EFFECTS OF SEATED POSTURE ON STATIC STRENGTH, 
LOWER-BODY ISOMETRIC MUSCLE CONTRACTIONS, AND 
MANUAL TRACKING PERFORMANCE 

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(ABSTRACT)

This research evaluates the effects of seatback angle and armrest angle on performance of the following variables: (1) static force generation capabilities on an isometric force-stick; (2) lower-body isometric muscle contractions used in anti-gravity straining maneuvers (AGSMs); and (3) tracking performance for a manual tracking task. The purpose of this research is to determine if certain body postures significantly affect force generation, isometric muscle contractions, and tracking error.

Subjects perform three different tasks over four experimental sessions. In the first session, subjects generate maximum force on a sidearm isometric force-stick at 18 seatback and armrest combinations (six seatback angles x three armrest angles) in two directions (roll left and roll right). In the next three sessions, subjects perform either a manual tracking task or a manual tracking task concurrent with lower-body isometric muscle contractions at each of the 18 seatback and armrest combinations.

The dependent measures used to evaluate performance are stick force, blood pressure, and tracking error. The results indicate the following: (1) static force generation ability is significantly affected by gender, seatback angle, and direction in which the force is applied; (2) lower-body isometric muscle contractions used to elevate blood pressure are
not significantly affected by seatback angle and armrest angle; and (3) tracking error is significantly affected by seatback angle.

Some results are consistent with previous research that found force capabilities are affected by the direction in which force is applied, and that body posture does not affect isometric muscle contractions used to increase blood pressure. However, other results indicate the need for further research to determine the relationship of body posture to isometric muscle contraction used in AGSMs and manual tracking.
Dedicated to Dr. Daniel J. Weintraub

teacher, colleague, friend
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1. INTRODUCTION

1.1 Rationale

Future high-performance fighter aircraft will sustain more G forces than pilots can tolerate. These futuristic aircraft will have "super-maneuvering" capabilities that will provide a significant advantage in air combat environments. Currently, there is active research in both the United States Air Force and the United States Navy addressing the issues related to super-maneuverability aircraft, particularly the design of a high acceleration cockpit (HAC) to protect and enhance tolerance and performance of the pilot.

Advances in technology of modern day high-performance fighter aircraft (HPA) have placed considerable physiological strain on the human operator. The speed and maneuverability of existing, and proposed, aircraft are such that the capabilities of the pilot can be exceeded. The maneuverability of HPA can exert sustained linear accelerations on the pilot that lead to decrements in flying performance. Forces in the +Gz (vertical) direction are of major concern in aerospace medicine. Sustained linear acceleration in HPA usually has a centrifugal force vector (+Gz inertial) from head to foot (see Figure 1.1) which is most often experienced when a pilot is pulling out of a dive or performing a tight inside turn or loop. Large +Gz forces can cause loss of peripheral vision and can lead to visual blackout. If the force is large and the exposure duration long, the pilot can lose consciousness (see Figure 1.2).

Several techniques have been developed to improve human tolerance to acceleration forces in the +Gz direction. These techniques fall into two major categories: (1) mechanical techniques for increasing tolerance, and (2) physiological methods for increasing tolerance. Examples of mechanical interventions are anti-gravity suit and valve, positive pressure breathing systems, and body positioning (seat design). Anti-gravity straining maneuvers,
Figure 1.1 Inertial G forces (reaction forces) under different acceleration directions. (Reproduced from Sharp and Ernsting, 1978)
Figure 1.2 G-time tolerance curve including energy reserve capacity, central nervous system responses, and baroceptor reflexes. Energy reserve is the body's oxygen reserve in the cells after blood flow is reduced to that region of cells. GLOC stands for gravity-induced loss of consciousness. Baroceptor reflexes are responses of the cardiovascular system to counteract the acceleration stress. (Reproduced from Gillingham and Fosdick, 1988)
physical conditioning, and training are examples of physiological methods currently employed to increase tolerance.

Seating posture is an important area for consideration in the design of a HAC. The effects of body position on tolerance of +Gz stress are quite evident when a hydrostatic column model is considered. With an acceleration-induced force vector in the +Gz direction, reclining the pilot backward (or leaning the pilot forward) from an upright position decreases the distance between the heart and the brain relative to the vector (see Figure 1.3). As distance decreases, less arterial pressure at the heart is required to maintain blood perfusion to the retina and the brain. Reclining or leaning forward afford the pilot greater +Gz tolerance.

Anti-gravity straining maneuvers (AGSMs) are physiological techniques used by pilots to increase their tolerance to +Gz forces. Straining maneuvers are the oldest known method for increasing +Gz tolerance, dating to World War II. AGSMs are highly protective (Coté, Tripp, Jennings, Karl, Goodyear, and Wiley, 1986), raising the +Gz tolerance by 2 to 4 +Gz above the 4 to 5 +Gz level attained by wearing an inflated G-suit (White and Morin, 1988). Pilots of fighter aircraft use two major straining types: the M-1 and the L-1 maneuvers (described in detail in section 2.4.1). In both, a major component is lower-body isometric muscle tensing. This muscle contraction (1) aids in limiting blood flow to the lower extremities, (2) increases intra-abdominal and intrathoracic pressure, and (3) increases arterial blood pressure by aiding in venous return to the heart. Increased blood pressure at heart level also raises blood pressure at head level and helps maintain perfusion of blood to the eyes and brain (Coté et al., 1986).

Different body postures may affect the performance of a straining maneuver. Williams, Lind, Wiley, Douglas, and Miller (1988) found that opening the hip angle posture from 70° to 105° had no effect on the performance of an L-1 maneuver to raise arterial blood pressure at +1 Gz (see Figure 1.4). This is contrary to an earlier report by
Figure 1.3 Hydrostatic column length (aortic valve to eye) changes as the body is reclined relative to the +Gz vector. As column length is decreased, lower blood pressures at the heart are needed to maintain blood perfusion to the eyes and the brain.
Figure 1.4 "Open" to "closed" body postures (hip angles ranging from 70° to 105°) used in the experiment by Williams et al. (1988). While the seatback angle was held constant, variations in hip angle were achieved by raising or lowering a foot platform. (Adapted from Williams et al., 1988)
Nelson (1987) who hypothesized that body posture may affect the performance of an AGSM. Nelson (1987) theorized that as angulations of body links are changed (particularly hip angle) it may become more difficult to perform an effective M-1 straining maneuver.

This research is designed to determine the effects of body positioning, in particular seatback and armrest angles, on performance of the lower-body isometric muscular tensing portion of AGSMs and on performance of a manual tracking task.

1.2 Experimental Approach and Objectives

The purpose of this study is to examine the effects that isometric muscle contractions have on increasing blood pressure as a function of hip angle. The methods employed in this research are adapted from techniques used by Glaser, Ezenna, and Popper (1990), Williams et al. (1988), and Williams, Martin, Moffatt, Douglas, and Lind (1990) to determine how body angulation and isometric muscle contractions affect variables that increase +Gz tolerance. Subjects perform the lower-body isometric muscle tensing part of an AGSM, not including the Valsalva maneuver. (The Valsalva maneuver is the process of making a forceful attempt at expiration while keeping the glottis fully closed or partially closed, thereby raising intra-thoracic pressure.)

Increases in blood pressure are measured to determine the effectiveness of the isometric contractions in raising tolerance to +Gz forces. Concurrent with the isometric muscular tensing, subjects also perform a simple manual tracking task that simulates motor functions involved in flying an airplane. Tracking error is recorded to determine the effect seated posture has on flying performance. A sidearm isometric force-stick is used as the control input for the tracking task. Subjects perform maximum voluntary force generation on the control stick to determine the control/response ratio for the experimental session.
2. BACKGROUND

2.1 Overview

The following sections review topics relevant to sustained acceleration forces experienced by pilots of high performance aircraft, and methods used for increasing tolerance to these forces. Human physiological responses to +Gz forces are explained as they affect the cardiovascular, pulmonary, and central nervous systems. Methods for improving +Gz tolerance, specifically body positioning (seat design) and anti-gravity straining maneuvers, are discussed.

2.2 Physiological Response to +Gz Stress

2.2.1 Cardiovascular System Response

The cardiovascular system is most important for determining tolerance to +Gz stress. Understanding cardiovascular system response to +Gz stress is key to developing techniques to counteract the effects of +Gz stress (Leverett and Whinnery, 1985).

Hydrostatic column theory is used for modeling the effects of +Gz forces on the circulatory system. Under the assumption that the circulatory system can be treated as a mechanical system that is nondistensible and without physiological reflexes, the model provides a method to estimate the vascular pressure within the system under the forces of gravity. The pressure in the system at a particular point is dependent upon the height of the hydrostatic column of fluid (blood) above that point and the +Gz forces acting on the fluid.

For a pilot in an upright seated position, at +1 Gz, the hydrostatic pressure of arterial blood at the heart is approximately 120 mm Hg, assuming a 30 cm heart-to-brain distance. From this, one can estimate a pressure of about 97 mm Hg at eye level. For each +1 Gz increase, blood pressure at the eyes is reduced by 22 mm Hg. Thus, under a +5.5 Gz load, the pressure at the eyes is reduced to 0 mm Hg. One possible solution to lower
the effect of the hydrostatic column is to reduce the distance between the heart and the brain. This is one of the techniques used to increase +Gz tolerance.

The hydrostatic column model is appropriate for rapid-onset, short duration +Gz stress. Rapid-onset rate accelerations are defined as +1 G/sec or greater. Gradual-onset rates allow physiological reflexive responses of the cardiovascular system, such as heart rate, cardiac output, and vasoconstriction, to counteract some of the effects of the hydrostatic column. Reflexive responses also occur during rapid-onset accelerations but adjustments to the cardiovascular system are not made until after 6 to 10 seconds have passed which may be too late to prevent some physiological consequences such as loss of consciousness. The 6 to 10 second delay is caused by the slow response of baroreceptors and reaction to nerve impulses to constrict blood vessels and shunt blood flow to non-essential organs. Figure 1.2 (see section 1.1) illustrates the lag time for cardiovascular reflexes to respond to increased +Gz stress and the consequences for both gradual-onset and rapid-onset rate accelerations.

One reflexive response of the cardiovascular system is an increase in heart rate. This can occur before the onset of +Gz stress, due to apprehension and anticipation by the pilot of the upcoming stress. Heart rate alone has little value in predicting +Gz tolerance; however it does play a role in determining actual tolerance levels because of its influence on cardiac output (Leverett and Whinnery, 1985).

Cardiac output is also influenced by +Gz forces. As +Gz stress is increased, cardiac contractile force, along with output from the heart (blood-volume per ventricular contraction) increases to maintain sufficient blood flow to the body. Increased cardiac output is a result of increased stroke volume and increased heart rate. Vasoconstriction increases venous blood return to the heart which affects the increase in stroke volume by increasing the volume of blood in the left ventricle at the time of ventricular contraction. Pumping action of skeletal muscles, shunting of blood flow to specific organs, and deep
respiratory inspirations also aid in increasing venous return (Leverett and Whinnery, 1985). High sustained acceleration in the +z direction (headward acceleration) causes blood to pool in the lower segments of the body, thereby decreasing venous return of blood to the heart. Preventing blood from pooling in the extremities is a method for increasing +Gz tolerance.

Coronary blood flow is of great importance to pilots under +z acceleration. Concern for coronary blood flow stems from the fact that arterial pressure in the aorta may drop so low, under high +Gz loads, that blood flow to the heart is impaired leading to myocardial infarction. This could determine an upper limit of +Gz tolerance for air crews (Leverett and Whinnery, 1985). Measurement techniques that monitor blood flow throughout the body need to be developed that are effective in a +Gz environment.

2.2.2 Pulmonary System Response

Tolerance to +Gz stress, mission performance by the pilots, and protection of the pilots are all dependent on proper functioning of the pulmonary system. Three major effects of +Gz stress on the lungs are: 1) altered ventilation and perfusion which may lead to hypoxemia, 2) airway closure, and 3) atelectasis (Leverett and Whinnery, 1985).

Respiration rate increases as +Gz load increases, causing regional changes in ventilation and perfusion. As +Gz stress increases, the forces acting on the lungs distend them, causing the pressure gradient that exists between the apex (top) and basilar (bottom) regions of the lungs to increase. This increase in the pressure gradient changes ventilation and perfusion of gases in the lungs by accentuating the differences in expansion between the apex and base of the lungs. Perfusion of the pulmonary vessels is increased in the dependent areas of the lungs--the basilar regions--and decreased in the apex region. This should not affect ventilation as long as lung capacity exceeds the functional residual capacity. A problem arises when the downward force (+Gz) is great and the upward shift
of abdominal contents due to an inflated G-suit closes off air passages in the basilar region, thereby decreasing ventilation.

Atelectasis occurs when these regions become closed off, trapping gases in the alveoli of the basilar regions of the lungs. If the trapped gases are high in oxygen concentration, rapid absorption occurs and the alveoli collapse. Because absorption is dependent on the slowest absorbed gas present in the mixture, normally nitrogen, consideration should be taken towards the air mixture pilots' breath when performing maneuvers that may induce high +Gz stress.

2.2.3 Central Nervous System Response

The major responses of the central nervous system to high +Gz stress concern vision and consciousness. These responses result from decreased retinal and cerebral blood flow caused by pressure drops in the hydrostatic column.

The retina must be well supplied by blood to maintain a full field of vision. As blood flow to the retina decreases, peripheral vision is lost. This is followed by loss of central vision and complete blackout if the +Gz force is large and the exposure duration long. These symptoms are found to occur when the arterial pressure in the eyes falls below the intraocular pressure, which is approximately 20 mm Hg. Since pressure in the retina is approximately 20 mm Hg greater than the intracerebral pressure, blood circulation to the retina fails before circulation to the brain (Fraser, 1973). Mean +Gz forces at which these symptoms occur are listed in Table 2.1.

Loss of consciousness and complete impairment of cerebral function can occur between +3 Gz and +8 Gz, depending on subjects, the rate-of-onset of the acceleration, and the level and duration of the +Gz load (Fraser, 1973). Gz-induced loss of consciousness is defined as "...a state of altered perception wherein (one's) awareness of reality is absent as a result of sudden, critical reduction of cerebral blood circulation caused
Table 2.1 Range of visual threshold and consciousness. Subjects were in a relaxed, unprotected, upright-seated position. (Data from Fraser, 1973)

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Mean Tolerance Thresholds (+Gz)</th>
<th>Standard Deviation (+Gz)</th>
<th>Range (+Gz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of peripheral vision</td>
<td>4.1</td>
<td>± 0.7</td>
<td>2.2 - 7.1</td>
</tr>
<tr>
<td>Blackout (loss of central vision)</td>
<td>4.7</td>
<td>± 0.8</td>
<td>2.7 - 7.8</td>
</tr>
<tr>
<td>Unconsciousness</td>
<td>5.4</td>
<td>± 0.9</td>
<td>3.0 - 8.4</td>
</tr>
</tbody>
</table>
by increased G force." (Burton, 1988, p.2) Positive Gz-induced loss of consciousness (GLOC) has been attributed to severe reduction (almost complete cessation) of blood flow to the brain (Werchan, 1991). Events associated with GLOC are as follows: (1) a rapid reduction in central nervous blood perfusion that induces unconsciousness, (2) symptoms following unconsciousness, such as tingling in the extremities, dream experiences, and myoclonic jerks, (3) a rapid reperfusion inducing a return to consciousness, and (4) upon return to consciousness, a period of confusion and disorientation lasting from 5 to 20 seconds (Burton, 1988; Burton and Whinnery, 1985; and Whinnery, 1989).

### 2.3 Seating Design and Geometry

#### 2.3.1 Body Position

Body position affects tolerance to +Gz stress as demonstrated by the hydrostatic column model. If an acceleration-induced force vector is in the +Gz direction, reclining the pilot (or leaning the pilot forward) from an upright position decreases the distance between the heart and the eyes relative to the vector. As distance decreases, less arterial pressure at the heart is required to maintain blood perfusion of the retina and the cerebral cortex. Therefore, reclining (or leaning) the pilot in the cockpit affords greater +Gz tolerance (Wood, 1986).

Burns (1975) and Burton, Lampietro, and Leverett (1975) examined the effects that different seatback angles have on relaxed tolerance to +Gz stress. Relaxed tolerance is determined on subjects who passively ride in the centrifuge, without performing any straining maneuver against increasing +Gz stress or inflating a worn g-suit. Relaxed +Gz tolerance was used because the researchers wanted to isolate the effect reclining the seat had on tolerance without confounding the data with other protection means such as the G-suit or straining maneuvers. The criterion used was subjects' loss of peripheral vision, *i.e.*,
they could no longer see lights present in the periphery or when there was a 50% decrease in the visibility of the center fixation light.

Wood, Code, and Baldes (1990) reviewed early research—circa 1942—on partial reclusion of the pilot. Significant benefits in +Gz tolerance occurred at seat angles greater than 45° (measured from vertical), but smaller angles provided no benefit significantly different from that afforded by a 13° seatback angle, which is standard in most HPA. Burns (1975) reported that for a 13° seatback angle the mean relaxed tolerance was 4.0 ± 0.2 +Gz, and for a 75° seatback angle the mean relaxed tolerance was 8.0 ± 0.4 +Gz. The hydrostatic column difference between the eyes and the aortic arch for a 75° supination was half the distance of that for a 13° supination.

Reclining seats have been used in fighter aircraft such as the General Dynamics F-16. Burton et al. (1975) examined seatback angles of 23°, 28°, and 40° which are equivalent to seatback angles of 13°, 18°, and 30° plus a 10° angle of attack. The study found no significant benefit in relaxed +Gz tolerance afforded by the 30° seat in the F-16, when compared to the 13° upright seat used in most aircraft.

Researchers have reported that pilots flying in the 30° seat actually sat upright and even crouched forward when experiencing high +Gz (Burton et al., 1975; and Wood et al., 1990). Sitting upright defeats the potential benefits afforded by the reclining seat. Burton et al. (1975) found no significant difference in relaxed +Gz tolerance when centrifuge subjects sat back in the 30° seat compared with the 13° upright seat. Wood et al. (1990, p. 857) found an "...associated tendency for decreased psychomotor tension, heart rate, and arterial pressure just prior to Gz exposure..." in reclining pilots. Their findings offer an explanation for the lack of protection provided by a 30° inclination and evidence for deleterious effects. They recommend that the pilot in a 30° reclined seat assume an upright and forward crouched position before onset and during sustained +Gz maneuver.
Headrest geometry in fighter aircraft also plays an important role in visibility and +Gz tolerance. A zero degree headrest angle places the headrest into the same geometric plane as the seatback. As headrest angle increases, the head is raised in relation to the acceleration vector, therefore increasing the distance between the heart and the eyes relative to the acceleration vector (Burns and Whinnery, 1984). Thus, large headrest angles can reduce benefits to the hydrostatic column offered by large seatback angles.

2.3.2 Seat Design

A high acceleration cockpit (HAC) often includes an articulating seat: as +Gz loads increase, the articulating seat reclines, thus repositioning the pilot to a supine (reclined) position. Pilot tolerance increases because the G forces are no longer pushing blood from the brain to the feet, but instead are now pushing the blood from the front of the chest to the back.

Von Beckh (1972) and Zenobi, Tung, and McConnell (1988) investigated the design and feasibility of incorporating articulating seats into combat aircraft. Von Beckh (1972) provides an historical review of +Gz protection leading up to protection by transverse body positioning--either prone or supine. Research gliders and airplanes in World War II equipped with prone pilot beds provided excellent +Gz tolerance--well above +9 Gz for sustained periods. Because of poor rearward visibility and lack of pilot acceptance, prone seating research declined.

Supine seating for pilots was also researched. Reclining the pilot offered greater rearward visibility, but did not offer the same protection from +Gz forces as forward tilting. This is due to the fact that the eyes lie ventral to the heart, therefore making the hydrostatic column greater when a pilot is reclined than when leaned forward at the same angle. Problems can arise with supinated seating arrangements when linear loads are placed on the pilot, e.g. arrested landings and catapult take-offs on aircraft carriers.
Therefore, bi-positional and multi-positional seat assemblies have been developed which allow pilots to remain in the traditional upright seated position during take-off and landing and recline the pilot under high +Gz loads. Pilot evaluations of multi-positional seats used in operational aircraft indicated vision problems. Because of these comments, and the lack of high g-load aircraft of the 1950's, research on supinating seat assemblies was abandoned for several years.

In the late 1960's and early 1970's, designs for high g-load aircraft were proposed and interest in increased G protection resurfaced, especially in protection relating to seat design. Based upon the experience made with supine position seating designs in the 1940's and 1950's, von Beckh (1972) felt that maintaining forward vision for the pilot was an important concern in the design of a multi-positional seat. Therefore, he developed the pelvis and legs elevating (PALE) seat design. The PALE seat maintains a pilot's forward visibility in both the upright and the supinated positions. This is accomplished by articulating the seat at pivot points in the shoulder, hip and headrest to place the body in a supine position without displacement of the head, or sliding of supported body surfaces. The design should provide adequate forward visibility to allow the pilot to land the aircraft should the seat fail in the supine position. Aircraft controls and displays have to be modified to incorporate the radical body positions of the pilot inside the cockpit; controls can be incorporated into armrests (von Beckh, 1972). Centrifuge tests confirmed the G protective capabilities of the PALE seat (von Beckh, 1981; Zenobi et al., 1988). A Sikorsky CH-53A helicopter was used as a test bed. The helicopter was flown reliably and comfortably from the supine position (von Beckh, 1981).

Zenobi et al. (1988) experimentally evaluated two types of Gz sensitive automatic reclining seats. One type was the PALE seat and the other was a two-position tilt-back seat. The PALE seat is electro-hydraulic actuated and uses automatic and continuous pilot repositioning, sensing +Gz forces and positioning the seat according to a pre-determined
seatback angle schedule for that particular +Gz force. The range of seatback angles is from 25° reclined to 65° reclined. The PALE seat begins to tilt the pilot at +2.5 Gz and reaches maximum recline at +6 Gz.

The tilt back seat is a passive system, moved by the +Gz induced force. The tilt back seat reclines the pilot to a 67° supine seatback angle by rotating the entire seat around a shaft under the seatpan. The designed rotation force is +3 Gz. An hydraulic cylinder returns the seat and pilot to the upright position (30° reclined seatback), when the +Gz force is less than approximately +3 Gz.

Testing on the Naval Air Development Center (NADC) centrifuge was performed to evaluate: (1) the adequacy of seat positioning response time to varying +Gz profiles, and (2) pilot acceptance of automatic repositioning under varying +Gz levels. The results demonstrated that the tilt back seat could respond quickly to fast +Gz onsets, therefore not allowing subjects' visual systems to be compromised, and subjects had no complaints regarding the motion of the tilt back seat.

The PALE seat was reported to exert minor discomfort to the subject when the seat was fully reclined. Because the subject's head did not move as the seat repositioned, the subject's chest was raised up close to his chin causing discomfort in the neck (Zenobi et al., 1988). The minimum time taken for the PALE seat to fully recline was long enough (2.25 seconds) to place the subject in jeopardy of possibly experiencing grayout. The problem of slow response time can be remedied by manipulating the hydraulics in the seat repositioning mechanism to increase response speed, decreasing time-to-recline.

The major drawback to the implementation of any radical seat design is the necessary modification to the aircraft cockpit. Prone seating was suggested as the best method for +Gz protection, but the necessary radical redesign of the cockpit makes it difficult to implement on current aircraft (Wood, 1986). Both supine and prone seating arrangements alter visibility of the instruments and reach to the controls. If these seating
systems are to be implemented they must be introduced early in the design phase of the aircraft to allow for space, visibility, and control considerations.

2.4 Anti-Gravity Straining Maneuver

2.4.1 Types of Maneuvers

Straining maneuvers are the oldest known method for increasing +Gz tolerance, raising a pilot’s tolerance by 2 to 4 +Gz. Three major straining maneuvers are used by pilots of fighter aircraft: called M-1, L-1, and Q-G maneuvers (Guo, Zhang, Jing, and Zhang, 1988).

The purpose of these techniques is to elevate blood pressure, particularly in the head, to maintain supply of blood to the eyes and brain (Coté et al., 1986). All current straining maneuvers raise intrathoracic pressure which in turn elevates blood pressure thereby maintaining perfusion of the eyes and the brain. The M-1 and L-1 maneuvers consist of first pulling the chin in and shoulders up, decreasing the distance between the eyes and heart before the onset of +Gz. At the same time, the pilot contracts abdominal muscles, as if straining at stool, to increase intra-abdominal pressure. The intra-abdominal pressure pushes up on the diaphragm preventing the heart and lungs from distending into the abdominal cavity when high +Gz forces are experienced, thereby maintaining a shorter hydrostatic column length under sustained +Gz. As all this is going on, the pilot produces a forced expiration (Valsalva maneuver) against either a fully closed (L-1 maneuver) or partially closed (M-1 maneuver) glottis (White and Morin, 1988). Both the M-1 and the L-1 maneuvers include lower-body muscle tensing that aids in raising arterial pressure, as well as increasing venous return to the heart and decreasing blood pooling in the extremities and abdomen.

Increases in tolerance afforded by an AGSM is highly dependent on proper execution of the maneuver. A poorly performed straining maneuver can reduce +Gz
tolerance. The Valsalva maneuver combined with lower-body muscle tensing, performed repetitively under high +Gz loads, greatly fatigues the pilot. When fatigue occurs, execution and effectiveness of the maneuver are influenced. This leads to a decrease in protection and subsequent decrease in +Gz tolerance of the pilot. Strength training is one solution for reducing the effects of fatigue.

Different body postures have various effects on the performance of a straining maneuver. Muscles have a length-contraction force relationship. The amount of force a muscle can exert is related to the length of the muscle at the time of contraction. Williams et al. (1988) found that opening the hip angle posture from 70° to 105° had no effect on performance of an L-1 maneuver to raise arterial blood pressure at +1 Gz. The results are contrary to earlier research by Nelson (1987) who reported that body posture may affect the performance of an AGSM. Nelson (1987) hypothesized that as angulations of body links are changed—particularly hip angle—it may become more difficult to perform an effective M-1 straining maneuver. Further research is necessary to find a definitive answer for the effects of body posture on the performance of AGSMs.

A newer straining maneuver called the Q-G maneuver, from its origins in Traditional Chinese Medicine and Qigong, appears to be an effective alternative to the M-1 and L-1 maneuvers. The Q-G maneuver produces the same effect of increasing arterial pressure and +Gz tolerance with less fatigue, thereby extending the time a pilot might be able to withstand sustained +Gz loads. The maneuver is described in detail as follows:

"The essentials of the Q-G maneuver are as follows: 1) with volition method (a practice in Qigong), the whole body is set in readiness and heightened arousal; 2) during onset of G load, the muscles of both legs are set in tension explosively, immediately followed by abdominal straining; 3) at the same time, breath is held transiently, followed by forceful, rapid,
shallow thoracic respiration, at a rate about 50-70 per min, while expanding and elevating the ribs and exerting slight limitation on expiration; 4) in ground practices, the duration of the maneuver was 60 seconds (s), and in actual flight, the duration varies with the need of acrobatics." (Guo et al., 1988, p. 968)

This method was conceived to avoid some of the undesirable features of the M-1 and L-1 maneuvers, such as fatigue and the need for a quick inspiration to maintain intrathoracic pressure and oxygenation of the blood. Guo et al. (1988) stated the Q-G method was effective in raising arterial blood pressure to over 200 mm Hg, and subjects were able to maintain this increased pressure for periods of time greater than 30 seconds at +1 Gz. Zhang, Guo, Jing, Wang, and Zhang (1991) reported average tolerances of +6.64 Gz (unprotected) using the Q-G maneuver for centrifuge test subjects, an improvement of +2.82 Gz over relaxed tolerance. Pilot's average +Gz tolerance when performing the L-1 or M-1 maneuver is raised approximately +2 Gz. Thus, it appears that the Q-G maneuver adds almost an additional +1 Gz in protection when compared to the L-1 or M-1 maneuver.

2.5 Summary

The background review provides insight into human physiological responses to sustained linear acceleration and methods used for increasing +Gz tolerance. The following topics are important in understanding and improving tolerance to +Gz forces experienced by pilots of high-performance aircraft:

1) Blood flow through the body, particularly to the brain, is important when a pilot is experiencing +Gz stress. The cardiovascular system essentially determines a pilot's response and tolerance to the +Gz stress. Improving cardiovascular
system response, especially the ability to raise blood pressure, can increase 
tolerance to +Gz stress.

2) As +Gz force increases, blood flow to the retina and brain is decreased. First 
vision and then consciousness are compromised as +Gz force is applied and 
maintained. Blood pressure must be raised to maintain blood perfusion of the 
eyes and brain, counteracting the +Gz force's effect on the central nervous 
system.

3) Body position affects +Gz tolerance by changing the direction in which the 
force vector acts upon the pilot. Prone or supine body positions increase 
tolerance to +Gz stress significantly by reducing the hydrostatic column of 
blood, thereby reducing the amount blood pressure must be increased to 
maintain blood perfusion of the eyes and brain. A pilot's body can be 
positioned relative to the force vector by different seat designs.

4) Anti-gravity straining maneuvers (AGSMs) are methods for increasing +Gz 
tolerance. They elevate blood pressure by increasing intrathoracic and intra-
abdominal pressure, increasing venous return of blood, and preventing blood 
from pooling in the extremities. However, different body postures introduced 
by new seat designs may affect performance of an AGSM.

The purpose of this research is to study the relationship between seated posture and 
(1) force generation used for manipulating aircraft controls, (2) performance of lower-body 
isometric muscle contractions used in anti-gravity straining maneuvers, and (3) 
performance of a manual tracking task that simulates flying. This research uses as 
dependent measures force generation, blood pressure, and tracking error to examine the 
following hypotheses:
H₁ Significant differences in static force generated by the control hand exist, resulting from changes in body posture (determined by seatback and armrest geometry).

H₂ Significant differences in static force generated by the control hand exist between straining and non-straining conditions at similar body postures therefore affecting tracking performance.

H₃ Significant differences exist in the increase of blood pressure by lower-body muscle tensing as body posture changes.

H₄ Blood pressure increases significantly when lower-body muscle contractions are performed as compared to no muscle contractions.

H₅ Significant differences in tracking performance exist as body posture changes.

H₆ Significant differences in tracking performance exist between straining and non-straining conditions in similar body postures.
3. EXPERIMENTAL METHOD

3.1 Overview

The experiment measures static force generation, blood pressure, and tracking performance of subjects at six seatback angles, three armrest angles, and two lower-body isometric straining conditions.

The experimental task is a simplified simulation of flying high-performance aircraft. The task consists of pursuit tracking, similar to that of targeting enemy aircraft in a gunsight, using a target forcing function composed from the sum of ten sine waves in the horizontal direction (simulating aircraft roll tracking). Tracking error is used to determine "flying" performance by the subject. Maximum force generated by the subject on a sidearm isometric force-stick is used to determine the control/response ratio for tracking. Blood pressure measurements are used to determine the effectiveness of lower-body isometric muscle contractions used in straining condition trials.

3.2 Subjects

Subjects in the experiment are 12 Virginia Tech students: six males and six females, chosen from the graduate and undergraduate student population. Only physically capable individuals participate who are representative of the active military flying population for high-performance aircraft (HPA). Each subject's medical history and answers to a medical questionnaire (see Appendix A) are reviewed to decide about participation in the study. The experiment requires four one-hour sessions per subject. Each subject is paid $5.00 per hour.
3.3 Experimental Apparatus

The experimental apparatus consists of an instrument to measure blood pressure; a closed-loop tracking display; force measurement equipment; and an articulated and adjustable seat (see Figure 3.1).

3.3.1 Blood Pressure Measurement

Blood pressure is measured using a Critikon Corporation Dinamap 1255 research monitor. The technique used for measuring blood pressure is based upon the arterial occlusion method. The blood-pressure-measurement instrument uses the oscillometric method in determining systolic, diastolic, and mean arterial pressure. Small amplitude oscillations in cuff pressure identify the mean arterial pressure. Each subject has an inflatable arterial occlusion cuff placed on the left arm just above the elbow at approximately heart level. The cuff is attached to the monitor which contains an electric pump to inflate the cuff a specified amount each time the pump is activated. The electric pump also has a constant leak mechanism that deflates the cuff at a predetermined rate, once maximum inflation has been reached.

First, the experimenter activates the measurement instrument and the electric pump inflates the cuff pressure above systolic pressure to occlude blood flow past the cuff. The monitor then activates the constant leak mechanism in the electric pump to slowly reduce pressure in the cuff at the appropriate rate. Electronics contained in the monitor measure pressure oscillations in the cuff and determine systolic, diastolic, and mean arterial pressure. Heart rate is also recorded by the monitor. The total cycle time for the blood pressure monitor is approximately 30 seconds. At the end of each blood pressure measurement, the experimenter records the subject's systolic pressure, diastolic pressure, mean arterial pressure, and heart rate for that particular experimental condition.
Figure 3.1 Block diagram of experimental setup. (Adapted from Rockwell, 1992)
3.3.2 Closed-loop, Tracking Display System

The tracking display uses an IBM PS/2 microcomputer, a VGA color display, and a sidearm isometric force-stick controller. The acquisition and storage of tracking error and force generation is facilitated by the IBM PS/2 microcomputer via a 16 channel analog to digital (A to D) converter connected to the various measurement systems. Computer software generates the pursuit tracking task. A computer generated target (a circle) moves in the x direction across the screen according to a random sinusoidal function. The addition of ten sine curves together makes the task of tracking appear to be random to the subject; therefore the subject should neither be able to predict target movement, nor to memorize the task (Davis, Ratino, Van Patten, Repperger, and Frazier, 1984). The subject tracks the target using a sidearm isometric force-stick by attempting to maintain a cross in the center of a circle. Force input from the stick controls the amount of deviation of the cross from the center of the circle. The greater the force exerted on the stick, the greater the distance the cross deviates from the center of the screen. The greater the distance between the cross and the circle, the more (or less) force input the subject must exert on the stick to bring the cross back into the center of the circle. All subjects track with the right hand.

3.3.3 Static Strength Measurement

A sidearm isometric force-stick is used for the tracking task. The stick is attached to a load cell that detects and measures force placed on the handle. The load cell measures applied force by changing the output voltage of the cell. The load cell is connected to the computer via the A to D board and input force is measured and recorded on the computer. Since the tracking task is solely in the x direction, only lateral forces (forces orthogonal to the sagittal plane of the subject) applied to the force-stick are recorded.
3.3.4 Data Acquisition System

An IBM PS/2 microcomputer equipped with one VGA display is a central piece of experimental apparatus. The tracking task and isometric force measuring equipment are controlled by the computer. Data collection for the tracking system and force generation measurement system is accomplished using a programmable 16 channel analog to digital (A to D) converter housed in the computer. The A to D converter is operated in bipolar mode with both equipment software and hardware gain factors adjusted to the full -2048 to +2048 integer range. This corresponds to voltage inputs of ± 0.5 volts. Because of the adjustability of the system, high resolution is achieved in data collection of the tracking error and force measurements.

3.3.5 Articulated and Adjustable Seat

An articulated and adjustable seat is used to place subjects in the desired body geometry required by each experimental trial (see Figure 3.2). Seatback, armrests, and footrest are adjustable. The seatback is adjusted to angles of 60° reclined, 45° reclined, 30° reclined, 15° reclined; 0° (perpendicular to floor plane); and 10° inclined--leaned forward (see Figure 3.3a). The armrests are adjusted to angles of 60°, 90° (orthogonal), and 120° as measured from the seatback plane (see Figure 3.3b). The armrest angles are measured between the top portion of the seatback and the top of the armrest. The armrests are also adjusted along the seatback plane to maintain a constant elbow point location (shoulders at 0° abduction in the sagittal plane and 0° flexion in the coronal frontal plane), and account for subject anthropometric variability. The footrest is adjusted to maintain a constant 90° knee flexion for each subject during the experiment. The seatpan angle is 10° from the floor plane, the standard seatpan angle of seats in current high performance aircraft. The sidearm isometric stick controller for the tracking task is attached to the right armrest. The stick is adjustable to accommodate varying forearm lengths of the subjects.
Figure 3.2 Schematic of the articulated and adjustable seating system.
Figure 3.3 Schematic of (a) seatback angles and (b) armrest angles used in the experiment.
3.4 Experimental Design

A mixed-factors design with one between-subjects variable (gender) and three within-subjects variables (seatback angle, armrest angle, straining condition) is used for the experiment. The within-subjects factors include six levels of seatback angle (measured from vertical: 60° reclined, 45° reclined, 30° reclined, 15° reclined, 0°, and 10° inclined), three levels of armrest angle (measured from the seatback plane: 60°, 90°, and 120°), and two levels of straining (either straining or no straining). The experimental design is shown in Figure 3.4.

The order of treatment conditions is balanced among subjects: the six levels of seatback angle are counterbalanced across experimental sessions using a randomly-generated balanced Latin Square. Each subject receives a different sequence of seatback conditions for each of the four sessions. The three levels of armrest angle are also counterbalanced using a randomly-generated balanced Latin Square. Each subject receives a different sequence of armrest conditions blocked by the last three experimental sessions (see Figure 3.5). The seatback angles are likely to have the most effect on lower-body isometric muscle contractions used in straining maneuvers; counterbalancing spreads out any effect due to muscle fatigue. Straining conditions are alternated for each trial to minimize the effects of fatigue (e.g., the first trial is a non-straining trial, followed by a straining trial, followed by a non-straining trial, etc.).

Mean arterial pressure during a trial is the dependent measure used to evaluate the effectiveness of the isometric muscle contractions during straining conditions at different seat angles. This measure provides information about the effects different seat angles may have on isometric muscle contraction used in a straining maneuver to increase +Gz tolerance.

The dependent measure used to evaluate tracking performance is the average absolute tracking error as a proportion of the maximum force generated (%MVC) by that
Figure 3.4 Experimental design.
Figure 3.5  Example of order of presentation for experimental trials. The top rectangle (containing numerals) represents the order of seatback angles presented to each subject for one experimental session. The columns are randomized for each subsequent session so each subject never receives the same order of seatback angles for an experimental session. The bottom rectangle (containing letters) represents the armrest angles presented by session for each subject.
particular subject (Berkowitz, 1990; Rockwell, 1992). This measure of tracking error accounts for performance in the x tracking direction. Setting the tracking force (control/response ratio) as a percentage of each subject's maximum voluntary contraction (%MVC) removes the effects of between-subject strength variability. A value of 65 percent of the subject's maximum force generated is used as the tracking force function for each subject's experimental session. Berkowitz (1990) and Rockwell (1992) found a value of 65 percent MVC to be an optimal control/response (C/R) ratio for subjects using a force-stick in similar type pursuit tracking tasks.

The absolute force generated in the x direction is the dependent measure used to determine the control/response ratio for the tracking task. This is measured prior to the experimental session for that day. During the first session of the experiment, subjects' maximum voluntary contraction forces (MVC force) are recorded for each of the 18 seating positions (six seatback angles x three armrest angles). These measures correspond to forces necessary to control current fly-by-wire aircraft such as the F-16, and can be used to determine how capable men and women would be flying such aircraft under certain adverse conditions (i.e., engine failure, control failure, spins, etc.).

3.5 Experimental Procedures

Subjects perform the following: (1) static, maximum force generation trials (roll left and roll right) during the first one-hour experimental session; and (2) isometric contractions of muscles in the legs and abdomen combined with tracking trials during the final three one-hour experimental sessions.

3.5.1 Force Generation Measurement

Force generation in both the roll left and the roll right direction is determined using standardized maximum strength testing procedures (Caldwell, Chaffin, Dukes-Dobos,
Kroemer, Laubach, Snook, and Wasserman, 1974). The procedure used in this study consists of a six-second trial where subjects increase to their maximum force capability within two seconds, hold it there for three seconds, and then release. One second is added to account for possible effects due to anticipating the end of the particular trial. The maximum force is averaged over the time interval from seconds two to five. For a strength trial to be accepted, it must remain within a ± 15 percent confidence interval about the mean values for the recorded time interval (Caldwell et al., 1974). Force generation measurements are taken at the 18 seat combinations (three armrest x six seatback combinations) to determine subject's force generation capabilities at each different body posture.

The subject is given a "ready, go" command. No encouragement or coaching is given by the experimenter. The experimenter monitors force output on the computer screen. The trial is accepted if there are no deviations from the criteria mentioned above. If the trial must be discarded, the subject rests for a three minute period and then repeats the same trial. Subjects perform one maximum left and right trial.

3.5.2 Isometric Contractions

The subject performs isometric contractions of the lower legs, upper legs, and abdomen during straining condition trials. These contractions are demonstrated to the subject by the experimenter and the subject is allowed to practice then.

3.5.3 Tracking Task

All experimental trials include a single axis, pursuit tracking task using the sidearm isometric stick. The task is similar to that used by Berkowitz (1990) and Rockwell (1992). The tracking task is to maintain a cross within a moving circle on the computer screen using the stick. The green circle (10 pixels in diameter) moves horizontally, left and right, across
the screen. The subject must try to maintain a yellow cross (10 pixels in each arm) in the center of the green circle.

The control/response (C/R) ratio for the tracking task is determined individually for each subject. This is accomplished by taking a percentage of each subject's maximum force generation (left and right respectively). Sixty-five percent of subject's MVC is used to determine the tracking force function. The C/R ratio is determined while the subject is seated in the 15° reclined position, with the armrest positioned at the angle assigned for that particular experimental session and the shoulder at 0° abduction in the sagittal plane and 0° flexion in the coronal frontal plane. Two MVC trials (one left and one right) are assessed, and 65 percent of the respective averages form the tracking force function for that particular subject. The control/response ratio remains constant for all treatment conditions for that particular armrest angle, experimental session, and individual subject. This removes any effects of control gain due to armrest angle, experimental session, and between-subject strength variability.

The software generates cues to prepare the subject for each tracking trial. As the target begins to move, the subject starts to track. Each tracking trial lasts 30 seconds. Data is recorded for the last 20 seconds of the trial. The first 10 seconds of tracking allow the subject practice time. The reason for choosing a 30 second duration for experimental trials is because that is the time necessary for the blood-pressure-measurement instrument to cycle and measure the dependent variables (systolic pressure, diastolic pressure, mean arterial pressure, and heart rate).

3.6 Experimental Protocol

Each subject participates in four experimental sessions that last approximately one hour each. Subject participation is determined by use of a medical questionnaire and medical history screening to ensure minimal risk. Each subject's medical history is
reviewed by Dr. Phillip Barkley, Chief Medical Officer for Health Services at Virginia Tech, prior to any participation by the subject in the experiment.

At the laboratory, each subject receives a set of written instructions (see Appendix B) and is asked to read them. Next, the subject receives an informed consent form (see Appendix C) and is asked to sign it. After reading the informed consent and subject instructions, initial blood pressure measurements are taken to determine if the subject falls within acceptable limits for participation in the study. Subjects who do not meet the medical questionnaire requirements and medical history screening, or have abnormal blood pressure measurements, are dismissed from the experiment. If blood pressure measurements are normal, the experimenter reviews the procedures for the subject and answers any questions that may arise.

The experimenter then leads the subject to the experimental apparatus and demonstrates the equipment. The experimenter also demonstrates and explains the isometric muscle contractions used in anti-gravity straining maneuvers (AGSMs), which are performed by the subject during straining-condition experimental trials. The subject is trained in the proper execution of the straining maneuver and given time to practice. The manual tracking task is also demonstrated to the subject. Upon completion of the demonstrations, the subject's questions are answered. When the subject is familiar with the experimental apparatus and procedures, he or she is seated in the articulated and adjustable seat and force generation measurements are taken at the 18 seat combinations (six seatback x three armrest) described in section 3.5.3. The first experimental session concludes upon completion of the force generation measurements.

Prior to the second, third, and fourth experimental sessions, the subject is allowed to practice the isometric muscle contractions used in AGSMs and the tracking task. When the subject is familiar with performing both tasks, the experimental session begins. Using the order of presentation diagram (see Figures 3.5 for an example), the seat is adjusted for
the first trial, and the experimental session begins. During each experimental trial, blood pressure and tracking error are recorded. After completion of a 30 second experimental trial, a three-minute rest period is provided and the procedure is repeated for the next treatment condition.

Twelve treatment combinations are applied during each of the final three experimental sessions. After the last treatment condition is complete--on the fourth session of the experiment--the subject is debriefed and paid. The entire experimental session lasts approximately four hours, one hour a day for four days.
4. DATA ANALYSIS AND RESULTS

4.1 Overview

An analysis of variance (ANOVA) is performed for each of the dependent measures related to force generation, lower-body isometric muscle contractions, and manual tracking (Abacus Concepts, 1991). ANOVAs are performed to determine the effects gender, seatback angle, armrest angle, and straining condition have on each of the dependent measures. ANOVA tables are presented for force generation data, mean arterial pressure data, systolic pressure data, diastolic pressure data, heart rate data, and tracking error data. The p-values reported are corrected using the Greenhouse-Geisser (G-G) correction factor. The G-G correction factor corrects for the maximum heterogeneity of covariance among repeated measures by negatively biasing the F-test, thereby making the test more conservative. Newman-Keuls post-hoc analyses are conducted on significant ANOVA results.

4.2 Force Generation

The term Force Generation refers to the hand force applied by subjects on the sidearm isometric force-stick. This force is applied and recorded only in the lateral direction, either orthogonal towards the sagittal plane or orthogonal away from the sagittal plane of the subject.

Force generation data is analyzed in a mixed-factor ANOVA against the independent variables: seatback, armrest, and roll direction. Gender is included as a between subjects variable. Three main effects are significant: gender, $F(1,10) = 8.086$, $p < 0.05$; seatback, $F(5,50) = 9.089$, $p < 0.001$; and roll direction, $F(1,10) = 55.787$, $p < 0.0005$. Only one interaction is significant, the two-way interaction of roll direction with gender, $F(1,10) = 11.398$, $p < 0.01$. A complete ANOVA table is presented in Appendix D, Table D.1.
The three main effects of gender, seatback, and roll direction are shown in Figures 4.1, 4.2, and 4.3 respectively. Males are able to apply greater force to the isometric force-stick than females as shown by the results collapsed across the other independent variables of seatback, armrest, and roll direction (see Figure 4.1). The ability to generate force on the force-stick increases as seatback angle changes from 65° reclined to 10° inclined (see Figure 4.2). A Newman-Keuls post-hoc test for the main effect of seatback shows that the 60° reclined, the 45° reclined, the 30° reclined, and the 15° reclined conditions are significantly different from the 0° and the 10° inclined seatback but not from each other, and the 0° seatback is significantly different from the 10° inclined seatback. Subjects are able to generate greater force in the direction orthogonal towards the sagittal plane than away from the sagittal plane (see Figure 4.3).

The two-way interaction of roll direction with gender is shown in Figure 4.4. In general, males are able to consistently generate greater force on the isometric force-stick than females, for both roll directions (left and right). The largest difference in force generation between males and females is demonstrated in the roll left direction. Finally, both males and females are capable of generating greater force in the roll left direction than in the roll right direction.
Figure 4.1 Main effect of Gender on the dependent variable Force Generation. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
Figure 4.2 Main effect of Seatback on the dependent variable Force Generation. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
**Figure 4.3** Main effect of Roll Direction on the dependent variable Force Generation. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
Figure 4.4 Two-way interaction of Roll Direction and Gender for the dependent variable Force Generation. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
4.3 Lower-body Isometric Muscle Contractions

The dependent measure used to evaluate the effectiveness of the isometric muscle contractions during straining conditions at different seat angles is the mean arterial pressure measured during an experimental trial.

4.3.1 Mean Arterial Pressure

Mean arterial pressure data is analyzed in a mixed-factor ANOVA against the independent variables: seatback, armrest, and straining. Gender is included as a between subjects variable. Three main effects are significant: seatback, $F(5,50) = 4.865, p < 0.005$; armrest, $F(2,20) = 10.709, p < 0.005$; and straining, $F(1,10) = 25.181, p < 0.001$. A complete ANOVA table is presented in Appendix D, Table D.2.

The three main effects of seatback, armrest, and straining are shown in Figures 4.5, 4.6, and 4.7 respectively. Mean arterial pressure increases as seatback angle changes from 65° reclined to 10° inclined (see Figure 4.5). A Newman-Keuls post-hoc test for the main effect of seatback shows the 60° reclined, the 45° reclined, the 30° reclined, and the 15° reclined seatback are significantly different from the 0° and the 10° inclined seatback but not from each other, and the 0° seatback is significantly different from the 10° inclined seatback.

Mean arterial pressure increases as armrest angle opens from 60° to 120°, as measured from top of seatback (see Figure 4.6). A Newman-Keuls post-hoc test for the main effect of armrest shows the 60° armrest and the 90° armrest are significantly different from the 120° armrest but not from each other.

Mean arterial pressure is greatest when straining (see Figure 4.7). This is true when collapsed across the other independent variables of gender, seatback, and armrest.
Figure 4.5 Main effect of Seatback on the dependent variable Mean Arterial Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
Figure 4.6 Main effect of Armrest on the dependent variable Mean Arterial Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
**Figure 4.7** Main effect of Straining on the dependent variable Mean Arterial Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
4.3.2 Systolic Pressure

Systolic pressure data is analyzed in a mixed-factor ANOVA against the independent variables: seatback, armrest, and straining. Gender is included as a between subjects variable. Three main effects are significant: seatback, $F(5,50) = 6.574$, $p < 0.005$; armrest, $F(2,20) = 11.3$, $p < 0.001$; and straining, $F(1,10) = 13.007$, $p < 0.005$. A complete ANOVA table is presented in Appendix D, Table D.3.

The three main effects of seatback, armrest, and straining are shown in Figures 4.8, 4.9, and 4.10 respectively. Systolic pressure increases as seatback angle changes from 65° reclined to 10° inclined (see Figure 4.8). A Newman-Keuls post-hoc test for the main effect of seatback shows the 60° reclined, the 45° reclined, the 30° reclined, and the 15° reclined seatback are significantly different from the 0° and the 10° inclined seatback but not from each other, and the 0° seatback is significantly different from the 10° inclined seatback.

Systolic pressure increases as armrest angle opens from 60° to 120°, as measured from top of seatback (see Figure 4.9). A Newman-Keuls post-hoc test for the main effect of armrest shows the 60° armrest and the 90° armrest are significantly different from the 120° armrest but not from each other.

Systolic pressure is greatest when straining (see Figure 4.10). This is true when collapsed across the other independent variables of gender, seatback, and armrest.
**Figure 4.8** Main effect of Seatback on the dependent variable Systolic Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
**Figure 4.9** Main effect of Armrest on the dependent variable Systolic Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
Figure 4.10 Main effect of Straining on the dependent variable Systolic Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
4.3.3 Diastolic Pressure

Diastolic pressure data is analyzed in a mixed-factor ANOVA against the independent variables: seatback, armrest, and straining. Gender is included as a between subjects variable. Three main effects are significant: seatback, $F(5,50) = 5.758, p < 0.005$; armrest, $F(2,20) = 6.233, p < 0.05$; and straining, $F(1,10) = 23.87, p < 0.001$. A complete ANOVA table is presented in Appendix D, Table D.4.

The three main effects of seatback, armrest, and straining are shown in Figures 4.11, 4.12, and 4.13 respectively. Diastolic pressure increases as seatback angle changes from 65° reclined to 10° inclined (see Figure 4.11). A Newman-Keuls post-hoc test for the main effect of seatback shows the 60° reclined, the 45° reclined, and the 30° reclined seatback are significantly different from the 15° reclined, the 0°, and the 10° inclined seatback but not from each other. The 15° reclined seatback is significantly different from the 0° and the 10° inclined seatback, and the 0° and 10° inclined seatback do not differ.

Diastolic pressure increases as armrest angle opens from 60° to 120°, as measured from top of seatback (see Figure 4.12). A Newman-Keuls post-hoc test for the main effect of armrest shows the 60° armrest and the 90° armrest are significantly different from the 120° armrest but not from each other.

Diastolic pressure is greatest when straining (see Figure 4.13). This is true when collapsed across the other independent variables of gender, seatback, and armrest.
Figure 4.11 Main effect of Seatback on the dependent variable Diastolic Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
Figure 4.12 Main effect of Armrest on the dependent variable Diastolic Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
Figure 4.13 Main effect of Straining on the dependent variable Diastolic Pressure. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
4.3.4 Heart Rate

Heart rate data is analyzed in a mixed-factor ANOVA against the independent variables: seatback, armrest, and straining. Gender is included as a between subjects variable. Two main effects are significant: seatback, $F(5,50) = 3.851, p < 0.05$; and straining, $F(1,10) = 36.199, p < 0.0005$. A complete ANOVA table is presented in Appendix D, Table D.5.

The two main effects of seatback and straining are shown in Figures 4.14 and 4.15 respectively. Heart rate increases as seatback angle changes from 65° reclined to 0° but may decrease again as seatback changes to 10° inclined (see Figure 4.14). A Newman-Keuls post-hoc test for the main effect of seatback shows the 60° reclined and the 45° reclined seatback are significantly different from the 30° reclined, the 15° reclined, the 0°, and the 10° inclined seatback but not from each other. The 30° reclined, the 15° reclined, the 0°, and the 10° inclined seatback do not differ.

Heart rate is greatest when straining (see Figure 4.15). This is true when collapsed across the other independent variables of gender, seatback, and armrest.
**Figure 4.14** Main effect of Seatback on the dependent variable Heart Rate. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
Figure 4.15 Main effect of Straining on the dependent variable Heart Rate. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
4.4 Tracking Error

The dependent measure used to evaluate tracking performance is the average absolute force error between the target forcing function and the subject's tracking response as a function of the maximum force generated (%MVC for roll left and roll right) by that subject. Tracking error is calculated from the actual force output (force applied to the isometric force-stick for tracking) and the target forcing function for that trial.

Tracking error data is analyzed in a mixed-factor ANOVA against the independent variables: seatback, armrest, and straining. Gender is included as a between subjects variable. Only one main effect is significant: seatback, $F(5, 50) = 7.414$, $p < 0.005$. A complete ANOVA table is presented in Appendix D, Table D.6.

The main effect of Seatback is shown in Figure 4.16. Tracking error decreases as seatback angle changes from 65° reclined to 10° inclined (see Figure 4.16). A Newman-Keuls post-hoc test for the main effect of seatback shows the 10° inclined, the 0°, the 15° reclined, and the 30° reclined seatback are significantly different from the 45° reclined, and the 60° reclined seatback but not from each other. The 45° reclined and the 60° reclined seatback do not differ.
Figure 4.16 Main effect of Seatback on the dependent variable Tracking Error. Bold letters indicate significant differences in treatments. Treatments not sharing a common letter differ significantly from each other.
5. DISCUSSION

5.1 Overview

The purpose of this research is to investigate the relationship between seated posture, specifically seatback and armrest angles, and the performance of (1) static force generation, (2) lower-body isometric muscle contraction used in anti-gravity straining maneuvers (AGSMs), and (3) a manual tracking task. The results are categorized into three areas: static force generation performance on the sidearm isometric force-stick, lower-body isometric muscle contraction performance as it relates to blood pressure measurements, and tracking performance for a manual tracking task.

5.2 Static Force Generation Performance

The effect of body posture on static force generation is determined from the amount of force applied to the sidearm isometric stick by subjects. Force is applied and recorded in the two directions either orthogonal towards the sagittal plane or orthogonal away from the medial plane of the subject only. The information gained from force generation performance is useful in determining control gain for fly-by-wire aircraft systems. The results indicate expected differences in force generation for the independent variables: gender, seatback angle, armrest angle, and roll direction (applied force direction).

Males are able to generate greater force than females, independent of seatback angle, armrest angle, and roll direction (see Figure 4.1). Further investigation of the results reveal both males and females generate greater force in the direction toward the sagittal plane, independent of seatback angle and armrest angle (see Figures 4.3 and 4.4). Kroemer (1975) and Rockwell (1992) found similar results with subjects demonstrating larger force generation capabilities in the direction orthogonal towards the sagittal plane for similar force-stick placement. The largest difference in force generation between males and
females is found for force applied in the direction toward the sagittal plane (see Figure 4.4). Males show larger differences in force generation as a function of roll direction, while females show smaller differences.

Hypotheses $H_1$ and $H_2$ (see section 2.5) were that significant differences in static force generated by the control hand exist as body posture changes (as a function of seatback and armrest geometry) and between straining and non-straining conditions at similar body postures. Indeed, significant differences in force generation ability are found to exist, however they did not affect tracking performance (see section 5.4).

The results demonstrate a significant difference in the ability to generate force as a function of seatback angle, independent of gender, armrest angle, and roll direction. Force generation increases as seatback angle changes from 60 degrees reclined to 10 degrees inclined (see Figure 4.2). It was believed that armrest angle, but not seatback angle, would play a significant role in affecting force generation. An explanation for why seatback angle did affect force generation is not easily derived. However, one idea is that the moment arms where the muscles act change lengths as body posture changes; therefore affecting force generation ability. Another idea is that as body posture--specifically seatback angle--changes, subjects are able to recruit more muscles from the right arm, shoulder, and thoracic region which yield greater force generation capabilities. Both hypotheses would require further experimental testing and validation.

5.3 Lower-body Isometric Muscle Contraction Performance

Systolic pressure and diastolic pressure are used in calculating mean arterial pressure (Mean Arterial Pressure = (0.33*(Systolic - Diastolic)) + Diastolic). Therefore, the dependent measure of mean arterial pressure is used to evaluate the effect that body posture has on performance of lower-body isometric muscle contractions used in anti-gravity straining maneuvers (AGSMs). Mean arterial pressure is increased during
performance of an AGSM thereby increasing tolerance to +Gz stress. Conclusions about the effects of gender, seatback angle, armrest angle, and straining condition are derived from the data analysis of mean arterial pressure. However, data is also collected and analyzed for systolic pressure, diastolic pressure, and heart rate. Each measure of mean arterial pressure, systolic pressure, and diastolic pressure show similar trends and differences in the analysis results, as expected from the formula.

Body posture, specifically seatback angle and armrest angle, has a significant effect on mean arterial pressure, systolic pressure, and diastolic pressure. Mean arterial pressure, as well as systolic and diastolic pressure, increases as seatback angle changes from 60 degrees reclined to 10 degrees inclined (see Figures 4.5, 4.8, and 4.11). One explanation for the results is that blood pressure is typically lower when a person is supine (or prone) than when sitting upright. The cardiovascular system requires less pressure to move blood when a person is supine or prone, because no large difference in vertical height exists between any of the organs and blood vessels in the body. However, when a person is sitting upright, larger differences in vertical height between organs and blood vessels in the body exist, therefore pressure in the cardiovascular system increases to move blood throughout the body. In this study, subjects are positioned in both reclined and upright postures.

Armrest angle significantly affects mean arterial pressure, systolic pressure, and diastolic pressure when collapsed across gender, seatback angle, and straining condition. Mean arterial pressure, systolic pressure, and diastolic pressure increase as elbow included angle opens from 60 degrees flexion to 120 degrees extension (see Figures 4.6, 4.9, and 4.12). Post-hoc analysis reveals no difference in blood pressure measurements for the 60 degree and the 90 degree armrest position. However, the 120 degree armrest angle affects pressure measurements. Elbow angle was not believed to affect blood pressure. A possible explanation for the results is the blood pressure cuff and monitor used in the
experiment are influenced by elbow included angle of the arm on which the cuff is placed. Cuff type blood pressure monitors are typically less accurate than direct, invasive methods of blood pressure measurement. Another possible explanation is that blood pressure is very sensitive and easily influenced by other factors such as arm height relative to the heart. The height relationship of the left arm to the heart may have influenced the current findings and requires further investigation.

The claim that body posture significantly affects the increase in blood pressure during lower-body muscle tensing is not supported (see Hypothesis H3 in section 2.5), except when a significant interaction of seatback angle with straining condition exists. The ANOVA for mean arterial pressure (see Table D.2) resulted in a marginally significant interaction of seatback with straining (p < 0.10 without the G-G correction factor). The interaction of armrest with straining is clearly non-significant (p < 0.80 without the G-G correction factor) for mean arterial pressure data. These results support the findings of Williams et al. (1988) that pressures generated during an L-1 maneuver were not significantly affected by different body postures.

Blood pressure is significantly affected by the lower-body isometric muscle contractions used in straining. Mean arterial pressure, systolic pressure, and diastolic pressure significantly increased during straining trials (see Figures 4.7, 4.10, and 4.13). This supports the hypothesis that blood pressure increases significantly when lower-body muscle tensing is performed as compared to no lower-body muscle tensing (see Hypothesis H4 in section 2.5).

Results indicate an effect on heart rate due to straining and to seatback. Heart rate significantly increases during straining trials (see Figure 4.15) and as seatback angle changes (see Figure 4.14). In general, heart rate increases as the level of physical activity increases or when body position changes from a supine (or prone) posture to a more upright posture. In this research, lower-body muscle tensing increases the physical
activity of subjects therefore increasing their heart rate; and subjects are positioned in both reclined and upright postures.

5.4 Tracking Performance

Tracking error is calculated from the actual force output by the subject and the target forcing function for a given experimental trial. Tracking performance is determined by measuring the average absolute force error between the target forcing function and the subject's tracking response as a function of maximum force generated (%MVC for roll left and roll right) by each subject.

Hypothesis H₅ (see section 2.5) claims that tracking performance is significantly affected by body posture (seatback and armrest geometry). Seatback angle significantly affects tracking performance, as shown by the results collapsed across gender, armrest, and straining variables. As the seatback is reclined, tracking error increases (see Figure 4.16). A significant difference in tracking performance exists for the 45 degree reclined and the 60 degree reclined seatback angles. The monitor, on which the tracking task is presented, did not move with respect to the seatback angle changes. Therefore, the decrease in tracking performance may be explained by the fact that subjects' eyepoint is far enough from the monitor that acuity required for tracking is degraded at the 45 degree reclined and the 60 degree reclined seatback positions.

It was believed that armrest angle, not seatback angle, would affect tracking performance. However, armrest angle did not significantly affect tracking performance. A reasonable explanation for the results is the control/response (C/R) ratio was determined individually for each subject at each armrest angle. Prior to each experimental session, subjects were positioned in the armrest condition for that particular session and maximum force generation on the control stick was measured. Because C/R ratio is derived as a percentage of each subject's maximum force generated, any effect of control gain due to
armrest angle is removed. Control gain must remain constant as armrest angles change for any effect to be determined. Not keeping the gain constant is a fault of this research. Therefore, further research should be done to determine if armrest angle—specifically elbow angle—affects tracking performance.

The hypothesis that tracking performance is significantly affected during execution of lower-body muscle contractions, independent of body position, is not supported by the results (see Hypothesis H6 in section 2.5). The independent variable of straining was not significant (p < 0.57). Subjects were able to track equally well during straining trials as during non-straining trials.

5.5 Future Research

As pointed out in the discussion on performance measures, there are some problems with the methods employed in this research. Improvements in the methodology may lead to more robust statistical results which in turn would provide a better understanding of the effects of seated posture on performance of static force generation, lower-body isometric muscle contractions, and manual tracking. The following areas should be considered for improvements in future research:

- **Force Generation Measurement**: an improved sidearm isometric force-stick should be incorporated that collects force measurement data in both x and y directions. Force generation data in the y direction would provide insight into the effects of armrest position, including applied force vector direction and how that changes as armrest position changes.

- **Blood Pressure Measurement**: a system where beat-by-beat blood pressure is recorded should replace the single-measurement system used in this research. The system should be highly reliable and not easily influenced by extraneous factors such
as arm movement during straining. These requirements suggest the use of a direct, invasive blood pressure measuring device.

- **Control/Response Ratio:** control gain should be determined a priori and remain constant for each subject throughout the entire experiment. This could have been accomplished in the current research by arbitrarily selecting a seatback and armrest angle combination used in determining C/R ratios, and use that value in subsequent experimental sessions by subjects.

- **Tracking Task Display:** the display, on which the tracking task is presented, should be adjustable to maintain constant viewing distance and viewing angle with respect to the subject's eyepoint. Tracking performance may have been affected in this research by different visual acuity required to perform the tracking task at different seatback angles (i.e., 45 degree reclined and 60 degree reclined).

The question of whether body posture affects straining and/or tracking is not satisfactorily answered by this research. Problems with the methodology may have influenced the results, therefore requiring further investigation. Some significant results are not easily explained. In summary, recommendations for future research include:

- Repeat the current methodology under increasing +Gz stress conditions, incorporating the suggestions for improving the methodology and increasing the number of participants to reduce variability in the data.

- Perform smaller studies which investigate only one parameter at a time (i.e., force generation or isometric muscle contractions or tracking), and use the results from those studies in a sequential experimentation design to determine body postures which yield optimal performance in the areas investigated.

- Investigate tracking performance with a two-dimensional forcing function, not the single-dimension forcing function used in the current research.


APPENDICES
APPENDIX A: MEDICAL QUESTIONNAIRE
Seating, Lower-Body Isometric Muscle Contractions, and Tracking Study:  
Medical Questionnaire

There is minimal risk associated with this experiment. You will be raising your blood pressure during the straining maneuver trials (muscle tensing trials). Increased blood pressure could lead to blood vessel failure in the body, but the level of increase in pressure is no greater than you would experience when weight lifting, or straining at a stool. You may experience some muscle fatigue and soreness after the completion of the experiment. However, the fatigue and soreness should be short-lived and pose no further complication or discomfort to you.

It is important that you answer the following questions honestly and to the best of your knowledge. Your medical history will be reviewed by Dr. Phillip Barkley, Chief Medical Officer for Health Services at Virginia Tech, along with your answers to these questions. Upon complete and thorough review of your medical history and answers to this questionnaire, you will be informed about further participation in this experiment.

Questions:

1) Do you have a family history of cardiovascular disease (i.e., heart problems, high blood pressure, vascular disease, diabetes)?

2) Does your own medical history include any of the following:
   a) cardiovascular problems of any sort?
   b) diabetes?
   c) vascular disease of any kind?
   d) headaches during exercise?
   e) neurological symptoms of any kind during exercise (i.e., dizziness, lightheadedness, nausea)?
   f) head trauma of any sort?
   g) visual problems or retinal disorders?
   h) gastro-intestinal problems of any sort?
   i) kidney problems of any kind?
j) asthma?

k) other?

3) Are you currently taking any medications, prescription or over-the-counter? If so, please indicate which ones.

4) Do you consume alcohol regularly? If so, how much?

5) Do you use recreational drugs?

**Blood Pressure Parameters**

Pre-experimental trials:
    If resting blood pressure is 160/110 or greater, dismiss subject from participation.

During experiment:
    If systolic pressure reaches >200 mmHg, stop experiment immediately and dismiss subject after monitoring for a brief time until blood pressure returns to baseline.
APPENDIX B: INSTRUCTIONS
Seating, Lower-Body Isometric Muscle Contractions, and Tracking Study: Instructions for Experiment

Thank you for agreeing to participate in this study. This study is being conducted by the Industrial Ergonomics Laboratory of the Human Factors Engineering Center at Virginia Tech. The experiment is being run by Andrew Gellatly under the supervision of Dr. K.H.E. Kroemer, a professor in Industrial and Systems Engineering and Director of the Industrial Ergonomics Laboratory.

The purpose of this research is to study the relationship between sitting posture and (1) performance of lower-body muscle tensing used in anti-gravity straining maneuvers, and (2) performance of a manual tracking task, which simulates flying. The experiment will measure the muscle tensing (via blood pressure measurements), force generation (forearm strength measurements), and tracking performance at six seatback angles, three armrest angles, and two lower-body muscle tensing conditions.

If you agree to participate in this experiment you will be expected to attend four experimental sessions. Each session will take approximately one hour of your time. You will perform the actual tracking task, or tracking plus muscle tensing tasks for 30 seconds during each of 12 experimental trials in one session.

MUSCLE TENSING TASK
During half of the trials you will be performing lower-body muscle tensing (isometric contractions) of muscles in the legs and abdomen along with a tracking task. These contractions are similar to those performed by pilots flying high-performance aircraft while pulling Gs. Isometric muscle contractions result when the muscle exerts a force against resistance without producing any motion (i.e., to "flex" your biceps without moving your forearm closer to your upper arm). You will be given a visual demonstration on how to perform the muscle tensing and be allowed to practice. Your blood pressure will be monitored and recorded using a blood pressure cuff and an automatic monitoring device during each trial. Blood pressure measurements will be used to determine the effectiveness of the muscle tensing at each different seat geometry. During the straining trials please perform your maximum voluntary isometric contractions (muscle tensing) as will be demonstrated to you.
In summary, we are looking at how seatback angle and armrest angle affect the performance of the isometric muscle contraction in the anti-gravity straining maneuver using indirect blood-pressure measuring techniques.

FORCE GENERATION TASK
Before any tracking is performed, you will be asked to perform two maximum strength trials with the isometric force-stick. These strength measurements will be performed at each of the six seatback by three armrest combinations for a total of 18 trials. One maximum roll left and one maximum roll right per trial will be evaluated. This is accomplished by rising to a maximum effort in two seconds, hold it for four seconds, and release. It is important that you give your maximum effort during these trials. The risk of muscle strain associated with the procedures used is minimal.

In summary, we are looking at how seatback and armrest angle affect forearm muscle force generation on the force-stick.

TRACKING TASK
The tracking task consists of a manual control task using an isometric force-stick. When force is applied to the force-stick, the position of the computerized object moves; more force leads to greater object movement. The tracking task is to maintain a yellow cross within a moving target on the computer screen. The target is a green circle which will be moving only horizontally, back and forth, across the screen. Your job is to try and keep the yellow cross inside the green circle at all times. This is accomplished by altering the amount of force applied to the force-stick (either to the left or to the right). During each trial the target will move in a non-predictable manner, back and forth on the screen, in a horizontal direction. Please attempt to track the target as accurately as possible for all experimental trials. You will have time to practice before the experiments begin.

In summary, we are researching how accurately you can track the target under different straining conditions, seatback angles, and armrest angles.

PROCEDURE
The entire experiment will take approximately four hours, one hour a day over four days. You will be paid $5.00 per hour. After reading these instructions and filling out the
informed consent form, you will be ready for the first experimental session. First, you will be seated in the experimental chair, demonstrated the isometric straining maneuver, demonstrated the force generation task, and shown the tracking task. Then you can practice until you feel comfortable with the tasks.

If, for any reason, you feel that you are experiencing pain or abnormal discomfort during the session, please inform the experimenter immediately. You are free to stop the experiment if you need any clarification about the study, or if you feel that you cannot perform the experimental tasks.

The data from the experiment should be analyzed by May, 1994. The results will be made available to you should you desire to review them.

Thank you again for your participation. If at any time today you have questions about the experiment please feel free to ask the experimenter. We hope you enjoy your experience in this research effort.
APPENDIX C: INFORMED CONSENT
Seating, Lower-Body Isometric Muscle Contractions, and Tracking Study: Informed Consent Form

This form constitutes informed consent by you to participate in this study. Please read it carefully, as well as the attached sheet, and then sign it below.

Your Rights as a Subject are:

1) It is your right as a subject to withdraw from the study at any time and for any reason.

2) Any of the research team members will answer any questions that you may have, and you should not sign this consent form until you understand fully all of the terms involved. The research team members are:

   Andrew Geliaty, ISE graduate student
   Dr. K.H.E. Kroemer, ISE professor

3) You have the right to see your data and withdraw them from the study if you so desire. Please inform the experimenter immediately of this decision, as the data will be handled anonymously and cannot be tracked once the session is over.

4) You have the right to be informed of any risks or discomforts in this research. There is minimal risk associated with this experiment. You will be raising your blood pressure during the straining maneuver trials, but the level of increase in pressure is no greater than you would experience when weight lifting, or straining at stool. You may experience some muscle fatigue and soreness after the completion of the experiment. However, the fatigue and soreness should be short-lived and pose no further complication or discomfort to you.

5) Your medical history, and answers to a medical questionnaire, will be reviewed by Dr. Phillip Barkley, Chief Medical Officer for Virginia Tech, before being allowed to continue in the study. Answers to the medical questionnaire will be viewed only by Dr. Phillip Barkley.

6) Should any further questions arise, please contact one of the team members. If you have any concerns about the way the experiment is being conducted or the way you are being treated, you may contact Ernest R. Stout, Associate Provost for Research at 231-6077.
Your participation is greatly appreciated and we hope that you will find the study a pleasant and interesting experience. Your signature below indicates that you have read this document and the description of the experiment attached to it in its entirety, that your questions have been answered, and that you consent to participate in the study described.

Signature: ___________________________________________ Date: __________________

Address: ____________________________________________

___________________________________________________
APPENDIX D: EXTENDED ANOVA TABLES
Table D.1 Complete ANOVA summary table for Force Generation data.

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Dependent: Force Generation
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Dependent: Mean Arterial Pressure
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Dependent: Systolic Pressure
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Dependent: Diastolic Pressure
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<td>20.405</td>
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</table>

Dependent: Heart Rate
Table D.6  Complete ANOVA summary table for Tracking Error data.

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<th>Mean Square</th>
<th>F-Value</th>
<th>P-Value</th>
<th>G-G</th>
<th>H-F</th>
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<td>.001</td>
<td></td>
<td>.9794</td>
<td>.9292</td>
<td>.9774</td>
</tr>
</tbody>
</table>
\[Armrest * Straining\]  | 2  | .059           | .030        | .660    | .5275   | .4698   | .4942   |
\[Armrest * Straining * Gender\]  | 2  | .143           | .071        | 1.598   | .2270   | .2349   | .2328   |
\[Armrest * Straining * Subject(Group)\]  | 20 | .894           | .045        |         |         |         |         |
| Seatback * Armrest      | 10 | .010           | .001        | .895    | .5407   | .4813   | .5313   |
| Seatback * Armrest * Straining | 10 | .004  | 3.703E-4    | .318    | .9747   | .8767   | .9649   |
\[Seatback * Armrest * Straining * Subject(Group)\]  | 100 | .116   | .001        |         |         |         |         |
VITA

Andrew William Gellatly was born on July 18, 1967 in Weymouth, Massachusetts. He received a B.S. degree in psychology from The University of Michigan in December of 1989. For almost two years he worked as a research assistant and research associate for the University of Michigan Transportation Research Institute (UMTRI) in the Human Factors Division. While at UMTRI he conducted research on vehicle lighting, vehicle conspicuity, glare scaling techniques, traffic signing, and rear vision systems. He went on to pursue an M.S. degree in industrial and systems engineering (human factors and safety option) at Virginia Polytechnic Institute and State University. While at Virginia Tech he interned one summer with Delco Electronics Corporation, working on automotive head-up displays. He is currently an active member of the Aerospace Medical Association, American Society of Safety Engineers, Human Factors and Ergonomics Society, and Systems Safety Society. He is continuing his graduate education at Virginia Tech in pursuit of a doctorate degree in industrial and systems engineering.

Andrew William Gellatly