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Composite Data from Centrifugal Experimentation Regarding Human Information Processing

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COMPOSITE DATA FROM CENTRIFUGAL EXPERIMENTATION REGARDING HUMAN INFORMATION PROCESSING

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Engineering

By

RONALD KEITH BUTCHER
B.S., Wright State University, 2005

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Ronald Keith Butcher ENTITLED COMPOSITE DATA FROM CENTRIFUGAL EXPERIMENTATION REGARDING HUMAN INFORMATION PROCESSING BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Engineering.

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ABSTRACT

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A cognitive model illustrating decrement in human performance as a function of increased G-forces has been highly sought after by the Department of Defense (DoD) for various reasons. The F-16 and other air combat platforms are super-agile aircraft that are easily capable of imposing G-forces on a pilot that are beyond human physiological limitations. Knowledge of these physiological limits and more importantly the resultant restrictions in cognitive function could prove invaluable to those who design and pilot such aircraft. The model may be utilized in the construction of improved flight simulators that incorporate more realistically performing enemy targets and therefore enhance the training of the air warfighter. Command and control functions may also benefit from a thorough understanding of the boundaries of human cognition in these dynamic environments.

NTI is a research firm based in Fairborn, Ohio that has formulated just such a model. NTI has devised this model while contracted by the USAF Air Force Research Laboratory (AFRL) under a Phase II Small Business Innovation Research (SBIR) grant. The three primary principles that are employed in the NTI models' construction are the T-matrix, a previously developed G-effective model and the G-Performance Assessment Simulation System (G-PASS) battery of tests. The T-Matrix concept has been developed emulating the Educational Testing Service (ETS) Q-Matrix with the exception that it is based on cognitive tests as an alternative to interview questions. The G-Effective Model is based on the fact that human performance is not decremented by increased G-Forces encountered by the air warfighter instantaneously. Rather, a decrease in performance is the result of a subsequent reduction in cerebral blood flow that is in turn affected by both the G-profile as well as the onset rate of imposed G-forces. The G-PASS battery of tests is intended to be performed in the Dynamic Environment Simulator (DES) human centrifuge at the Air Force Research Laboratories (AFRL) Human Effectiveness Protectorate-G (HEPG) located at Wright Patterson Air Force Base. These tests are utilized to probe critical cognitive functions that are essential to pilots of combat aircraft.

Results of a descriptive comparison of the NTI model versus the composite data obtained from the DES experimental results are presented in this thesis. Results show that the decrement of cognitive function as a result of increased Gz forces obtained in the HEPG experiments is consistently lower than what is predicted by the NTI model. These results may be partially accounted for by the fact that the NTI model is based on relaxed G conditions, whereas the DES experimentation was performed utilizing G-suits, positive pressure breathing and straining maneuvers.

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ACKNOWLEDGMENTS

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For preparation of the statistical reports from which the composite data was obtained.

1.0 INTRODUCTION

1.1 Overview and Problem Description

Historically human performance modeling has been "non-cognitive" in nature and was based on science that had its roots in control theory and network modeling, (Pew & Baron, 1983). More recently a cognition based approach has been incorporated particularly for utilization in armed forces simulations (Pew, Richard and Anne Mavor, et al. 1998). Psychologists see human behavior as a complicated mixture of sociological dynamics, values, beliefs, training and cognition. Human Factors Engineers may view human behavior in a procedural light where activities occur in sequence or as control loops that are conducive to software programming. A panel formed by the National Research Council (NRC) views human performance as a many-sided problem that requires a cross-functional approach in order to produce a plausible model. The Department of Defense's Modeling and Simulation Master Plan (DoD-MSMP) has stated an urgent need for a model of human decision making for incorporation in constructive simulation (Defense Modeling and Simulation Office. 1995). Keeping abreast of current developments in human performance modeling as well as defining exactly what constitutes human behavior is crucial in the construction of any simulations that may involve human in the loop (HITL) systems. Hence, it is no surprise that the DoD views cognitive modeling in a dynamic environment with such high regard.

The construction of a cognitive model emulating human cognition is a complex endeavor. A model that can account for the stress imposed on subjects as a result of increased G-forces is even more problematic. However, the effort is facilitated by groundwork that has already been laid in the form of past research. The utilization of cognitive modeling architectures in constructive simulations is a relatively new undertaking and would surely have beneficial implications toward the growing bio-technology and information technology areas as well as the obvious military benefits.

1.2 Objectives

The primary goal of this research is the investigation of cognitive modeling within the dynamic environment that ensues from the application of increased G-forces on a human subject. Investigation of an existing model prepared by a research firm contracted under the Small Business Innovative Research (SBIR) program is highlighted. Experimental results gleaned from human subjects performing cognitive tasks while within a human centrifuge will be examined and compared to the existing model. Specifically, composite data showing mean human performance will be descriptively and graphically compared to the core data of the cognitive architecture formulated by the aforementioned research firm known only as NTI. This "core" data is in the form of look-up tables depicting percent human performance at G levels ranging from 1 to 10 Gz. Comparisons are made at 1, 3, 5, and 7 Gz.

Additionally, a graphical description of a preliminary model of human performance as a function of increased G-forces will appear in the suggestions for future research section of this thesis. Future research should focus on actually formulating and refining a formal model intended for utilization in constructive simulations.

1.3 The Dynamic Environment Simulator (DES)

The Dynamic Environment Simulator (DES) is a three axis human centrifuge (see figure 1) located at Wright-Patterson Air Force Base in Dayton, Ohio. The DES is operated and maintained by the Air Force Research Laboratories Human Effectiveness Protectorate-G (HEPG). The DES (figure 1) has been in use since 1969 and is capable of generating G-forces of 20 G at a rotational velocity of 56 RPM. Weighing in at 163,000 kilograms the spherical (three meters in diameter) gondola is capable of carrying a payload of over 1,364 kilograms. The DES is usually employed to examine the effects of increased G-forces on pilot performance. However, pilot training, development and evaluation of hardware and protective equipment, and human physiologic studies are also carried out. The DES has been programmed and equipped to perform the tests incorporated in the NTI model with human subjects. Data obtained from these tests will be used to verify the NTI model.

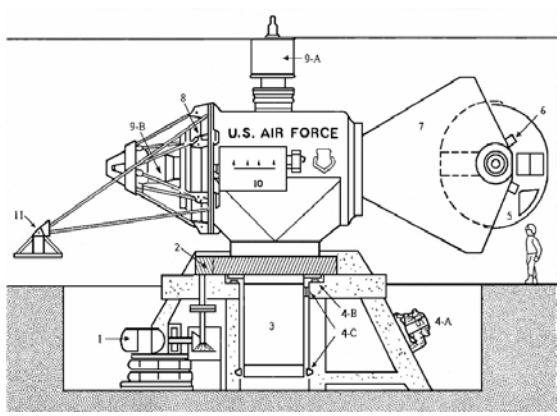


Figure 1: The Dynamic Environment Simulator (DES)

2.0 RELATED RESEARCH

2.1 Literature Review

Many of the tests performed in the DES intended to verify the NTI model are patterned after those utilized in previous research involving human centrifugation. Appearing here is reference to and a brief description of these studies. Appearing here is reference to and a brief description of these studies. All the citations appear in the reference section of this thesis.

Spatial Orientation: In this study subjects manipulated an arrow to indicate what they perceived to be the downward direction. The enclosed centrifuge cab was rotated off vertical (randomly) and the subjects indicated their estimation of down while under g-force. G-force was varied from 1 to 3 G in increments of 0.5 G. (Albery, W. B. (1990)).

Slow and Fast Motion Inference: Here a subject views a target moving across a video display for either 8 or 15 seconds (8 seconds for fast motion inference, 16 seconds for slow). The target disappears but continues to move across the display invisibly. The subject must give a cue in the form of a button press when they believe the target has reached a hash mark near the edge of the display (Repperger, D. W., Frazier, J. W., Popper, S., & Goodyear, C. (1990)).

Tracking: This study consisted of a computer generated target and crosshairs simulating an aerial tracking task (Rogers, D. B., Ashare, A. B., Smiles, K. A., Frazier, J. W., Skowronski, V. D., & Holden, F. M. (1973)).

Complex Decision Making Reaction Time, Accuracy, and Efficiency: This experiment simulated a "bail out" maneuver where subjects were signaled to raise their arms, grasp a D-ring and pull down a face curtain simulating ejection seat activation (Cochran, L. B. (1953)).

Visual Acuity: Here NTI draws upon four separate studies evaluating visual acuity under increased G. The first study deals with visual thresholds (White, W. J. (1960)). The next study has the subject view a circular test patch against various backgrounds. Subjects indicate the appearance and disappearance of the test patch. The results are reported as contrast sensitivity (Chambers, R. M., & Hitchcock, L. (1963)). This study involved dial reading under various brightness levels. Subjects were instructed to report the dial reading to the nearest unit (White, W. J. (1962). In the fourth study subjects were to discern where a gap appeared in a Bostrom test figure. Results were reported as a percent error in visual acuity (Frankenhauser, M. (1958)).

Simple Decision Making: Two studies helped to determine this test variable. The first study had subjects indicate through a four button response which of four circles presented on a visual display were illuminated along with the number and position of said circles. In addition the subjects were required to enter a six digit number (also presented on the visual display) into a standard telephone keypad (McClosky, K., Albery, W. B., Zehner, G., Bolia, S. D., Hundt, T. H., Martin, E. J., & Blackwell, S. (1992). The next study utilizes three colored lights; red, green and white. The subject has a button in each hand. The subject must press the right button for either the illumination green light or the red and white light lights illuminating simultaneously. The left hand button is pressed for illumination of the red light or the green and white light simultaneously. No response is required for simultaneous illumination of the red and green lights (Frankenhauser, M. (1949)).

Instrument Reading: In this experiment the participants viewed eight instrument dials with a corresponding number above the dials representing the dial reading. Some numbers were markedly different from the dial reading and subjects responded in a true-false format (Warrick, M. J., & Lund, D. W. (1946)).

Perceptual Speed: Two studies are highlighted for this variable. The first task presents the subject with five test figures and a stimulus figure and involves matching the stimulus figure with the correct test figure (Frankenhauser, M. (1958). The second test involves a test stimulus surrounded by four choice stimuli above, below, to the right and to the left. The subjects respond with the choices up, down, right or left respectively with the goal of selecting the matching stimuli (Comrey, A. L., Canfield, A. A., Wilson, R. C., & Zimmerman, W. S. (1951)).

2.2 Protective Equipment and Procedures

One of the primary hazards faced by the air warfighter while in combat is gravity induced loss of consciousness (G-LOC). G-LOC occurs when increased gravitational or accelerative forces move blood away from the brain as in positive Gz acceleration or toward the brain as in negative Gz acceleration. Typically G-LOC takes place in unprotected subjects that experience increased G-forces equivalent to approximately +4.5 Gz. However, G-LOC may also result within the range of +2Gz to +6.5Gz. Aircraft pilots are protected against G-LOC in wearing G-suits and performing positive pressure breathing maneuvers. Though it is not within the scope of this work to do an in depth analysis of all protective equipment and procedures, anti G-suits and straining maneuvers are briefly discussed here in that they do affect the comparison of the NTI model to the experimental results.

2.2.1 Anti G-Suits

An Anti G-suit, or more commonly (albeit erroneously) referred to as a G-suit, is a garment worn by pilots and astronauts as a protection against G-LOC. The first anti G-suits were developed around 1941 for use by Royal Air Force (RAF) pilots. Most anti G-suits function by exerting a distributed force on the legs and lower body and thereby enhance cerebral blood flow. Anti G-suits have undergone many design changes since their inception. Some have incorporated fluids in their bladder systems but most utilize compressed air. Some G-suits inflate in a retrograde fashion cephaladward (up the legs from the foot toward the head) and have withstood thorough evaluation (Tripp, L. D., McCloskey, K., Repperger, D., Popper, S. E. & Johnston S. L. (1992)). It should be noted that anti G-suits can enhance G-tolerance by approximately 1.0-1.5 Gz (Nicholas D. C. Green (1999)).

2.2.2 Straining Maneuvers

Straining maneuvers or more specifically, anti-G straining maneuvers (AGSM) are procedures employed by air combat pilots to ward off G-LOC. These methods usually constitute muscle straining with positive pressure breathing techniques. "*To increase G-force tolerance, pilots typically perform the L1/M1 anti-G straining maneuver while encountering high G-forces. The AGSM utilizes intense static contractions of the arm, abdominal and leg muscles to decrease fluid shifts that result in blood pooling in the lower extremities, and to maintain blood pressure and cardiac output* (Glaser, R. M., Ezenwa, B. & Popper, S. (1990))". Also known as the "grunt" the L1/M1 AGSM is essential when encountering g-forces in excess of 5.5 Gz. The Navy has researched the "HOOK" maneuver where pilots vocalize the word "HOOK" to bring about voluntary closure of the glottis which is a very important part of the AGSM (http://www.simhq.com/_air/air_036a.html). Typically anti-G straining maneuvers can increase G-tolerance by 4 Gz (Nicholas D. C. Green (1999)). However, this value can be lower depending on how well the AGSM is performed.

3.0 RESEARCH APPROACH

3.1 Methodology

In this thesis the average values for human performance are taken from composite data in the form of statistical reports prepared by the staff statistician at the Human Effectiveness Directorate of the Air Force Research Laboratory (HEPG). Composite data for six of the twelve G-PASS tests performed in the DES were utilized in this research as the remainder of the data was unavailable. The addition of future test results may have some impact on the results shown in this report. Those values were weighted by NTI's T-matrix and subsequently compared to values taken from look-up tables from which the NTI model is generated. The comparison is performed graphically via Microsoft EXCEL® plots and a trendline is superimposed on the resultant plots. The trendline gave an estimation of the (linear) degradation in human performance as a function of increased G-force.

A plot of cumulative performance data from past literature appearing in the NTI report is reproduced and means are taken across G-forces producing a new plot. Description of a preliminary model is made based on this new plot. A trendline for the new plot is taken and compared to a similar plot generated from data in the NTI model.

3.1 The NTI T-Matrix

A problem inherent in cognitive testing is that few if any tests measure a single cognitive function or process. To alleviate this problem NTI developed the concept of the "T-matrix". Patterned after a technique developed for the Educational Testing Service (ETS) known as the Q-matrix (DiBello, Stout, and Roussos, 1995), the T-matrix is based on tests rather than questions. Generally, the T-matrix (Table 1) is a means of weighting the resultant data from a given cognitive test in order to measure a specific cognitive function. The values (in bold) near the top of the matrix represent weighting factors that were arrived at by a panel of cognitive scientists. The version of the T-matrix employed is based on a pop-up bombing maneuver. However, it is possible to develop a T-matrix based on other air combat maneuvers also. Ratings or performance measurements from the various cognitive tests are introduced into the cells of the matrix. The end result is a multiplicative matrix (Table 2) that yields a composite score for a skill/test match. A simple summation is then performed to reveal a numerical assessment of the cognitive process.

Table 1 shows the ratings that were generated from expert opinion of the G-PASS tests as related to the pop-up bomb maneuver. These ratings appear in bold in the row just below the names assigned to the individual G-PASS tests. The entries in the remaining cells of the table are ratings that denote the relevance the cognitive processes to the associated G-PASS test. These ratings are the result of expert opinion gathered from a panel of cognitive scientists. Table 2 illustrates how the tests were optimized in that the ratings of each test are multiplied by their relevance ratings associated with the various cognitive processes. Table 3 shows the summation of the multiplicative values for each cognitive process. In this way the researchers at NTI were able to generate composite scores and resultant rankings for the most important cognitive processes (shaded in table 3) involved with a pop-up bomb maneuver and eliminate cognitive processes that have little or no importance.

The T-matrix utilized by this researcher in the validation of the NTI model is not as extensive as that shown in the illustrations. At the time this work was prepared raw data for three of the cognitive tests and composite data for six of the tests were available. Performance values for six of the tests for which composite data were available was inserted into the cells of the matrix and performance (as a percent) for the cognitive functions were subsequently derived. Though additional data may yield varying results, the available data should be sufficient to construct a descriptive comparison between the NTI model and the experimental results.

Table 1: The NTI T-Matrix

Pop-Up Bomb Maneuver	Instrument Reading **9**	Simple Decision Making **5**	Visual Acuity **6**	Complex Decision Making Accuracy **7**	Complex Decision Making RT **8**	Complex Decision Making Efficiency **7**	Tracking **9**	Slow Motion Inference **2**	Fast Motion Inference **9**	Spatial Orientation **9**	Perceptual Speed **6**
Perception of Relative Motion	0	1	0	0	0	0	4	3	4	7	6
Precision Timing	0	4	0	0	0	0	8	6	5	0	9
Motion Inference	0	6	0	0	0	0	4	9	9	0	7
Pitch/Roll Capture	0	3	0	0	0	0	8	2	2	3	2
Peripheral Processing	5	6	9	0	0	0	0	0	0	0	7
Decision Making	0	2	4	9	9	9	0	1	3	0	1
Basic Flying Skills	7	3	0	0	0	0	2	0	0	4	0
Gunsight Tracking	0	1	4	0	0	0	9	5	7	0	4
Situation Awareness	6	1	5	5	2	2	3	2	2	8	0
Unusual Attitude Recovery	9	3	0	6	3	8	0	0	0	9	2
Short Term Memory w/ Distraction	0	4	0	3	1	3	0	0	0	3	0
Visual Monitoring	4	1	6	0	0	0	6	0	0	0	3

Table 2: The Multiplicative Matrix

Pop-Up Bomb Maneuver	Instrument Reading **9**	Simple Decision Making **5**	Visual Acuity **6**	Complex Decision Making Accuracy **7**	Complex Decision Making RT **8**	Complex Decision Making Efficiency **7**	Tracking **9**	Slow Motion Inference **2**	Fast Motion Inference **9**	Spatial Orientation **9**	Perceptual Speed **6**
Perception of Relative Motion	0	5*1=5	0	0	0	0	9*4=36	2*3=6	9*4=36	9*7=63	6*6=36
Precision Timing	0	5*4=20	0	0	0	0	9*8=72	2*6=12	9*5=45	0	6*9=54
Motion Inference	0	5*6=30	0	0	0	0	9*4=36	2*9=18	9*9=81	0	6*7=42
Pitch/Roll Capture	0	5*3=15	0	0	0	0	9*8=72	2*2=4	9*2=18	9*3=27	6*2=12
Peripheral Processing	9*5=45	5*6=30	6*9=54	0	0	0	0	0	0	0	6*7=42
Decision Making	0	5*2=10	6*4=24	7*9=63	8*9=72	7*9=63	0	2*1=2	9*3=27	0	6*1=6
Basic Flying Skills	9*7=63	5*3=15	0	0	0	0	9*2=18	0	0	9*4=36	0
Gunsight Tracking	0	5*1=5	6*4=24	0	0	0	9*9=81	2*5=10	9*7=63	0	6*4=24
Situation Awareness	9*6=54	5*1=5	6*5=30	7*5=35	8*2=16	7*2=14	9*3=27	2*2=4	9*2=18	9*8=72	0
Unusual Attitude Recovery	9*9=81	5*3=15	0	7*6=42	8*3=24	7*8=56	0	0	0	9*9=81	6*2=12
Short Term Memory w/ Distraction	0	5*4=20	0	7*3=21	8*1=8	7*3=21	0	0	0	9*3=27	0
Visual Monitoring	9*4=36	5*1=5	6*6=36	0	0	0	9*6=54	0	0	0	6*3=18

Table 3: T-Matrix Composite Scores

G-Pass Test	T-Matrix Composite Score	Rank
Perception of Relative Motion	182	7
Precision Timing	**203**	**6**
Motion Inference	**207**	**5.5**
Pitch Roll Capture	148	10
Peripheral Processing	171	8
Decision Making	**267**	**3**
Basic Flying Skills	132	11
Gunsight tracking	**207**	**5.5**
Situation Awareness	**275**	**2**
Unusual Attitude Recovery	**311**	**1**
Short Term memory	97	12
Visual Monitoring	149	9

3.3 The G-Effective Model

It is a well known fact that human cognition is not affected instantaneously by a given G load. In fact the rocket sled experiments in the late 1940's revealed that humans could tolerate very high G-forces (46 Gx) for very short durations of time. Further, human physiology is not affected linearly as a function of increased G-forces. The true or "effective" g-force that a subject experiences, is dependent primarily upon cerebral blood perfusion. Cerebral blood flow is in turn affected by the rate of G onset and the duration for which one is exposed to increased G-forces. Dr. Dana Rogers, a prominent and experienced scientist in the area of human centrifuge research; devised a proprietary model of the physiological and hemodynamic effects of increased G on human performance. This model allows analysis of a given G-profile with the end result being an accurate prediction of the actual or "effective G" that the human body is actually experiencing. NTI has been able to employ this "G-effective" model to extrapolate data from existing studies and therefore estimate human performance capabilities where no previous studies have been performed.

Though it is not within the scope of this work to investigate the G-effective model or the effects of G duration or onset rates, the G-effective model bears mention here as it is a novel approach toward the investigation of human cognition under the stress imposed by increased G-forces. It should also be noted that the data utilized for this comparison was taken from 3 Gz, 5 Gz and 7 Gz plateaus where the initial rate of G onset was approximately 1 Gz/sec.

3.4 Cognitive Processes

It may come as little surprise that the cognitive processes examined by the NTI model are those considered to be critical to the air combat pilot in an accelerative environment. Following is a listing along with a brief description of these functions.

Spatial Orientation: Spatial orientation refers to one's ability to infer position and execute movement within a given environment.

Motion Inference: This form of cognition shows one's ability to estimate the position of a moving object when taking into consideration speed and perceived time.

Tracking: Tracking is the ability to utilize hand-eye coordination in order to keep a moving object within pre-set spatial boundaries.

Simple Decision Making: This is the ability to differentiate between easily distinguishable choices in a swift and proficient manner.

Complex Decision Making: This is the ability to differentiate between multiple distinguishable choices in a swift and proficient manner. Reaction time, accuracy and efficiency are integral to this cognitive function.

Visual Acuity: Visual acuity involves the identification and elucidation of visual information and is highly dependent upon both peripheral and focal recognition.
Instrument Reading: This is the ability to accurately discern the reading of various instruments incorporating aneroid, digital or strip readouts.

Perceptual Speed: This is the speed involved with discriminating and accurately perceiving between various stimuli.

3.5 The G-PASS Test Battery

NTI has devised a battery of tests designed to measure cognitive function known as the G-Performance Assessment Simulation System (G-PASS). The G-PASS test battery consists of a total of 12 tasks specifically designed to gauge 11 cognitive processes. Following is a list of the 12 G-PASS tests (Table 1) along with a brief description of the 6 tests that were utilized in this comparison.

Table 4: The G-Pass Test Battery

The G-PASS Test Battery			
Test No.	**Test Name**	**Data Availability**	
		Raw	**Composite**
1	Perception of Relative Motion	✓	✓
2	Precision Timing	✓	✓
3	Motion Inference	✓	✓
4	Pitch/Roll Capture	✓	✓
5	Peripheral Vision	✗	✓
6	Rapid Decision Making	✗	✓
7	Basic Flying Skills	✗	✗
8	Gunsight Tracking	✗	✗
9	Situation Awareness	✗	✗
10	Unusual Attitude Recovery	✗	✗
11	Short-term Memory with Distraction	✗	✗
12	Visual Monitoring	✗	✗

Perception of Relative Motion: The emphasis of this task is on the visual-motor skills. In essence this is a tracking task. An image of a fighter aircraft remains fixed in the bottom center of the subject's view screen and represents the piloted aircraft. Another image of a tanker aircraft appears on the right or left of the screen and has a boom protruding from its tail section. The end of the boom is green in color representing a safe docking section.

The subject is instructed to manipulate a joystick and throttle thereby bringing the fighter into formation with the tanker. As the subject closes in on the target aircraft it will change in size proportional to the resultant reduced distance between the two aircraft. The subject must make contact with the green portion of the boom for at least two seconds. The goal is to establish the rendezvous in a minimum period of time.

Precision Timing: This task loads primarily on visually directed precision timing. Here, the subject views a 180 degree arc (figure 2) with a hash mark appearing somewhere in the latter two-thirds of the semi-circle. A white light then begins to traverse the arc at a constant rate of speed that varies between trials. The subject is instructed to press a button on the joystick stopping the light as close to the mark as possible. The metric of this task is based upon the precision (distance and/or timing error) with which the subject "hits" the hash mark.

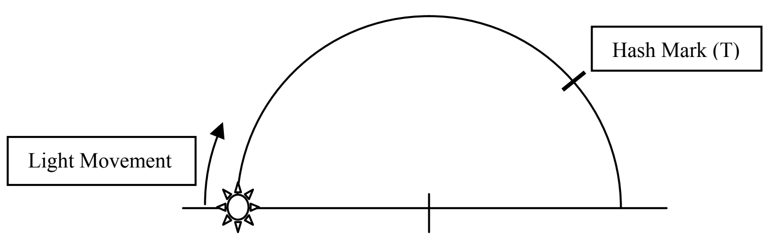


Figure 2: Precision Timing Test

Motion Inference: Similar to the precision timing task, the motion inference task is comprised of an image (see figure 3) of an 180° arc depicted on a computer screen. Somewhere on the latter half of the arc there is shown a hash mark. A light visibly begins to traverse the arc at a constant rate of speed until a point (S) is reached. At the point (S) the light is extinguished but continues to move (invisibly) at the same rate of speed until the subject presses a joystick button that essentially stops the (invisible) light. The subjects mission is to stop the (invisible) light as close to the hash mark as possible. The metric of this task is based upon the precision (distance and/or timing error) with which the subject "hits" the hash mark. In addition the test may incorporate a distracter in which the subject is presented with four letters appearing within the semi-circle. In this instance the subject must press a button indicating that the set of letters contains a vowel. The distraction is presented and requires response during the time elapsing between the disappearance of the light and the light stop position. This task measures the subject's ability to estimate motion based on a preceding perception of motion.

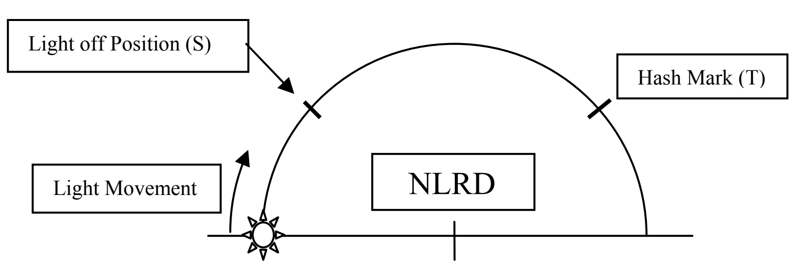


Figure 3: Motion Inference Task with Distracter

Pitch/Roll Capture: Here the subject is presented with a first-person or out-of-cockpit view. The display also shows a circular gun sight between two parallel vertical lines. The subject is instructed to move the joystick left or right (roll maneuver) until a target aircraft is brought between the two parallel lines. Subsequently, the subject moves the joystick forward or rearward (pitch maneuver) until the target is within the crosshairs of the gun sight. The primary measurement involved with this task is the time taken to bring the target aircraft within the crosshairs. This test engages visual-motor control and visual/vestibular interactions.

Peripheral Information Processing: In this task the subject is presented with a fixation point. The subject is then presented with a stimulus in the visual periphery. These stimuli (at the experimenter's discretion) may consist of an aneroid (circular gauge) display, a strip display or a spot of light that is either moving or stationary. In the instance that the spot of light is utilized the subject indicates when the stimulus appears and/or its direction of movement. At the discretion of the experimenter either of the two types of displays may be utilized and the subject may be required to indicate an approximate reading.

Rapid Decision Making: In this task, three concentric circles define three separate areas similar to a radar warning receiver. The "bull's eye" of this pattern is defined as a critical threat area. The middle zone is defined as a moderate threat area and the outer zone a low threat area. In addition, three symbols consisting of the letter “x”, the letter “o” and a question mark define critical, moderate and low threats respectively. The subject must indicate with a joystick which symbol represents the greatest threat. The subject is instructed to make this decision first with respect to threat zones and then with respect to the threat represented by the symbol itself. For example, the greatest threat in the first figure (figure 4) below would be the letter “o” while the greatest threat in the second figure (Figure 5) would be the question mark. Reaction time and accuracy are the primary metrics for this test.

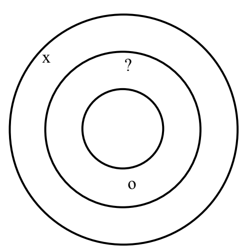


Figure 4: RDM with “o” as threat

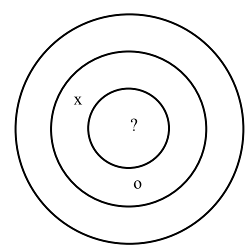


Figure 5: RDM with “?” as threat

4.0 EVALUATION

Evaluation was initiated in the inspection of the plot of cumulative performance data from past literature appearing in the NTI report. Performance data from previously executed cognitive tests carried out from 1 Gz through 8 Gz appear in figure 6. An average performance was calculated at all G levels and a new plot (figure 7) was created utilizing these values. Subsequently a trendline was superimposed on this plot to get a rough idea as to what the percent performance decrement would be according to past studies. Data from the NTI model look-up tables were treated in a similar fashion (figure 8) in preparation for a comparison with the 1 Gz to 5 Gz data available from the HEPG experiments. The (nearly) matching values for performance decrement between the past literature data and the NTI look-up tables should come as no surprise due to the fact that much of the NTI model was constructed by extrapolation of the data from previous studies.

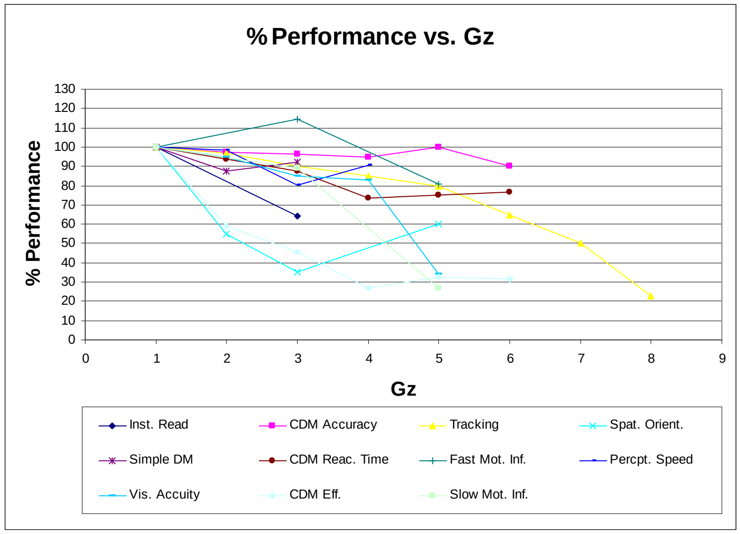


Figure 6: Performance Data From Past Literature

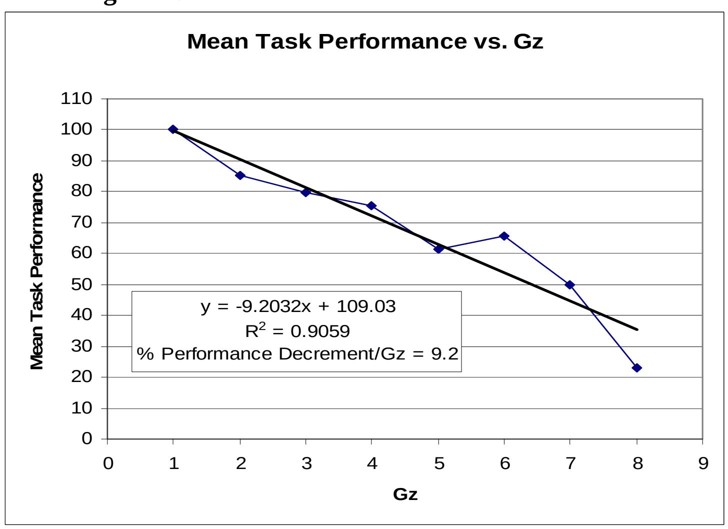


Figure 7: Task Performance vs. Gz

Most of the evaluation procedure entailed inserting data from the NTI look-up tables and HEPG experiments into the NTI T-matrix in preparation for validation of the NTI model. Automated Excel spreadsheets were employed to accomplish this end and appear in soft copy on a computer disk that will accompany this report. Data from the Tmatrices were then placed in tabular form to facilitate comparison of the model and experimental results. Table 4 shows an overall average of all G-Pass tests at one,

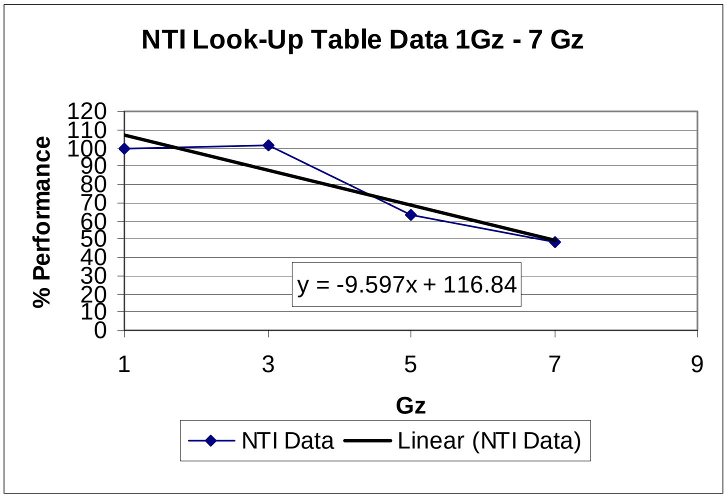


Figure 8: Plot of 1 Gz – 7Gz Performance of NTI Look-Up Table Data

three, five and seven Gz respectively. Similar treatment was afforded the corresponding performance values taken from the NTI look-up tables. As expected, human performance shows a decreasing trend in either case. The experimental (DES) data shows a decrease in performance of approximately 6.5% within the range of 1-7 Gz. However, theoretical performance decreases by approximately 52% within the same range. This radical difference in performance is attributable to the various protective measures afforded test subjects in the DES experiments.

Table 5: Data Evaluation

Gz	Cognitive Function	NTI [%]	DES [%]	Diff.	NTI (Avg)	DES (Avg)
1	Dial Reading	100.00	100.00	0.00		
1	Simple Decision Making	100.00	100.00	0.00		
1	Visual Acuity	100.00	100.00	0.00		
1	Complex Decision Making Accuracy	100.00	100.00	0.00		
1	Complex Decision Making Reaction Time	100.00	100.00	0.00		
1	Complex Decision Making Efficiency	100.00	100.00	0.00		
1	Tracking	100.00	100.00	0.00		
1	Slow Motion Inference	100.00	100.00	0.00		
1	Fast Motion Inference	100.00	100.00	0.00		
1	Spatial Orientation	100.00	100.00	0.00		
1	Perceptual Speed	100.00	100.00	0.00	100.00	100.00
3	Dial Reading	64.00	101.10	37.10		
3	Simple Decision Making	90.00	99.76	9.76		
3	Visual Acuity	85.00	100.89	15.89		
3	Complex Decision Making Accuracy	96.00	99.47	3.47		
3	Complex Decision Making Reaction Time	87.00	100.40	13.40		
3	Complex Decision Making Efficiency	45.00	100.40	55.40		
3	Tracking	90.00	98.80	8.80		
3	Slow Motion Inference	89.00	99.25	10.25		
3	Fast Motion Inference	114.00	99.29	14.71		
3	Spatial Orientation	35.00	98.18	63.18		
3	Perceptual Speed	80.00	99.58	19.58	79.55	99.74
5	Dial Reading	46.40	88.80	42.40		
5	Simple Decision Making	72.50	93.31	20.81		
5	Visual Acuity	34.00	91.11	57.11		
5	Complex Decision Making Accuracy	100.00	96.30	3.70		
5	Complex Decision Making Reaction Time	75.00	96.30	21.30		
5	Complex Decision Making Efficiency	33.00	96.30	63.30		
5	Tracking	80.00	96.42	16.42		
5	Slow Motion Inference	27.00	95.31	68.31		
5	Fast Motion Inference	81.00	95.47	14.47		
5	Spatial Orientation	60.00	98.63	38.63		
5	Perceptual Speed	83.30	94.95	11.65	62.93	94.81
7	Dial Reading	28.80	85.10	56.30		
7	Simple Decision Making	47.50	90.67	43.17		
7	Visual Acuity	28.40	89.29	60.89		
7	Complex Decision Making Accuracy	85.00	98.70	13.70		
7	Complex Decision Making Reaction Time	69.50	98.70	29.20		
7	Complex Decision Making Efficiency	28.30	98.70	70.40		
7	Tracking	50.00	94.28	44.28		
7	Slow Motion Inference	20.20	92.44	72.24		
7	Fast Motion Inference	52.60	92.87	40.27		
7	Spatial Orientation	46.70	95.18	48.48		
7	Perceptual Speed	70.00	92.19	22.19	47.91	93.46

5.0 RESULTS

5.1 Cognitive Functions: Theoretical vs. Experimental

In this section results are depicted in scatter plots showing theoretical versus experimental performance at 3, 5 and 7 Gz. A trendline that approximates a linear regression has been added to the plots to show the overall decrement in cognitive function.

Figure 9 shows a scatter plot of average performance values within the range of 1 to 7 Gz for the instrument reading task. An average decrease in performance of 3% for each one Gz increase in acceleration is shown in the empirical results as opposed to nearly 10% performance decrease for the NTI model.

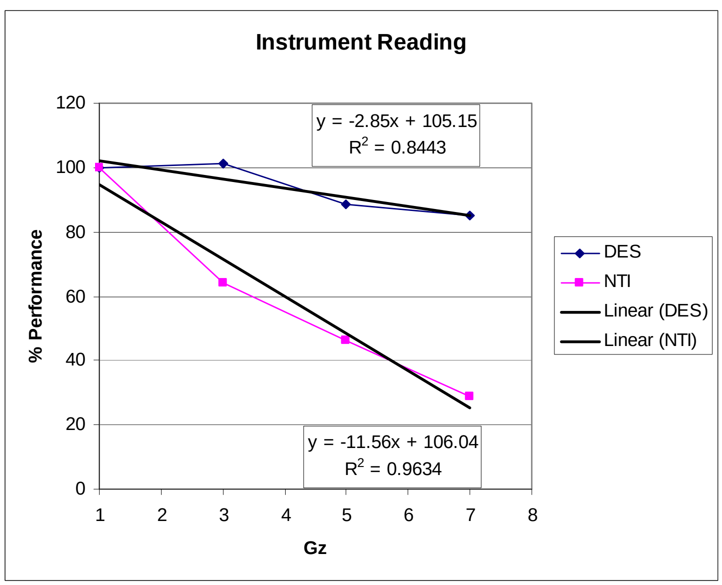


Figure 9: Instrument Reading

Figure 10 shows a similar scatter plot showing the performance decrement associated with the simple decision making task. In this area there was a performance decrease of about 2 and 9 percent per Gz increase for experimental and theoretical results respectively.

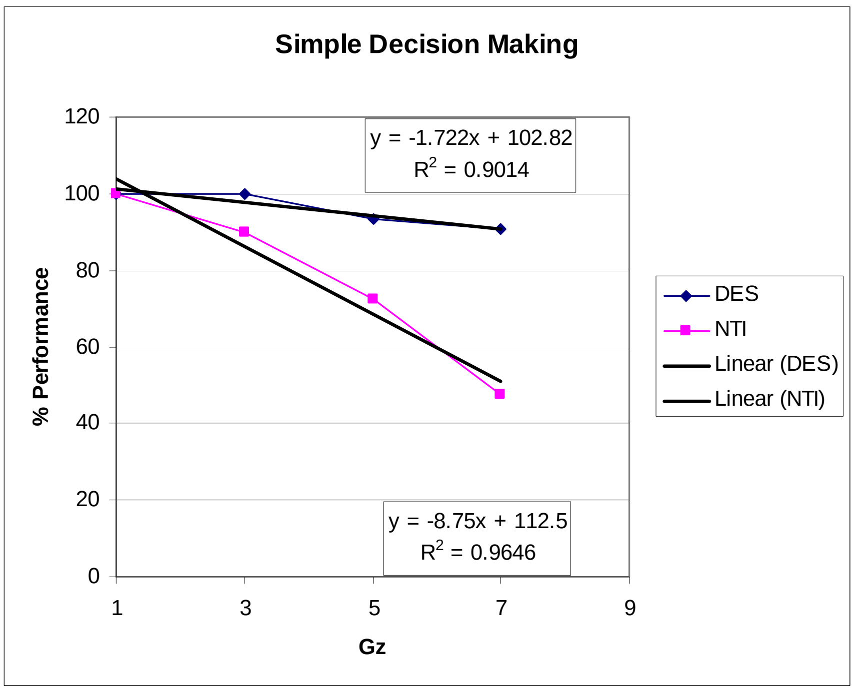


Figure 10: Simple Decision Making

Performance decrement for the visual acuity task as shown below exhibited a marked divergence from the theoretical values resulting in 13% per Gz increase experimentally versus 2% per Gz increase for the NTI model.

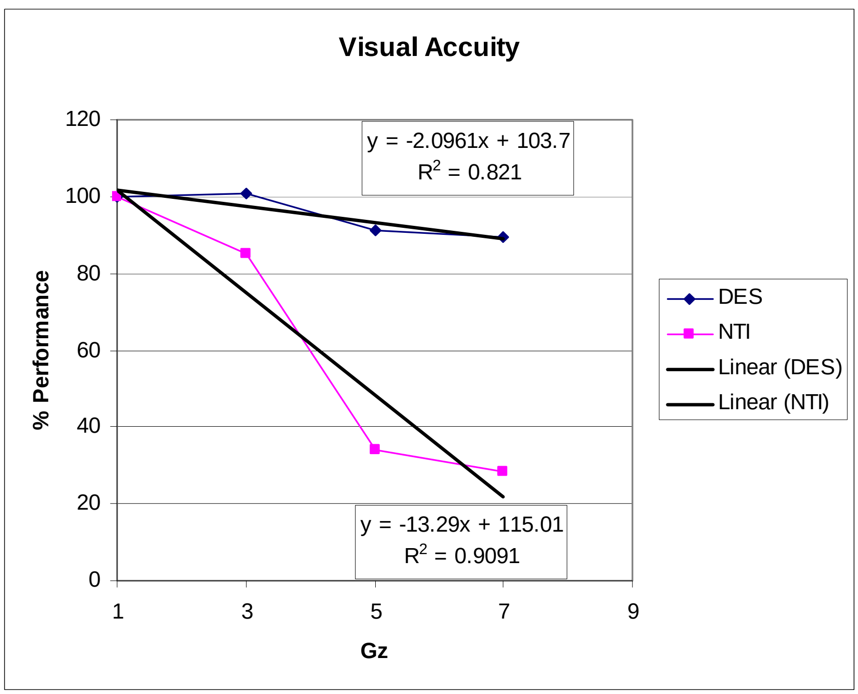


Figure 11: Visual Accuity

The complex decision making accuracy results shown in figure 12 below showed the least divergence of all G-PASS tests when compared to the results predicted in the NTI look-up tables. It also bears notice that experimental results at the five Gz level show a lesser per Gz performance decrement of 0% than the theoretical results predicted in the NTI model of 4% at this same level of G-force. This was one of two instances of such an occurrence, the other being at the three Gz level for the fast motion inference task. Otherwise there was an overall decrease in performance of approximately ½ % per Gz experimentally as opposed to 2% per Gz theoretical.

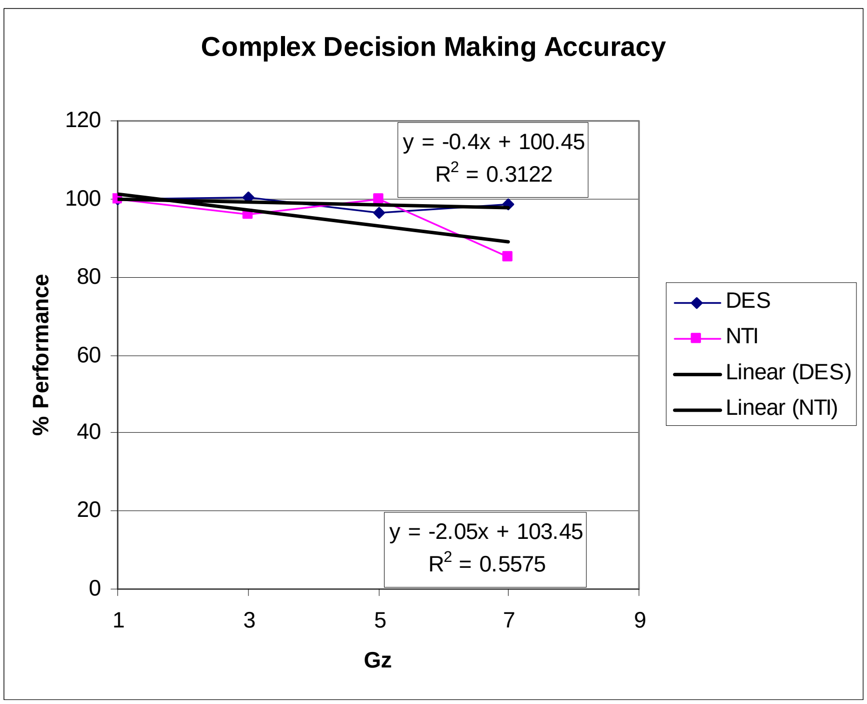


Figure 12: Complex Decision Making Accuracy

The scatter plot for the complex decision making reaction time test is shown in figure 13 below. Here, theoretical values for performance decrease by approximately ½ % per Gz increase as opposed to a little over 5% performance decrement per Gz increase empirically.

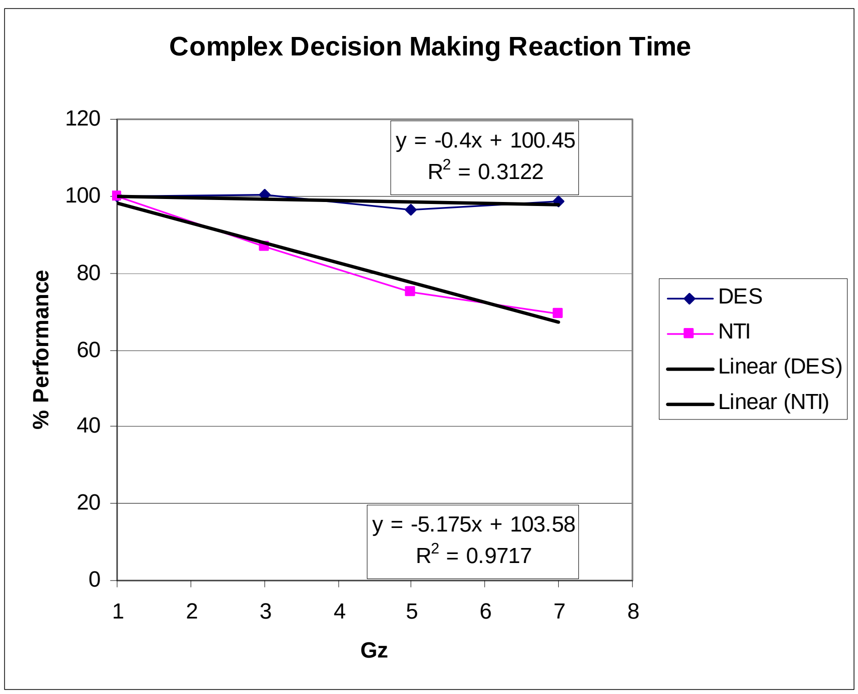


Figure 13: Complex Decision Making Reaction Time

The plot for complex decision making efficiency illustrated in figure 14 shows a large divergence between the theoretical prediction and experimental results. Average performance decrement of almost ½ % per Gz increase experimentally is contrasted to over 11% performance decrement for each Gz increase theoretically.

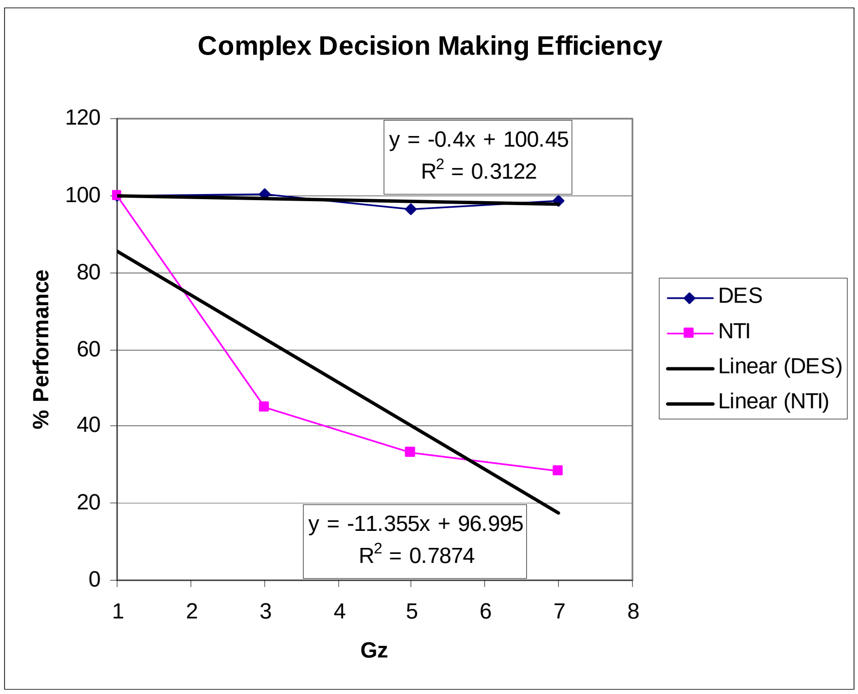


Figure 14: Complex Decision Making Efficiency

For the tracking test shown in figure 15 it was found that a 1% performance decrement per Gz increase occurred experimentally as opposed to 8% for the NTI model.

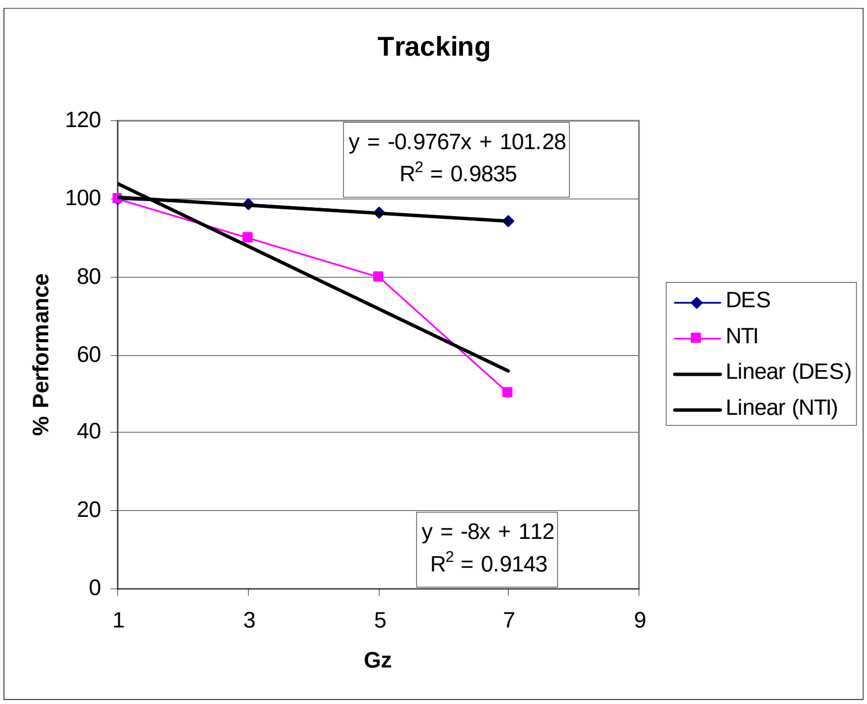


Figure 15: Tracking

Figure 16 shows the results for the slow motion inference task. This task exhibited the greatest degree of divergence between theoretical and empirical results. Experimentally, performance decreased by a little over 1% per Gz increase as opposed to a 15% decrement in performance per Gz theoretically.

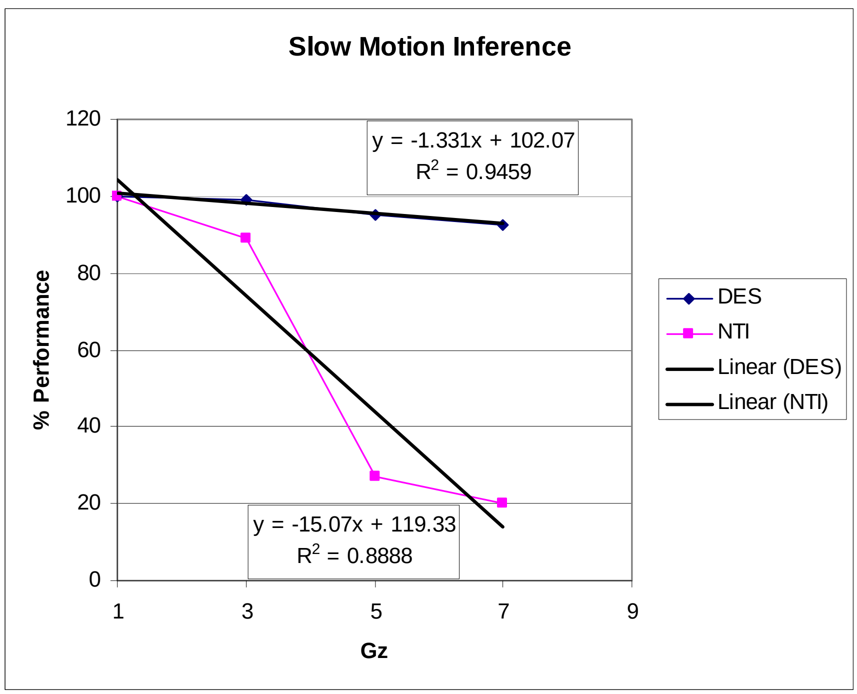


Figure 16: Slow Motion Inference

At the three Gz level, fast motion inference was one of two instances where the value for performance exceeded that exhibited empirically shown in figure 17 below. Overall, performance decreased by about 1¼ % per Gz increase experimentally as compared to about 9% per Gz increase predicted by the NTI model.

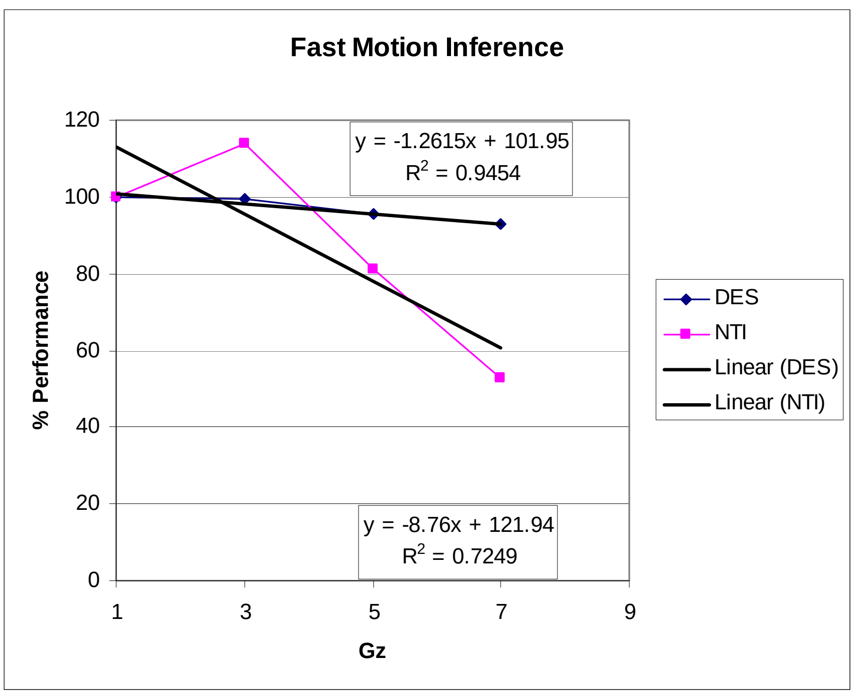


Figure 17: Fast Motion Inference

Figure 18 shows a decrease in performance at nearly 1% per Gz increase experimentally as opposed to nearly 7% performance decrement predicted by the NTI model.

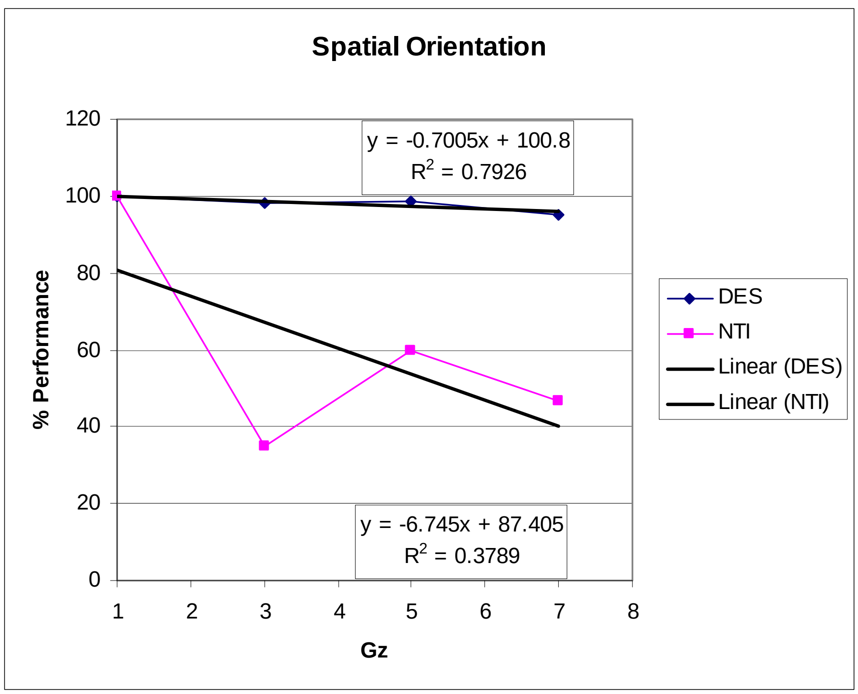


Figure 18: Spatial Orientation

5.2 Cognitive Functions, Theoretical vs. Experimental Results at 3, 5 & 7 Gz

Results are here represented in clustered column plots showing a comparison of experimental data processed by means of the NTI T-matrix versus cognitive function (as a percentage) predicted by the look-up tables found in the NTI model.

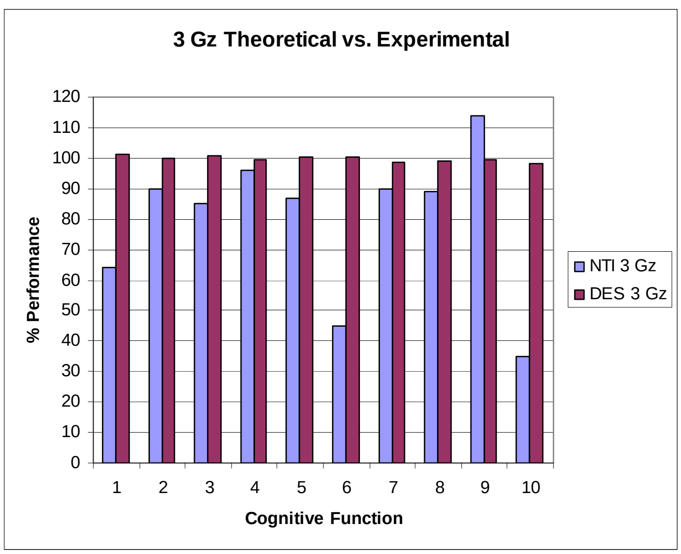


Figure 19: 3 Gz Clustered Column Plot of Performance at 3 Gz

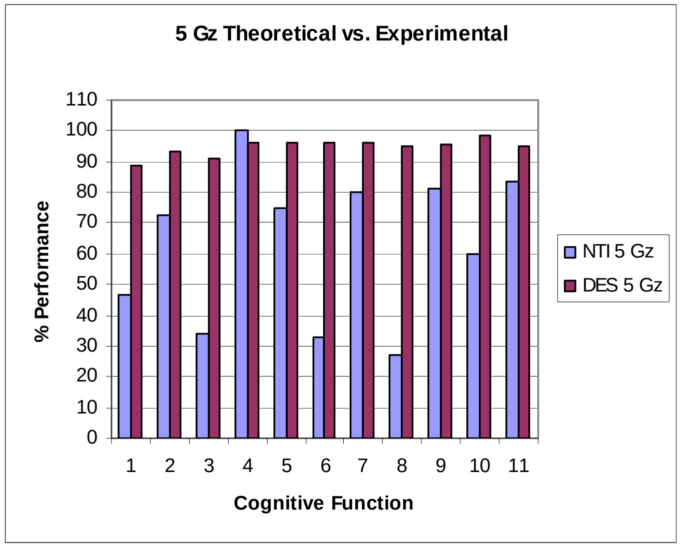


Figure 20: 5 Gz Clustered Column Plot of Performance at 5 Gz

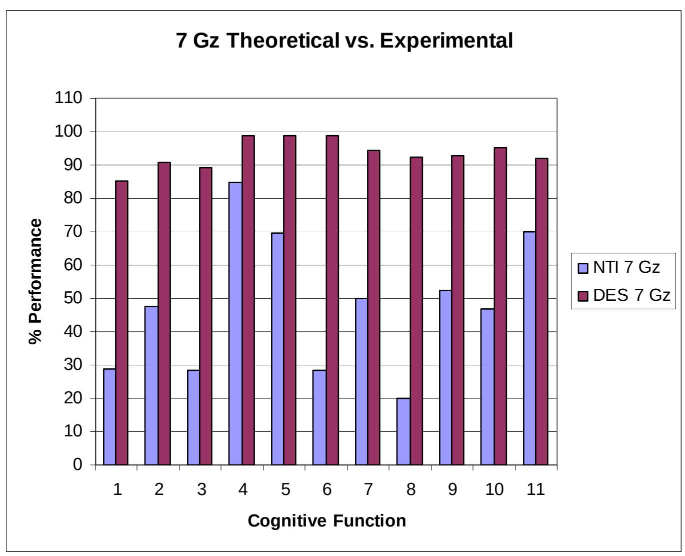


Figure 21: 7 Gz Clustered Column Plot of Performance at 7 Gz

5.3 Tabular Results of Estimated Performance Decrement at 3, 5 and 7 Gz

Here are presented the results (in tabular form) for the estimated performance decrement per Gz. These results arise from the equation of the trendlines superimposed on the previous plots of cognitive function. The values for performance decrement per Gz are taken from the trendline equations and represent the slope of this line.

Table 6: Theoretical vs. Experimental Performance Decrement (/Gz)

Cognitive Function	% Decrement/Gz NTI	% Decrement/Gz DES	% Decrement/Gz Difference
Instrument Reading	11.56	2.85	8.71
Simple Decision Making	8.75	1.72	7.03
Visual Accuity	13.29	2.10	11.19
Complex Decision Making (Accuracy)	2.05	0.40	1.65
Complex Decision Making (R. T.)	5.18	0.40	4.78
Complex Decision Making (Eff.)	11.36	0.40	10.96
Tracking	8.00	0.98	7.02
Slow Motion Inference	15.07	1.33	13.74
Fast Motion Inference	8.76	1.26	7.50
Spatial Orientation	6.75	0.70	6.05
Perceptual Speed	4.34	1.40	2.94
Average	**8.65**	**1.23**	**7.42**

5.4 Comparisons of n Gz Theoretical to 7 Gz Experimental Performance

This section compares theoretical performance at 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 Gz to the 7.0 Gz DES experimental results. Comparisons are depicted in both tabular and graphical formats.

Table 7: 1.0 Gz Theoretical vs. 7.0 Gz Experimental

Cognitive Function	1.0 Gz NTI Perf. [%]	7 Gz DES Perf. [%]	Difference (Abs.Val)	Avg. Abs. Diff.
Dial Reading	100.000	85.100	14.900	
Simple Decision Making	100.000	90.673	9.327	
Visual Acuity	100.000	89.285	10.715	
Complex Decision Making Accuracy	100.000	98.700	1.300	
Complex Decision Making Reaction Time	100.000	98.700	1.300	
Complex Decision Making Efficiency	100.000	98.700	1.300	
Tracking	100.000	94.283	5.717	
Slow Motion Inference	100.000	92.438	7.562	
Fast Motion Inference	100.000	92.865	7.135	
Spatial Orientation	100.000	95.180	4.820	
Perceptual Speed	100.000	92.188	7.812	6.535

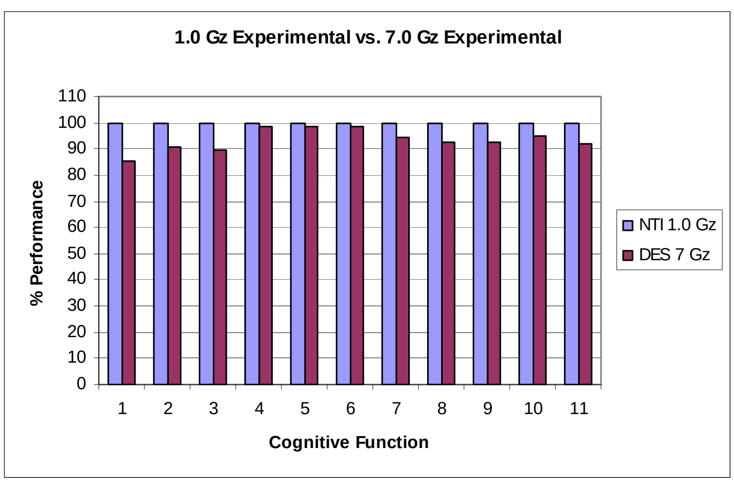


Figure 22: 1.0 Gz Theoretical vs. 7.0 Gz Experimental

Table 8: 1.5 Gz Theoretical vs. 7.0 Gz Experimental

Cognitive Function	1.5 Gz NTIPerf. [%]	DES 7.0 Gz [%]	Difference (Abs. Val.)	Difference [%]
Dial Reading	100.000	85.100	14.900	
Simple Decision Making	93.500	90.673	2.827	
Visual Acuity	97.500	89.285	8.215	
Complex Decision Making Accuracy	98.500	98.700	0.200	
Complex Decision Making Reaction Time	97.000	98.700	1.700	
Complex Decision Making Efficiency	79.500	98.700	19.200	
Tracking	98.500	94.283	4.217	
Slow Motion Inference	97.300	92.438	4.862	
Fast Motion Inference	103.500	92.865	10.635	
Spatial Orientation	78.500	95.180	16.680	
Perceptual Speed	99.000	92.188	6.812	8.204

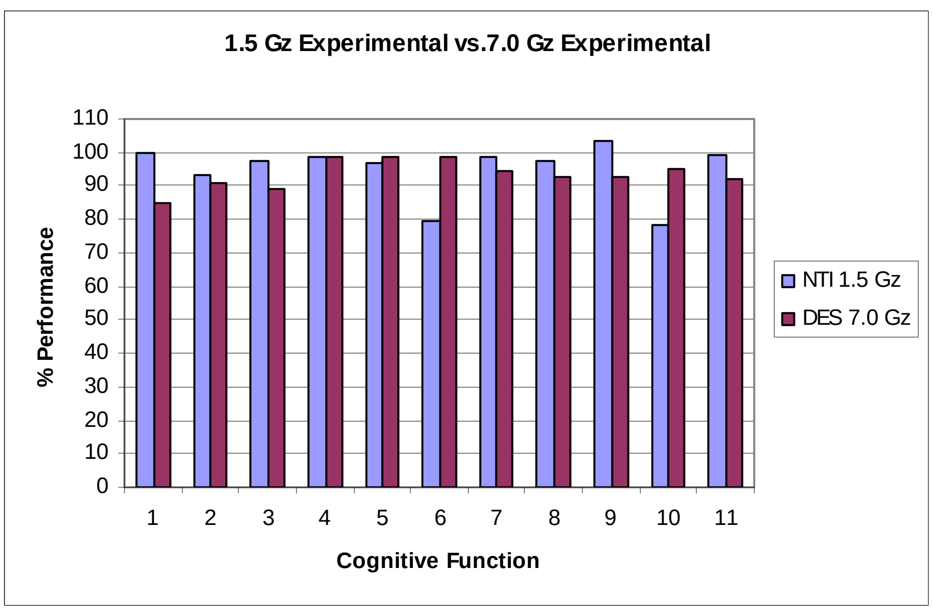


Figure 23: 1.5 Gz Theoretical vs. 7.0 Gz Experimental

Table 9: 2.0 Gz Theoretical vs. 7.0 Gz Experimental

Cognitive Function	NTI 2.0 Gz [%]	DES 7.0 Gz [%]	Difference (Abs. Val.)	Difference [%]
Dial Reading	88.000	85.100	2.900	
Simple Decision Making	87.000	90.673	3.673	
Visual Acuity	95.000	89.285	5.715	
Complex Decision Making Accuracy	97.000	98.700	1.700	
Complex Decision Making Reaction Time	94.000	98.700	4.700	
Complex Decision Making Efficiency	59.000	98.700	39.700	
Tracking	97.000	94.283	2.717	
Slow Motion Inference	94.500	92.438	2.062	
Fast Motion Inference	107.000	92.865	14.135	
Spatial Orientation	57.000	95.180	38.180	
Perceptual Speed	98.000	92.188	5.812	11.027

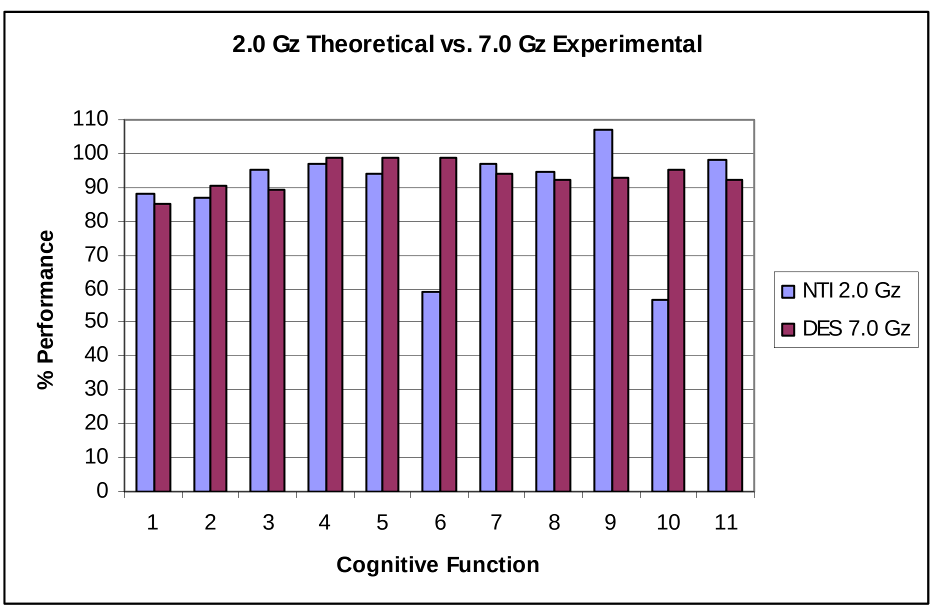


Figure 24: 2.0 Gz Theoretical vs. 7.0 Gz Experimental

Table 10: 2.5 Gz Theoretical vs. 7.0 Gz Experimental

Cognitive Function	NTI 2.5Gz [%]	DES 7.0 Gz [%]	Difference (Abs. Val.)	Difference [%]
Dial Reading	76.000	85.100	9.100	
Simple Decision Making	92.000	90.673	1.327	
Visual Acuity	90.000	89.285	0.715	
Complex Decision Making Accuracy	96.500	98.700	2.200	
Complex Decision Making Reaction Time	90.500	98.700	8.200	
Complex Decision Making Efficiency	52.000	98.700	46.700	
Tracking	93.500	94.283	0.783	
Slow Motion Inference	91.800	92.438	0.638	
Fast Motion Inference	110.500	92.865	17.635	
Spatial Orientation	46.000	95.180	49.180	
Perceptual Speed	89.000	92.188	3.188	12.697

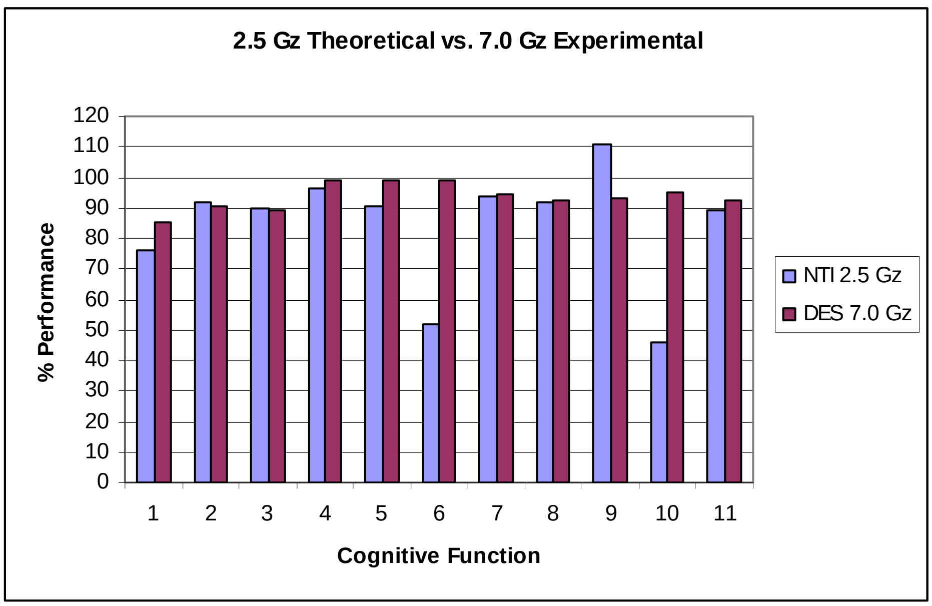


Figure 25: 2.5 Gz Theoretical vs. 7.0 Gz Experimental

Table 11: 3.0 Gz Theoretical vs. 7.0 Gz Experimental

Cognitive Function	NTI 3.0 Gz [%]	DES 7.0 Gz [%]	Difference (Abs. Val.)	Difference [%]
Dial Reading	64.000	85.100	21.100	
Simple Decision Making	90.000	90.673	0.673	
Visual Acuity	85.000	89.285	4.285	
Complex Decision Making Accuracy	96.000	98.700	2.700	
Complex Decision Making Reaction Time	87.000	98.700	11.700	
Complex Decision Making Efficiency	45.000	98.700	53.700	
Tracking	90.000	94.283	4.283	
Slow Motion Inference	89.000	92.438	3.438	
Fast Motion Inference	114.000	92.865	21.135	
Spatial Orientation	35.000	95.180	60.180	
Perceptual Speed	80.000	92.188	12.188	17.762

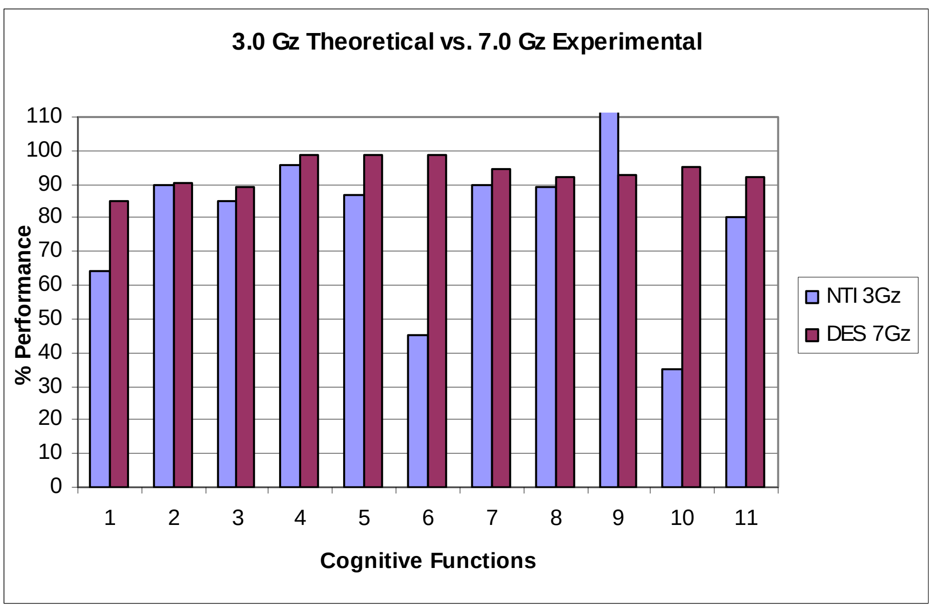


Figure 26: 3.0 Gz Theoretical vs. 7.0 Gz Experimental

Table 12: 3.5 Gz Theoretical vs. 7 Gz Experimental

Cognitive Function	NTI 3.5 Gz [%]	DES 7.0 Gz [%]	Difference (Abs. Val.)	Difference [%]
Dial Reading	59.600	85.100	25.500	
Simple Decision Making	87.500	90.673	3.173	
Visual Acuity	84.000	89.285	5.285	
Complex Decision Making Accuracy	95.500	98.700	3.200	
Complex Decision Making Reaction Time	80.000	98.700	18.700	
Complex Decision Making Efficiency	36.000	98.700	62.700	
Tracking	87.500	94.283	6.783	
Slow Motion Inference	73.500	92.438	18.938	
Fast Motion Inference	105.800	92.865	12.935	
Spatial Orientation	41.300	95.180	53.880	
Perceptual Speed	85.000	92.188	7.188	19.844

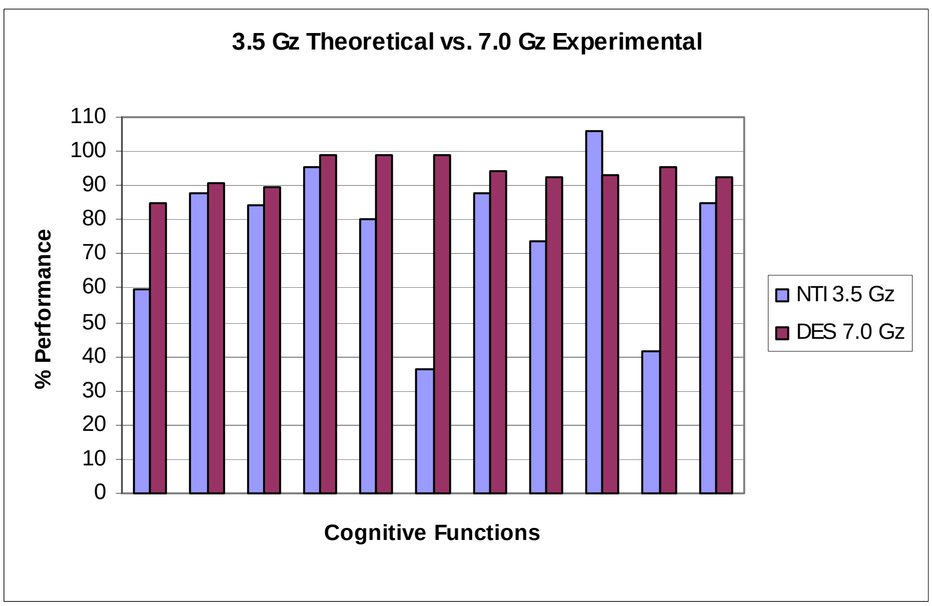


Figure 27: 3.5 Gz Theoretical vs. 7.0 Gz Experimental

6.0 Discussion and Conclusions

The greatest differences in cognitive function within the 3 Gz theoretical versus experimental results occurred with spatial orientation showing a disparity of nearly 63.2 %. Within the 5 Gz and 7 Gz comparisons slow motion inference exhibited the greatest differences of 68.3% and 72.2% respectively. Slow motion inference also showed the greatest difference in a comparison on a percent performance decrement per Gz basis. In this respect the NTI model predicts nearly a 14 percent increase in performance over the AFRL/HEPG results. The greatest variations in performance may be observed in the 7 Gz theoretical versus experimental comparison. This is not surprising when one considers that anti-G suits and AGS maneuvers were employed in the procurement of the experimental results.

The problem of comparing a theoretical model based on “relaxed G” conditions to experimental results that utilize anti-G suits is particularly vexing but not insurmountable. The solution to this problem lay in comparing lower Gz results for the NTI model to higher (7 Gz) results for the AFRL/HEPG experiments. This is possible because it is known that anti-G suits and straining maneuvers may add up to 6.5 Gz to relaxed G tolerance (Nicholas D. C. Green (1999)).

Subject participation and effort can have a significant effect on the efficacy of an AGSM. Hence, a range of NTI model performance data is here compared to the AFRL/HEPG experimental results. Differences in percent performance for the NTI model from 1.0 - 3.5 Gz, versus AFRL/HEPG experimental data at +7.0 Gz appear in table 10.

AFRL/HEPG subjects are rigorously trained and coached in the performance of the AGSM and it can be assumed that the first entry in table 10 has the greatest validity showing a difference in performance of 6.5%. The last entry in the table would represent a tendency for most subjects to execute the AGSM very poorly obtaining an average increase in G tolerance of only 2.5 to 3.0 Gz.

The apparent conclusion would seem to be that the NTI model is indeed validated. However, upon completion of the study, additional data may show otherwise or perhaps bring the experimental results even closer to the NTI model.

Table 13: Comparison of +n Gz Theoretical to +7.0 Gz Experimental

+ n Gz Theoretical vs. +7.0 Gz Experimental	
Theoretical Gz	**Difference [%]**
1.0	6.54
1.5	8.20
2.0	11.03
2.5	12.70
3.0	17.76
3.5	19.84

7.0 Future Research

Future research being conducted at AFRL/HEPG is of great importance and may prove to be an indispensable addition to the field of acceleration science. When all of the pertinent data is collected a true empirical model may be formulated and an approximate equation for cognition as a function of increased G force may be formulated. This end would necessarily be accomplished in rigorous statistical analysis but may also be approximated with composite data and simple curve fitting. This graduate student has utilized the MatLab® basic fitting function for the NTI theoretical data. The Empirical data has been treated in a similar fashion and has been fitted with a 4th degree polynomial. The fitted curves along with the corresponding equations are shown for the NTI theoretical and DES empirical data in figures 28 and 29 following.

Figure 28: Fourth Degree Polynomial Curve Fit for Theoretical Data

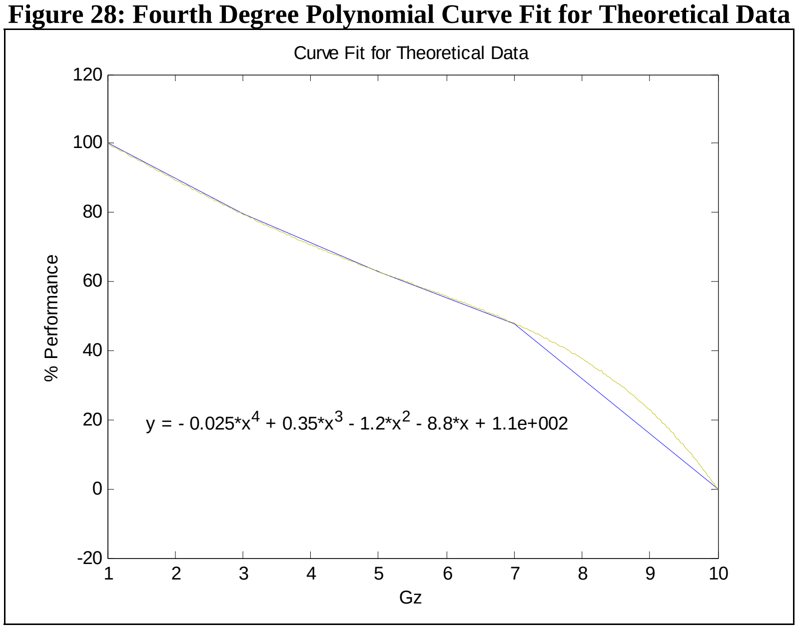
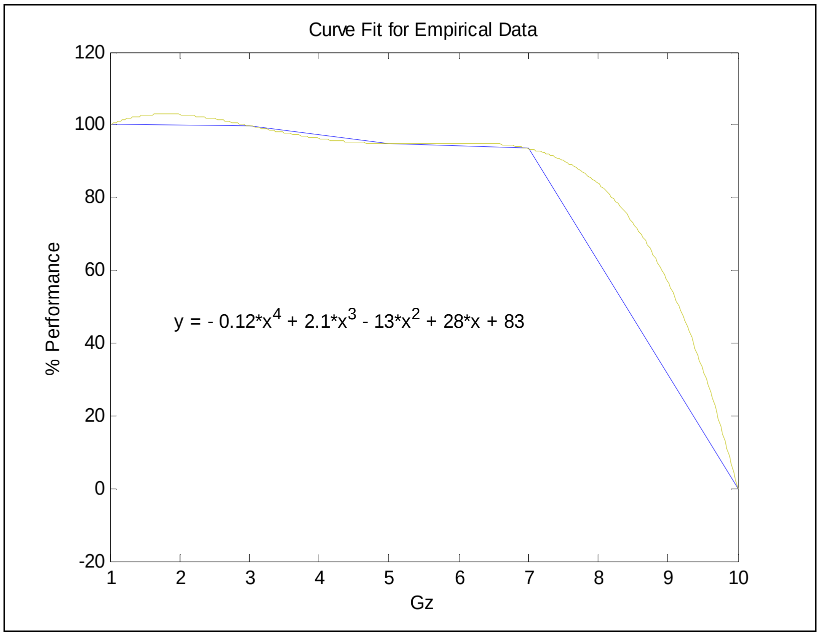


Figure 29: Fourth Degree Polynomial Curve Fit for Empirical Data



As previously stated models of this nature lend themselves to programming applications and may be utilized for approximating human performance under varying G conditions in a combat simulator or for other appropriate purposes. More empirical data in the form of performance values under more G plateau levels could serve to produce models having a greater degree of accuracy.

There are some inconsistencies that tend to appear when human experimentation involves a stressor. This graduate student found it interesting that subjects actually seemed to exhibit increased performance at 2 to three G's as compared to static (1 G) conditions in a cockpit simulator. Increased G forces imposed on humans are nothing if not a source of stress. When experiencing stress the human mind sets itself to the task of relieving or escaping the source of the stress as soon as possible. Subconsciously, one believes that finishing the trial at hand quickly will reduce the total amount of time where stress is experienced even though nothing could be further from the truth. For example, when starting an automobile on a bitterly cold winter day, persons tend to insert the key into the ignition switch more quickly than they would on a day where the temperature is moderate. Consciously, the person realizes that the extra split second gained from this action will not really make much difference (if any) as to how quickly they begin to feel warmth. In fact, in ones' haste they may miss the switch and as a result have to repeat this trial resulting in an even longer period of time exposed to the stressor. As the old adage goes, "the hurrier we go the behinder we get". If the level of the stress is low to moderate the subjects increased speed could result in an (erroneously) increased value for performance. At higher stress levels the true value for performance will be observed.

Wickens et al. described a phenomena which they coined perceptual tunneling. Perceptual tunneling (Wickens, C. D., Lee, J., Liu, Y. D., & Gordon-Becker, S., 2003) "describes the tendency to restrict the range or breadth of attention, to concentrate very hard on one "thing," and to ignore surrounding information sources (this "thing" is often the source of stress or information on how to avoid it)". Cognitive tunneling "describes the tendency to focus attention exclusively on one hypothesis of what is going on (e.g., only one failure candidate as the cause of an alarm) and ignore a potentially more creative diagnosis by considering a wider range of options" (Wickens, C. D., Lee, J., Liu, Y. D., & Gordon-Becker, S., 2003). Cognitive tunneling (also known as attentional narrowing) may be associated with arousal. A given level of arousal may be associated with measurable physiological attributes such as heart rate or pupil diameter. "These measures reflect increased arousal or effort associated with the motivational variable of "trying harder" as tasks impose increasing difficulty (Wickens, C. D., & Hollands, J., 2000)."

Any or all of these theories may be responsible for increased performance levels observed at lower G as compared to 1 G baseline performance values. Moreover, studies that build upon these concepts should make for excellent resources for further research.

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