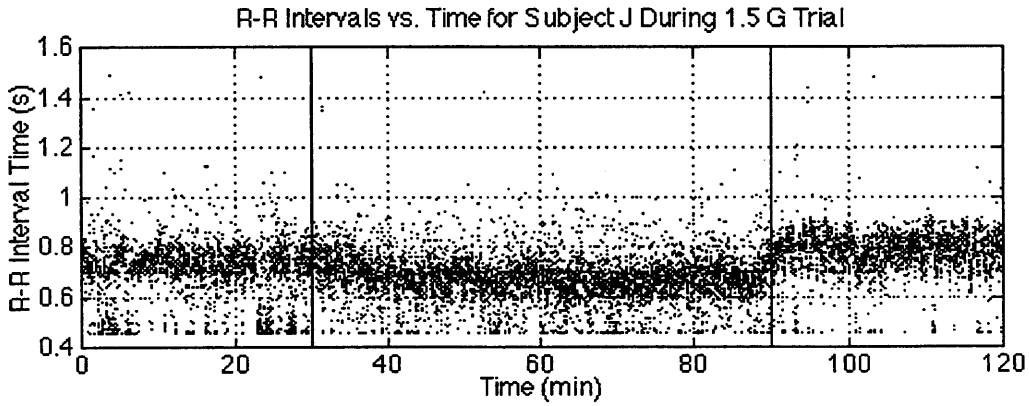

Instantaneous Heart Rate vs. Time for Subject J During Control Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

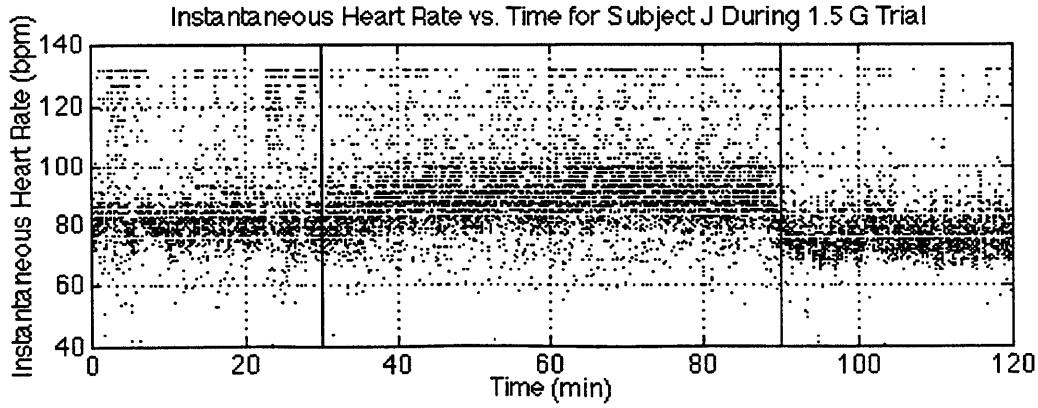

R-R Intervals vs. Time for Subject J During 0.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject J During 0.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)


R-R Intervals vs. Time for Subject J During 1.0 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)


Instantaneous Heart Rate vs. Time for Subject J During 1.0 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

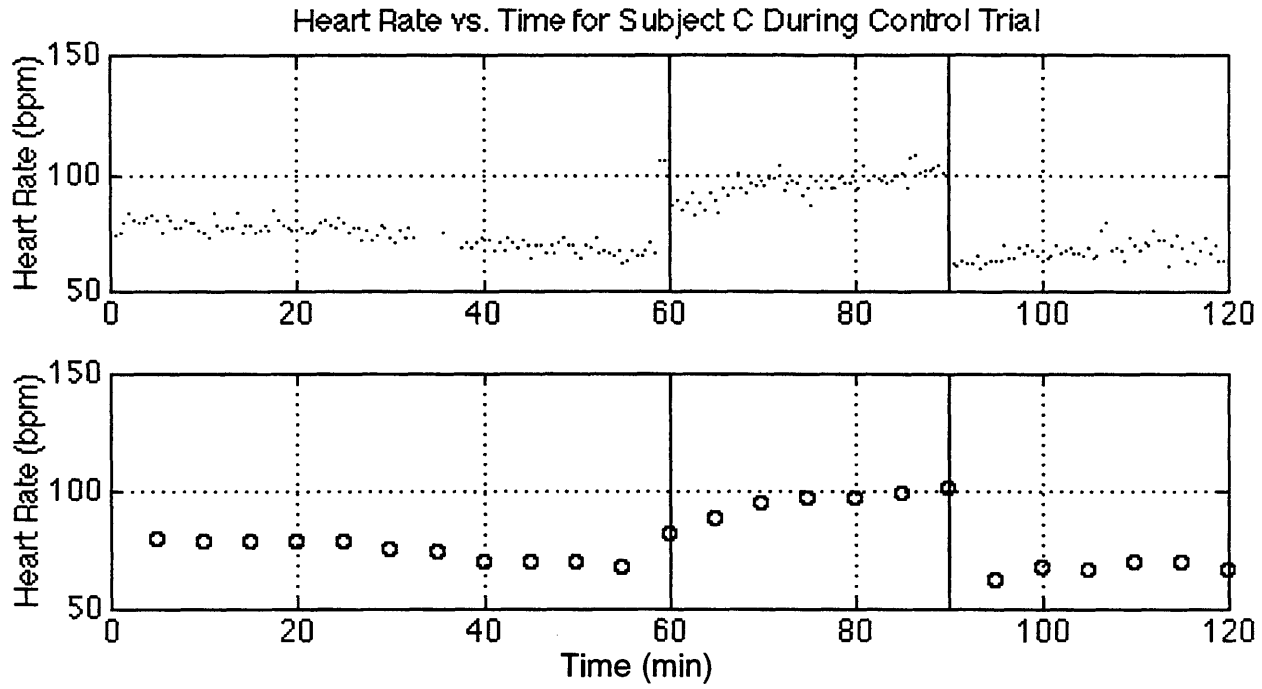

R-R Intervals vs. Time for Subject J During 1.5 G Trial
R-R Interval Time (s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0
20
40
60
80
100
120
Time (min)

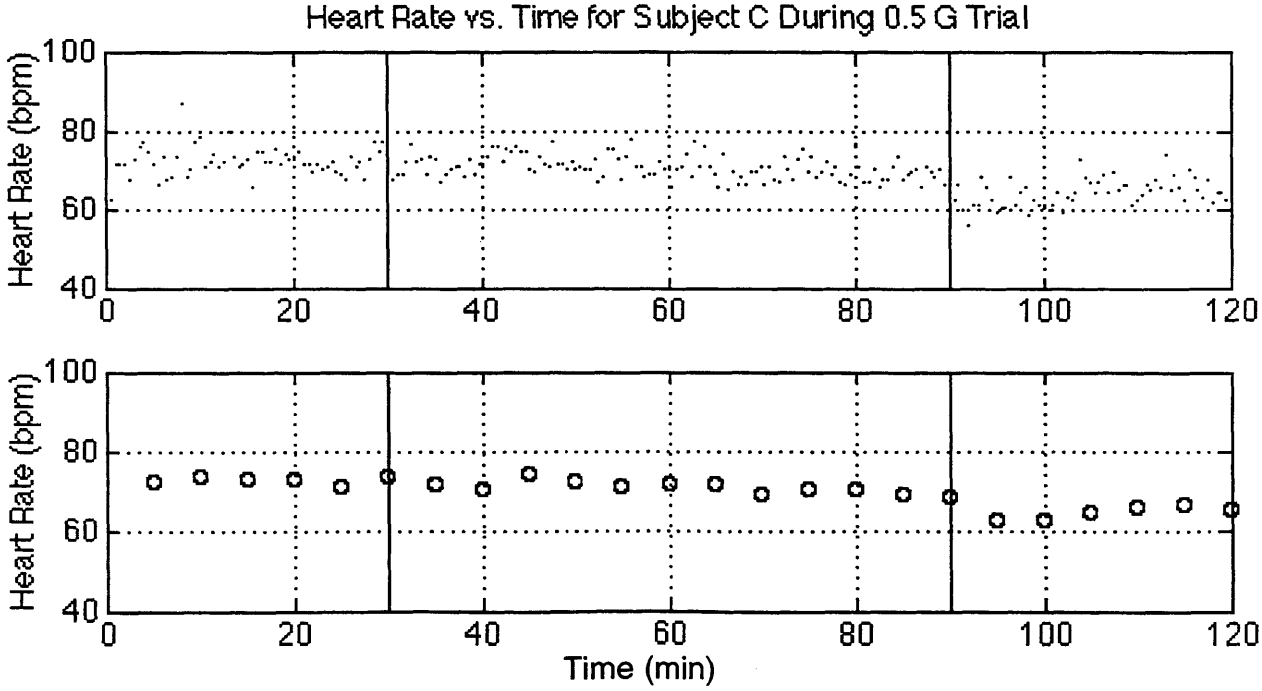

Instantaneous Heart Rate vs. Time for Subject J During 1.5 G Trial
Instantaneous Heart Rate (bpm)
140
120
100
80
60
40
0
20
40
60
80
100
120
Time (min)

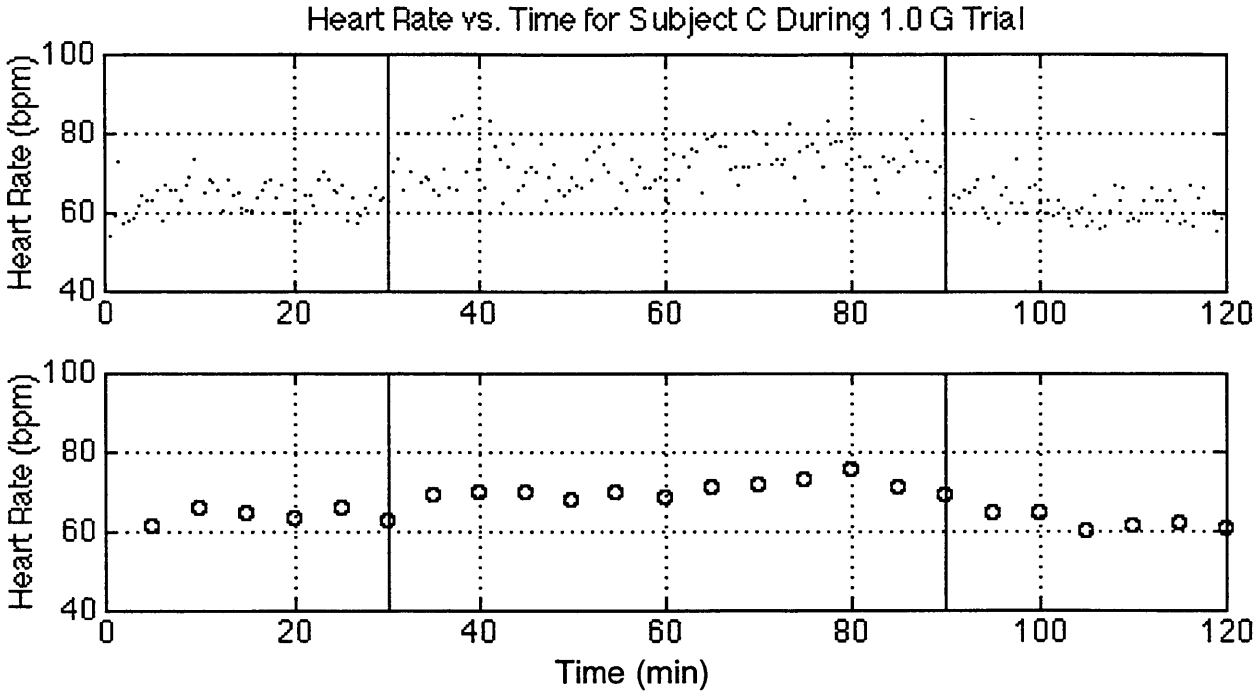
Plots of Heart Rate Averaged Over Intervals

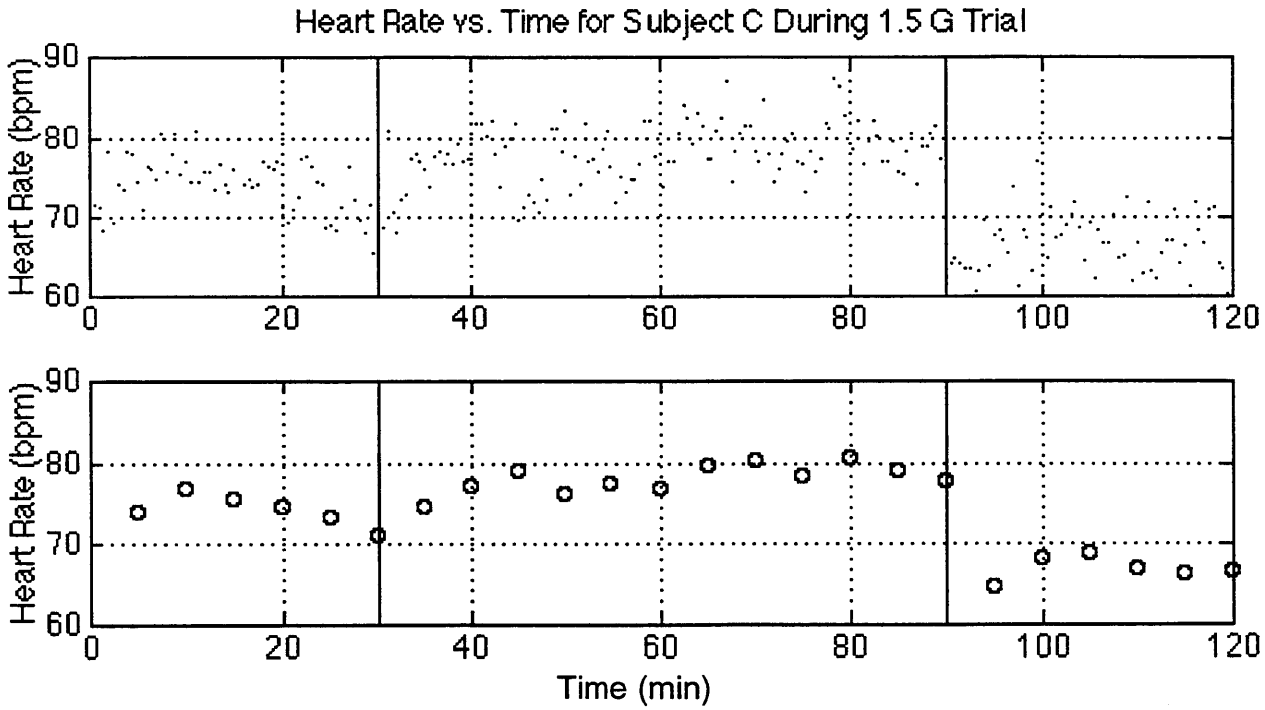
The following plots display heart rate averaged over 30 s and 5 min. intervals. The vertical lines in the plots represent the onset or end of a stimulus.

Subject C

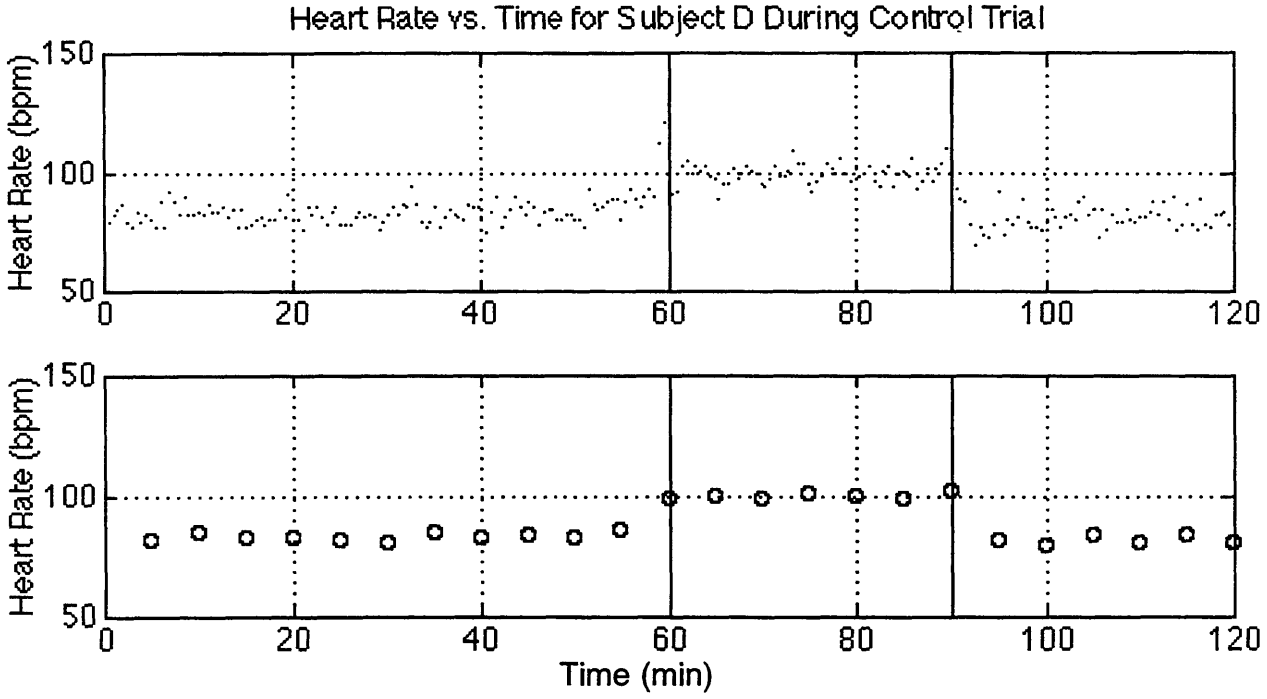


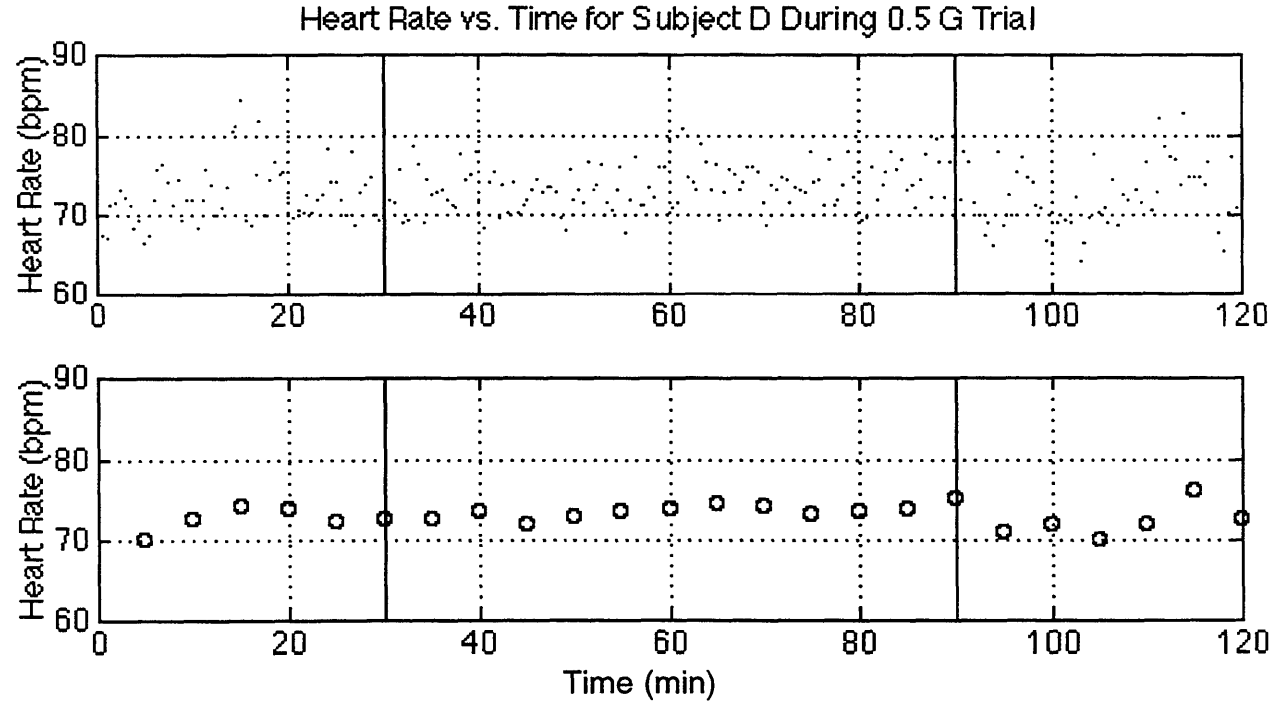


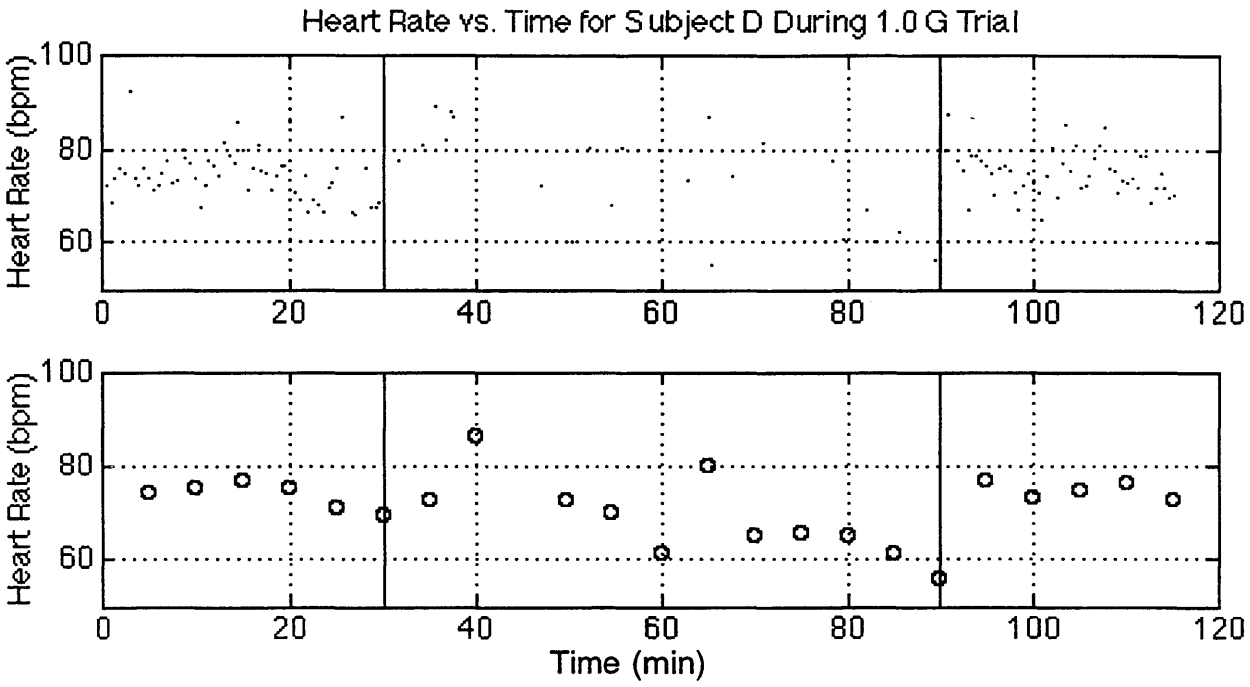

Heart Rate vs. Time for Subject C During 1.0 G Trial
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
Time (min)

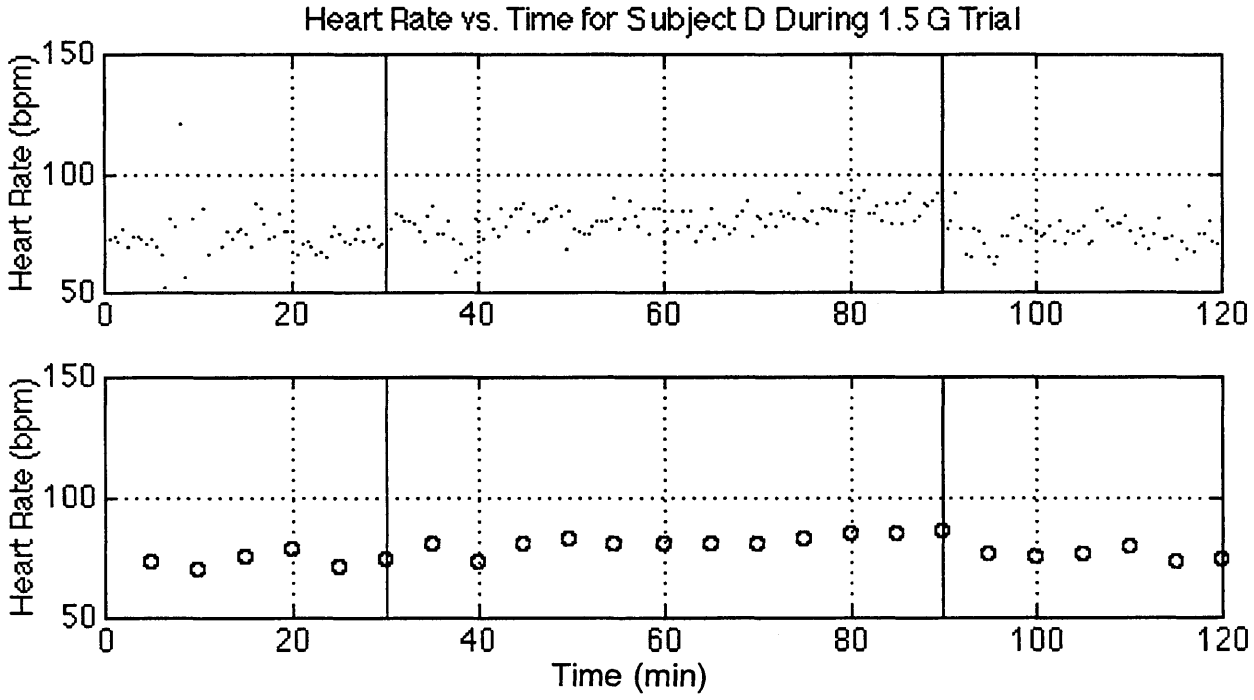

Heart Rate vs. Time for Subject C During 1.5 G Trial
Heart Rate (bpm)
90
80
70
60
0
20
40
60
80
100
120
Heart Rate (bpm)
90
80
70
60
0
20
40
60
80
100
120
Time (min)

Subject D

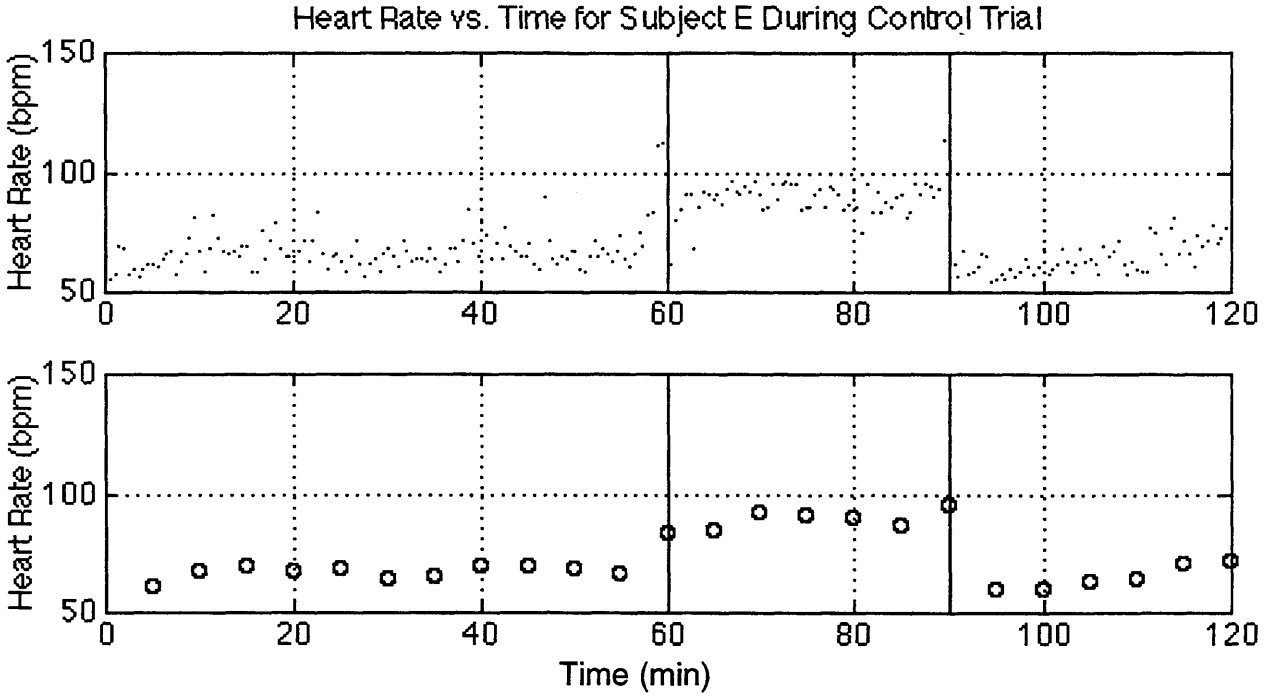

Heart Rate vs. Time for Subject D During Control Trial
Heart Rate (bpm)
150
100
50
0
20
40
60
80
100
120
Time (min)

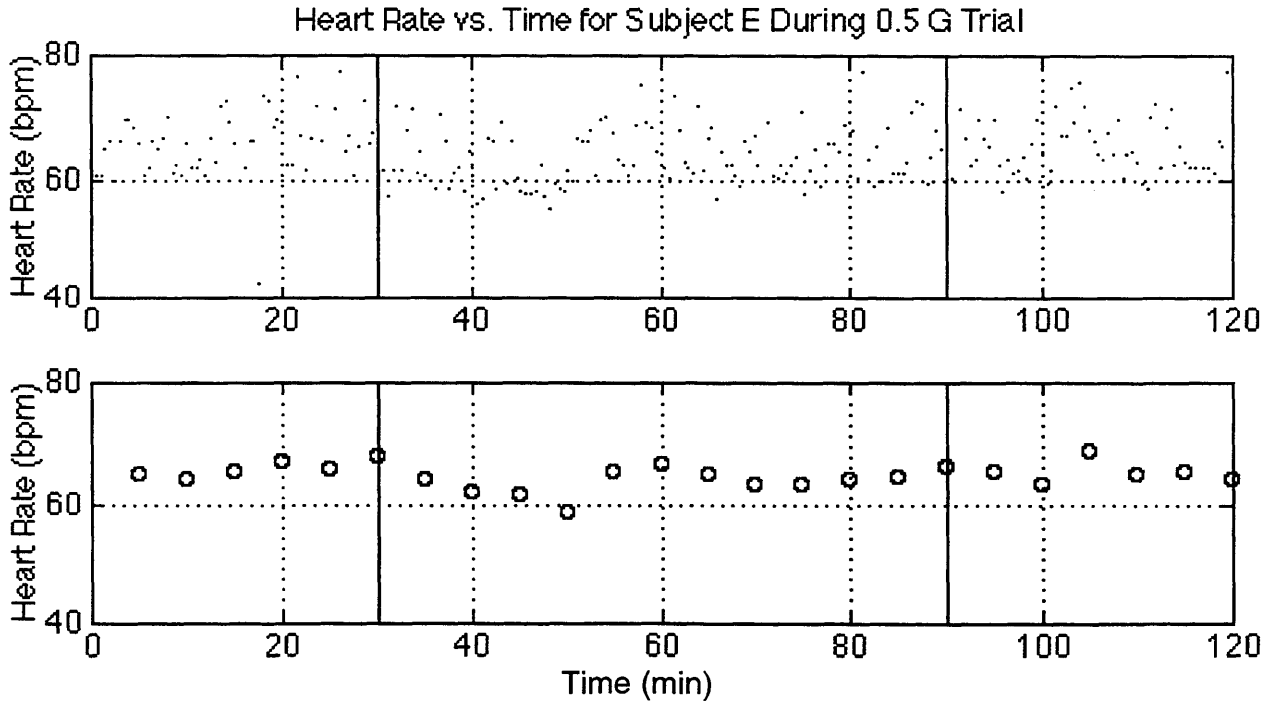

Heart Rate vs. Time for Subject D During 0.5 G Trial
Heart Rate (bpm)
90
80
70
60
0
20
40
60
80
100
120
Time (min)

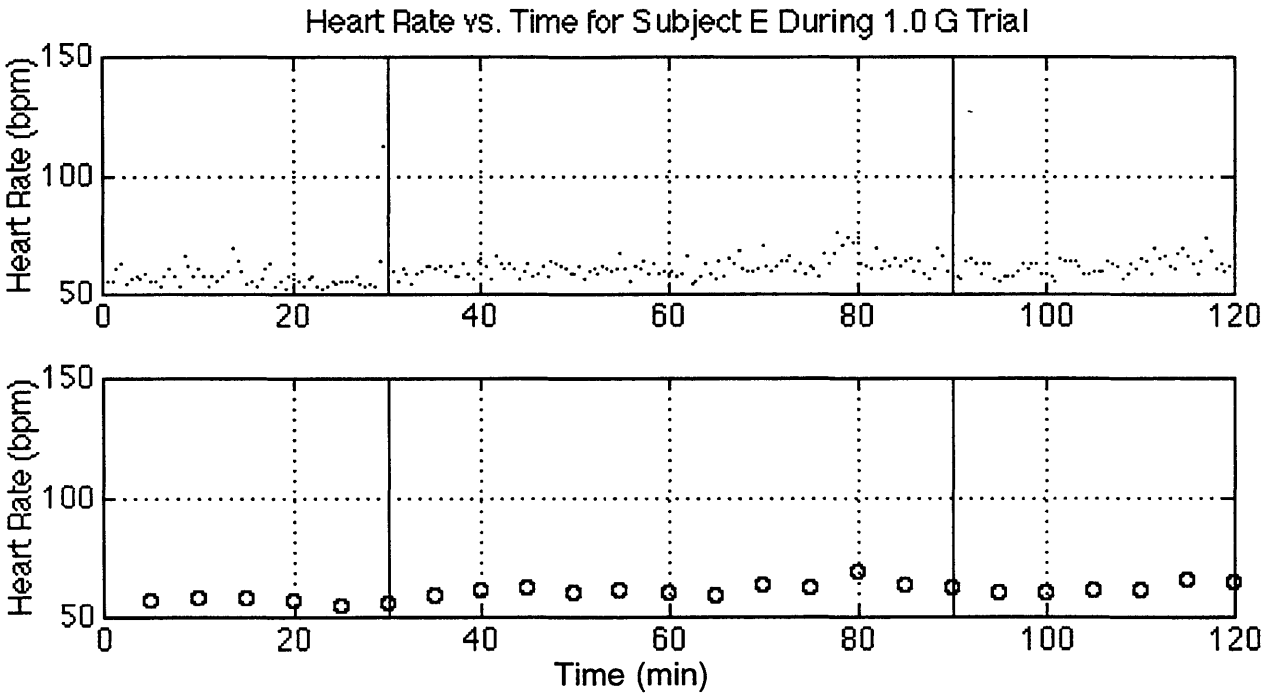

Heart Rate vs. Time for Subject D During 1.0 G Trial
Heart Rate (bpm)
100
80
60
0
20
40
60
80
100
120
Heart Rate (bpm)
100
80
60
0
20
40
60
80
100
120
Time (min)

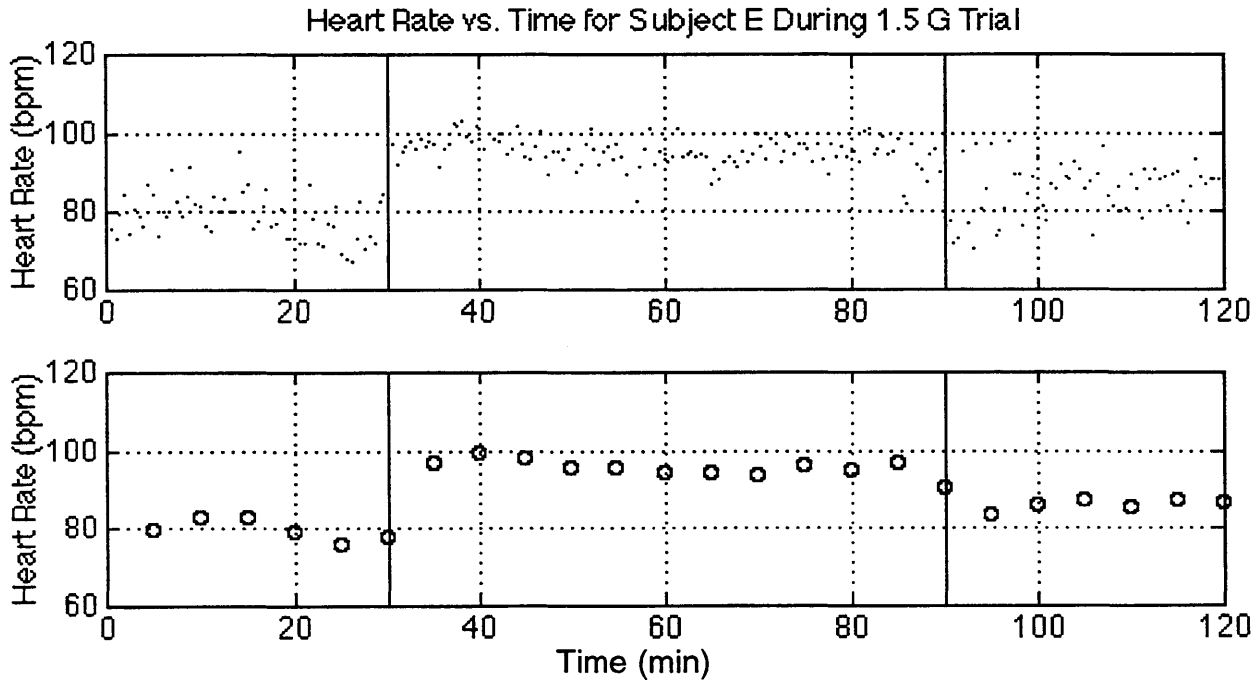

Heart Rate vs. Time for Subject D During 1.5 G Trial
Heart Rate (bpm)
150
100
50
0
20
40
60
80
100
120
Heart Rate (bpm)
150
100
50
0
20
40
60
80
100
120
Time (min)

Subject E

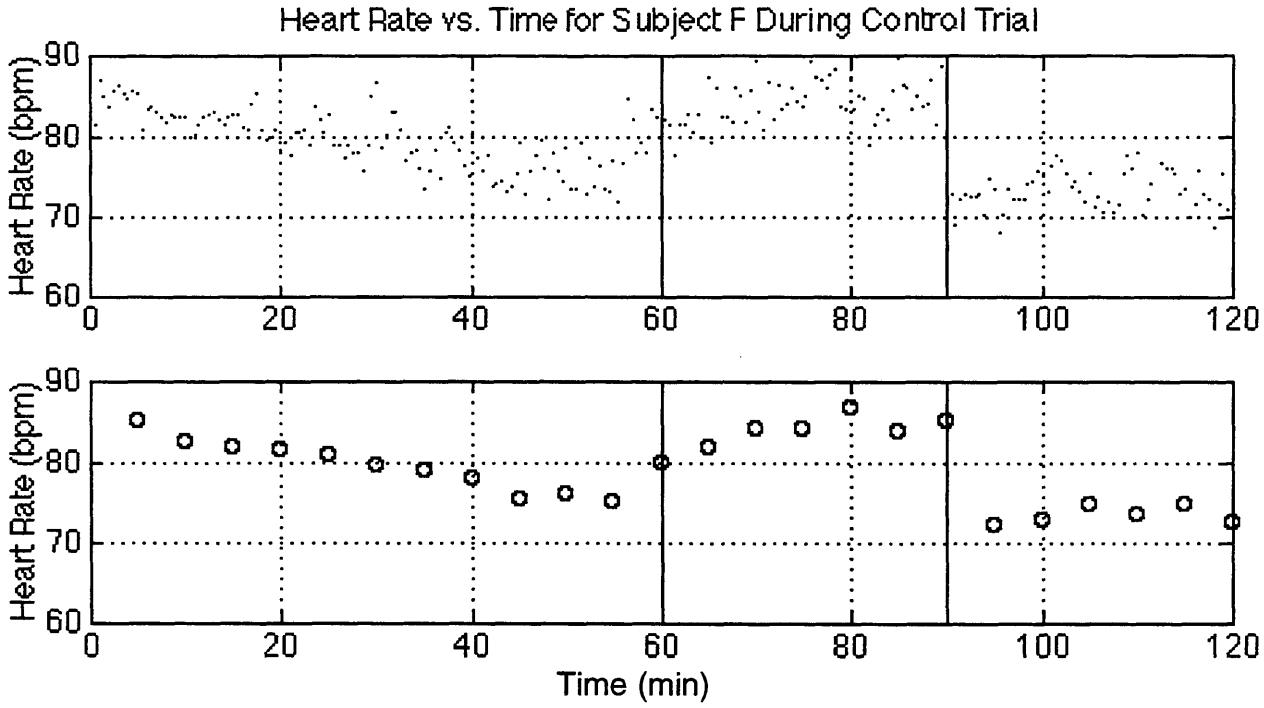

Heart Rate vs. Time for Subject E During Control Trial
Heart Rate (bpm)
150
100
50
0
20
40
60
80
100
120
Time (min)

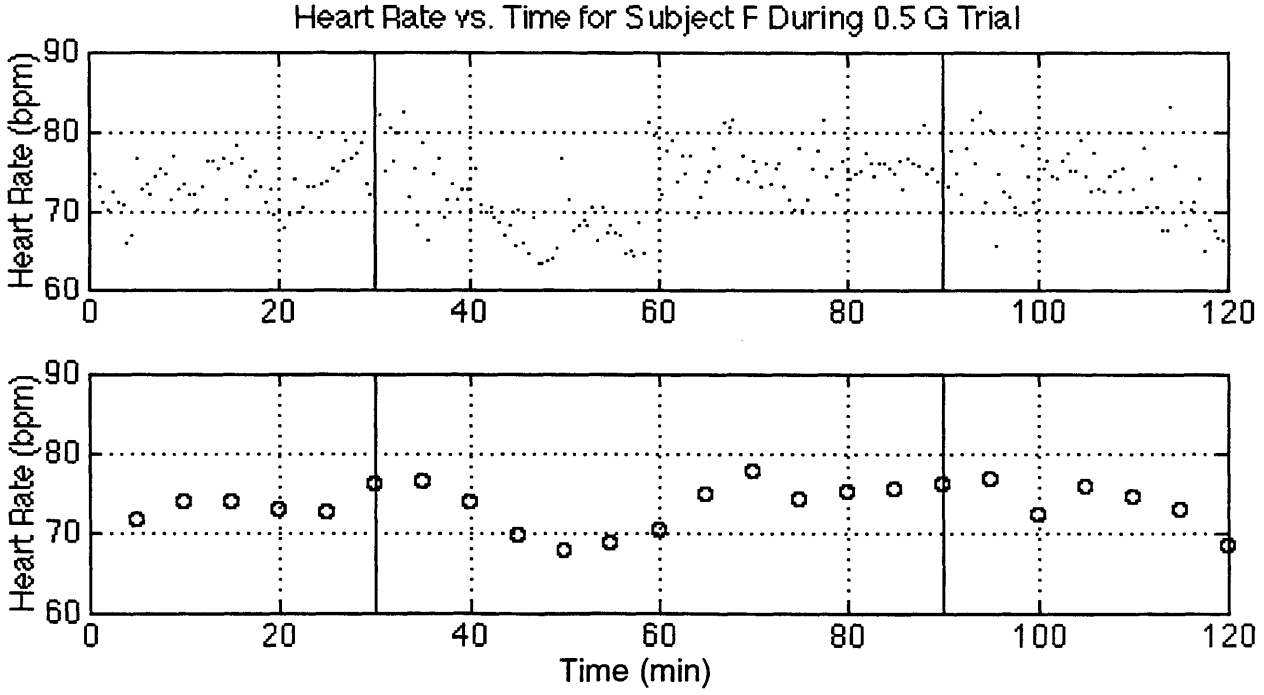

Heart Rate vs. Time for Subject E During 0.5 G Trial
Heart Rate (bpm)
80
60
40
0
20
40
60
80
100
120
Time (min)

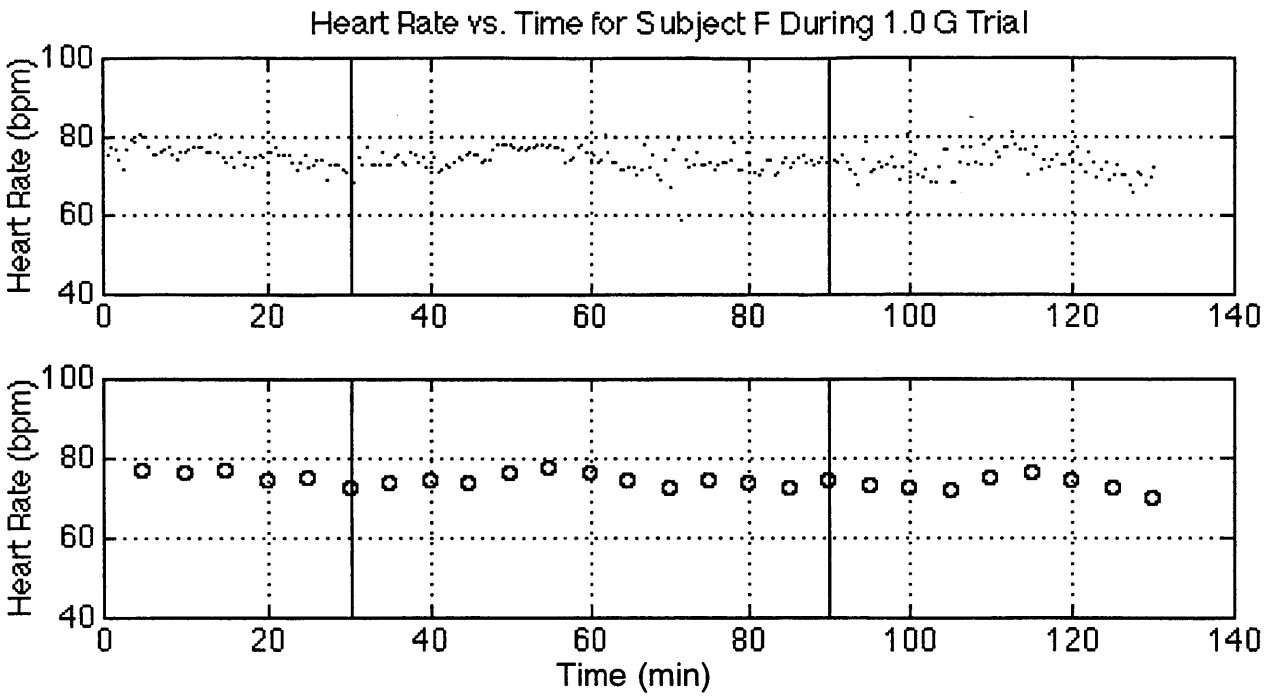

Heart Rate vs. Time for Subject E During 1.0 G Trial
Heart Rate (bpm)
150
100
50
0
20
40
60
80
100
120
Time (min)

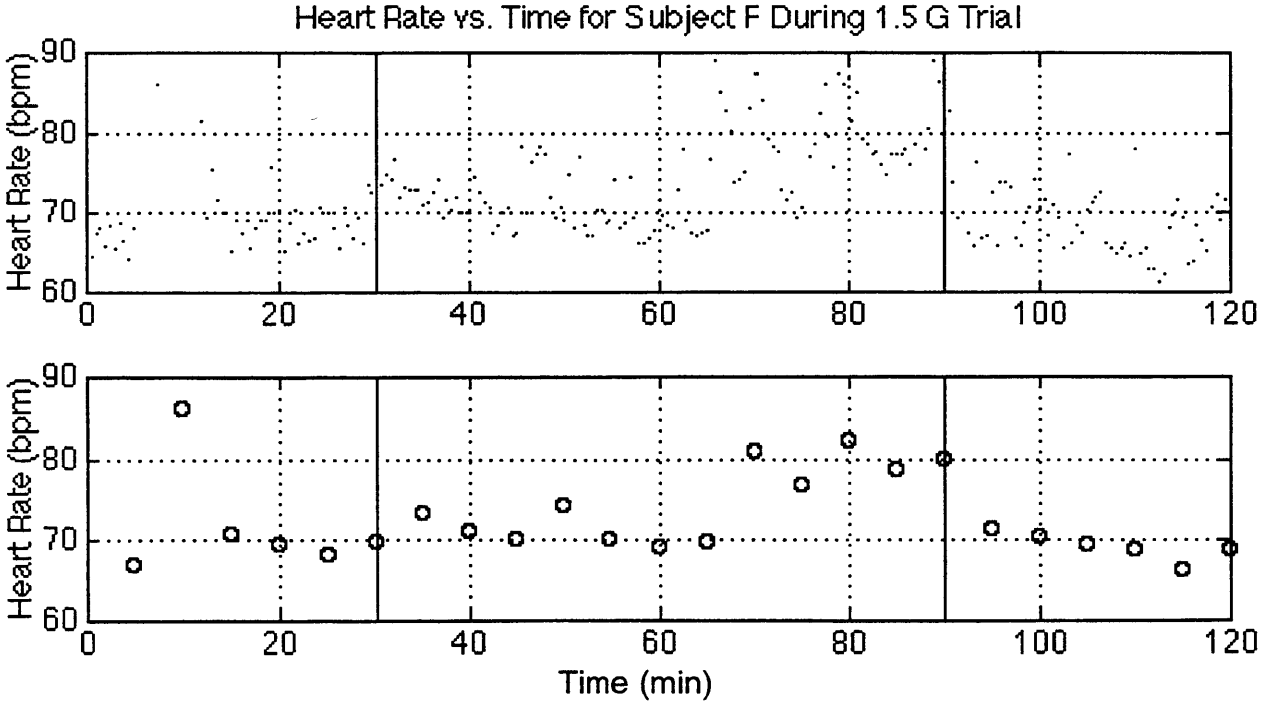

Heart Rate vs. Time for Subject E During 1.5 G Trial
Heart Rate (bpm)
120
100
80
60
0
20
40
60
80
100
120
Time (min)

Subject F

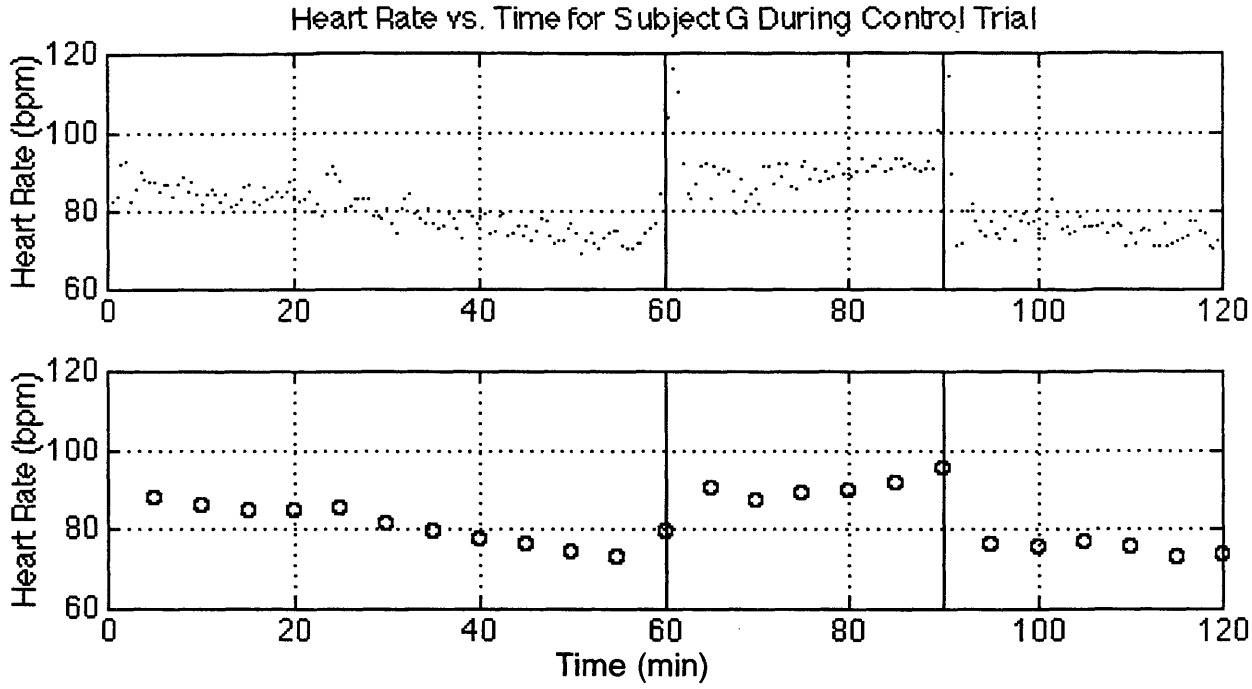

Heart Rate vs. Time for Subject F During Control Trial
Heart Rate (bpm)
90
80
70
60
0
20
40
60
80
100
120
Time (min)

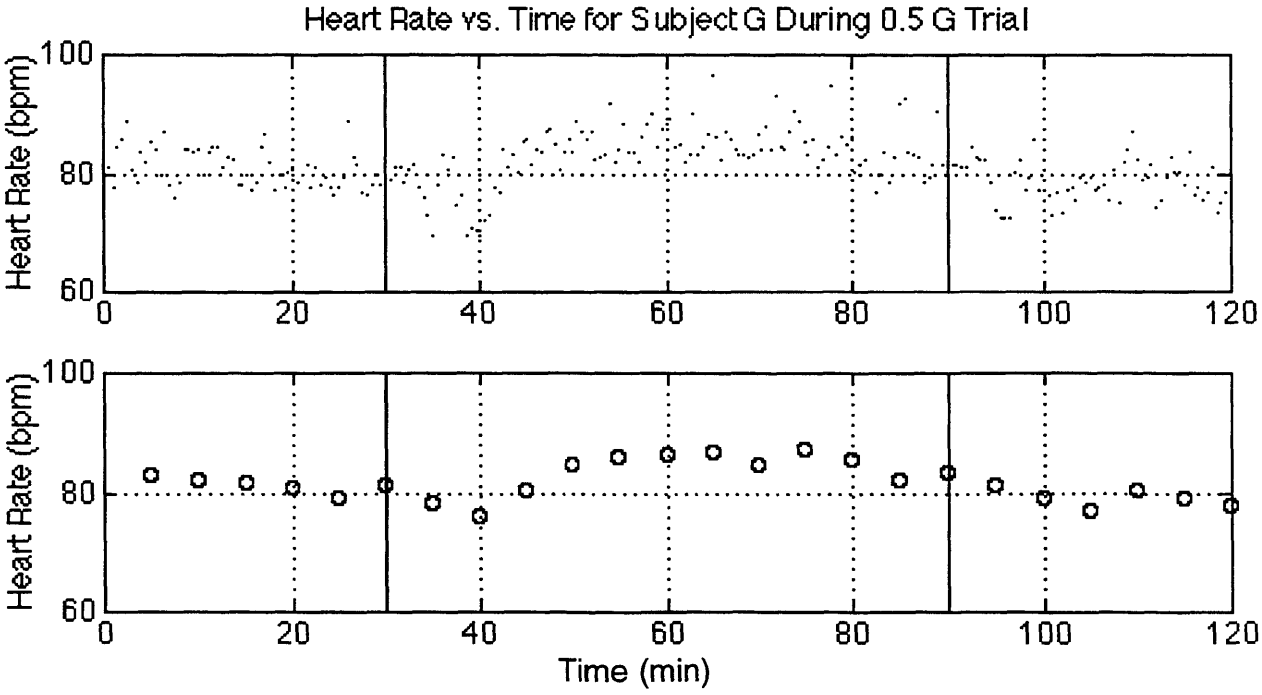

Heart Rate vs. Time for Subject F During 0.5 G Trial
Heart Rate (bpm)
90
80
70
60
0
20
40
60
80
100
120
Time (min)

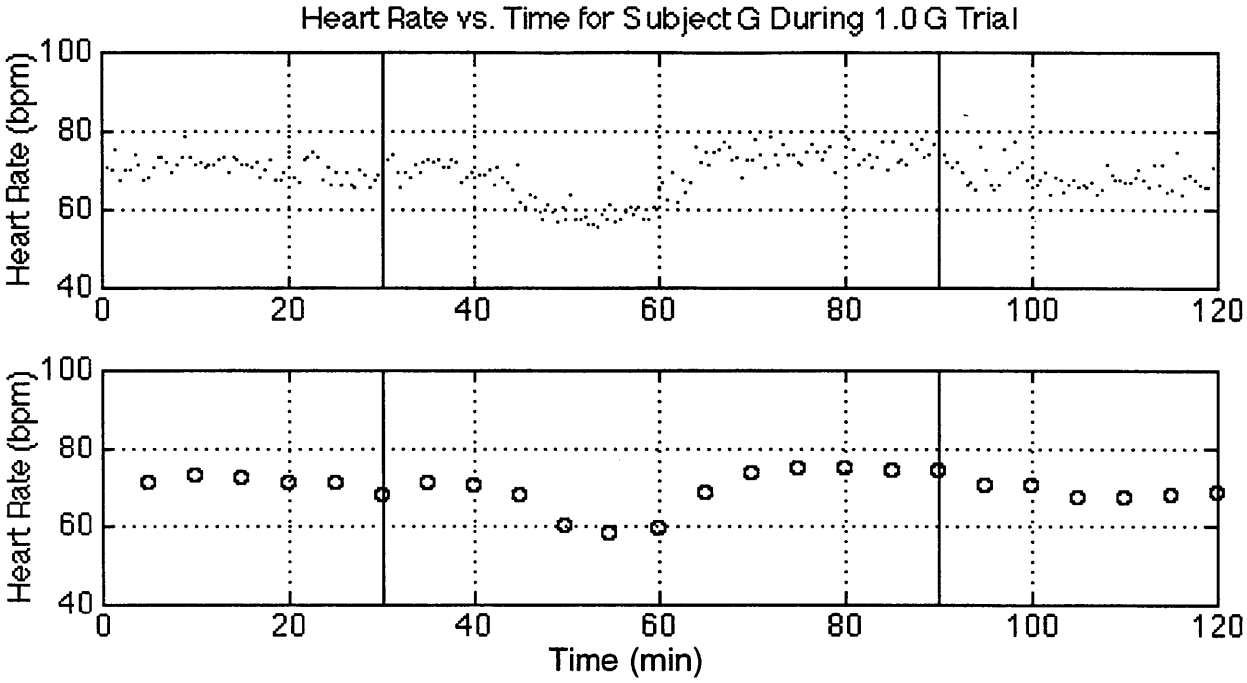

Heart Rate vs. Time for Subject F During 1.0 G Trial
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
140
Time (min)

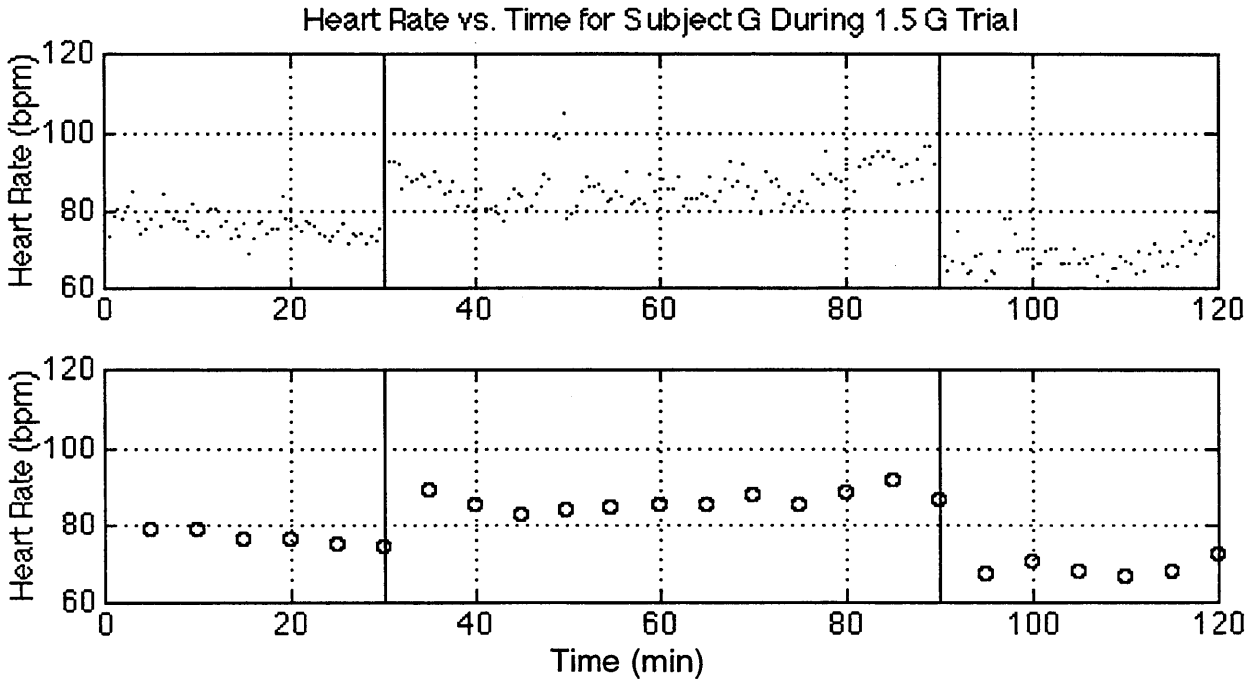

Heart Rate vs. Time for Subject F During 1.5 G Trial
Heart Rate (bpm)
90
80
70
60
0
20
40
60
80
100
120
Time (min)

Subject G

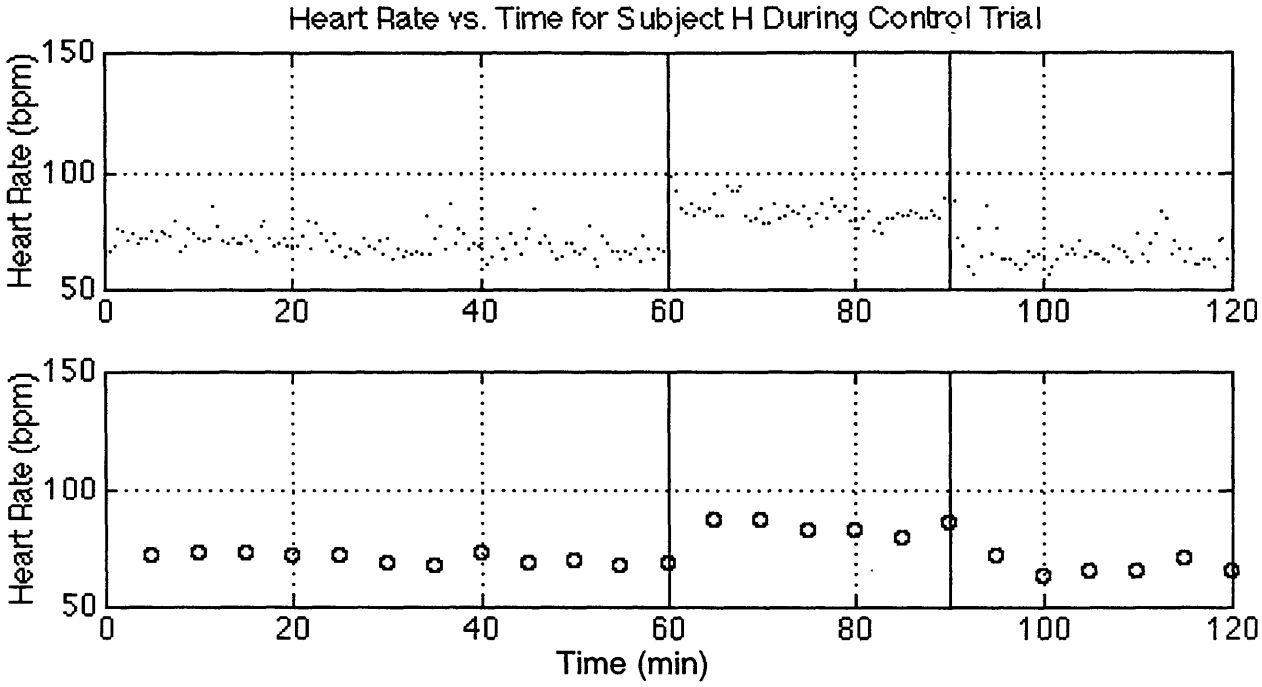

Heart Rate vs. Time for Subject G During Control Trial
Heart Rate (bpm)
120
100
80
60
0
20
40
60
80
100
120
Time (min)

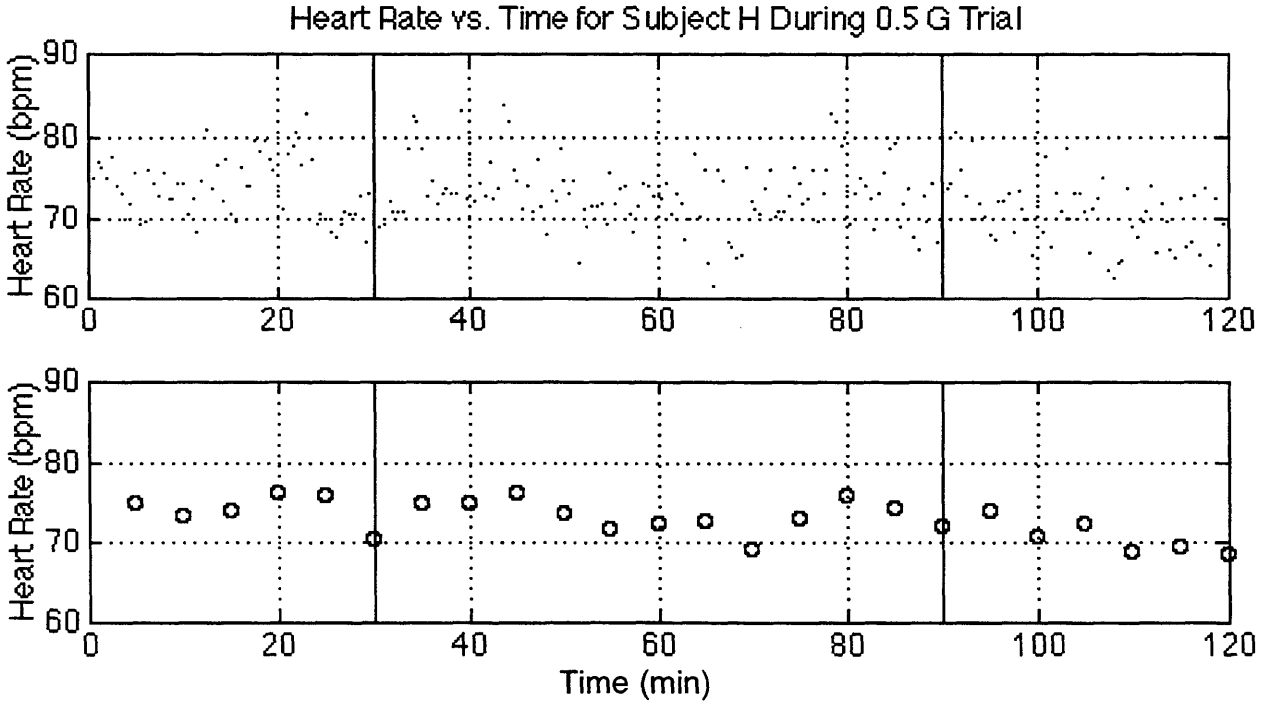

Heart Rate vs. Time for Subject G During 0.5 G Trial
Heart Rate (bpm)
100
80
60
0
20
40
60
80
100
120
Time (min)

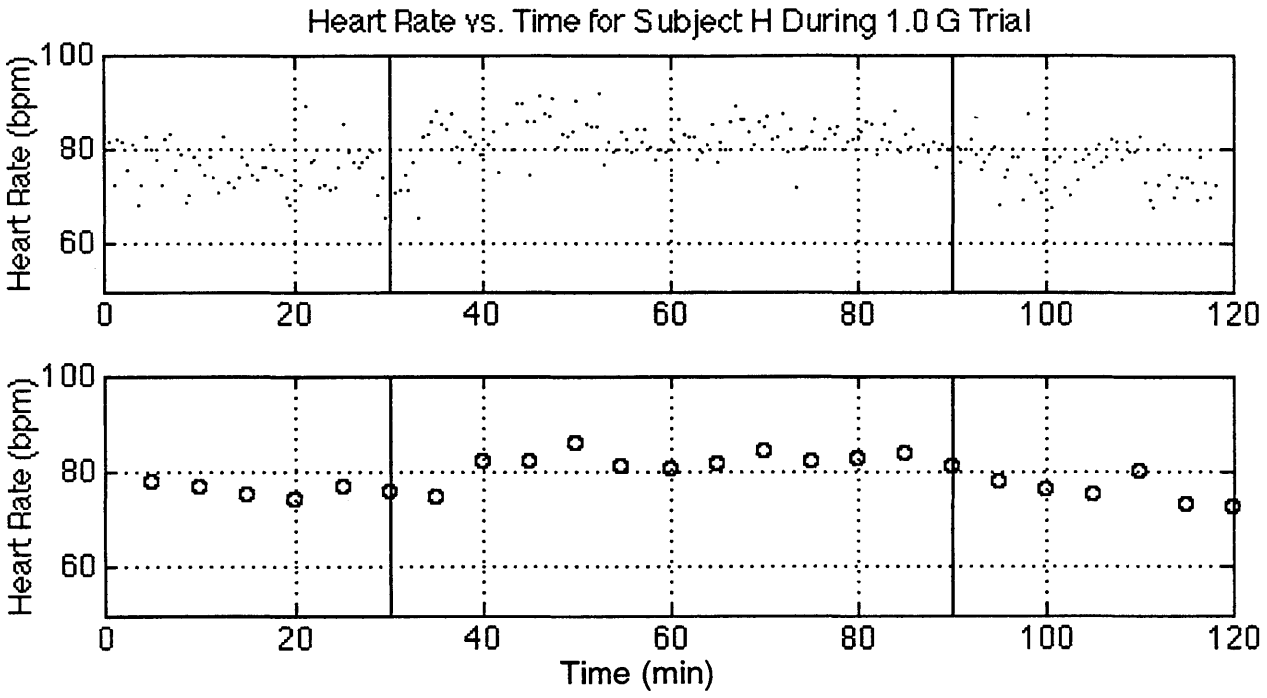

Heart Rate vs. Time for Subject G During 1.0 G Trial
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
Time (min)

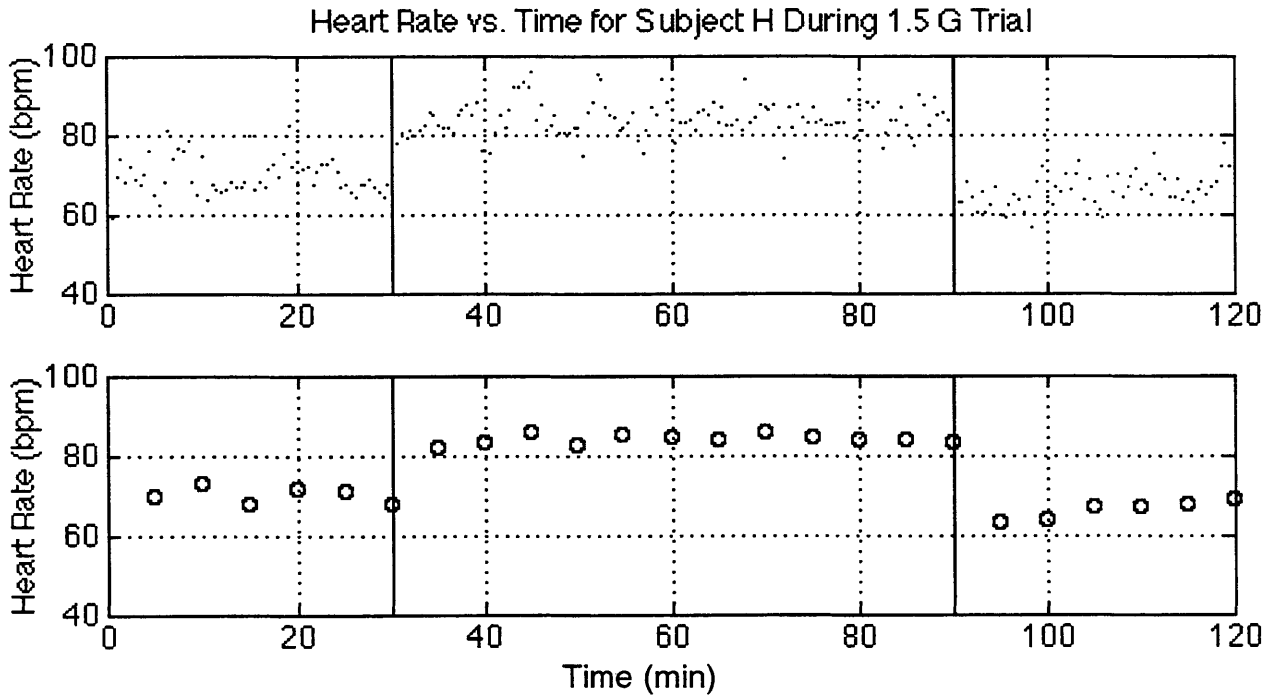

Heart Rate vs. Time for Subject G During 1.5 G Trial
Heart Rate (bpm)
120
100
80
60
0
20
40
60
80
100
120
Time (min)

Subject H

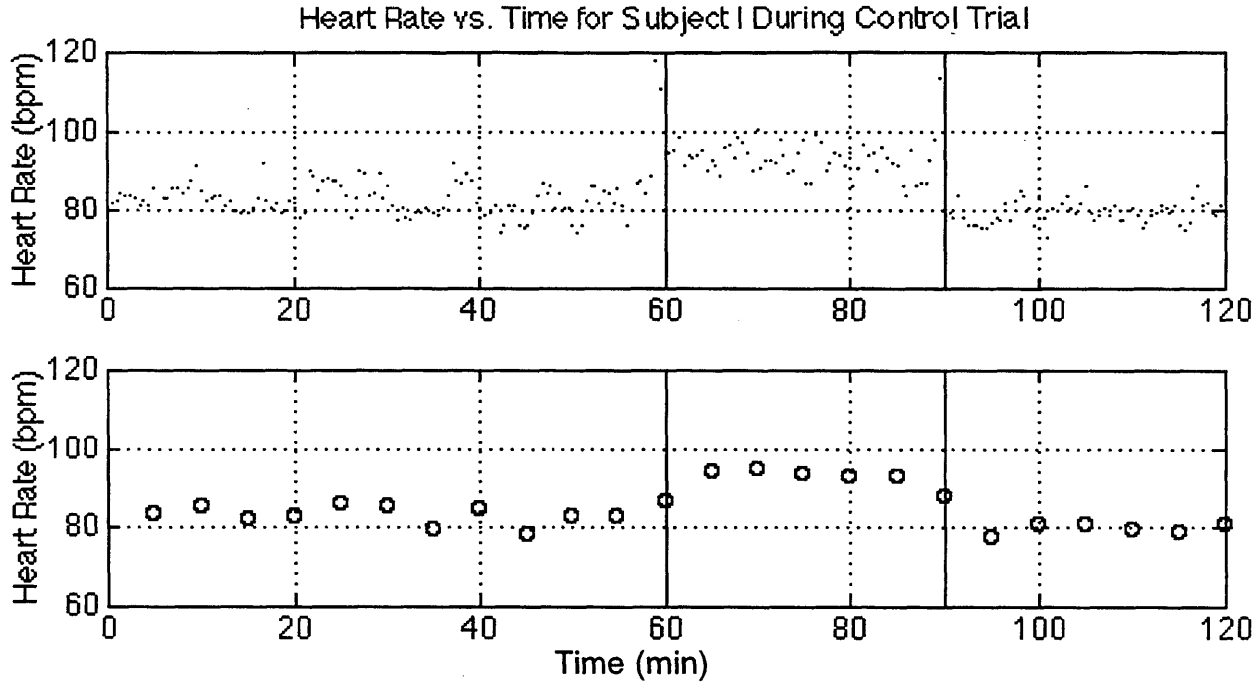

Heart Rate vs. Time for Subject H During Control Trial
Heart Rate (bpm)
150
100
50
0
20
40
60
80
100
120
Time (min)

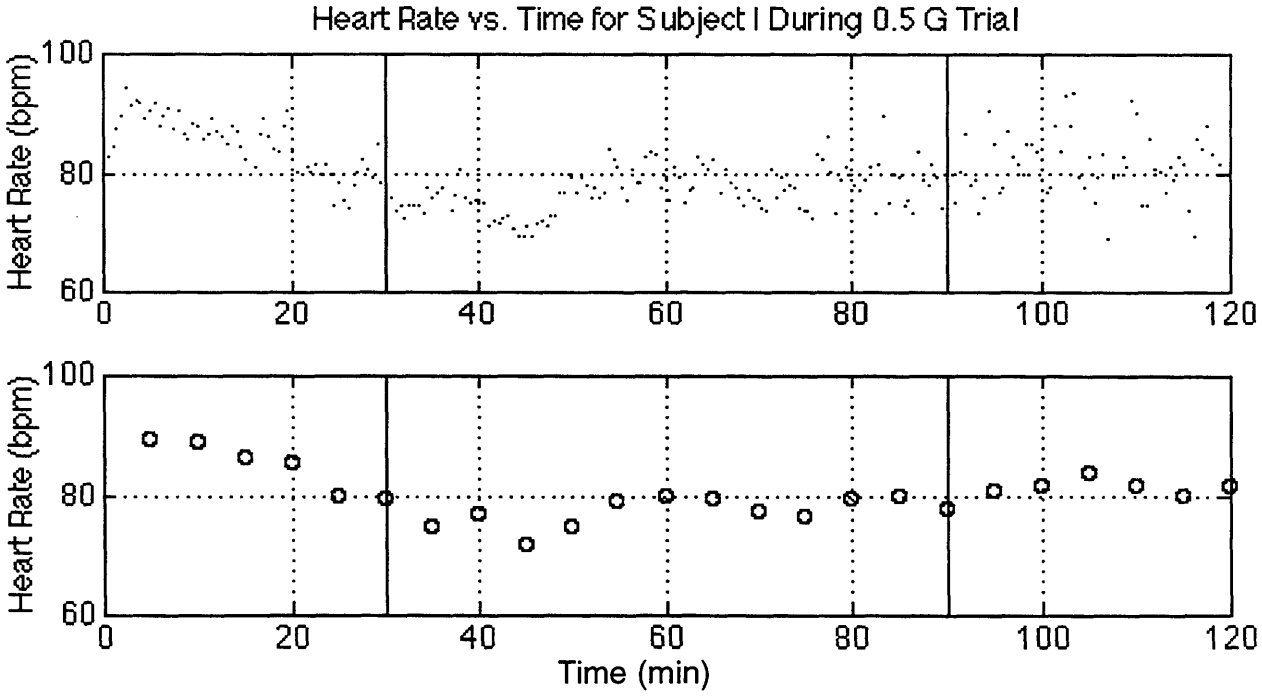

Heart Rate vs. Time for Subject H During 0.5 G Trial
Heart Rate (bpm)
90
80
70
60
0
20
40
60
80
100
120
Time (min)

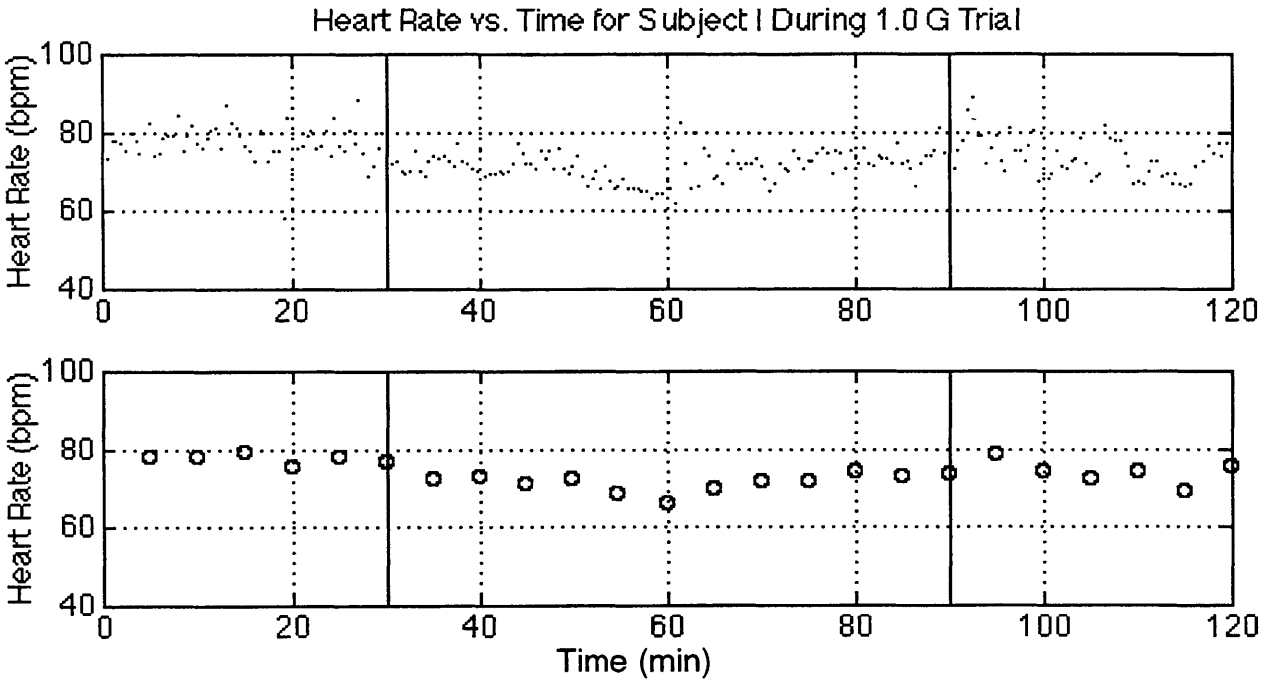

Heart Rate vs. Time for Subject H During 1.0 G Trial
Heart Rate (bpm)
100
80
60
0
20
40
60
80
100
120
Time (min)

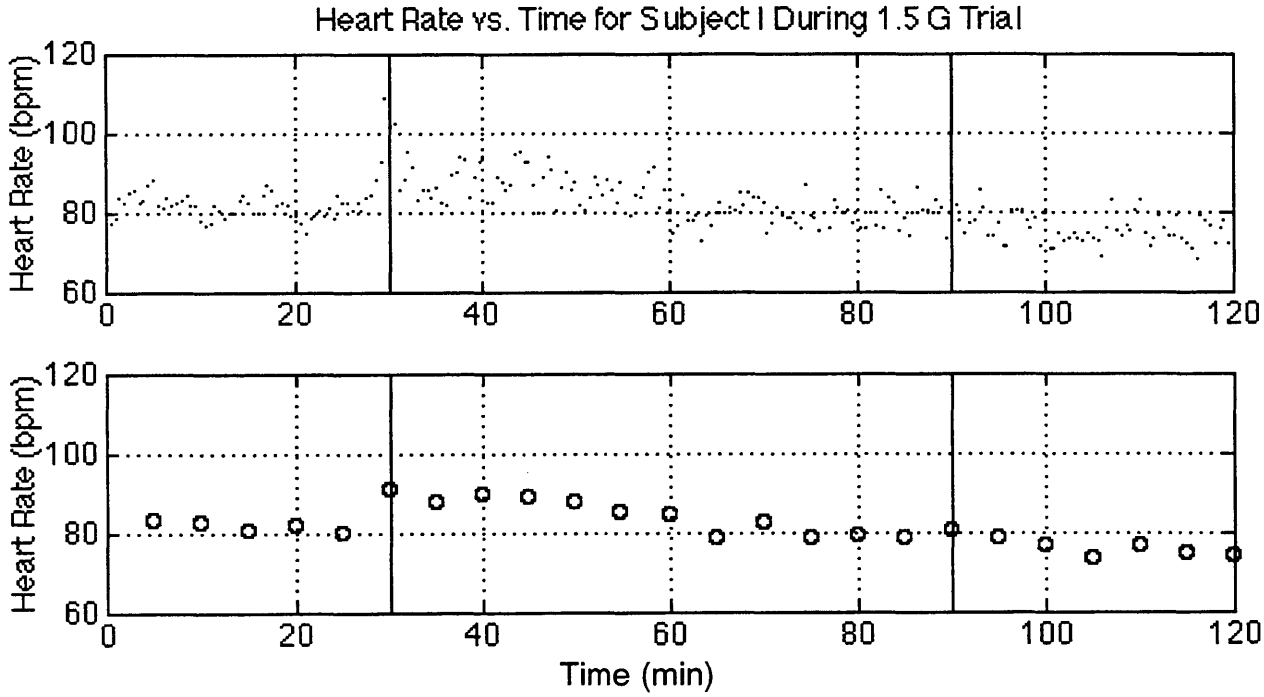

Heart Rate vs. Time for Subject H During 1.5 G Trial
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
Time (min)

Subject I

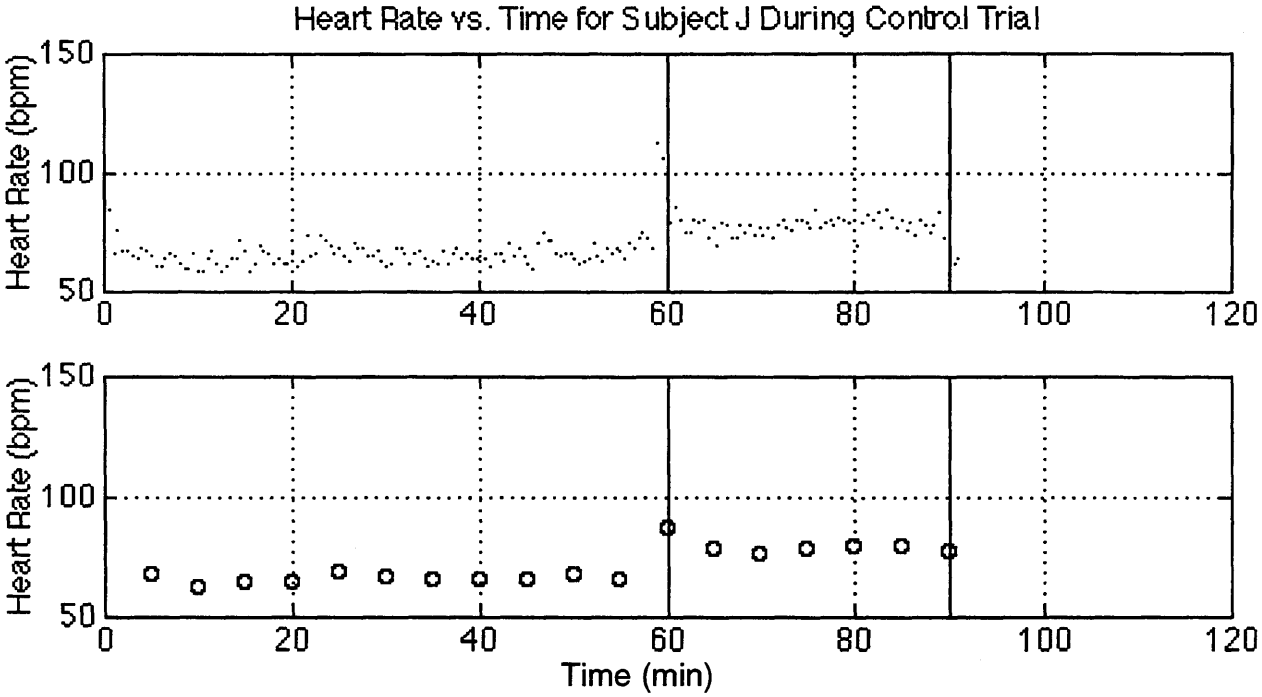

Heart Rate vs. Time for Subject I During Control Trial
Heart Rate (bpm)
120
100
80
60
0
20
40
60
80
100
120
Time (min)

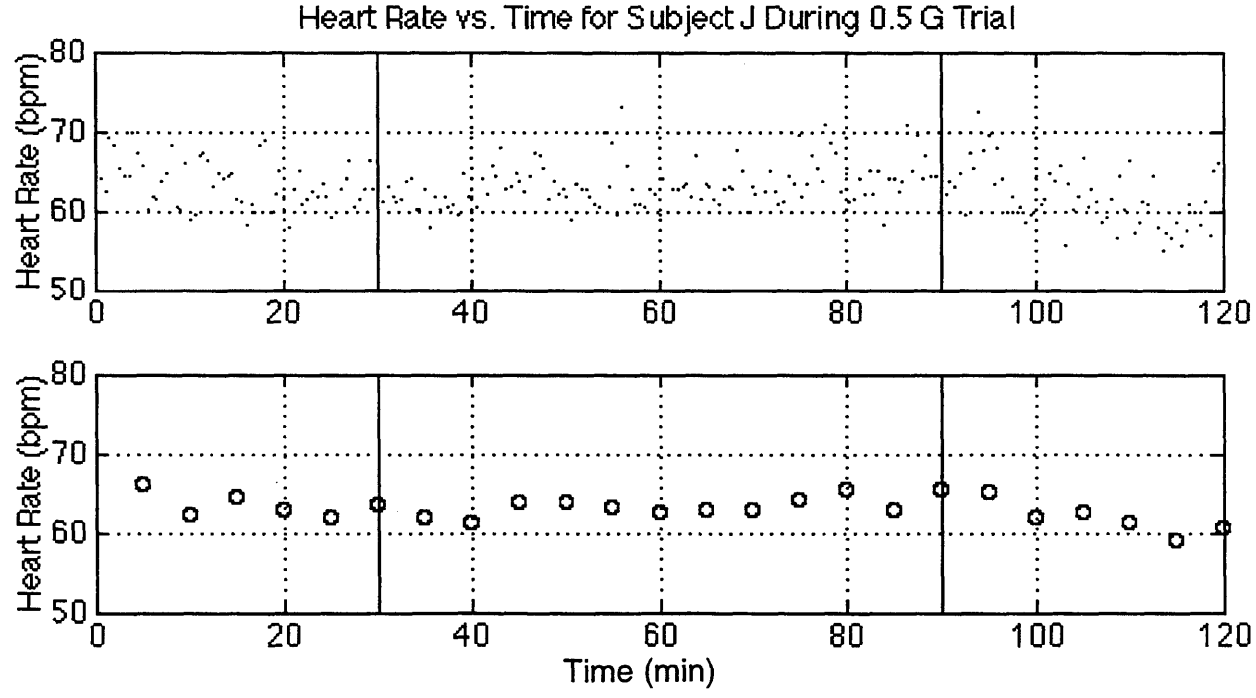

Heart Rate vs. Time for Subject I During 0.5 G Trial
Heart Rate (bpm)
100
80
60
0
20
40
60
80
100
120
Time (min)

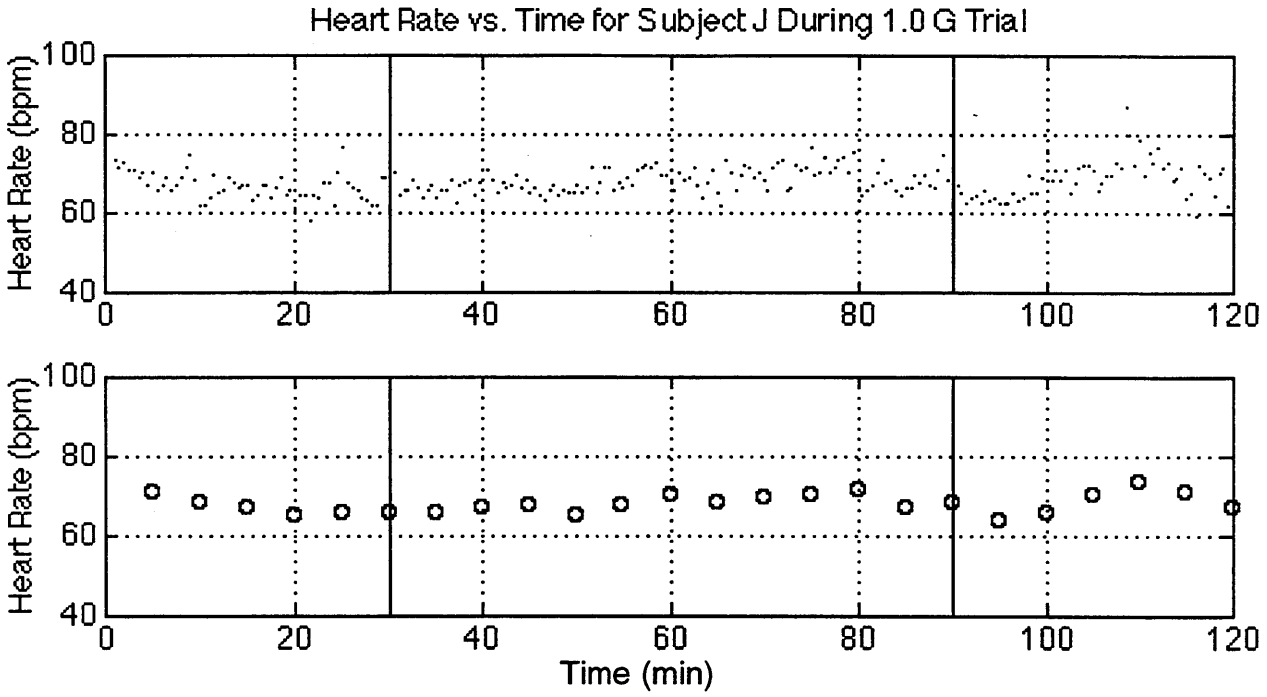

Heart Rate vs. Time for Subject I During 1.0 G Trial
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
Time (min)

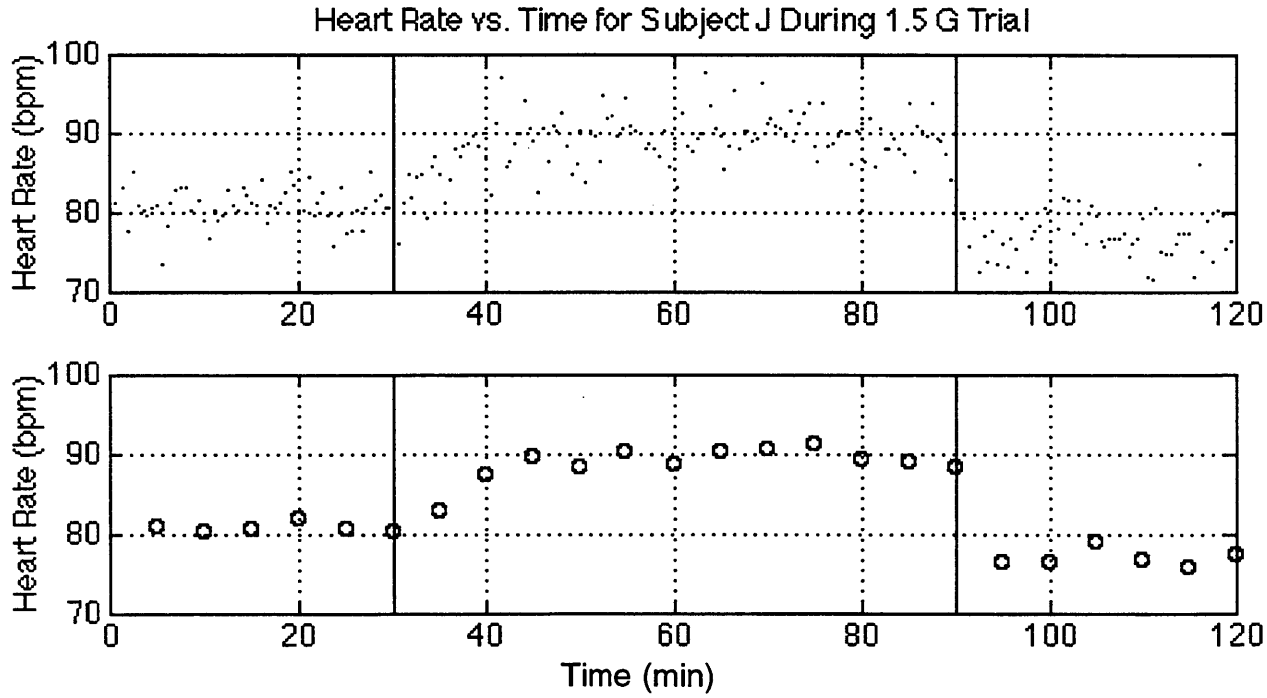

Heart Rate vs. Time for Subject I During 1.5 G Trial
Heart Rate (bpm)
120
100
80
60
0
20
40
60
80
100
120
Heart Rate (bpm)
120
100
80
60
0
20
40
60
80
100
120
Time (min)

Subject J


Heart Rate vs. Time for Subject J During Control Trial
Heart Rate (bpm)
150
100
50
0
20
40
60
80
100
120
Time (min)


Heart Rate vs. Time for Subject J During 0.5 G Trial
Heart Rate (bpm)
80
70
60
50
0
20
40
60
80
100
120
Time (min)


Heart Rate vs. Time for Subject J During 1.0 G Trial
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
Heart Rate (bpm)
100
80
60
40
0
20
40
60
80
100
120
Time (min)

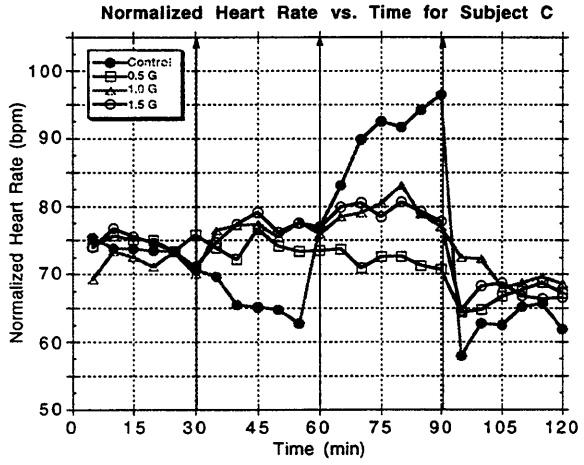

Heart Rate vs. Time for Subject J During 1.5 G Trial
Heart Rate (bpm)
100
90
80
70
0
20
40
60
80
100
120
Heart Rate (bpm)
100
90
80
70
0
20
40
60
80
100
120
Time (min)

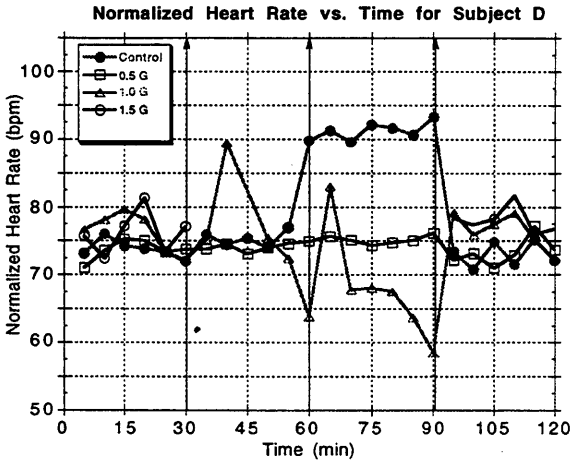
Measured and Normalized Heart Rate Data

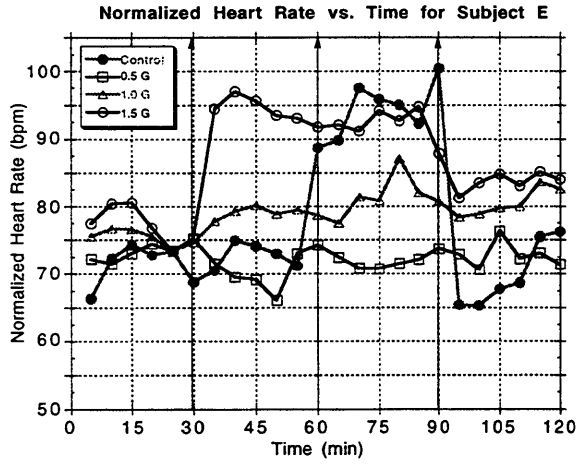
Actual HR									Normalized HR at t = 25 min. by Differences								Statistics Based on Normalized HR			
Control HR (bpm)																				
Time (min)/Subject	C	D	E	F	G	H	I	J	C	D	E	F	G	H	I	J	Average	Std. Dev.	Number	Std. Error
5	79.56	81.40	61.13	85.17	87.47	71.60	83.32	66.81	75.41	73.10	66.33	77.68	75.54	72.98	70.60	72.09	72.97	3.489	8	1.233
10	78.02	84.33	67.05	82.70	85.95	72.66	85.46	62.27	73.87	76.03	72.25	75.21	74.02	74.04	72.75	67.55	73.21	2.586	8	0.914
15	77.89	82.49	69.10	82.02	84.28	72.81	81.79	63.93	73.74	74.19	74.30	74.54	72.35	74.19	69.07	69.21	72.70	2.296	8	0.812
20	77.63	82.09	67.56	81.53	84.41	71.08	82.45	64.00	73.48	73.79	72.76	74.05	72.48	72.45	69.74	69.28	72.25	1.796	8	0.635
25	77.52	81.67	68.16	80.85	85.30	71.99	84.08	68.08	73.37	73.37	73.37	73.37	73.37	73.37	73.37	73.37	73.37	0.000	8	0.000
30	74.83	80.25	63.61	79.76	81.10	67.78	85.33	65.78	70.68	71.95	68.82	72.28	69.17	69.15	72.62	71.06	70.72	1.519	8	0.537
35	73.75	84.24	65.27	79.12	79.21	67.64	79.36	64.68	69.60	75.94	70.47	71.64	67.28	69.01	66.64	69.96	70.07	2.879	8	1.018
40	69.67	82.69	69.73	78.05	77.18	72.52	84.68	64.82	65.52	74.39	74.93	70.57	65.25	73.89	71.97	70.10	70.83	3.783	8	1.337
45	69.31	83.66	68.88	75.99	75.97	68.44	78.23	65.09	65.16	75.36	74.08	68.10	64.03	69.81	65.51	70.38	69.05	4.161	8	1.471
50	69.00	82.26	67.79	76.13	74.44	69.56	82.31	67.66	64.84	73.96	72.99	68.65	62.51	70.94	69.60	72.94	69.55	4.093	8	1.447
55	66.90	85.26	65.98	75.18	72.68	67.29	82.72	65.45	62.75	76.96	71.18	67.70	60.75	68.67	70.01	70.73	68.39	5.067	8	1.792
60	81.13	98.09	83.48	80.16	79.61	68.79	86.31	86.65	76.97	89.79	88.68	72.67	67.68	70.17	73.59	91.93	78.94	9.689	8	3.425
65	87.24	99.49	84.60	81.96	90.28	86.90	94.19	77.59	83.09	91.19	89.81	74.47	78.35	88.28	81.48	82.88	83.69	5.784	8	2.045
70	93.99	97.87	92.31	84.13	86.92	86.05	94.99	75.42	89.84	89.57	97.52	76.65	74.99	87.42	82.28	80.70	84.87	7.583	8	2.681
75	96.64	100.36	90.62	84.16	89.10	82.09	93.26	77.71	92.49	92.06	95.82	76.67	77.17	83.46	80.55	83.00	85.15	7.364	8	2.604
80	95.79	99.91	89.83	86.72	89.85	82.73	92.80	79.40	91.64	91.61	95.03	79.24	77.92	84.10	80.09	84.68	85.54	6.485	8	2.293
85	98.33	98.90	87.06	83.86	91.50	79.15	92.74	79.27	94.18	90.60	92.26	76.38	79.56	80.52	80.03	84.55	84.76	6.728	8	2.379
90	100.58	101.56	95.22	85.27	95.18	85.00	87.44	77.33	96.43	93.26	100.42	77.78	83.25	86.38	74.72	82.61	86.86	9.082	8	3.211
95	82.08	81.71	80.21	72.35	76.07	71.95	77.50		57.93	73.41	65.42	64.87	64.14	73.32	64.78		66.27	5.473	7	2.068
100	66.91	79.11	60.09	72.95	75.65	62.79	80.87		62.76	70.81	65.29	65.46	63.72	64.16	68.15		65.77	2.807	7	1.061
105	66.66	83.14	62.55	74.91	76.67	64.93	80.69		62.51	74.84	67.75	67.43	64.74	66.30	67.97		67.36	3.829	7	1.447
110	69.34	79.85	63.52	73.66	75.22	65.57	79.04		65.19	71.55	68.72	66.17	63.29	66.94	66.32		66.88	2.639	7	0.998
115	69.87	83.48	70.27	74.68	73.00	70.49	78.71		65.72	75.18	75.47	67.20	61.07	71.86	65.99		68.93	5.388	7	2.037
120	66.05	80.40	71.00	72.44	73.81	65.03	80.44		61.90	72.09	76.21	64.96	61.88	66.41	67.72		67.31	5.281	7	1.996
0.5 G HR (bpm)																				
Time (min)/Subject	C	D	E	F	G	H	I	J	C	D	E	F	G	H	I	J	Average	Std. Dev.	Number	Std. Error
5	72.00	69.92	64.75	71.47	82.90	74.79	89.37	66.22	74.14	71.00	72.20	72.17	77.50	72.30	83.06	77.74	75.01	4.115	8	1.455
10	73.57	72.48	64.01	73.92	82.13	73.20	88.83	62.31	75.71	73.55	71.47	74.63	76.73	70.72	82.52	73.82	74.89	3.672	8	1.298
15	73.00	74.22	65.57	73.90	81.49	73.86	86.12	64.45	75.14	75.30	73.03	74.60	76.09	71.37	79.81	75.97	75.16	2.460	8	0.870
20	72.87	73.98	66.97	72.92	80.57	76.05	85.37	62.94	75.01	75.05	74.42	73.63	75.17	73.56	79.06	74.46	75.05	1.736	8	0.614
25	71.22	72.29	65.91	72.66	78.76	75.86	79.68	61.85	73.37	73.37	73.37	73.37	73.37	73.37	73.37	73.37	73.37	0.000	8	0.000
30	73.70	72.68	67.76	76.14	80.89	70.46	79.44	63.54	75.84	73.75	75.21	76.85	75.49	67.97	73.13	75.06	74.16	2.759	8	0.975
35	71.71	72.66	64.08		78.04	74.87	74.69	62.03	73.85	73.73	71.53		72.64	72.38	68.38	73.55	72.29	1.921	7	0.726
40	70.02	73.45	62.09	73.85	75.88	74.74	76.71	61.28	72.16	74.52	69.55	74.56	70.48	72.25	70.40	72.79	72.09	1.869	8	0.661
45	74.51	71.97	61.70	69.65	80.09	76.15	71.58	63.94	76.65	73.04	69.16	70.35	74.69	73.66	65.27	75.46	72.29	3.781	8	1.337
50	72.01	72.87	58.65	67.80	84.32	73.62	74.43	63.85	74.15	73.95	66.11	68.51	78.92	71.13	68.12	75.37	72.03	4.316	8	1.526
55	71.20	73.50	65.56	68.84	85.64	71.46	78.77	63.24	73.35	74.58	73.02	69.55	80.24	68.97	72.46	74.76	73.37	3.494	8	1.235
60	71.30	73.88	66.80	70.34	86.34	72.41	79.80	62.69	73.44	74.95	74.26	71.05	80.94	69.92	73.49	74.20	74.03	3.277	8	1.158
65	71.56	74.58	64.97	74.72	86.77	72.58	79.36	63.01	73.70	75.66	72.43	75.43	81.37	70.09	73.05	74.53	74.53	3.294	8	1.164
70	68.77	74.06	63.33	77.61	84.48	69.18	77.21	63.05	70.91	75.13	70.78	78.32	79.08	66.69	70.90	74.56	73.30	4.226	8	1.494
75	70.43	73.27	63.31	74.35	86.97	72.81	76.51	64.24	72.57	74.34	70.76	75.06	81.58	70.33	70.20	75.75	73.82	3.816	8	1.349
80	70.48	73.65	64.06	75.10	85.32	75.91	79.37	65.51	72.62	74.73	71.51	75.81	79.92	73.42	73.05	77.03	74.76	2.743	8	0.970
85	69.08	74.01	64.60	75.53	81.89	74.11	79.68	62.80	71.23	75.08	72.06	76.23	76.49	71.62	73.37	74.32	73.80	2.059	8	0.728
90	68.54	75.08	66.24	76.02	83.23	72.08	77.54	65.58	70.68	76.16	73.70	76.72	77.83	69.60	71.22	77.10	74.13	3.260	8	1.153
95	62.31	71.08	65.42	76.78	81.09	73.82	80.30	65.28	64.45	72.16	72.87	77.48	75.69	71.33	74.19	76.79	73.12	4.135	8	1.462
100	62.64	72.06	63.12	72.19	78.79	70.73	81.64	62.03	64.79	73.14	70.57	72.90	73.39	68.24	75.33	73.55	71.49	3.457	8	1.222
105	64.64	69.89	68.90	75.84	76.68	72.37	83.86	62.51	66.78	70.97	76.36	76.55	71.28	69.88	77.55	74.02	72.92	3.799	8	1.343
110	65.64	71.83	64.75	74.61	80.04	68.63	81.44	61.24	67.79	72.90	72.21	75.31	74.64	66.15	75.13	72.76	72.11	3.404	8	1.203
115	66.60	76.10	65.58	72.92	79.06	69.42	79.85	59.02	68.74	77.18	73.04	73.63	73.66	66.93	73.54	70.54	72.16	3.250	8	1.149
120	65.08	72.60	63.92	68.45	77.55	68.37	81.60	60.74	67.22	73.68	71.38	69.15	72.15	65.88	75.29	72.26	70.88	3.215	8	1.137
1.0 G HR (bpm)																				
Time (min)/Subject	C	D	E	F	G	H	I	J	C	D	E	F	G	H	I	J	Average	Std. Dev.	Number	Std. Error
5	61.54	74.06	56.76	76.81	70.93	77.88	78.08	70.69	69.22	76.68	75.48	76.49	73.47	74.36	73.56	78.03	74.66	2.718	8	0.961
10	65.63	75.43	58.01	74.06	73.03	76.65	78.36	68.29	73.32	78.05	76.73	73.74	75.57	73.13	73.84	75.62	75.00	1.783	8	0.630
15	64.84	77.05	57.85	74.76	72.05	75.45	79.63	66.84	72.52	79.68	76.57	74.45	74.59	71.93	75.11	74.18	74.88	2.419	8	0.855
20	63.37	75.49	56.75	72.02	70.72	74.20	75.31	65.46	71.06	78.12	75.47	71.70	73.26	70.68	70.79	72.79	72.98	2.622	8	0.927
25	65.68	70.74	54.65	73.68	70.83	76.89	77.89	66.03	73.37	73.37	73.37	73.37	73.37	73.37	73.37	73.37	73.37	0.000	8	0.000
30	62.26	69.56	55.87	74.27	67.89	75.95	76.66	66.13	69.95	72.19	74.58	73.96	70.43	72.43	72.14	73.47	72.39	1.618	8	0.572
35	68.76	72.57	59.09	73.74	70.71	74.83	72.19	65.82	76.44	75.20	77.81	73.42	73.25	71.31	67.67	73.16	73.53	3.140	8	1.110
40	69.46	86.79	60.48	76.25	70.59	82.05	73.16	67.03	77.15	89.41	79.19	75.93	73.13	78.53	68.64	74.37	77.05	6.025	8	2.130
45	69.69		61.41	77.48	68.06	82.37	71.21	67.45	77.38		80.12	77.17	70.60	78.85	66.69	74.79	75.09	4.828	7	1.825
50	67.81	72.82	60.11	76.19	60.08	86.19	72.35	65.45	75.49	75.44	78.83	75.87	62.62	82.67	67.83	72.78	73.94	6.271	8	2.217
55	70.00	69.77	60.72	74.28	58.35	81.34	68.34	68.06	77.68	72.40	79.44	73.96	60.89	77.82	63.82	75.40	72.68	6.801	8	2.405
60	68.25	61.16	59.94	72.06	59.48	80.56	65.72	70.28	75.94	63.78	78.65	71.74	62.02	77.04	61.21	77.61	71.00	7.487	8	2.647
65	70.73	80.37	58.75	74.14	68.68	81.80	69.49	68.08	78.42	83.00	77.47	73.82	71.22	78.28	64.97	75.41	75.32	5.452	8	1.927
70	71.33	65.07	62.68	73.83	73.70	84.62	71.56	69.36	79.02	67.70	81.40	73.51	76.24	81.10	67.04	76.70	75.34	5.563	8	1.967
75	72.75	65.43	62.08	72.47	74.70	82.52	71.37	70.64	80.44	68.06	80.79	72.15	77.24	79.00	66.86	77.97	75.31	5.540	8	1.959
80	75.39	64.89	68.34	74.21	74.93	82.88	74.09	71.62	83.08	67.52	87.06	73.89	77.47	79.36	69.57	78.96	77.11	6.571	8	2.323
85	71.12	61.05	63.21	72.89	74.27	83.65	73.19	67.24	78.81	63.68	81.93	72.57	76.81	80.13	68.67	74.58	74.65	6.160	8	2.178
90	69.29	55.87	61.99	72.53	74.43	81.07	73.27	68.57	76.98	58.50	80.71	72.22	76.97	77.55	68.75	75.91	73.45	7.047	8	2.491
95	64.78	76.62	59.60	71.65	70.52	78.16	78.81	64.12	72.47	79.25	78.32	71.33	73.06	74.64	74.29	71.46	74.35	2.988	8	1.056
100	64.52	73.30	60.14	74.52	70.18	76.32	73.95	65.94	72.21	75.92	78.86	74.20	72.72	72.80	69.43	73.28	73.68	2.783	8	0.984
105	60.29	74.88	60.98	76.39	66.92	75.21	71.97	70.13	67.98	77.51	79.69	76.08	69.47	71.69	67.45	77.47	73.42	4.831	8	1.708
110	61.06	76.50	61.25	74.17	67.22	80.21	73.90	73.84	68.75	79.12	79.97	73.86	69.76	76.69	69.39	81.17	74.84	5.097	8	1.802
115	61.89	72.58	64.90	72.53	67.90	73.08	69.26	70.87	69.58	75.21	83.61	72.22	70.44	69.56	64.74	78.21	72.95	5.899	8	2.085
120	60.95		63.82	69.86	68.28	72.84	75.18	67.34	68.63		82.53	69.54	70.83	69.32	70.67	74.68	72.31	4.919	7	1.859
1.5 G HR (bpm)																				
Time (min)/Subject	C	D	E	F	G	H	I	J	C	D	E	F	G	H	I	J	Average	Std. Dev.	Number	Std. Error
5	73.82	72.74	79.65	66.71	78.56	69.42	83.48	80.87	73.94	75.70	77.46	72.05	76.97	71.90	77.14	73.57	74.84	2.278	8	0.805
10	76.71	69.39	82.56		78.55	72.85	82.30	80.36	76.82	72.35	80.36		76.97	75.33	75.97	73.06	75.84	2.675	7	1.011
15	75.51	74.23	82.69	70.57	76.23	67.89	80.47	80.63	75.62	77.19	80.50	75.90	74.65	70.37	74.14	73.33	75.21	2.950	8	1.043
20	74.54	78.36	78.93	69.22	76.16	71.51	82.07	81.97	74.65	81.32	76.74	74.55	74.58	73.99	75.74	74.67	75.78	2.397	8	0.847
25	73.25	70.41	75.56	68.04	74.95	70.89	79.70	80.67	73.37	73.37	73.37	73.37	73.37	73.37	73.37	73.37	73.37	0.000	8	0.000
30	70.97	74.16	77.43	69.65	74.33	67.99	90.71	80.25	71.09	77.11	75.24	74.98	72.75	70.47	84.37	72.95	74.87	4.431	8	1.566
35	74.57		96.61	73.37	89.29	81.77	87.82	83.06	74.68		94.42	78.70	87.70	84.25	81.49	75.76	82.43	7.002	7	2.647
40	77.22		99.18	71.12	84.85	82.94	89.44	87.34	77.34		96.99	76.45	83.27	85.41	83.10	80.04	83.23	6.891	7	2.605
45	79.02		97.85	70.10	82.42	85.78	89.32	89.56	79.13		95.66	75.43	80.83	88.26	82.98	82.26	83.51	6.628	7	2.505
50	76.05		95.68	74.08	84.11	82.67	87.70	88.40	76.16		93.48	79.41	82.53	85.14	81.36	81.10	82.74	5.479	7	2.071
55	77.41		95.29	70.14	84.60	85.07	85.38	90.42	77.53		93.09	75.47	83.02	87.55	79.05	83.12	82.69	6.113	7	2.311
60	76.79		93.96	69.08	85.31	84.67	84.47	88.83	76.90		91.77	74.41	83.72	87.15	78.13	81.53	81.95	6.107	7	2.308
65	79.77		94.30	69.61	84.98	83.97	78.47	90.35	79.89		92.11	74.94	83.40	86.45	72.14	83.05	81.71	6.783	7	2.564
70	80.39		93.37	81.02	87.42	85.64	82.81	90.49	80.50		91.18	86.35	85.84	88.11	76.48	83.19	84.52	4.917	7	1.858
75	78.30		96.40	76.89	84.89	84.37	78.71	91.16	78.41		94.21	82.22	83.31	86.84	72.38	83.86	83.04	6.778	7	2.562
80	80.52		94.84	82.26	88.63	83.75	79.52	89.51	80.63		92.65	87.39	87.05	86.23	73.19	82.21	84.22	6.232	7	2.356
85	79.08		96.93	78.61	91.73	84.09	78.42	88.94	79.19		94.74	83.95	90.14	86.57	72.08	81.64	84.04	7.419	7	2.804
90	77.66		90.04	80.07	86.20	83.39	80.36	88.41	77.77		87.85	85.40	84.62	85.87	74.02	81.11	82.38	4.980	7	1.882
95	64.55	75.43	83.39	71.13	66.91	63.53	78.49	76.56	64.66	78.39	81.20	76.47	65.33	66.01	72.16	69.26	71.68	6.397	8	2.262
100	68.17	74.46	85.66	70.30	70.64	63.77	76.93	76.55	68.28	77.42	83.47	75.63	69.06	66.25	70.60	69.25	72.49	5.820	8	2.058
105	68.58	75.27	87.01	69.48	67.91	67.10	73.31	78.93	68.69	78.23	84.82	74.82	66.33	69.58	66.98	71.63	72.63	6.349	8	2.245
110	66.68	78.72	85.23	68.74	66.35	66.86	76.49	76.70	66.79	81.68	83.04	74.07	64.77	69.34	70.15	69.40	72.40	6.710	8	2.372
115	66.29	73.04	87.34	66.08	67.65	67.70	74.87	75.87	66.40	76.00	85.15	71.41	66.07	70.18	68.53	68.57	71.54	6.336	8	2.240
120	66.46	73.81	86.17	68.62	72.11	68.96	74.30	77.37	66.57	76.76	83.98	73.95	70.53	71.43	67.97	70.07	72.66	5.587	8	1.975

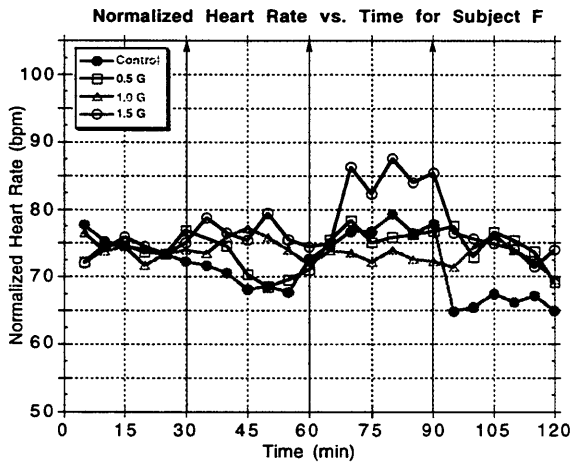
Plots of Normalized Heart Rate

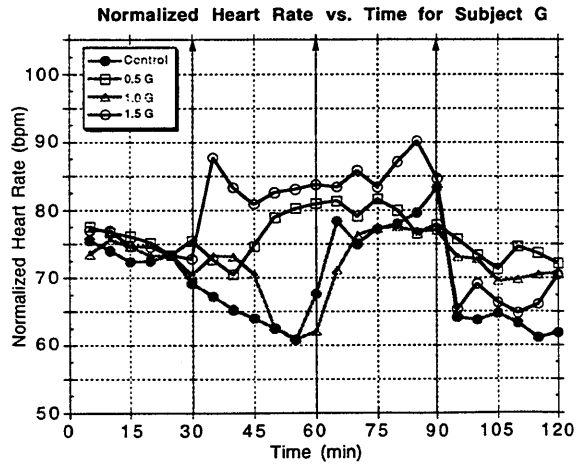
The vertical lines with arrows represent the initiation or cessation of a stimulus.

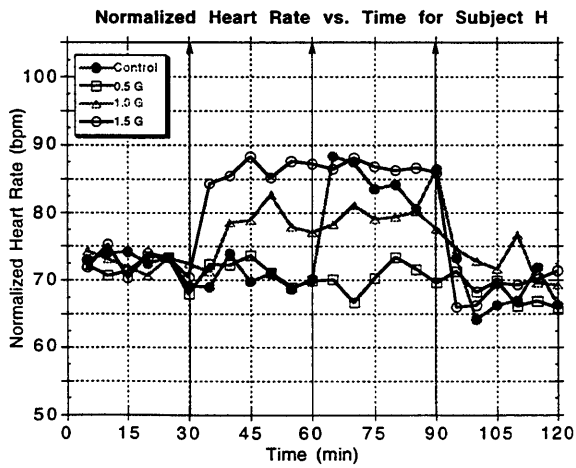


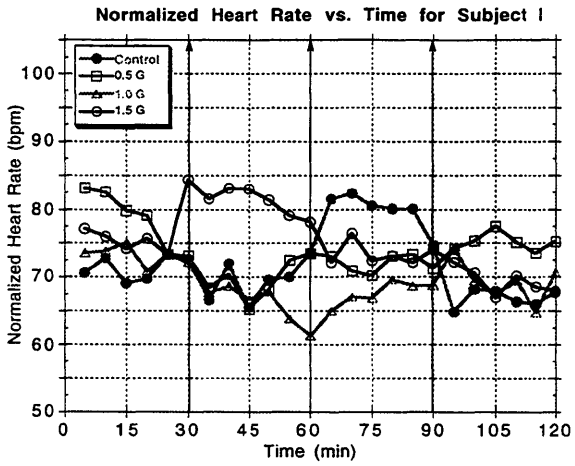


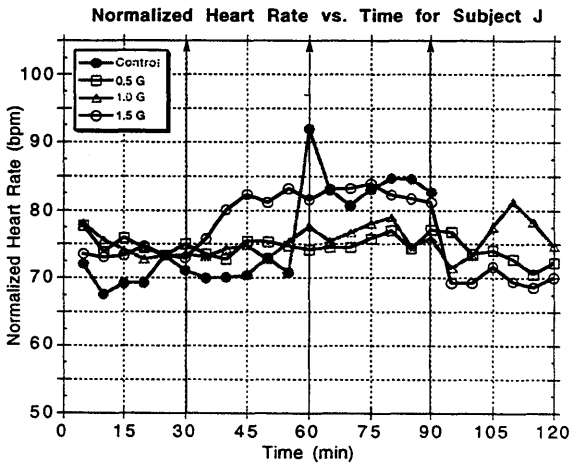









Normalized Heart Rate vs. Time for Subject I
Control
0.5 G
1.0 G
1.5 G
Normalized Heart Rate (bpm)
100
90
80
70
60
50
0
15
30
45
60
75
90
105
120
Time (min)


Normalized Heart Rate vs. Time for Subject J
Control
0.5 G
1.0 G
1.5 G
Normalized Heart Rate (bpm)
100
90
80
70
60
50
0
15
30
45
60
75
90
105
120
Time (min)

APPENDIX J

Suggested Artificial Gravity Research Program

The author feels that six categories of research are needed to answer the questions posed in Table 2: 1) computer modeling, 2) studies of simulated microgravity by bed rest or water immersion, 3) short-arm centrifuge studies, 4) long-arm centrifuge studies, 5) rotating room studies, and 6) experiments in space. Presumably, these levels would be carried somewhat out in order, but certain aspects, such as adaptation research, do not require completion of research at the previous level.

The importance of computer modeling was stressed previously. The BRC study only modeled the vestibular and cardiovascular systems. Available models for these systems on Earth and in spaceflight were utilized. Spaceflight models of the vestibular and cardiovascular systems are by no means satisfactory. As with all other aspects of AG physiological research, more knowledge about how the human body responds to microgravity is required. The next steps in the computer modeling area would be to incorporate the muscular, endocrine, and skeletal systems and run simulations of intermittent 1 G stimulation. Hopefully, this level of AG research will become advanced enough so that all studies will be modeled using this system before physical trials.

After a sufficient number of simulations are run with the computer model, trials of simulated microgravity by horizontal rest can begin. The primary purposes of this level of investigation are to ascertain what amount of 1 G stimulation the human body requires and to develop an optimum plan for 1 G exposure. The optimum plan would address issues of time of day, intermittence, and types of activities. Essentially, it would answer Questions 1-4 listed in Table 2. Two methods are available for simulating microgravity's effects on earth: horizontal bed rest and dry immersion suspension in water. Vernikos, et al. recommend 4-day -6° head-down bed rest studies as an economical model for ground-based AG research at this level (1992). However, for studies that attempt to answer Question 5, bed rest durations on the order of months may be necessary. Vernikos's experiments (see Appendix) supply an excellent base from which to undertake investigation. The next step is try different combinations of time periods and the actions of standing, walking, jumping, and upright bicycling.

Once the optimum stimulation plan for 1 G is defined, tests should commence to see if the total exposure time can be shortened by increasing the G level. The impetus for decreasing exposure time is reduce the amount of time astronauts must spend away from microgravity research in order to maintain their stamina. Tests with hyper-G would answer Question 6 and parts of Questions 7-9 in Table 2. The simplest method of increasing the G level on Earth is with a

SAC like the AGS. The USAFSAM also operates a 1.5 m rotating disk for research purposes of this nature. John Space Center hosts their own Artificial Gravity Simulator modeled after but larger than the MIT-AGS. NASA Ames Research Center in Moffett Field, CA operates an enclosed 1.8 m-radius centrifuge that is powered by pedaling from either two subjects or an unrelated person (Greenleaf, et al. 1995). Hopefully, research at this level will arrive at a new optimum stimulation plan, shorter in duration than the previous.

To see if removing the G gradient can improve even further on the optimum stimulation plan, long-arm centrifuge (LAC) studies should be performed after SAC studies. Question 10 in Table 2 will be answered then because only by removing the G gradient can its effects be seen. Approximately 24 LAC facilities are available around the world, 4 of which are located in the U.S. The U.S. centrifuges range in radius from 5.8 to 15.85 m (Burton, et al. 1991; Meeker 1985).

The last ground-based AG investigation level should be conducted in rotating rooms. This research is only necessary for a Mars mission if engineering and cost requirements dictate that the entire spacecraft must be spun to provide AG. However, in the eventuality that a rotating G environment for permanent habitability is provided in space, on the moon, or on Mars, these studies will be fundamental in determining the best ways to live in a rotating environment. Questions 10-14 in Table 2 are the primary physiological concerns for a rotating environment in which extended movement is allowed. A criticism of past rotating room studies, and of microgravity research on humans in general, is that it is unclear whether some effects are due to the rotation environment or confinement (Sandler 1995). Simple control studies of confinement of similar duration in a stationary room would nullify these concerns. While most of the rotating rooms utilized in the 1960's and 1970's have been dismantled, Brandeis University's Graybiel Laboratory and NASA Ames Research Center both currently operate rotating rooms.

The above outlined ground studies are will take many years even if the appropriate agencies recognize their need and immediately allocate funding. However, in a view also held by another researcher (Burton 1988), to attempt AG experiments in space before they are performed on the ground would be a waste of time, resources, and money. Once the technology is established in space, NASA could begin tests with the optimum stimulation plan without countless unnecessary trials. The purposes of the space-based research should only be to verify and modify ground results and help answer Questions 15-16 in Table 2. Space is also the only environment where partial gravity stimulation at the cellular level can be performed. Experiments in partial gravity for the sole purpose of physiological study could determine the answers to the second half of Questions 7-9.

Where should AG experiments be performed in space? Several design studies have confirmed that a SAC could fit in a payload bay Spacelab module (Meeker, et al. 1996; Pancratz, et al. 1994). However, the short duration of Shuttle missions and future access to a space station

make this idea experimentally unfavorable and economically unwise. Also, rotation of an entire space station is impractical because its primary purpose is to study the effects of microgravity. The current design for the international space station incorporates a 2.5 m-radius SAC capable of 0.01-2 G for animal experiments (Sandler 1995). It is not inconceivable that someday a module could be added to the station containing a SAC for human experiments. In addition, the National Commission on Space in 1986 recommended the construction of a Variable Gravity Research Facility (VGRF) in orbit for the purpose of establishing design parameters for long-duration space missions. This would be a free-flying mini-station for the sole aim of studying AG in space. Major design studies have already been performed for a VGRF (Smith, et al. 1990; *Newton* 1989).

Several other concerns regarding AG research need to be addressed. The physiological parameters that should be monitored at the 6 levels are numerous. The reader is referred to *Newton* (1989) for a detailed listing. It is important, though, that a broad spectrum of effects across all physiological systems be observed in each experiment. To not do so will lead to repetitions of costly trials. The study presented in this paper was a prelude to a bed rest study that will monitor more than the cardiovascular system. Another concern is how many and what kinds of subjects to use. For space experiments this question is answered easily since NASA and the Russian space program have the only control over who becomes an astronaut and who flies in space. For ground-based research, the answer is not so clear. For the experiments presented here, subjects were college age for the primary reason that they were the easiest accessible at an academic institution. However, most of the astronauts are twice college age. Additionally, it is strongly suggested that half of the subjects be male and half be female. Not only will this aid assessment of differences in stimulation response due to gender, but the current astronaut pool is moving toward the general population gender percentages. Also, not all subjects should have high previous exposure levels to stressful G environments, such as pilots. A more accurate reflection of the anticipated responses of the current astronaut pool will then result.

The research strategy presented does not include several parallel studies that should be conducted to fully understand AG. Habitability and performance requirements on rotating spacecraft are also critical to development of an AG design. Furthermore, it is not clear how they interrelate with the physiological responses to AG. Also, the importance of animal experiments in AG should not go unmentioned. They should be precursors to any experiments in space and as much ground-based research as possible. Interestingly, Cardús has suggested that research related to the physiological requirements of AG can help clinical medicine on Earth. NASA's Artificial Gravity Simulator was built partially to investigate how rotation can help patients of extended bed rest, fractured bones, osteoporosis, heterotopic calcification in paralysis, certain forms of pulmonary edema, and other diseases (1993a).

Finally, an educated prediction of the requirements for a Mars mission can be made based on current knowledge. Anticipating a round-trip duration of 2-3 years, a SAC may be able to provide adequate intermittent stimulation. The apparatus would have to be long enough (> 2 m in radius) to support movements such has jumping. The best stimulation plan may be to expose the astronauts to 0.38 G on the way out to Mars and to 1 G on the way back to Earth. Not only would emergency situations such as loss of orthostatic tolerance and bone fracture be prevented, but astronauts would then be pre-adapted to their next environment. The details, of course, will be provided by the conclusions of the recommended 6 levels of AG research.