MODELING AND CHARACTERIZATION OF ACUTE STRESS UNDER DYNAMIC TASK CONDITIONS

by

ANGEL M. MILLAN B.
M.S. Embry-Riddle Aeronautical University, 2004
B.S. Universidad Nacional Experimental Politécnica de la Fuerza Armada, 1999

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2011

Major Professor: Lesia L. Crumpton-Young, Ph.D.

ABSTRACT

Stress can be defined as the mental, physical, and emotional response of humans to stressors encountered in their personal or professional environment. Stressors are introduced in various activities, especially those found in dynamic task conditions when multiple task requirements must be performed. Stress and stressors have been described as activators and inhibitors of human performance. The ability to manage high levels of acute stress is an important determinant of successful performance in any occupation. In situations where performance is critical, personnel must be prepared to operate successfully under hostile or extreme stress conditions; therefore training programs and engineered systems must be tailored to assist humans in fulfilling these demands. To effectively design appropriate training programs for these conditions, it is necessary to quantitatively describe stress. A series of theoretical stress models have been developed in previous research studies; however, these do not provide quantification of stress levels nor the impact on human performance. By modeling acute stress under dynamic task conditions, quantitative values for stress and its impact on performance can be assessed.

Thus, this research was designed to develop a predictive model for acute stress as a function of human performance and task demand. Initially, a four factor two level experimental design [2 (Noise) x 2 (Temperature) x 2 (Time Awareness) x 2 (Workload)] was performed to identify reliable physiological, cognitive and behavioral responses to stress. Next, multivariate analysis of variance (*n*=108) tests were performed, which showed statistically significant differences for physiological, cognitive and behavioral responses. Finally, fuzzy set theory techniques were used to develop a comprehensive stress index model. Thus, the resulting stress index model was constructed using input on physiological, cognitive and behavioral responses to stressors as well as characteristics inherent to the type of task performed and personal factors that interact as mediators (competitiveness, motivation, coping technique and proneness to boredom). Through using this stress index model to quantify and characterize the affects of acute stress on human performance, these research findings can inform proper training protocols and help to redesign tasks and working conditions that are prone to create levels of acute stress that adversely affect human performance.

To my lovely and understanding wife, who has endured the sacrifices and disappointments of being married to an engineer working on a Ph.D. Only you know what it took for us to reach this goal.

This work is especially dedicated to you; my beautiful Ailed

To my: Father, Mother, and Sister, Angel Jóse, Maria Auxiliadora and Mariangel, who have always been present in every step of my life, supporting me and most importantly cheering me up when things were not happening as planned, I say thanks!.

ACKNOWLEDGMENTS

I am sincerely grateful to all of the key individuals who have helped in successfully completing this research.

I am thankful to Dr. Crumpton-Young, my mentor in academia and life, for supporting and believing in me, pushing me to strive higher and for giving me the opportunity to be your mentee; and

Also, I am grateful to Dr. Christopher Geiger, my second mentor, for his support, words of encouragement and important teachings. Thanks for being an excellent role model.

Mere words cannot express my gratitude to Dr. Clarence Rodrigues who encouraged me to consider embarking upon this rewarding adventure of pursing a Ph.D.

Additionally, I thank Dr. Pamela McCauley-Bush, Dr. Dima Nazal, and Dr. Kent Williams for serving on my committee and providing expertise, knowledge and support.

Finally, thanks to all my research participants who made this work possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

This research presents a predictive model for quantifying acute stress as a function of human performance and task demand. The model uses inputs from human responses to stressors (physiological, cognitive and behavioral) as well as characteristics inherent to the type of task performed and personal factors, such as competitiveness, boredom proneness, achievement, coping technique. The model quantifies stress levels using performance and task demand factors as dependent variables.

1.1. Motivation

Human factors issues are present in all situations in which humans interact with technology to accomplish an objective. System demands and new technologies are growing in complexity thus demanding more from humans' capabilities. Human performance is influenced by task demands, equipment used, and environmental conditions. In fact, the more complex the task, the higher the chances of lower performance; which may lead to catastrophic consequences depending on the type of job (Driskell & Salas, 1996; Hancock & Warm, 1989; Combs & Taylor, 1952; Stranks, 2005). Furthermore, the presence of uncontrollable factors like environmental conditions (sound, temperature, air pollution, etc), type of task (physically vs. cognitive demanding) or individual factors or traits such as task appraisal, personality, and attitude, play a significant role in human performance. All of the aforementioned factors influence one's stress level either as contributors to increasing stress or as moderators to reduce its perception. The presence of stressors that cause stress strain during critical tasks or operations are conditions to avoid or mitigate. (Driskell & Salas, 1996). However, there are cases where humans have no choice but to interact with machines and systems under the presence of stressors. Assessment of human performance under these conditions is necessary to establish appropriate training techniques, environments, or evaluate new designs where humans are involved. This assessment is required to efficiently complete the mission and avoid undesirable consequences.

1.2. Significance of the Problem

The impact of stress on performance is perhaps greater now than at any time in our history (Driskell & Salas, 1996; Edwards et al., 2007). We are living in an increasingly complex, high-technology world in which the potential for catastrophic error while performing critical work tasks has greatly increased. The increase in information communication technology, globalization of industries, automation, and changes in workplace patterns have all contributed to the transformation of work tasks (Sparks, et al, 2001). This new job complexity, task load and time pressure increases the potential of errors occurring. Stress has played a significant role in accident causation. Stress is the result of poor design methodologies and training philosophies that have not considered the impact of stressors on human operators while performing critical tasks within demanding environments. Early examples of this phenomenon are the Chernobyl accident, the USS Vincennes shooting of an Iranian plane, and the Tenerife aircraft catastrophe where two aircraft collided in the runway becoming the accident with most fatalities in the history of aviation totaling 583 deaths.

All of these accidents have a common factor, and it is the presence of stressors that were originated before or after the critical event was triggered. During the Chernobyl accident, a variety of unapproved changes in the operating procedure were deliberately made on the spot due to time pressure. Failure to include appropriate mechanisms and procedures that consider human capabilities under these conditions in the design and operation of the nuclear plant led to the catastrophic event. The Tenerife aircraft disaster was principally triggered by the urgency of the captain to take-off before violating the strict no-delays philosophy of the airline. Time pressure prevented the crew from effectively assessing weather conditions and heeding air traffic control instructions.

Finally, there are a variety of potential factors that could be considered as stressors and that contributed to the shot down of the Iranian commercial flight by the USS Vincennes. Some of these possible stressors are: lack of training on electronic warfare, psychology and mindset after engaging on a previous battle, confusion with flight time tables and time zones, poor design of radar interface. However, the most singular is the lack of proper illumination in the vessel's Combat Information Center. This environmental condition precluded the officer, who first spotted the plane on the radar screen, from adequately identifying and keeping track of the plane as a commercial flight.

1.3. Problem Statement

Human performance models have been used to evaluate work place and work task designs because full scale studies are costly, time consuming and require a significant amount of personnel. Because people are a crucial and an irreplaceable part of human-machine systems, it is substantially wiser and less expensive to consider the impact of human capabilities and limitations on system operation and modify the system before it is built, than to modify it to conform to human limitations after it has been constructed. Additionally, human capabilities need to be tested to determine appropriate training modules, and human performance modeling offers a tool for developing and enhancing training by evaluating human limitations. This information can be used to determine constraints for designing new systems. The combination of certain environmental conditions, type of task performed and individual factors create unpredictable performance scenarios that exceed human performance limitations. Advanced analysis and predictive modeling of these conditions will help to forecast the impact of acute stress on human performance, thereby, informing the design of future systems and the improvement of current systems as well as enhancing training protocols.

1.4. Research Goals and Objectives

The goal of this research is to develop a quantitative predictive model that will provide values for stress and human performance as a function of task demands. The primary objectives of this research are as follows:

1. To measure physiological, cognitive and behavioral responses to stressors;
2. To characterize the level of stress resulting from special stressors; and
3. To model stress and human performance as a function of task demands.

The intent of this research is to aggregate inputs of physiological, cognitive and behavioral responses of acute stress experienced by humans while performing work task into a quantitative model. This comprehensive quantitative model can be used to describe levels of stress experienced by humans as a result of stressors present in fulfilling task demands.

1.5. Research Scope

This research focuses on characterizing acute stress and its impact in human performance. The objective of this study is not to address chronic or long term stress; rather it focuses on acute stress which occurs for a short duration of time as a result of a specific situation and environmental conditions. The current research literature does not contain any unified stress measurement tools or quantitative models for predicting stress levels and performance output. The creation of a predictive model based on physiological, cognitive and behavioral responses to stressors will produce quantitative values for determining stress levels related to human performance capabilities and task demands.

CHAPTER 2: LITERATURE REVIEW

2.1. Stress

The word stress is derived from the latin word *strictus*, which means “to tighten.” Stress has traditionally been associated with negative affects on human behavior and performance. The contributors of stress are rarely understood and there is no single test that can clearly explain one’s stress level. Stress is used by researchers not only as a stimulus but as a process that links variables, inside and outside the individual, to produce a reaction that is psychologically, and, often, physically debilitating in studies to understand this phenomenon (Koslowsky, 1994).

Stress has different meanings to different people. Almost anything that a person can think of, pleasant or unpleasant can be described as a source of stress (Stranks, 2005). The word has always been linked to a negative image, despite the fact that stress is experienced under thrilling situations such a ride in a roller coaster. The literature presents several definitions for stress according to the field of study and the objective of the research. From a physiological perspective, stress has been observed as the taxation of the body’s resources in order to respond to some environmental circumstances; the non-specific response of the body to any demands made upon it. From a psychological perspective, stress is a dynamic phenomenon associated with the quality of transactions between a person and their environmental demands (Lazarus & Folkman, 1984; Hancock & Warm, 1989). Stress has also been identified as the common response to attacks (Selye, 1976). More specifically to the work setting, stress has been described as an incompatibility between the individual expectation and his or her work environment. Stress at work maybe referred to as a psychological injury or illness (McDonald, W. 2003).

From a system point of view, stress occurs when demands made on individuals do not match the resources available or meet the individual’s needs and motivation. Stress will arise if the workload is too large for the number of workers and time available. Equally, a boring or repetitive task which does not use the potential skills and experience of some individuals will cause them stress (Stranks, 2005).

Stress can be defined as the mental, physical, and emotional response of humans to stressors encountered in their environment. Anything can be considered as source of stress or stressor depending on the person and or the environment where he or she is interacting on. Example of stressors include: temperature, food/water deprivation, task demand, noise, and light, among many others. The effects of the stressors over the human have being studied according to their duration. Thus, the literature defines three specific levels of stress according to the exposure level to stressors: Acute, episodic and chronic.

1. Acute stress is the most common; it results from demands and pressures of the recent past and anticipated demands and pressures of the near future. In small doses, acute stress can be thrilling and exiting like the one experience on a roller coaster but too much is exhausting. In the same way, overdoing on short-term stress can lead to psychological distress, tension headache, upset stomach and other symptoms. Due to its short term nature acute stress does not have enough time to cause extensive damage associated with long term stress; however it creates changes in performance (APA Help Center).

2. Episodic is a form of acute stress that occurs more frequently. Episodic stress is present in people whose lives are so chaotic that they operate in constant chaos and crisis; always in a rush but always late. It is common for these people to be over-aroused, short-tempered, irritable, anxious, and tense. They tend to be abrupt and sometimes their irritability becomes hostility. People with type-A personality or those who are pessimistic tend to develop this type of stress during their lives. The symptoms of episodic stress are the symptoms that can be expected from over exposure to acute stress: persistent tension headaches, migraines, hypertension, chest pain, and heart disease. This type of stress needs to be treated by a professional and may require several months of therapy, because it is so ingrained with the individual's personality that he or she does not see anything wrong with their behavior (APA Help Center).

3. Chronic stress is the opposite of acute stress. This is the type of stress that wears people down and it is usually experienced day after day, with no visible escape. It adversely affects both mental and physical health, leading to mental breakdown and possibly death. This type of stress can be caused by poverty, dysfunctional families, living in a war zone, or being trapped in an undesirable situation for a long period of time such as an unhappy marriage or in a despised job or career. The worst aspect of chronic stress is that people get accustomed to it. Under these conditions, people are brought to a final, fatal mental/physical breakdown. Chronic stress can ultimately lead to suicide, violence, heart attack, stroke, and perhaps, even cancer. Because physical and mental resources are

exhausted through long-term attrition, the symptoms of chronic stress are difficult to treat and may require extended medical as well as behavioral treatment and stress management (APA Help Center).

Of these three types of stress, acute stress is the kind that induces the greatest variety of physiological and cognitive responses in the shortest amount of time. Acute stress is sudden, novel, unexpected, and of short duration. Stressors for this type of stress would include personal threats, time constraint, noise, task overload, and so on. Unlike the other types of stress, people are aware of acute stress because physical and mental resources change through short term attrition, thereby causing changes in performance (Driskell, et al., 1988).

2.2. Stress and Human Performance

Stress and its impact on human performance has been the object of several discussions throughout the years. Several works have established a consistent relation between stress and performance (Hancock, et al., 2003; Kosloswsky, 1998; Edwards et al., 2007). Although there has not been agreement to how stress and stressors affect performance there is an indisputable idea that these do influenced human behavior.

Moreover, the impact of stress on human performance has raised enough concern to develop countermeasures and training programs to cope with the phenomena. Disasters such as Three Mile Island, Chernobyl and the USS Vincennes have underscored the importance of developing training intervention to offset the effects of real world stressors on complex cognitive tasks. There have been some efforts to address this issue (Cannon-Bowers, et al., 1991). One remarkable example of this has been the research conducted to develop a training program for enhancing the tactical decision making performance of Navy Combat Information Center (CIC) operators. The training is the result of scenarios developed after the incidents of the USS Vincent. These CIC environments are characterized by the rapidly unfolding events of warfare scenarios that create stressors such as high workload, information ambiguity, sever time pressure and sustained operations (Driskel & Salas, 1996).

Johnson, Smith-Jentsch and Cannon-Bowers (1997) highlight the need for development of training that incorporates naturalistic stressors so that performance is enhanced. They include as naturalistic stressors both high- and low-demand task situations. For example, sustained operations, ill-structure problems, complex tasks, uncertainty, time pressure, high stakes, multiple players, interpersonal conflicts, and physical danger imply high-demand task situations. However, underutilization of skills and highly routine, boring tasks can be stressors as well.

Research has shown that training intervention that include task specific stressors have been successful in improving performance (Larsson, 1987; Meichenbaum, 1996; Siegel et al., 1980). Some examples of this are the cognitive and behavioral stress coping training program such as Meichenbaum's (1996) Stress Inoculation Training, Smith's (1980) Stress Management Training, and Suinn's (1990) Anxiety Management Training gradually expose trainees to stressors while they practice stress-coping skills (Meichenbaum, 1996).

The literature reports that performance increases and diminishes under the presence of stress and various stressors (Hancock & Warm 1989). Stress has been a key contributor in accident causation. Stress has been described as an activator and also inhibitor of human performance initially by Yerkes and Dodson (1908) in their arousal performance theory, and later by Hancock, Ganey and Szalma (2003). The research literature established that the ability to manage high levels of acute stress is an important determinant of successful performance in any occupation.

In situations where performance is critical, personnel must be prepared to operate successfully under hostile or extreme stress conditions, therefore training must be tailored to fulfill this demand. In order to design appropriate training for these conditions, it is necessary to first quantify stress and then assess its impact on performance. By modeling stress under dynamic conditions quantitative values for stress could be assessed. Quantitative modeling and assessment of stress has not been performed before; researchers have developed a series of theoretical models, correlations have been established between stressors and responses, but these models have not been quantified.

Driskell and Salas (1996) present a heuristic model of the stress process. This model provides a basic framework for discussing the determinants and consequences of stress. It describes the process in a four stages cascade scheme that is activated by the introduction of environmental stimuli such as noise, threat, time pressure, task load, or other potential stressors. The presence of these stressors leads to the second stage which is referred as the appraisal process. The appraisal process is the evaluation of the environmental event. According to Lazarus and Folkman, (1984) there are two phases of event appraisal. The primary appraisal involves evaluation of the extent of a threat that an event pose. Secondary appraisal is an evaluation of perceived capacity or resources to meet this threat. Appraisal is also associated with the degree of discrepancy between demand and capacity.

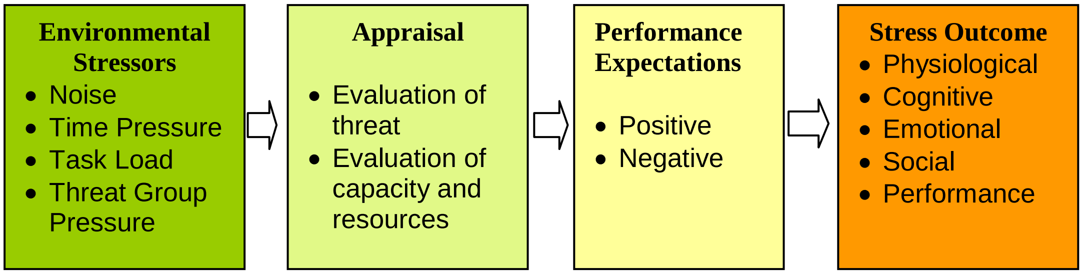


Figure 1. A Four Stage Model of Stress and Performance (Driskell & Salas, 1996)

The appraisal process leads to the formation of performance expectations. If demands exceed available resources, negative performance expectations are formed. If the perception of available resources exceeds the perceived threat, positive performance expectations are formed instead. The development of positive performance expectations is a crucial factor in preparing personnel to operate under high-demand conditions. Research has shown performance expectations as a strong predictor of actual performance (Bandura, et al., 1982; Locke, et al., 1984).

Additionally, Driskell and Salas (1996), state that this process results in a number of types of outcomes of interest, including physiological reactions, cognitive effects, emotional reactions and performance outcomes. Physiological responses have been assessed in a variety of studies through measurements such as, skin conductance, pulse rate, heart rate, heart rate variability, electrocardiograph (EKG) and impedance cardiographic (ZKG) signals, pulse transit time (PTT, the interval between EKG R-wave and rise of the finger pulse wave), salivary immunoglobulin A (IgA), systolic and diastolic blood pressure, catecholamine (e.g. adrenaline and noradrenaline) output, glucorticoid (e.g., cortisol) output, electromyography level (EMG), blood glucose level, palmar sweating, and P300 evoked potential response, muscle tension, eye blinking rate, respiration rate and a number of other measures. Although the variety of physiological responses is daunting these measures are often inconsistent and difficult to interpret. Moreover, the relationship of physiological state performance is unclear. Nevertheless, the physiological responses can be also seen as a source of distraction to the task performer and yet influencing the task and affecting performance. Worchel and Yohai (1979) found that individuals who were able to relate their physiological reactions to a logical cause were less distress or aroused.

As for the emotional reactions to stress, the literature has identified subjective feelings of fear, anxiety, annoyance, tension, frustration, etc. Since all these measures are self-reported and they are subjective in nature, they only assess transitory states. Acute stressors have little impact on these types of measures. Other measures of subjective stress include trait anxiety, and specific measures of performance anxiety such as speech anxiety, test anxiety or computer anxiety. Acute stressors are known to have little impact on trait anxiety measures.

The cognitive effects of stress may include distraction, narrowing of attention, tunnel vision, decreased search activity, increased errors, memory deficits, response rigidity, and longer reaction time to peripheral stimuli. Researchers have established that the most common cognitive response to stress is to narrow attention breadth (Combs & Taylor, 1952; Eastbrook, 1959).

When individuals have to attend to more complex tasks, this narrowing of attention may result in the elimination of relevant task information that affects task performance. Therefore, stress may result in degraded overall performance on complex tasks as attention is narrowed in response to overload. There have been research in other stress-induced cognitive changes; one example found is that individuals tend to scan solution alternatives less effectively when under stress. Wright (1974) found that fewer data dimensions were considered when individuals were under time pressure. Cohen (1952) found that stressful conditions lead to greater problem-solving rigidity, a tendency to persist with a set method of problem solving when it ceased to provide a direct task solution. Dorner (1990) found that individuals under stress were prone to impulsive decision making, therefore making decisions without assessing the consequences of such decisions.

Social responses to stress are shown to be as reduction of interpersonal skills, increased interpersonal aggression, overlooking social or interpersonal cues (Cohen, 1978, 1980). Driskell et al., (1995) found that team members were less likely to cooperate and instead maintain individualism and self-focus resulting in lower team performance. Driskell and Salas (1996) mentioned that performance outcomes frequently used in research include performance accuracy, usually measure in terms of numbers of errors committed on a task, time required to complete the task, and performance variability which measures variability in speed and accuracy.

2.3. Stressors

It has been stated that stress is caused by the presence of stressors. Therefore, stressors can be defined as any factor that causes stress. The work-environment exposes humans to many potential stressors, depending on the type of work and how they perceive the environment. These conditions may produce a numbers of health, safety or performance consequences. Folkman (1984) defined some common features of stressors; stressors tax or exceed a person’s resources, they create overload, and they threatens the person’s well-being. Driskell and Salas (1991) expanded this list of characteristics by including the condition that stressors overload situations where demand exceeds available resources. These characteristics correspond to the three major categories for stressors presented by Edland (1989): those linked to impeding failure at a task, those linked to task overload, and those linked to various type of threats. The presence of each of these three conditions in a situation is sufficient to be considered a stressor. Summarizing, all events that make demand greater than capacity are considered stressors and they do not need to be threatening factors in order to fall under these considerations (Driskel & Salas, 1996; McGrath, 1970).

Stressors need to first be considered according to their impact in time as chronic or acute. Those events or factors that are constant part of a person’s life or job are considered chronic, while acute stressors are more deterministic in time and they are not considered part of a routine. To properly define these stressors it is necessary to specify their frequency and intensity. This is important because it is possible that although a particular stressful event does not occur frequently, it may nevertheless have a very negative impact on performance due to its intensity

(Jex, 1998). Acute stressors are those that are sudden, novel, unexpected and short in duration. These will include noise, task overload, time constraint, task demands, and so on (Driskel & Salas, 1991).

There are several categorizations techniques for stressors. However, one of the most common approaches for differentiating them is by their origin. Ivancevich and Matteson (1980) in their study for occupational stress divided stressors into two basic groups: intra-organizational and extra-organizational. Specifically, the intra-organizational stressors describes four classes of stressors that operate within an organizations; those that derive from physical, individual, group and organizational conditions. Extra-organizational stressors are related to family relations, economic problems, race and class residential. Koslowsky (1998), on the other hand defines them in three different groups; individual, group/organizational and extra-organizational. The only difference with the previous classification is that the later places environmental stressors under extra-organizational along with the family relations, economics problems, job security, punctuality, and so on. A description of the four common groups of stressors follows below. However, it should be noted that extra organizational stressors related to family relations and economic problems as described by Ivancevich and Matteson (1980) and Koslowsky (1998), are more related to chronic stress than acute stress.

1. Physical or Environmental Stressors: These type of stressors need to meet two specific conditions. The first one is that they refer to physical conditions in the environment which requires that the human adapts in order to maintain homeostasis (Ivancevich & Matterson, 1980). The second criterion is that these stressors have a direct impact on the

subject performing the task. Environmental stressors are derived from the physical features of the environment. They include factors such as heat, cold, noise, vibration, and so forth which are typically experienced directly through one of the five senses (Driskell & Salas, 1996).

2. Individual stressors are those associated with the role played by the human and the task to accomplish. These stressors occurred as a result of the functions required to perform a task. Stressors under this category account for the majority of the stress experienced within an organization. Examples of stressors that can be considered at the individual level are role ambiguity, conflict, work overload, and responsibility for people.
3. Group level stressor: These are defined as conditions that create stress within the individual due to some group influence. Crowding and competition are examples of this form of stressors. They originate due to the presence and interaction with other individuals within the organization.
4. Organizational stressors: These are higher in the hierarchy than the rest of the stressors. They are the result of an organization structure or culture values or influence. Some examples of these are: organizational climate, technology, management styles, and control systems. Almost all the stressors mentioned above can be influenced by this category since it is the higher in the hierarchy. Since the spectrum of action is much broader it can impact the other type of stressors. In fact, Michela et al. (1995) argues that stressors follow a hierarchy where all higher levels stressors influence lower levels.

Although these approaches have been focused on the job and organizational arena, they difference stressors according to their impact on humans and human's responses very explicitly. Acute stressors mostly result from specific environmental conditions or task demands. These can be identified as outside stressors since their source is external. Acute stressors are not prolonged in time, they are present in a specific setting affecting task performance until the human adapts or compensates for their presence. Responses to acute stressors are more specific in time.

The clearest source of outside stressors is the natural environment, whether at work or outside the workplace. Unlike other type of stressors such as time constraints or task demand, that are transmitted in a subtle way, environmental stressors are considerably more objective allowing the researchers, in most cases, to measure them. The environment is replete with potential stimuli that may, under certain circumstances, lead to negative reactions or consequences. As with most stressors, mere exposure may not be adequate to stimulate a negative reaction. Rather, only when stimulus has exceeded some threshold value does it have the potential to become a stressor. These thresholds have been identified and they have been used to establish safety limits. The stimuli may has been present for a long time and gone, generally, unnoticed, but when some type of change occurs, either in the stimulus or the exposed individual, psychological, physiological or behavioral effects begin to manifest themselves (Koslowsky, 1998).

Hancock and Warm (1989) established that the tasks are themselves stressors. In fact, they describe tasks as a source of stress; with sustain attention as the stress generator. Therefore automatic tasks, which need little attention, produce lower levels of stress. From a cognitive point of view, Hancock and Warm describe the effect of stress on task performance as the pressure an individual experienced when trying to maintain an optimal amount of information flow to perform a task. From a physiological point of view, it can be said that the task acts as a stressor when it demands body resources.

Another type of stressor is that associated with the occupational demand of the type of work and is more related to the group or organization. These are called conflicting job demands, excessive working hours, and interaction between job and family commitments. These stressors affect human performance basically when people are exposed to them in a prolonged manner, therefore more associated with chronic stress. However, for certain types of jobs, chronic stressors may not be the most salient source of stress. The presence of acute stressors might demand, in a specific time on the job, enough resources to activate those responses from the body even though another type of stress might had been previously present.

Stressors can be identified according to their affect on the body. There are two categories of stressors: processive stressors and systemic stressors.

- Processive stressors are those that elicit what is called the “fight or flight” reaction. When humans sense danger, the pituitary gland automatically activates an alarm by releasing a burst of adrenocorticotropic hormone (ACTH), which signals the adrenal glands to release adrenaline and cortisol, also known as the “stress hormones”. These hormones function as the safeguard that helps to focus on the situation, speed up reaction times, and temporarily boost physical strength and agility. Processive stressors activate a wide array of stimuli that do not pose an immediate threat to homeostatic balance but instead require more cognitive processing on the part of the organism (ex. Occupational and financial stressors.)

- Systemic stressors are the bodies' automatic physiological responses to stress, such as the loss of equilibrium (dizziness) that it is felt before fainting or the release of acid that turns and churns the stomach during a stressful situation. Systemic stressors may be released simultaneously along with processive stressors and can increase the level of stress because they create a greater sensation of danger (e.g.: extreme temperature or water/food deprivation.)

2.4. Human Responses to Stressors and Measurements

As these processive and systemic stressors elicit multiple responses from the body, a number of measurable effects to these have been reported in previous studies such as; increased heart beating, labored breathing, trembling, motivational losses, fingertip temperature, hormonal release, brain activity, redirection of attention and increased errors, increased self monitoring, longer reaction time and decreased vigilance among many others (Driskell, Carson & Moskal 1988; Hart & Hauser (1987); Hockey (1986); Shipley & Baranski, 2002; Soga & Wada, 2004). A detailed list of physiological and psychological/cognitive responses to stressors is explained as follows.

2.4.1. Physiological Responses

- Neurochemistry (hormone release): As a result of an unbalanced homeostasis the body requires secretions of specialized chemicals or hormones secreted by glands in the endocrine system. Control and coordination of the endocrine system is exerted via the central nervous system, through the network of the autonomic nervous system (Fraser, 1983). The process is much more complex than it is described above, however the main objective of the autonomic nervous system is to control homeostasis and adapt the body to new conditions.
- Salivary cortisol levels: Cortisol is secreted independent of circadian rhythm in response to physical and psychological stress. Activation of the hypothalamic-pituitary-adrenal axis (HPA axis) is considered a major biological pathway against acute stress, which increases glucocorticoid secretion from the adrenal cortex; therefore, cortisol is assumed to be one possible mental stress marker. Increases of salivary cortisol levels have been associated with periods of stress.
- Muscle tenseness: Under the presence of a stressful situation the fight or flight reaction often results in excessive and unnecessary muscle activity, which is called "Tension." Tension is contraction of the skeletal muscles of the body.
- Perspiration: Sweating increases under stressful conditions as a result of neurochemistry actions. Perspiration rate has been proved to increase under stress. Mental stress or emotional changes often result in perspiration in the palms of the hands or soles of the feet and is believed to be useful as an evaluation indicator for the function of the autonomic nervous system (Soga & Wada, 2004.)

- Skin temperature: As a direct result of the cooling processes generated by perspiration and diversion of blood (due to adrenaline levels) from the body surface to the core, in preparation for response to danger, skin temperature decreases under stressful conditions (Soga & Wada, 2004.) Skin temperature drops because less warm blood is going to the surface of the skin.
- Respiration rate: Respiration rate and volume are indicators of metabolic level which is certainly correlated to stress level. Increases on respiration rate indicate higher levels of stress. Under stress breathing becomes faster and deeper (Driskel, Carson & Moskal, 1988)
- Finger tip temperature: Peripheral blood circulation is the main reason for finger tip temperature changes under stress conditions. Change in peripheral blood flow occurs during stress or relaxation. It has been shown that blood volume in the periphery (fingers and toes) decreases during periods of stress and increases during periods of relaxation (Reisman, 1997).
- Blood pressure: During stressful conditions some blood vessels constrict, raising the blood pressure and almost closing the vessels right under the skin. Additionally, the release of epinephrine and norepinephrine by adrenal glands affect circulation, elevating heartbeat and blood pressure (Soga & Wada, 2004.)
- Heart rate: The heart rate increases due to the release of epinephrine and norepinephrine by adrenal glands into the blood stream. These hormones signal the spleen to release more red blood corpuscles. They enable the blood to clot more quickly, and encourage the bone marrow to produce more white corpuscles. They also increase the amount of fat

and sugar in the blood. Heart rate variability has also shown to be a good indicator of stress disturbance in the human body (Soga & Wada, 2004.)

- Brain activity: The electroencephalogram (EEG) is the integrated voltage observed on the surface of the scalp due to the activity of neurons in the brain. There are two measures of stress and relaxation which can be observed from the EEG. From the EEG spectrum, brain activity can be observed in the 8 - 12 Hz. (alpha) frequency band, where increased activity is related to increased relaxation or decreased stress (Soga & Wada, 2004.)

  A more sophisticated measure of stress and relaxation is the phase coherence, which shows the phase synchrony, as a function of frequency, from two different spatial locations on the surface of the scalp. This method measures the degree to which EEG changes in these regions. It has been shown that, during meditation, there is a marked increase in coherence, especially in the alpha frequency band (Reisman, 1997). Therefore, decrease in coherence can be associated with stressful conditions.
- Pulse oximetry is a method for measuring the level of oxygenation of a subject’s blood. Levels of oxygen are registered to be higher under stress as a result of higher heart rates and released of red blood cells (Soga & Wada, 2004)
- Skin conductance: As sweating increases skin gets wet. Skin that is damp (sweating) conducts electricity more effectively than skin that is dry. Therefore skin electrical conductance will increase (Soga & Wada, 2004)
- Pupil size: The pupils of the eyes dilate involuntarily (Soga & Wada, 2004)

- Felling of irritation: Studies have proven relationship between mood behavior and mood disturbance. Mood changes have been assessed and these evidenced that subjects become disturbed by the presence of stressors (Soga & Wada, 2004)
- Level of tiredness: As result of combined physiological and cognitive responses to stress, level of tiredness can be expected to increase (Driskell & Salas 1996)
- Anxiety levels: Anxiety is defined as an abnormal and overwhelming sense of apprehension and fear, often marked by physiological signs such as sweating, tension, and increased pulse. Anxiety is being used as a subjective measurement for stress and it has been proven to increase under this condition (Driskell & Salas 1996)

2.4.2. Cognitive Responses

- Response time: Longer response time has being observed when performing tasks under stressful conditions (Jamal 1984).
- Verbal memory recall: Verbal memory recall decreases when a person experiences stressful conditions (Driskell et al., 1988).
- Working memory: Working memory is a theoretical framework within cognitive psychology that refers to the structures and processes used for temporarily storing and manipulating information. This ability has been documented to degrade under stressful conditions. Memory capacity (storing) under stress becomes more constrained. Response accuracy decreases while speed of processing can remain relatively unaffected. (Stokes, et al., 1990).
- Spatial manipulation: Stokes, et al., (1990) shows that performance decreases in task involving spatial processes under the presence of stressful conditions.

- Blink rate: The blink rate reflects psychological arousal. The normal, resting blink rate of a human being is 20 closures per minute, with the average blink lasting one quarter of a second (Karson, 1988). Significantly faster rates may reflect emotional stress, as aroused, e.g., in the fight-or-flight response

Researchers have found positive associations between stressors and each of these physiological and cognitive responses to stress. However, the findings have not been consistent and it can be the case that individuals have different responses to a given stressor. Fried (1988) suggested that analyzing stimuli characteristics such as chronic vs. acute stressors and including self-report data as a support or additional indicator may help in reducing some of the ambiguity in the field.

Almost all of the physiological measures that can be used to describe stress can be objectively measured (e.g. heart rate, blood pressure, cortisol levels, pupil size, blink rate, response time, etc.) and they have been used in several studies as it has been previously described. However, there have been studies where subjective scales have been developed for the purpose of assessing stress levels and have served as the independent variable, predictor, or stressor (Koslwosky, 1998; Wellens & Smith, 2006; Ragland, et al. 1997). These instruments have often been used as the only predictor scale in the study and do not have any measure of an outside stimulus, demographic or description of the organization that could be used as an objective indicator. The following is a list and description of some general and specific scales commonly used by researchers.

2.4.3. General Subjective Scales

1. Social Readjustment Rating Scale: Developed by Holmes and Rahe, 1967, this instrument is the most popular scale in the stress field. It consists of forty-three items describing potential life events that may be responsible for strain reactions. Items are scored on a scale that represents the difficulty in adapting to that particular life event. The higher the score, the more difficult it is for the worker to adapt. As an example we have that a score of 100 is assigned to death of a spouse and 11, the lowest value, was assigned to minor violations of the law. Over the course of a year, scores over the major events experienced by individuals would be accumulated and if they exceed certain values, implications would be drawn (Koslowsky, 1998)

2. Human Factors Inventory: This is a 162 item survey that assesses various aspects of occupational stress (Jones, 1983). It contains six scales: job stress, job dissatisfaction, organizational stress, stressful life events, life and health risks, and accident risks. It has been prove to be very reliable and each scale has an extensive series of norms. It is typically used in organizational environments to compare departments, where stress levels can be evaluated to identify specific stressors. The only disadvantage of this instrument is the lack of a distinction between stressors variables, perceptions and strain responses.

3. Work Environment Scale: Developed by Moos (1981), it was designed to assess quality in work life and stress levels in different parts of the organization. There are ten subscales consisting of ninety items in total. Test-retest reliabilities are appropriate to this type of environments and norms are available from several thousand subjects. It is a relative pure

measure of stress stimuli. The ten subscales identified in this scale are: Involvement, Peer cohesion, Supervisor support, Autonomy, Task orientation, Work pressure, Clarity, Control, Innovation and Physical comfort.

4. The Job Stress Survey (JSS): The Spielberger Job Stress Survey was developed to deal with several of the measurement issues raised by previous scales in the literature, including several of those already mentioned. According to Spielberger and Reheirser (1994), the purpose of stress scales should be to assess the stimulus, antecedent or outcome variables as well as the frequency of the stressor. The JSS contains thirty items or stressors such as excessive paperwork and working overtime. The subjects are asked to rate the stressors on a nine points scale where two total scores are obtained; overall severity and frequency.

5. Barnett Job Experience Scale (BJSE): It is derived from a list of sixty items that assesses positive and negative job experiences. Using two judges, thirty-two of the items are assigned to seven subscales, where each subscale represents a relevant construct in the literature. With perfect agreement, the judges found that items fell into the following subscales: skill discretion, decision authority, schedule control, job demands, pay adequacy, job security and relations with supervisors. The original scale consists of four points Likert items, which indicates to what extent, if at all, each of the experiences described in the items are rewarding or of concern in their job. (Koslowsky, 1998)

6. Occupational Stress Evaluation Grid: This instrument is customizable to target specific organizations or type of assessment. Developed by Singer et al. (1987), the survey is based on a 7x3 matrix where the rows represent seven stress levels: physical, biological, psychological, interpersonal, work setting, organizational, and socio-cultural. The three columns refer to specific stressors at each level and two types of interventions relevant to each level, formal and informal ones. For each of the seven categories, a subscale consisting of highly related items is formed and used in stress surveys.

2.4.4. Specific Subjective Scales

1. Profile of Mood States (POMS): This self-report instrument is designed to measure six dimensions of mood: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment (McNair, Lorr, & Droppelman, 1992). The POMS consists of 65 adjectives describing feeling and mood which is answered on a five-point Likert scale, ranging from not at all to extremely. Respondents are asked to indicate mood reactions for the "past week including today" or for shorter periods of time such as "right now.” The participants are also asked to complete the POMS at the beginning and end of the testing session. Increasing scores show changes in mood states that can be correlated to stimulus.

2. Police Stress Survey and the Teacher Stress Survey: These two instruments are consistent with the Job Stress Survey (JSS) approach. Each one of the scales contains items aimed to measure specific stressors associated with the different jobs. The Police Stress Survey contains sixty items that focus on potential stressors which law enforcement officers can expect in their jobs. As with the JSS, the PSS also measures the perceived severity and frequency of occurrence of the items.

The approach for the Teacher Stress Survey is the same, of the sixty items in the Police Stress Survey, thirty nine of them also appear on the teacher survey; the only modification is substituting teacher and school for police and department. The rest of the items are identified as equally relevant for teachers (Koslowsky, 1998).

4. Teacher Stress Inventory: This survey was developed by Fimian and Fasteneau in 1990. It does not introduce anything new conceptually; rather it has mixed two types of items, stressors and strain reactions, in one scale. The final version of this survey instrument consists of forty nine items where the respondent is asked to react to each item on a scale from 1 (not noticeable) to 5 (noticeable). If used judiciously, this scale can provide the researcher with data on both the independent and depend variable.

4. Performance Assessment for Stress and Endurance (CPASE): Developed by the Army, it consists on a battery of cognitive measures to address changes in cognitive processing related to stress. This instrument includes four tests of high cognitive functioning that represent a range of skills that include verbal memory recall, logical reasoning, working memory, and spatial manipulation. All of the cognitive tasks have showed significant main effect across session with performance showing a decline till the lowest point during the late night. Logical reasoning however does not show significant changes. Additionally, CPASE was found to be sensitive to the changes in individual stress levels (Mullins, 2002).

5. Stress-Arousal Checklist (SACL). This instrument consists on a 30 item checklist with adjectives used to describe psychological experience of stress. The model used for this survey is two dimensional. The first dimension is labeled as stress and consists of feeling ranging from pleasant to unpleasant. The second dimension is labeled arousal and it ranges from feeling of wakefulness to drowsiness. The stress dimension is considered a subjective experience in response to the external environment, while the arousal dimension represents ongoing somatic or autonomic activity. (Mackay. C., et al., 1978)

6. Perceived Stress Scale (PSS). Developed by Cohen, et al. (1983), this psychological instrument has been extensively used for measuring stress perception. It basically measures the degree to which life situations are appraised as stressful. Items are designed to inquire how unpredictable, uncontrollable, and overloaded respondents find their lives. The scale also includes a number of direct questions about current levels of experienced stress. The PSS is designed to be used in populations with at least junior high school education. The items are easy to understand, and the response alternatives are simple to grasp. Furthermore, the questions are of a general nature and hence are relatively free of content specific to any subpopulation group. The questions in the PSS ask about feelings and thoughts during the last month. In each case, respondents are asked how often they felt a certain way.

2.5. Modeling Stress

The literature discussed three main approaches to stress: Stimulus-based approaches, Response–based approaches, and Transactional approaches (Stokes & Kite, 1994; Hancock & Desmond, 2001). Every model developed for stress has followed at least one of these approaches if not a combination of two or all of them. These approaches are not mutually exclusive. The three approaches emphasize, respectively, situational variables, generalized responses and intervening psychological variables.

Stimulus-Based Approach: This approach focuses on observing stress as a result of external events or conditions rather on the subjective experience itself. These events are called situational variables that are assumed to be aversive and therefore are considered as stressors. Research under this approach usually selects a given variable, manipulates it experimentally and styling the manipulation as stress. Thus, time restriction or increases in workload for example, are sometimes treated as though they were inherently stressful and may be labeled as stressful irrespective of whether the individuals studied reported or ever experienced distress or discomfort. Under this approach the list of stressors can be impressively long; almost anything physical, environmental and social conditions. There are two shortcomings on this approach; this approach ignores the individual differences and omits the emotional component of the experience of being subject to a stressful condition (Stokes & Kite 1994; Hancock & Desmond, 2001).

Response-Based Approach: Unlike the stimuli based approach, this approach focuses on the reactions to the external circumstances. Within this model the responses displayed in a given situation are considered to be defining parameters of stress. Therefore, stress is viewed as a set of symptoms rather than as a set of causes. In theory this conception of stress could incorporate many different responses; behavioral, affective, cognitive, and possible others. The most emphasis on this approach and stress has been placed in physiological responses. Perhaps the earliest reference to this approach can be attributed to Yerkes and Dodson (1908). However, the most often cited body of work is that of Hans Selye, whose research has exerted a profound influence on response-based approaches to stress. In this study he observed that responses such as increases in heart rate, respiration, adrenaline and a number of other metabolic and endocrine functions associated with autonomic nervous system, tended to appear in a wide variety of aversive or demanding situations (Stokes & Kite 1994; Hancock & Desmond, 2001). Table 1 shows the most common measures for stress. Stokes and Kite pointed out that as the researcher move down on the list from subjective to biochemical measures, the techniques tend to become more and more intrusive (and intimidating for the potential subject), involving costly blood analysis and urinalysis. They also mentioned that more complex and intrusive techniques not necessary leads us toward a more scientific measure of stress and sometimes there is dissociation between psycho-physiological or biochemical measures and subjective measures of stress.

Table 1. Frequently Used Measures or Indices of Stress (Source: Stokes & Kite, 1994)

Type of Measure	Description
Subjective	Ratings and protocols of how the person feels, how well he believes he is doing. Confidence/anxiety reports
Behavioral	Objective measures of performance change on real world's tasks or specialized performance tests, including computerized test batteries and instrumented flight simulators.
Psycho-physiological	Objective measures of variables such as heart rate, muscle tension, galvanic skin response (skin conductance), respiratory rate, etc.
Biochemical	Objective measures of neurotransmitters and their metabolites, e.g. serotonin, epinephrine, norepinephrine, dopamine.

This set of physiological reactions is typically associated with arousal which was originally coined by Canon (1915). However, this set of responses can be also associated with exhilaration, illness, effort, keen anticipation and sexual activity. Therefore, the shortcoming of this approach is also the tendency to bypass the role of the individual as a thinking, reflective, purposive, emotionally engaged participant in the process (Lazarus, et al. 1985). In this sense, neither the stimuli nor the response-based approach include things as perceptions of threat or challenge as influential variables for stress.

Transactional Approaches: Transactional approaches have been the result of the redirection of stress studies. These approaches conceptualize stress as inhering neither in the person nor the environment as such, rather in the transaction between the two. Transactional approaches emphasize the role of individual appraisal in the human responses. Rather than focusing exclusively on the stimuli or on responses to stress, the concern is with the appraisal of situations in terms of their demand and the individual's perception of his coping resources. Research under the transactional approach must recognize the importance of the stimulus and the responses but in an important sense they are more psychological than either of the two earlier approaches to stress. Transactional approaches must acknowledge the subjective nature of stress and emphasize the mental process that mediate the individual's reaction.

However, transactional approaches make stress models more complex and more difficult to operate experimentally. If stress is no longer conceptualized as a variable inhering in the person or in the environment, it is not easily measurable through metrics such as heart rate or ambient noise levels. This approach is especially useful to implement in fields where the assumptions underpinnings stimulus and response-based models have gone largely unchallenged for several decades.

The shortcoming of this approach is probably the concept of cognitive appraisal. In this framework, stress is viewed as the result of a mismatch between the individual's perception of the demands of the task or situation and their perceptions of the resources for coping them. Combination of these factors leads to underestimation or overestimation of an event that will affect the perception of a stressful situation.

McGrath (1976) defined stress in terms of three elements: perceived demand, perceived ability to cope and perception of the importance to coping. On this context, it seems that stress is the response of an imbalance on these three elements. For example, individuals with skill deficit may have little implication for psychological stress if the situation is one in which the individual has no need or expectation to fulfill.

Another variable that has sometimes been related to stress is uncertainty. According to Warburton (1979), this may be qualified as the fourth element in cognitive appraisal models. Cognitive appraisal is a cornerstone of transactional approaches to stress and represents an important consideration toward advancement in stress models (Hancock & Desmond, 2001)

Having defined the bases for all approaches on stress the next step is to address specific models on stress. There are many environments where stress plays a role on determining functioning, performance, or health. According to Koslowski (1998), a variety of studies have examined the various settings using different measures and assumptions for the relationship among the cause and effect variables. For example, the workplace, the home environment, social settings, vacations are all places where an individual confront stressors that have meaningful consequences for the individual and their surroundings.

Early studies used to identify two main variables when referring to stress models, namely: stressors and stress strain. Stress strain is commonly referred as the response or dependent variable while; independent variables are associated with stressors. However, due to the complexity of the interaction and the links between variables, stress studies have included mediators and moderators as factors to explain response variability across studies in responses to stressors. These variables influence the relationship between stressors and physiological cognitive and behavioral responses to stress.

2.5.1. Variables in a stress model

- Stressors: Individual, environmental, group or organizational factors that causes physiological, psychological and emotional reactions on the human body leading to stress strain.
- Mediators: These are the variables that either explain the relation between the stressor responses (independent variables) and the stress strain (dependent variable) or reduce the relation between these two (Baron & Kenny, 1996). These variables explain how external

physical events take on internal psychological significance. They, generally, correlate with the independent variable and are considered links between these and the dependent variables. The link between the predictor variable and the response or outcome goes through the mediator, and its impact is considered indirect. It can be the case that a direct link between mediator and stress strain is also observed. Mediators reduce the variance explained by the independent variable. In a complete mediated process, the variance explained by the predictor is reduced to zero. Mediators are associated usually in the form of cognitive and perceptual process. They usually include an active or conscious awareness on the part of the individual (Koslowsky, 1998). Some examples of mediators identified in the literature are: perceptual and cognitive mediators (Spaccarelli, 1994; Melamed et al., 1995), Coping strategies (Dewe & Guest, 1990; Folkman & Lazarus, 1980), Job control (Evans & Carrere, 1991).

- Moderators: A moderator is a qualitative or a quantitative variable that affect the direction and or strengths of the relation between the independent and the dependent variables. Moderators are independent of the predictor (independent variable). In a regression model a moderator will be the variable that is added to the equation after the independent variable with the purpose of explaining a significant portion of the response variable. The contribution of the moderator therefore is the interaction effect which allows for better prediction and sometimes an explanation for a stressor's influence that would not be available from the stressors by itself. Another specific characteristic of the moderators is that it is never a resultant variable (Koslowsky, 1998).

2.6. Modeling Human Performance

The main activity that human beings are born to do is to perform. Almost every action carried out by human beings demands successful performance. In the psychological sense, human beings perform every time they engage in a goal-directed activity. It has been said that behavioral competence, mastery over the environment or need of achievement may stimulate that urge to perform (Matthews et al., 2002)

Human performance constitutes a generalized term that involves any activity regarding the goal pursued. Job performance refers to all the behaviors human beings engage in while at work. However, this is a poor definition since people often engage in behaviors that are not related to the job tasks while at work. Thus, if performance is defined simply in terms of behaviors performed while at work, many behaviors that have no relation to job performance would be included. Therefore the term task performance would be more appropriate to analyze specific activities during a job, even if it may be leaving out tasks that might contribute to achieve a goal (Jex, 1998).

Job performance depends on various attributes: the overall nature of the task, the specific conditions under which the task must be performed, the requirements for specific capabilities, the attitudes of the person performing the task, the subjective value of the task to the person performing, and the social and task related goals of the individual (Hancock & Szalma, 2003)

It is unusual to measure human performance directly. Generally, the object of measurements is the results of job performance or some external assessment of performance. According to Murphy (1989), there are eight different ways in which performance can be assessed: paper/pencil tests, job skills tests, on site hands-on testing, off site hands-on testing, high fidelity simulations, symbolic simulations, task ratings and global ratings. The two most common performance assessment techniques described by Murphy are rating of employees' performance on specific tasks and ratings of overall performance on the job.

Performance outcomes that are typically found in the research literature include performance accuracy (usually assessed by the number of errors incurred during a task) (Lichacz, 2005), performance speed (the time required to perform a task) (Soga & Wada, 2004), and performance variability (variability in accuracy or speed) (Hancock & Vasmatzidis, 1998).

Regarding physical performance there are numerous tasks and tests that have been developed to assess an individual's physical performance, however they are more related to a specific task than a job. Some examples of physical performance tests are:

- The variety of dexterity test to evaluate hand work, manipulation, and coordination,
- Muscle strength tests (push/pull arm, Jackson strength evaluation test) to evaluate endurance
- Motion range test to evaluate body flexibility and reach (i.e., goniometers, sit and reach flexibility test)

- Heart rate to measure physical endurance (heart rate monitors).

Most of these tests are recommended and used as pre-employment screening instruments for assembly, packing, simple machine operation, and other jobs requiring extensive use of the hands and the body in general.

2.7. Mathematical and Statistical Techniques

The study of human performance and stress has been addressed by several researchers and organizations (e.g., Hancock & Warm 1989, Driskell et al. 1988, Hancock et al. 2003, Hockey 1986) with the objective of understanding how stress influences human performance, especially in those environments where adverse conditions in the form of stressors are actively present. Data for these types of studies come from physiological or cognitive measurements of performance.

Most of the quantitative studies assess performance under stress or its effects over the human body. There are two types of data being analyzed: discrete (number of errors under different conditions or treatments) and continuous (task completion time under different conditions or treatments, heart rate, skin resistance and conductivity), however the type of analysis pertains to inferential statistics and mostly consists on analysis of variance and correlation analyses (Shipley & Baranski, 2002; Takakuwa, 1971; Evans & Carrere, 1991) to prove the effects resulting from different treatments, device, event or conditions.

An example of this type of research is the one conducted by Lichacz (2005). The objective was to examine the combined effects of three stressors; sleep loss, time pressure, and work load on dynamic task performance. The task used during the study was an air traffic control (ATC) type of task, which represents a dynamic, ever changing environment. Sixty four participants were exposed to a 28 hr period of sleep deprivation while performing three different type of tasks; cognitive, psychomotor task battery, and personality measures randomized across the performance blocks and concluded with a series of questionnaires about sleepiness.

The objective of the task was to correctly route aircraft to their desire exit points at required altitude and heading within a specified period of time, land the aircraft when required and to maintain 1,000 ft separation between each aircraft. The aircraft entered the radar screen at random time intervals until the desired number of aircraft were reached. Participants manipulated all of the controls on the ATC display with the use of a mouse.

Workload was varied by manipulating the number of aircraft that each participant has to process. High workload condition contained six aircraft while low-workload condition contained three aircraft. Time pressure was manipulated by varying the aircraft position update interval. Aircraft position was updated every 3 sec (high time pressure) and 9 sec (low time pressure) such that the aircraft symbol advanced one position every 3 or 9 sec. Participants had these times to make changes to the aircraft before it changed position.

Two sets of dependent measures were collected in this study. First the error data associated with exit errors, loss of separation errors, landing and time violations were collected. Second, at the end of each ATC session, the workload ratings for the individual subscales of the NASA TLX workload survey (Hart & Staveland, 1988) were collected. Error data and subjective assessments of workload were subject to a correlation analysis across participants. The results showed that (a) all of the scales of the NASA TLX were correlated with each other, (b) the objective measures of performance were correlated, and (c) the subjective estimates of mental workload did not correlate with the exit errors and losses of separation.

ATC performance was analyzed by conducting ANOVAs. The exit error and loss of separation data were analyzed within separate 2 (time pressure: 3 vs. 9 sec) × 2 (workload: three vs. six aircraft) × 3 (sleep Loss: 8hr vs. 16hr vs. 24 hr) analyses of variance (ANOVAs) with repeated measures on the last variable. The results of this analysis revealed a significant effect of time pressure such that participants made more exit errors in the high than low time pressure condition (35 vs. 6, respectively). There was also an effect of workload such that participants committed more exit errors in the high- than low-workload condition (32 vs. 10, respectively). Furthermore, there was a significant interaction between time pressure and workload such that the effect of time pressure was greater in the high- than low-workload condition.

The results of the analysis for the loss of separation data were consistent with the analysis of the exit error data. The results of this analysis revealed a significant effect of time pressure such that participants committed more losses of separation during the high than low time pressure condition (12 vs. 3, respectively). There was also an effect of workload such that participants committed more losses of separation in the high- than low-workload condition (13 vs. 2, respectively). Moreover, there was a significant interaction between time pressure and workload such that the effect of time pressure was greater in the high- than low-workload condition. Workload measurements ratings were analyzed in the same manner. This experiment represents an example of instruments and statistic techniques used to described stressor effects on humans. Other researchers have used other statistical approaches such as t-tests to compare scores under different treatments (Shipley & Baranski, 2002).

There are several approaches to analyze data from stress and human performance, however most techniques are based on common statistic analyses. Specific techniques such as artificial neural networks and fuzzy set theory have not been extensively used on stress studies.

2.8. Fuzzy Set Theory

One of the most common problems on human factors and ergonomics research has been the integration of multiple properties and parameters that describe the complexity of the human body and its behavior. These parameters often have either categorical or dimensional characteristics making more difficult any relationship between them. The human work systems are complex, their structure and governing relations are not precisely known, its descriptions are generally linguistic in nature and definition of many variables and several concepts are vague. Additionally, human work systems suffer the impact of variability introduced by individual differences.

Fuzzy set theory addresses this problem with a special emphasis on categorical-linguistic variables. Fuzzy set theory is a multivariate method that aggregates variables through membership functions. First introduced by Lofti A. Zadeh (1965), FST is an extension of the classical notion of set. In classic set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition, either it belongs to the set or not. On the contrary, FST permits the gradual assessment of the membership of elements in a set by the use of membership function that maps values in the real unit interval [0,1]. Therefore a numeric degree of membership is assigned to each object on a set, ranging from 0 to 1. This procedure removes dimensional or categorical characteristics from the variables and stressors in order to aggregate them into one model.

Membership functions are mathematical elements that map variables (predictors or response to stressors in the present research) in the interval 0 (no membership) to 1(complete membership), thus assigning a degree of membership within the set. Membership functions can take several shapes (linear, bell shape, pi, etc) according to the type of variable.

Mital and Karwoski (1986) develop a framework to model homeostasis balance based on physiological and cognitive responses. They defined two sets: YES and NO, such that these indicate the state of a person who is under strain or not. An individual, completely destabilized steady state will be identified by a response membership value equal to 1 in the set YES or a response membership value equal to zero in the set NO. The different responses to stressors, N responses, form the elements of these two sets YES and NO. Since the transition from membership to non-membership in either set is gradual rather than sharp, sets YES and NO form fuzzy sub-sets.

According to this model, a fraction between 0 and 1 would then represent the grade of membership of each of the N responses in either YES or NO sets. For example, a membership grade of 0.9 represents a closer association with the fuzzy set YES. Similarly, a membership grade of 0.1 represents a closer association with the fuzzy set NO (Mital & Karwoski, 1986).

In this example the universe of discourse is defined by the N responses: $U=[Y_1, Y_2, Y_3,\ldots, Y_N]$ where Y_1, could be heart rate, Y_2, could be, for example level of attention. Then a fuzzy set YES of a universe of discourse U, characterized by a membership function $F_{YES} : U \rightarrow [0,1]$. The membership function will associate each element Y of U a number F_{YES} (Y) in the interval [0,1] which represents the grade of membership of Y in YES. The set YES is fuzzy since many aspect of possible response to stressors Y's cannot be represented as being included in or excluded from the set and thus making the set boundaries imprecise. The set YES may be now represented by (Mital & Karwoski, 1986):

$$YES=[f(Y_1)/Y_1, f(Y_2)/Y_2,\ldots, f(Y_N)/Y_N]$$

The procedure will grow more complex according to the number of variables and its types (quantitative or qualitative). The final equation evolved as follows:

$$YES=[W_1.f(Y_1)+W_2.f(Y_2)+\ldots+W_N.F(Y_N)]/W_1+W_2+\ldots+W_N$$

Where W_1, $W_2, \ldots, W_N$ are the respective weighting factors associated with N responses. Different weighting factors are necessary since, for a particular individual, all responses are not equally important (Mital & Karwoski, 1986). These weights can be obtained by means of pair-wise comparison and Analytical Hierarchy Process (AHP). By using fuzzy set theory, different variables can be aggregated into a model. Fuzzy set theory has applications in the different predictive models and specifically in regression analysis.

Another example of the use of fuzzy set theory in human factors is the development of mathematical models to assess total body fatigue conducted by Babski and Crumpton-Young (1999). The total body fatigue model developed in this research evaluated fatigue using subjective measures such as, Yoshitake Type I and II fatigue, and perceived level of tiredness surveys, in addition to objective measures, change in heart rate, percentage maximum heart rate, and performance in a tone identification task. The model was developed using data input from nursing, data entry operators and manufacturing personnel. The resulted model correctly predicted the fatigue levels of assessed nurses 52.5% of the time. This model can be applied to revising job tasks, work-shifts, work-rest schedules, and workloads that maximize worker performance while ensuring their safety (Soh, Crumpton, & McCauley-Bell, 1996).

Moreover the work of McCauley-Bell and Badiru (1996; 1997) provides a strong foundation for the use of fuzzy set theory in the development of quantitative models as assessment and predictive tools in ergonomics and human factors. As McCauley-Bell and Crumpton-Young

(1997) stated, “FST has provided a consistent and proved means to model many real-world environments”.

CHAPTER 3: METHODOLOGY

3.1. Research Approach

The goal of this research is to develop a comprehensive model that quantifies stress by combining the contribution of multiple body responses to stressors. Additionally, this research utilizes the resulting stress model to characterize performance changes resulting from acute stress. In order to create a mathematical model to quantify stress based on acute stressors it is essential to define the most relevant variables to the model. These variables include a combination of environmental and occupational factors such as temperature, noise, workload, and time awareness. All these variables have been studied under settings associated with stress.

This research effort begins with a review of the theoretical models produced in previous studies (Koslowsky et al. 1994; Hancock & Warm, 1989; Wray & Laird, 2003) to develop a combined transactional model that best describes the impact of acute stressors and its interaction with other variables. Koslowsky's framework is the best starting point for a model on acute stress, because it combines previous approaches and theories to develop a model that includes a comprehensive variety of variables. This framework describes stressor variables, intervening variables (in the form of mediators and moderators) and an outcome measure that is referred to as stress strain. His methodology consists of comparing theoretical models by correlation analysis for the hypothesized model. However, Koslowsky's model lacks on the final assessment of stress levels or quantification of the stress strain, which is the main objective of this research. Additionally, Koslowsky's framework was developed to address organizational and occupational stress or work setting stress while the present research focuses on acute stress independently of the work setting.

The present research departs from prior approaches by considering physiological, cognitive and behavioral responses to stressors as the dependent variables and including moderators and mediators in the analysis, modeling and quantification. The proposed model for this research is shown below in Figure 2, and expands upon the transactional framework developed in previous studies.

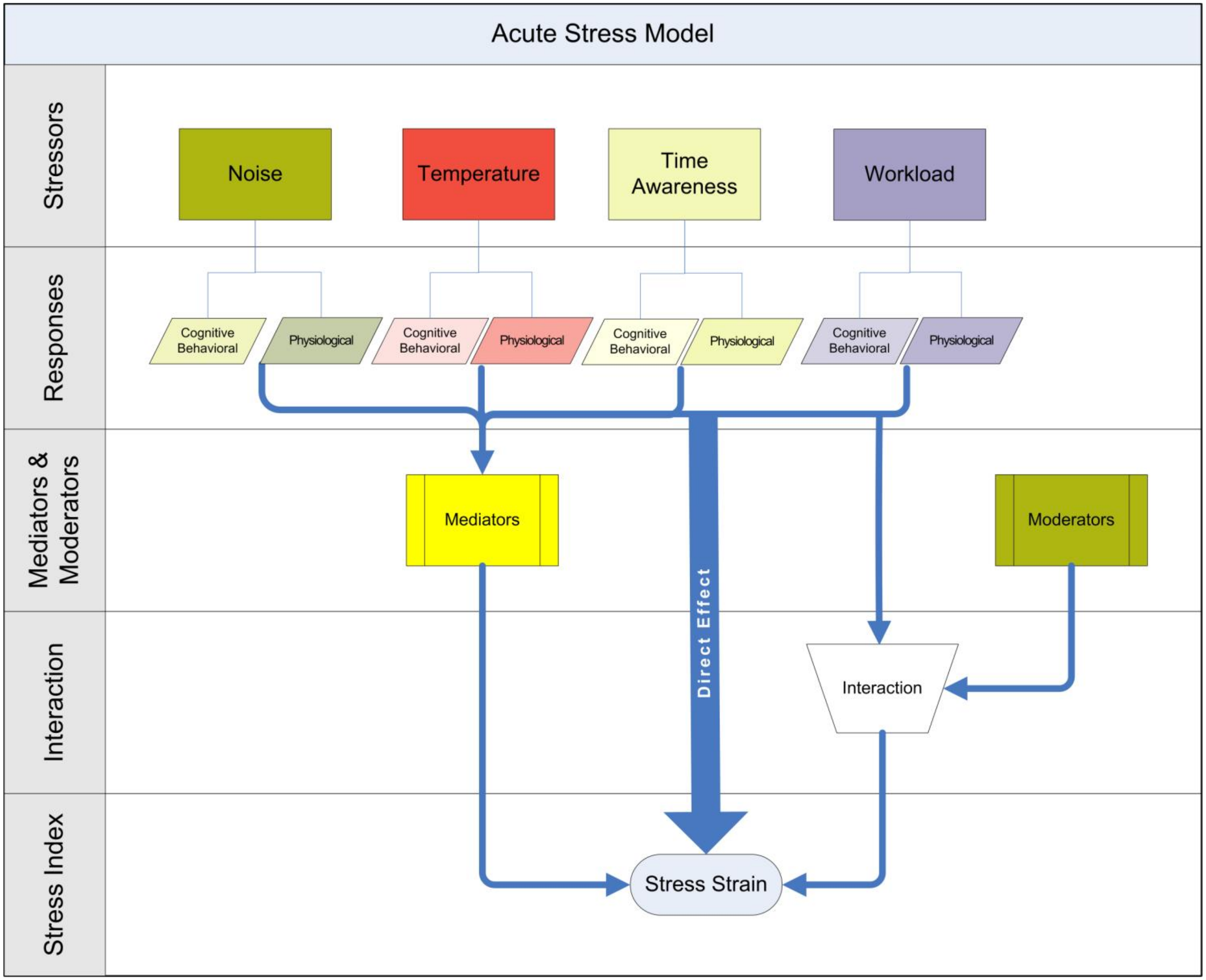


Figure 2. Representation of the Acute Stress Model

The model is initially based on the characterization of stressors through physiological, cognitive and behavioral responses. The objective of this approach is to be able, to conduct scenarios analysis by combining different stressors according to their levels or intensities. However, the challenge resides in analyzing the associations of multiples variables based on cause and effect models. In stress studies cause and effect is influenced by variables that operate as moderators and mediators which have been identified as those responsible for variability in the response to stress. Stressors, therefore, interact with mediators and moderators accordingly and a stress strain is produced. Nevertheless, stressors can also influence the stress strain directly without the presence of these two intervening variables. In these cases, the variability in the stress response does not need to be explained by other variables than the stressor.

According to the literature, mediators such as task appraisal, coping techniques, and job control either explain the relation between the stressors and the stress strain or reduce the relation between these two. They reduce the variance explained by the independent variable. In other words, in a completely mediated process, the variance explained by the predictor is reduced to zero (Baron & Kenny, 1986). Mediators are basically cognitive or perceptual processes (Koslowsky, 1998). Training or experience to avoid, confront, understand or suppress the stressor will mediate the stress-strain process.

Conversely, a moderator is independent of the predictor. In general terms, a moderator is a qualitative (e.g., gender, race, class, personality, IQ, education level) or quantitative (e.g., level of reward or level of motivation) variable that affects the direction and/or strength of the relation between an independent or predictor variable and a dependent or criterion variable. Therefore an interaction is registered. Koslowsky (1998) explains this relationship as the product of the independent variable by the potential moderator in a regression equation. If this measure explains a significant part of the variance not yet explained solely by the stressors, then it is assumed that there is a moderating effect on the stress strain.

This stress strain can be quantified and assessed based on responses to stressors and then be associated to measurements of performance according to the task. Figure 3 presents an scheme of this relationship that can be established based on the stress strain and performance curve first developed by Yerkes and Dodson (the inverted U-Theory) and later revised by Hancock et al. (2003). This relationship however is theoretical and it has been subject to different interpretations. It is not expected that the shape of the curve will necessary fit the traditional inverted U-theory. Validation of the model will allow for examination of this theory. Figure 4 shows the graphical relationship between stress, performance and task demand based on the theoretical inverted U-shape.

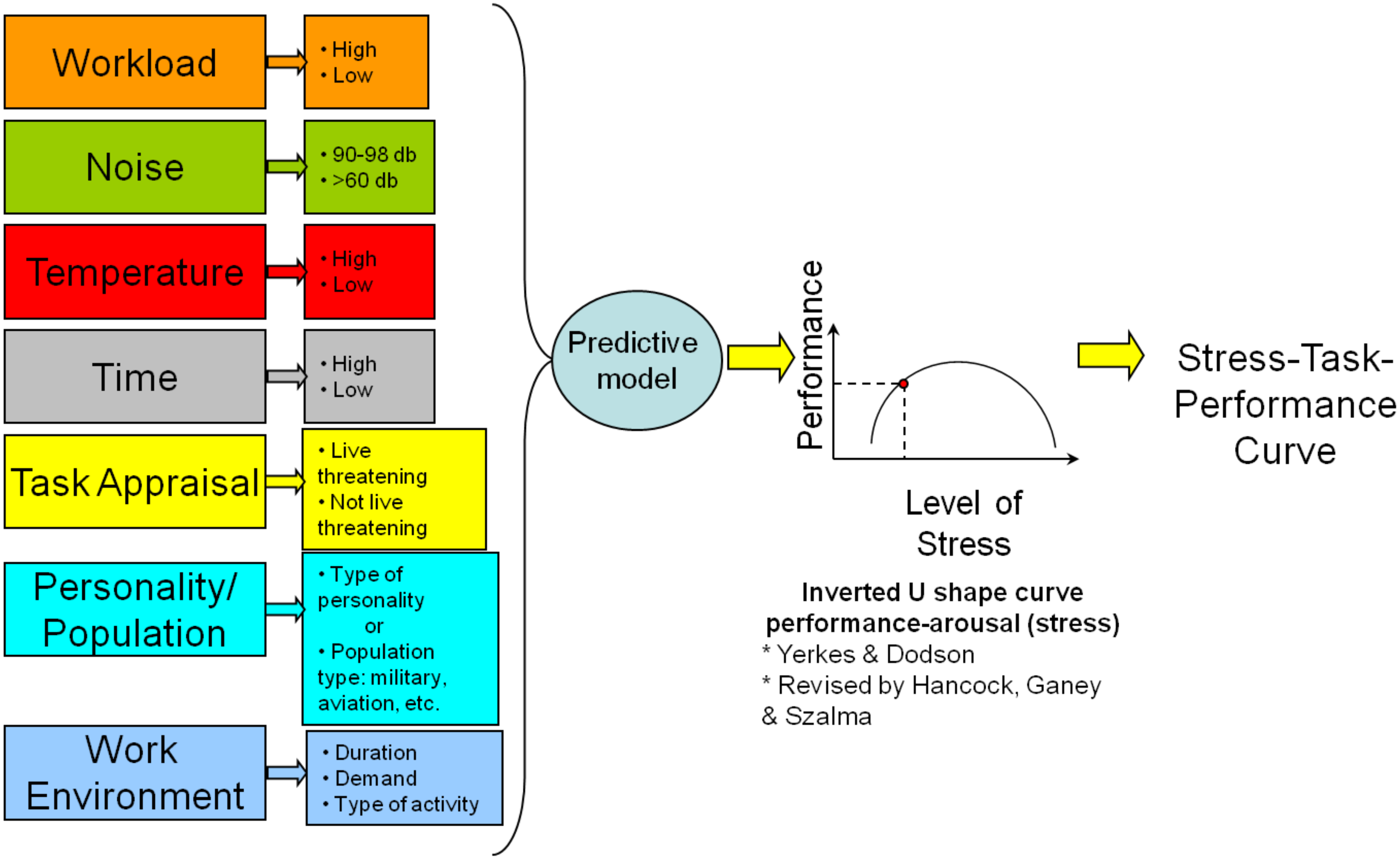


Figure 3. Relationship between Stressors and Performance

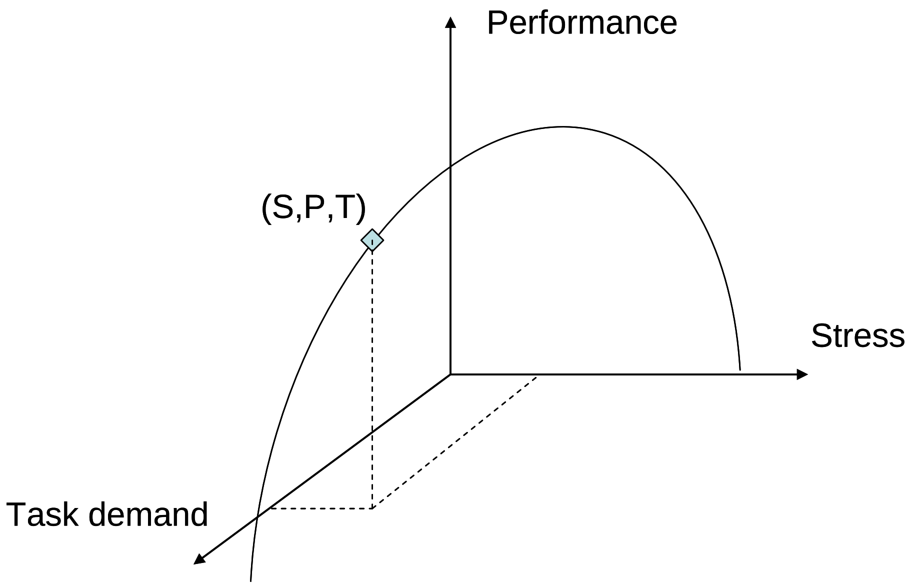


Figure 4. Relationship between Stressors, Performance and Task Demand (Inverted U-Theory)

3.1.1. Research Hypotheses

Based on the framework presented above, stressors need to be first characterized in the form of according to physiological, cognitive and behavioral responses. Specific models for some stressors already exist. Variables such as temperature, noise, time, task difficulty or workload, have been related to stress in a variety of studies. Thus, it is hypothesized that physiological, cognitive and behavioral responses to stress will be significant in the presence of stressors. In summary, the following hypotheses are examined.

1. There will be significant difference on physiological responses between the stress conditions.
2. There will be significant differences on cognitive responses between stress conditions.
3. There will be significant differences on behavioral responses between stress conditions

4. There will be significant differences on performance due to stress conditions.

Finally, it is hypothesized that using the combined effects of multiple stressors in terms of physiological, cognitive and behavioral responses to stress will lead to the development of a comprehensive quantitative model.

In order to address the goal of modeling human performance under acute stress, it is necessary to have a clear understanding of factors that determine stress responses and variables involved in this interaction. Because of the complexity of the variables (qualitative and quantitative) and the non-linearity nature of the problem, this research quantification approach uses fuzzy set modeling to quantify and predict level of stress and performance. The research is conducted in three phases with specific tasks for each phase:

- Phase I: Experiment
  - Select stressors: Selection of appropriate stressors, according to the environment and methods for measurement that will affect human performance.
  - Define appropriate body's responses: Identification of specific responses that can be used for developing mathematical models to be used in the development of a stress model.
  - Experimentation: Development of experiment to measure and collect data on responses to stress and performance variables.
- Phase II: Development of the Quantitative Model for Stress Index
  - Characterization and validation of physiological, cognitive and behavioral responses selected for the development of the stress model

  - Develop mathematical models (membership functions) for the different variables
  - Develop the predictive general model for stress-performance and task demand: A comprehensive model where variables are combined to generate the desired output.
- Phase III: Validation
  - Validate model: Establish credibility of the model. The model should represent human performance as a function of stress and task demand without contradicting any known phenomenon.

3.2. Phase I: Experiment

3.2.1. Sample size

For this type of research a homogenous sample is required. For a 2^4 factorial design, the number of participants was chosen based on the power and effect size of the experiment. With an effect size (ω^2) of 0.35 (large effect size because of the type of variables to be studied), a power of 0.80 and a significance level $\alpha=0.05$, the sample size is 6 subjects per treatment. Since there are sixteen treatments the total sample should be at least $n=96$ participants.

Participants used in this experiment included undergraduate and graduate students of the University of Central Florida ($n=108$). One hundred and eight participants ranging in age from 18 to 47 years of age (M=23.3, SD=5.11) were recruited from a student population. Seventy six individuals were undergraduate students and 23 were graduate students. Of the one hundred and eight students, thirty five were female and seventy three males. All participants were classified as fit to participate if they met the following criteria: a) were healthy, b) were in full control of their physical and cognitive capacities.

3.2.2. Experimental Design

A two-level four factors; Noise (2) x Temperature (2) x Time Awareness (2) x Workload (2) between subjects factorial design experiment is used to evaluate treatments and testing for interaction and main effects. The experimental unit is the human subject since the experiment is assessing impact of the stressors (factors) on performance, physiological, cognitive and behavioral responses (experimental responses). The factors are the stressors and for convenience these are set at two levels. Table 2 shows the randomized full factorial experimental design with treatments used on this research.

Table 2. Experimental design matrix

Noise	Temperature	Workload	High Time	Low Time
Noise	High	High	*n*=6	*n*=6
		Low	*n*=6	*n*=6
	Low	High	*n*=6	*n*=6
		Low	*n*=6	*n*=6
No Noise	High	High	*n*=6	*n*=6
		Low	*n*=6	*n*=6
	Low	High	*n*=6	*n*=6
		Low	*n*=6	*n*=6

Participants were randomly assigned to treatments. The experimental responses in the form of physiological, cognitive and performance measurements were taken continually. Behavioral data was taken through surveys before and after the task.

3.2.3. Experimental Task

The Multi Attribute Task Battery of computer programs (MAT) developed by NASA was used as the controlled task environment. This software provides the ability to develop experiments in multitask workloads and performances. The tasks are analogous to activities that aircraft crewmembers perform in flight. The primary display of the MAT battery is composed of four separate task windows as follows: a) Monitor task window, b) Resource-management task window, c) Tracking task window for the demands of manual control, d) Communication task window to simulate air-traffic control communications.

Each of these tasks generates performance data. Additionally, the program has a built in workload rating assessment program (NASA TLX) which allows for recording workload ratings during the experiment. The tracking task was not included in the battery of tasks because participants only had one hand available to operate the keyboard since the other hand is fitted with physiological sensors and all movement in that hand is restricted. The communication task was not included because of the limitation to hear other sounds under the high noise level condition. Therefore, the battery of tasks consisted only of the monitor task and the resource management task windows.

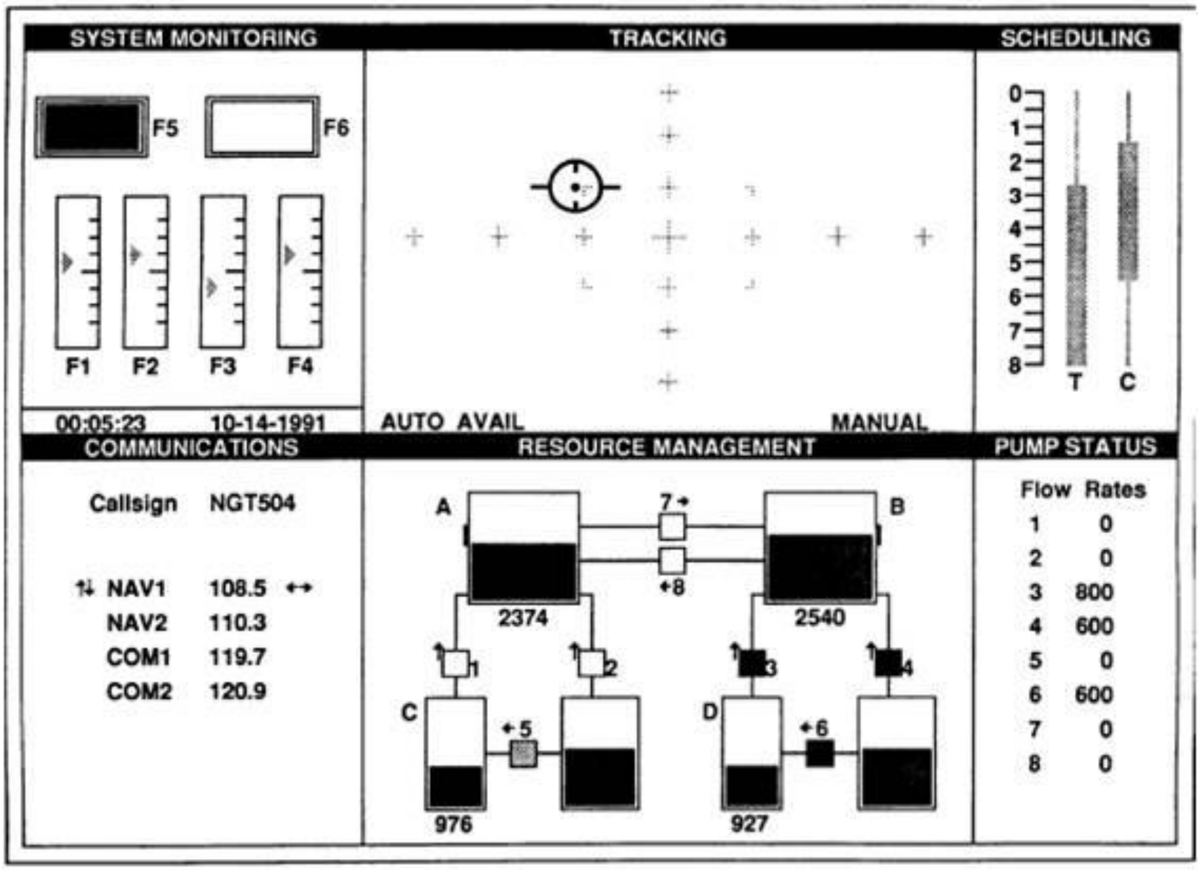
1. Monitoring task window is comprised of two sub-tasks; a) warning lights detection and b) gauges monitoring that the participants need to monitor and react to the condition. For

the light detection part of this task, subjects were required to detect the offset of a green light and the onset of a red light. Participants indicated detection by pressing the corresponding key on the keyboard for each light; F5 for the green light and F6 for the red light. If the participant failed to detect the light within 15 s (15 s is the time to react for the low workload condition, 6 s for high workload condition), the light remains in the failure state and the speed of detection is recorded. If the participant pressed a response key and no warning light has changed its status, the participant is credited with a false alarm. The gauges monitoring part consisted in monitoring four different yellow pointers and determining whether these move more than one unit above or below the center line. Participants were required to detect abnormal fluctuation and correct the situation by pressing the corresponding key on the keyboard for the corresponding gauge F1, F2, F3, and F4. After a executing the correcting action, the yellow pointer immediately moves back to the center line and begins its normal fluctuation again. If the participant failed to detect a shift within 20 s (20 s is the time to react for the low workload condition while 10 s for the high workload condition), the shift was reset and the participant was credited a miss. If the participant pressed a response key and no gauge had shifted from its center position, the participant is credited with a false alarm.

2. Resource-management task window consists in the maintenance of target levels on a fuel-management task. This task simulates the actions required to regulate fuel in an aircraft system. It is comprised of six tanks connected by a series of pumps and pipes. Participants were required to maintain tanks A and B at 2500 units each. Both tanks are depleted at the same constant rate, simulating fuel usage. In order to complete this task

participants have to transfer fuel from the lower supply tanks to tanks A and B. They toggle specific pumps on and off by pressing the corresponding key on the keyboard. When activated, a pump moved fuel from one tank to another at a fixed rate indicated under the pump status window and a direction indicated by the arrow next to the pump. The performance measure for this task is mean RMS error (deviation from the targeted value 2500) in the fuel levels of the main tanks A and B.

Figure 5 shows the Multi Attribute Task Battery (MAT) interface with the two task windows, Monitoring at the upper left corner and resource management at the bottom. In summary, performance measures recorded for the monitoring task are false alarms rate, missing rate, reaction times for both rates. For the resource management task, times to complete and maintain the condition were recorded as well as RMS error.



Callsign NGT504

NAV1 108.5
NAV2 110.3
COM1 119.7
COM2 120.9

Flow	Rates
1	0
2	0
3	800
4	600
5	0
6	600
7	0
8	0

Figure 5. Multi-Attribute Task Battery Interface

3.2.4. Experimental Variables

3.2.4.1. Factors

Stressors represent hindrances to task performance. They are considered independent variables in the model. Parameters for these variables can be estimated from the literature; standards and exposure limits for each of the environmental stressors as well as data from previous studies contributed to their characterization. Stressors have been evaluated and assessed individually in the past. The goal of this research is to develop a comprehensive model for acute stress, therefore, assessment and characterization of stressors constitutes the first step in this study.

After reviewing the literature, a list of most common acute stressors is developed. The paragraphs below describe the stressors used for experimentation and analysis. These stressors are selected based on the amount of research already performed and validated that identified them as possible contributors to acute stress. Table 3 shows a summary of these stressors and their experimental dimensions.

- Noise: A reliable guideline for noise parameters in terms of limits and exposure is available through OSHA standard 1910.95. Two levels of noise are evaluated; High level is considered above 90dB to a maximum of 98dB while Low level is bellow 60dB. These levels are defined according to current safety standards and based on previous research on performance and noise. Therefore, Low level of noise is defined by a quite room or no presence of noise at all. The High level of noise is obtained by reproducing a recording track with several continues noise (alarms, gun shots, drilling sounds, sirens among others) played at 90-98dB during the duration of the experiment through a set of headphones.
- Temperature: Two levels of temperature are selected. Because of the difficulty of the setting and materials to recreate extremely low temperature conditions, Low level temperature is assumed to be at indoors comfort zone. According to the Occupational Safety and Health Administration (OSHA) recommendations comfort zone temperature ranges from 68^{o} to$78\ ^{o}$ F and humidity in the range of 20% to 60%. The average temperature for the Low temperature level is then measured and controlled as 72^{o} F with an average humidity of 54%. The High temperature level is obtained and controlled by heating up the testing environment using three portable heaters. The average temperature

reached is 107 ° F (SD=3.76) with a humidity of 17% (SD=0.01) which is clearly outside the comfort zone.

- Time awareness: A two level variable can be defined for the experiment: Low and High time awareness. Low condition is defined as no time awareness; the operator does not have time constraints or knowledge of time. Conversely, high-time awareness occurs when the individual is aware of the time remaining. The time assigned for the task is 17 min. Participants were made aware of the duration of the task and provided with a timer located at the bottom of the monitoring task window in the MAT interface.
- Workload: High workload conditions are defined by reducing by half the time available to react to the warning lights (6 s) and gauges (10 s) in the monitoring task and the increment of depletion flow rate in the resource management task. Low workload condition is defined by the normal time to react (12 s) to a warning light and gauge fluctuation (20s) in the monitoring task and the use of normal flow for the resource management task.

Table 3. Summary of stressors factors.

Variable	Levels		Type of Variable	Unit of Measurement	Apparatus to control/measure
Noise	**Low** (<60dB) **High** (>90dB)		Quantitative	Decibels (dB)	Dosimeter
Temperature	**Low** (72^{0}F/54%) **High** (107^{0}F/17%)		Quantitative	Fahrenheit and Percentage humidity	Hygrometer
*Workload Monitoring	**Lights**	Low- (15s) High- (6s)	Quantitative	Seconds	Multi Attribute Task Battery (MAT)
	Gauges	Low (20s) High (8s)			
*Workload Resource Management	**Low**: Default flow rate **High**: (Depletion rate 40 % > feeding rate)		Quantitative	Units of volume	Multi Attribute Task Battery (MAT)
Time pressure	**Low** –Not aware of time **High**-Aware of time		Quantitative	Minutes, seconds	Multi Attribute Task Battery (MAT)

*MAT parameters for High condition are: warning times reduced by 60% and depletion rate is 40% higher

3.2.4.2. Response variables

Experimental response variables are represented as the physiological, cognitive, behavioral and performance responses to stress. These responses are measured continuously during the task to assess changes especially for high stress level tasks. Behavioral responses are assessed before and after the task to determine changes. For this experiment the dependent variables are:

- Finger tip temperature: Peripheral blood circulation is the main reason for finger tip temperature changes under stress conditions. Change in peripheral blood flow occurs during stress or relaxation. It has been shown that blood volume in the periphery (fingers and toes) decreases during periods of stress and increases during periods of relaxation (Reisman, 1997). Finger tip temperature is taken continuously during the task.

- Heart rate and maximum heart rate percentage: The heart rate increases due to the released of epinephrine and norepinephrine by adrenal glands into the blood stream. These hormones signal the spleen to release more red blood corpuscles. They enable the blood to clot more quickly, and encourage the bone marrow to produce more white corpuscles. They also increase the amount of fat and sugar in the blood. Maximum heart rate were calculated through the formula HR_{max} =208-(0.7 x Age) for male (Tanaka et al., 2001) and HR_{max}= 206-(0.88 x Age) for female (Gulati, et al, 2010). Percentage of maximum heart is the measurement used for this response variable.
- Galvanic skin resistance: As sweating increases skin gets wet. Skin that is damp (presence of sweat) conducts electricity more effectively than skin that is dry. Therefore skin electrical resistance decreases (Soga & Wada, 2004). The electrical resistance of the human body depends on the condition of the skin at the time of measurement. If the skin is wet, a resistance of only about 1100 Ohms can be registered. With dry skin, the amount is much higher around 495,000 Ohms. GSR measurements are taken continuously during the task.
- Salivary cortisol levels: Cortisol is secreted independent of circadian rhythm in response to physical and psychological stress. Activation of the hypothalamic-pituitary-adrenal axis (HPA axis) is considered a major biological pathway against acute stress, which increases glucocorticoid secretion from the adrenal cortex; therefore, cortisol is assumed to be one possible mental stress marker. Increases of salivary cortisol levels have been associated with periods of more stress. To assess differences in levels of cortisol, salivary samples are taken before and after task completion.

- Subjective stress and arousal levels: Arousal and stress are defined as a physiological and psychological state of being awake or reactive to stimuli. Common physiological signs to these phenomena are sweating, tension, and increased pulse. Arousal represents ongoing somatic or autonomic activity. Stress is considered a subjective experience in response to the external environment. These self-report measures are assessed through the Stress Arousal Checklist (SACL) inventory developed by Mackay. C., Cox, T., Burrows, G., and Lazzerini, T. (1978).
- Workload Index: The NASA Task Load Index (Hart & Staveland, 1988) uses six dimensions to assess mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Twenty step bipolar scales are used to obtain ratings for these dimensions. A weighting procedure is used to combine the six individual scale ratings into a global score; this procedure requires a paired comparison task to be performed prior to the workload assessments. Paired comparisons require the operator to choose which dimension is more relevant to workload across all pairs of the six dimensions. The number of times a dimension is chosen as more relevant is the weighting of that dimension scale for a given task for that operator. A workload score from 0 to 100 is obtained for each rated task by multiplying the weight by the individual dimension scale score, summing across scales, and dividing by 15 (the total number of paired comparisons). A global score is obtained based on these weighted averages (Rubio, S. et al., 2004).

- Response time: longer response time has been observed when performing tasks under stress. Times are automatically captured by the Multi Attribute Task battery software (MAT).
- Failure rate, missing rate: The number of errors defined by false alarms and failure to react to a warning tends to increase in the presence of stressors that tax cognitive resources.
- Deviation from target: The performance measure for this task is mean RMS error of deviation from the targeted value (2500 units of fuel) in main tanks A and B.

3.2.4.3. Mediators

In general, a given variable may be said to function as a mediator to the extent that it accounts for the relation between the predictor and the criterion. Mediators explain how external physical events take on internal psychological significance. Whereas moderator variables specify when certain effects will hold, mediators explain how or why such effects occur (Baron & Kenny, 1986). Because mediators are basically cognitive or perceptual processes, four particularly mediators are assessed in this research:

- Competitiveness: It has been studied as an individual trait and it is defined as ‘‘the enjoyment of interpersonal competition and the desire to win and be better than others’’ (Spence & Helmreich, 1983; Houston, et. al., 2002). Competitiveness trait is an individual difference that varies across people. It has been found that individuals scoring higher in trait competitiveness tend to report experiencing lower levels of stress (Fletcher, T., et al, 2008). The instrument used is the Competitiveness Scale developed by John Houston ($\alpha = .87$).

- Motivation: Measure the degree of motivation a person shows in his life. It is found that motivation is inversely proportional to levels of stress. The instrument used to measure this trait is the Ray's achievement motivation index, developed by J.J. Ray ($\alpha = .70$).
- Coping technique: Measures the coping abilities and skills of an individual to manage stressful situations. The instrument used is the Coping Inventory for Task Stress (CITS), developed by Gerald Matthews and Sian Campbel. It identifies three dimensions for coping; 1) avoidance focus, which refers to withdrawal of attention from the task and in the extreme case giving up; 2) Emotion focus refers to self criticism and worry, 3) task focus, which refers to planned actions. According to Matthew and Campbell (1998), choice of coping strategies is closely link to stress symptoms. Emotion focus relates to distress and intrusive, worry related thoughts. Avoidance and task focus are more associated with performance.
- Boredom Proneness (BP): Measures the personal trait for tendency or predisposition to boredom. The instrument used is the Boredom Proneness (BP) inventory developed by Richard Famer and Norman D. Sundberg ($\alpha = .79$). A boredom prone person experiences varying degrees of depression, hopelessness, loneliness and distractibility. Common tasks are perceived as requiring effort, with dissatisfaction with one's work and psychological well-being which elicits stress symptoms (Farmer & Sundberg, 1986)

Mediator variables have a discrete character into the model since they are specific characteristics of the individual or discriminating unchangeable condition in the environment. Table 4 shows variables for the experiment, their unit of measurements and the proposed apparatus.

Table 4. Summary of experimental response variables, mediators.

Mediator Variable	Type of Variable	Unit of Measurement	Measurement instrument
Competitiveness	Subjective	Score	Competitiveness Scale
Motivation	Subjective	Score	Ray's Achievement Motivation Scale
Coping Technique	Subjective	Score	Coping Inventory for Task Stress (CITS)
Boredom Proneness	Subjective	Score	Boredom Proneness Questionnaire
Response Variable	**Type of Variable**	**Unit of Measurement**	**Measurement instrument**
Finger Tip Temperature	Objective	Fahrenheit	Temperature Probe/ DataLab 2000/ Biobench
Heart Rate	Objective	BPS	Heart rate monitor Polar S80
Galvanic Skin Resistance	Objective	Ohms	GSR Probe/ DataLab 2000/ Biobench
Salivary Cortisol	Objective	µg/dL	Saliva Collection Kit Salimetric
Stress and Arousal	Subjective	Score	Stress Arousal Checklist
Workload	Subjective	Score	NASA TLX
Failure Rate (FR)	Objective	Score	Multi Attribute Task Battery (MAT)
Missing Rate (MR)	Objective	Score	Multi Attribute Task Battery (MAT)
Reaction Time (FR)	Objective	Time	Multi Attribute Task Battery (MAT)
Reaction Time (MR)	Objective	Time	Multi Attribute Task Battery (MAT)
Deviation from Target	Objective	Score	Multi Attribute Task Battery (MAT)

Summary of Data Collection

Objective measurements: Physiological and performance measures

1. Finger tip temperature: Continuous during experiment
2. Heart rate: Continuous during experiment
3. Cortisol level: Pre and post trial
4. Galvanic Skin Resistance: Continuous during experiment

5. Performance measures: Post trial

Subjective measurements: Self-report measures:

1. Boredom Proneness Scale (BPS): Pre trial
2. Ray's Achievement Motivation Index (RAMI): Pre trial
3. Competitiveness Index (CI): Pre trial
4. Coping Inventory for Task Stress (CITS): post trial
5. Stress Arousal Check List (SACL): pre and post trial
6. NASA TLX: post trial

3.2.5. Apparatus

The testing room was located inside a dedicated laboratory isolated from normal activities of the building. The testing room was arranged and equipped to recreate environmental or physical stressors at two levels; High and Low. To achieve high temperature level conditions, three portable room heaters were placed inside the testing room and activated at the same time blocking the air conditioning vent to reduce humidity and maintain a constant temperature. Measurements of temperature and humidity were taken using a digital indoor hygrometer (model Acurite 00613). High noise level condition was recreated through the use of professional headphones (model Sennheiser HD 201, max SLP 108 dB). A digital recording with a variety of continues noise (alarms, gun shots, drilling sounds, sirens among others) was played by a dedicated computer at the corresponding sound level for the high level noise condition (90-98 dB). Measurements of sound level pressure (dB) were taken using a noise level meter (model Exctech). Participants wore a heart rate monitor (model Polar S80) to continuously collect heart rate data. They were also fitted with a set of three physiological probes to continuously collect heart sounds (microphone attached to arm), finger tip temperature (probe attached to middle finger of non-dominant hand) and galvanic skin resistance (two electrodes attached to index and ring finger of non-dominant hand) while performing the task. These physiological responses were collected through a computerized recording data collection system (model DataLab 2000) and analyzed through data analysis software (Biobench). Additionally, as part of the physiological response, salivary samples were collected using a special salivary collection kit from Salimetric, and stored in a small refrigerator after collection. Samples were sent for analysis to the Salimetric lab in one batch at the conclusion of the experimental phase. An additional laptop with an external monitor and keyboard was used to present and run the battery of tasks used in the experiment. All behavioral information was collected by written and online surveys (see Appendix B).

3.2.6. Procedure

Participants received appointments to volunteer for the experiment. Due to the collection of salivary cortisol, participants were asked not to drink alcohol for 12 hours, do not eat major meals 60 minutes prior to the experiment, avoid dairy products 20 minutes before the experiment and avoid foods with high sugar or acidity (including all types of chewing gum), or high caffeine content (including soda products with caffeine) immediately before the experiment. Additionally, because of the location of the heart sound microphone, participants were asked to wear short sleeves for the experiment.

Once participants arrived to the lab, they were asked to rinse their mouth in preparation for the saliva sample. Following, all demographic information was collected. A battery of surveys was presented to the participant distributed in four different stations. Surveys on station 4 were administered after task completion.

Station 1

1. Demographic information (age, level of education, weight, height, race)
2. Stress arousal checklist (SACL)

Station 2

1. Ray's Achievement Motivation Index (RAMI),
2. Competitiveness Index (CI).

Station 3

1. Salivary cortisol sample collection
2. Boredom Proneness Scale (BPS),

Station 4: Testing Room

1. Stress arousal checklist (SACL),
2. Coping Inventory for Task Stress (CITS)
3. NASA TLX Weighting factor

A sample of saliva (baseline) was collected 10 min after participants rinse their mouths, using the salivary cortisol kit which consists on a cotton swab with its container. The cotton swab had to be hold under the tongue for 2 minutes. Following administration of surveys in stations 1 to 3, participants were presented with a 5-10 minutes instructional period about the task. Once participant felt knowledgeable about the task, they were asked to wear on the heart rate monitor transmitter before being brought to the testing room. Once inside the testing room, participants were instructed to sit and adjust the chair and monitor for the most comfortable position.

Physiological sensors (heart sounds, galvanic skin resistance and finger tip temperature) were attached to the non-dominant arm and hand to let participants operate the keyboard with the dominant hand. Figure 6 shows a right-handed participant fitted with electrodes, probe and microphone to her left arm and hand.

Figure 6. Right handed participant with sensors attached to left arm and hand

After all equipment is fitted and the participant is ready he or she is given the order to wait for the visual signal to begin the task. Once the researcher closed the door with the participant inside the testing room a visual signal is given and the task began. Participants executed the task for 17 minutes. At the end of the task they were given the last set of surveys and after 5 minutes a new sample of salivary cortisol was collected. In conclusion, the experiment had an overall duration between 75 to 95 minutes distributed as follows.

1. Pre-task (Duration 40-60 min)
   - Information and consent from participant
   - Assignment of identification number to participant
   - Demographic information: gender, age, weight, height, level of education (years of education, highest degree obtained).
   - Stress Arousal Checklist (SACL)
   - Salivary cortisol sample (base line)
   - Ray's Achievement Motivation Index (RAMI)
   - Competitiveness Index (CI)
   - Boredom Proneness Scale (BPS)
   - Training/instruction session
2. Task under treatment (Duration: 15 min)
3. Post-task (Duration: 20 min)
   - Stress arousal checklist (SACL)
   - Coping Inventory for Task Stress (CITS)
   - NASA TLX- Perceived workload pairwise comparisons
   - Salivary cortisol sample (post treatment)

3.3. Phase II: Quantitative Model for Stress and Performance Index

3.3.1. Analysis and Characterization

Traditional human performance modeling uses regression models as predicting tools to forecast and explain changes in a dependent variable due to the presence of independent variables. However, stress is perceived and appraised by each individual according to their own physical, cognitive and emotional resources. Variability in stress responses is represented by individual characteristics such as coping skills, experience, motivation, etc, which change from one person to another. These differences represent a decisive factor in stress studies that cannot be solely addressed using regression models.

Another problem with research on stress is the interaction between the variables. Specific interactions among certain variables have been studied and it has been found that under specific task settings some stressors are not significant when in the presence of others, for example, for a target acquisition task, high temperatures have greater impact on performance than high noise. Due to the variety of variables and interactions an algorithm is needed to associate stressor responses with moderators and mediators. Since each stressor has a different impact on physiological and cognitive responses, an ANOVA analysis is needed to select those responses that are impacted by stressful conditions. This step is a priority to prevent confounding effects and select critical interactions with moderators and mediators.

Factorial analysis is used to characterize stressors according to the physiological, cognitive and behavioral responses. This statistical analysis helps to identify experimental variables that contribute to the model as predictors of the response and those that do not have any impact in the response. Factor analysis also determines interaction among variables and the effect of this on the response. For the purpose of this research factorial analysis interactions are observed for up to the third order.

3.3.2. Fuzzy Set Modeling

During the previous step of the analysis, stress responses were analyzed to determine which variables add predictive value to the model. Only those variables that were found to be the best predictors of the dependent variables are considered into the model. In this step, those responses and intervening variables were included into the model. Although, objective measurements for stress responses, such as heart rate, skin temperature, etc have been assessed, these responses do not entirely reflect human behavior when exposed to stressors. As it has been mentioned, stress responses are tainted with vagueness and imprecision intrinsic to human individualities. Individual variables in the form of mediators or moderators, which are difficult to control, influence objective stress responses. Due to the complexity of the variables and the non-linearity nature of the problem Fuzzy Set Theory is the tool use to associate different stressors responses and the influence of moderators and mediators into a model for acute stress.

This research is aimed at the development of a fuzzy representation of human stress and performance. The model is developed as a function of physiological, cognitive and behavioral responses including mediators and moderators.

3.3.2.1. Fuzzy Model for the Stress Index

Because the focus of this research was to create an aggregated model for stress that includes physiological, cognitive and behavioral variables, aggregation operations for fuzzy sets were reviewed to accomplish this goal.

Aggregation procedures within fuzzy set theory are operations by which several fuzzy sets are combined in a desirable way to produce a single fuzzy set. There are a variety of approaches that can be utilized to produce this combination; however, because of the multicriteria nature of this stress model the most appropriate method for use was the weighted average technique. By definition this aggregate operation covers the entire interval between min and max of the fuzzy variables.

However, it is necessary to discuss first the basic of aggregation operations. Any aggregation operation on n fuzzy sets ($n \geq 2$) is defined by a function

$$h:[0,1]^n \rightarrow [0,1]$$

When applied to fuzzy sets $A_2, A_1, \ldots, A_n$ defined on X, function h produces an aggregate fuzzy set A by operating on the membership grades of these sets for each $x \in X$. Thus,

$$A(x) = h(A_1(x), A_2(x), \ldots, A_n(x))$$

Nevertheless, in order to qualify as an intuitively meaningful aggregation function, h must satisfy at least the following three axiomatic requirements.

1. Boundary condition should be [0,1];
2. Monotonic increasing in all its arguments; and
3. Continuous function.

Now for the weighted average method, a weighting vector is needed for this operation. Let

$$W = \langle \omega_1, \omega_2, \omega_3, \ldots, \omega_n \rangle$$

Be a weighted vector such that $\omega_i \in [0,1]$ for all $i \in \mathrm{N}_n$

$$\sum_{i=1}^{n} \omega_i = 1$$

Then, an ordered weights average operation associated with W

$$h(a_1, a_2, \ldots, a_n) = \sum_{i=1}^{n} \omega_i a_i,$$

Where $\omega_i > 0$ for all $i \in \mathrm{N}_n$

After reviewing the feasibility of an aggregate fuzzy model, it is established that the generic form of the Stress Index (SI) model should be expressed as the following:

$$SI = \omega f(\mathrm{Y}) + \omega f(\mathrm{X}) \times f(\mathrm{N})$$

Where:

Stress Index (SI)= value in the domain [0,1]

ω=*relative weight*

f(Y)=Physiological responses fuzzy set

f(X)=Cognitive and behavioral responses fuzzy set

f(N)=Mediators and/or moderators fuzzy set

This fuzzy singleton that defines stress as a stress index (SI) is comprised of several functions. Each of these functions contained in the model describe specific responses and they are defined as fuzzy sets representing responses to stress according to their type. Note that the fuzzy set that defines mediators affects (by a product operation) the aggregate fuzzy set within the brakes which is comprised of physiological, cognitive and behavioral fuzzy set responses.

The aggregated fuzzy sets that comprised the Stress Index model are presented as follows:

Physiological responses.

$$f(Y) = \left(\frac{\omega_1 f(y_1)}{W} + \frac{\omega_2 f(y_2)}{W} + ... + \frac{\omega_n f(y_n)}{W} \right)$$

Where:

$f(y_1), f(y_2), ..., f(y_n)$= physiological fuzzy function

$\omega_1, \omega_2, ..., \omega_n$=relative weight

Cognitive and behavioral responses.

$$f(X) = \left(\frac{\omega_1 f(x_1)}{W} + \frac{\omega_2 f(x_2)}{W} + ... \frac{\omega_n f(x_n)}{W} \right)$$

Where:

$f(x_1), f(x_2), ... f(x_n)$= cognitive and behavioral fuzzy function

$\omega_1, \omega_2, ..., \omega_n$=relative weight

Mediators and/or moderators;

$$f(N) = \left(\frac{\omega_1 f(n_1)}{W} + \frac{\omega_2 f(n_2)}{W} + ... + \frac{\omega_n f(n_n)}{W} \right)$$

Where:

$f(n_1)$, $f(n_2)$,... $f(n_n)$= *mediators fuzzy function*

ω_1, ω_2,..., ω_n=*relative weight*

Different weight factors are necessary since for a particular individual, all responses are not equally important. The same response also may not appear in all individuals. Each of these fuzzy functions has a specific weight (ω) in the model. It is defined that the closer the Stress Index (SI) is to a value of one (1) the higher the stress the human body is experiencing.

Performance Index (PI)

In addition to the Stress Index (SI) a Performance Index (PI) is developed to map level of stress to performance resulting from associated level of stress. In that the same approach is conducted for response variables describing task performance.

$$Performance\_Index = \left(\frac{\omega_1 f(z_1)}{W} + \frac{\omega_2 f(z_2)}{W} + ... + \frac{\omega_n f(z_n)}{W} \right)$$

Where:

Performance Index (PI)= value in the domain [0,1]

$f(z_1)$, $f(z_2)$,...$f(z_n)$= *Performance fuzzy set*

ω_1, ω_2,..., ω_n=*relative weight*

3.3.2.2. Membership Functions

Variables used in fuzzy sets need to be characterized by membership functions. Membership functions are mapping functions that allow association of objective and subjective measurements to specific levels of stress. This association is called level of membership and it is usually, expressed as a fraction between 0 and 1. Since physiological, cognitive and behavioral responses to stress form the elements of the fuzzy sets, membership functions for each of these responses are needed to define stress levels. In order to create these mapping functions it is necessary to be knowledgeable about certain variable parameters and how they relate to stress. Membership functions are characteristic of the dataset under analysis Thus, some parameters such as maximum and minimums values of a data set are needed to define membership functions and these can be obtained by data plots. Additionally, the literature shows ranges for most variables and this information helps in developing appropriate parameters for each variable. The mapping function provides a tool to view the progression of changes in state of a given variable.

Membership functions are also developed based on information obtained from previous research. Many responses are quantitative and for these cases the degree of membership can be modeled easily. For instance, in a membership function for heart rate the main parameter to define such function is increments in the number of beats per minute. Figure 7 shows a plot between information processing and incremental heart rate due to that activation (Mital & Karwowski, 1986). The degree of membership can be determined by a linear function of this plot. The plot shows that for an incremental heart rate of 30 BPM the degree of membership for information processing is one (1) while the degree of membership is zero (0) if a heart rate increment is less than 5 BPM.

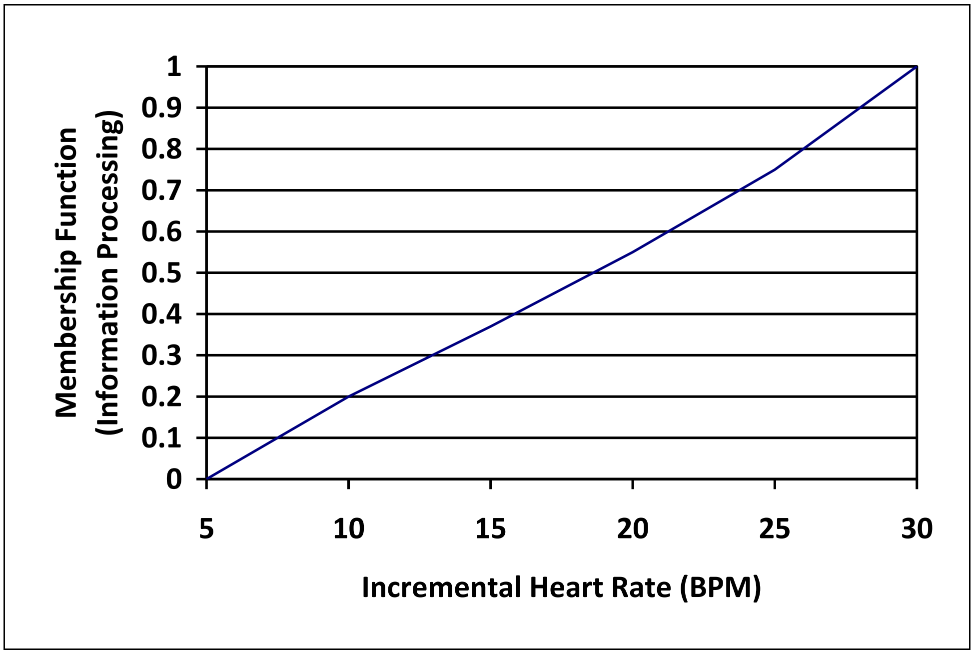


Figure 7. Membership function for the amount of information processed

Also, the degree of membership can be represented by a non-linear function if the trend is non-linear. The degree of membership for other quantitative responses to stress can be determined in a similar manner.

Determination of membership functions for qualitative variables requires a different approach. Linguistic terms (low, medium, high) need to be developed for each qualitative measurement and then be mapped to numeric values through membership functions. Membership functions for qualitative measurements are developed in a subjective manner and following previous knowledge of the phenomena.

3.3.2.3. Variables Weights (ω)

Different weighting factors for the variety of responses are necessary because each particular individual have different responses to stress. Subject matter experts (SMEs) performed a pair-wise comparison involving all variables within each type of response (physiological, cognitive and behavioral) and also intervening variables (mediators and moderators) that were deemed to be significant from the multivariate analysis. Each SME was asked to make comparisons in their field of expertise. The pairwise comparisons were used to determine the relative importance of each type of response. The importance was quantified on a scale (one to nine), showing the strength with which one factor dominated another. Comparisons were made within responses to determine the relationship between each of them. Once the pair-wise comparisons are completed, relative weights are obtained using analytical hierarchy process (AHP).

Analytical hierarchy process is a technique use to obtain ratings among variables. The goal of this approach is to compare variables though a pair wise comparison. The objective of such comparisons is to determine the relative ranking of the variables or items in a specific point value. AHP is especially useful on complex decision-making and sensitivity analysis. For this research AHP is use to rank variables within the model. The software used to perform this analysis was Expert Choice ®.

3.4. Phase III: Validation

The final step in this study consists of validating the models developed. In this particular research, validation ensures that the mathematical model represents an accurate interaction of performance, task demand and stress based on physiological, cognitive and behavioral responses to stressor and intervening variables.

The first stage for conducting validation takes place during the characterization of stressors based on physiological and behavioral responses. Statistical analysis was possible for this stage of the research. Analysis of variance for small variability between SI and PI outputs is performed to assess statistical significant differences between task demands, levels of stress and performance.

A second step of validation takes place during development of the fuzzy model and specifically during the AHP analysis. The consistency of pair-wise judgments provided by the SME is also calculated. As the number of AHP pair-wise comparison increases, it becomes more difficult to achieve consistency. In fact, some degree of inconsistency is expected in any set of pair-wise comparisons. If the consistency ratio is less than 0.10, the pair-wise comparisons are considered reasonable.

Once the final model was obtained the use of special cases demonstrated the validation of the model. Special cases included use of maximum, minimum and median values for stress responses. Specific cases such as high and low stressors level and task demand showed that the models can predict low or high performance and stress values according to the case following theoretical expectations. The output for these special cases follows theoretical assumptions regarding stress and human performance, where for instance, psycho-physiological behavior due to stressors cannot be altered. The model also needs to reflect the common knowledge on human performance changes when exposed to stressors.

CHAPTER 4: RESULTS

The following chapter presents analyses performed on the data collected and results. A multivariate analysis is presented for the Analysis and characterization part of Phase II following analysis and results Fuzzy Set Modeling part of Phase II. Results for validation of the model are presented at the end of this chapter.

4.1. Research Participant Demographics

This research was conducted within a student population. The following table describes the sample numbers and proportions according to gender, age, level of education, years of education, and personality type.

Table 5. Research demographics

Parameter	Dimensions	Number	Percentage (%)
Gender	Male	73	68
	Female	35	32
Age group	18-28 years old	97	90
	29-37 years old	9	8
	47 years old	2	2
Level of education	High School	84	78
	Bachelor	24	22
Personality trait	Introverted	65	60
	Extraverted	43	40

Out of the 108 participants tested, only data for 96 participants was used. Data from 2 subjects was discarded because they failed to properly follow instructions to complete the task. Eleven subjects were tested under different noise conditions, thus data associated with these participants was not used in the following analysis.

Personality trait, gender and level of education as possible moderators in this experiment were excluded from the analysis and quantification due to lack of significance in the sample. The only intervening variable used in the model was mediators in the form of coping technique, motivation, competitiveness and boredom.

4.2. Analysis and Characterization Results

4.2.1. Trend analyses

The following section presents results for the different experimental measurements on their trend according to treatments. All figures display means for each measurement. All measurements are differentials except performance measures. Table 6 shows treatment conditions.

Table 6. Experimental treatments

Treatment	Noise	Temperature	Time Awareness	Workload
1	High	High	High	Low
2	High	High	Low	Low
3	Low	High	High	Low
4	Low	High	Low	Low
5	High	High	High	High
6	High	High	Low	High
7	Low	High	High	High
8	Low	High	Low	High
9	High	Low	High	Low
10	High	Low	Low	Low
11	Low	Low	High	Low
12	Low	Low	Low	Low
13	High	Low	High	High
14	High	Low	Low	High
15	Low	Low	High	High
16	Low	Low	Low	High

Stress Arousal Checklist

Trend analysis for the Stress Arousal Checklist (SACL) is presented in Figure 8. Scores ranges from 0 to 18 for stress and from 0 to 12 for arousal scores. Differences between pre-task scores and post-task scores were taken. Higher scores reflect higher levels of stress and arousal. Zero values reflect no changes in mean difference for stress and arousal. Figure 8 shows trend for difference in mean stress and mean arousal per treatment. Negative values indicate that participants scored lower after the task mean difference for stress ranges from -2 to 6 while mean difference for arousal ranges from -1 to 5.

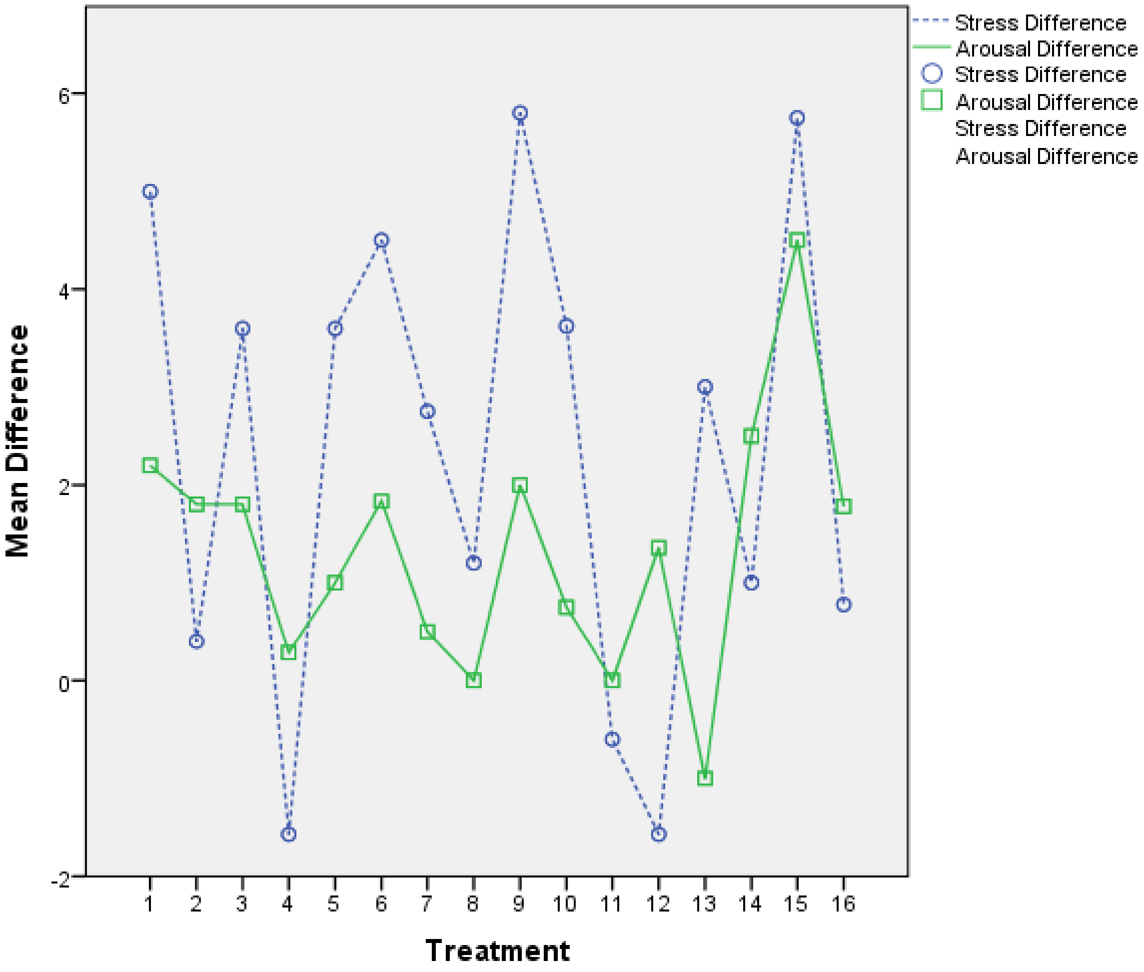


Figure 8. Stress arousal checklist levels by treatments

Workload Index NASA TLX

Figure 9 shows mean scores for workload index averages. Scores indicate global level of workload perceived by participants. The higher the workload index the more demanding the treatment.

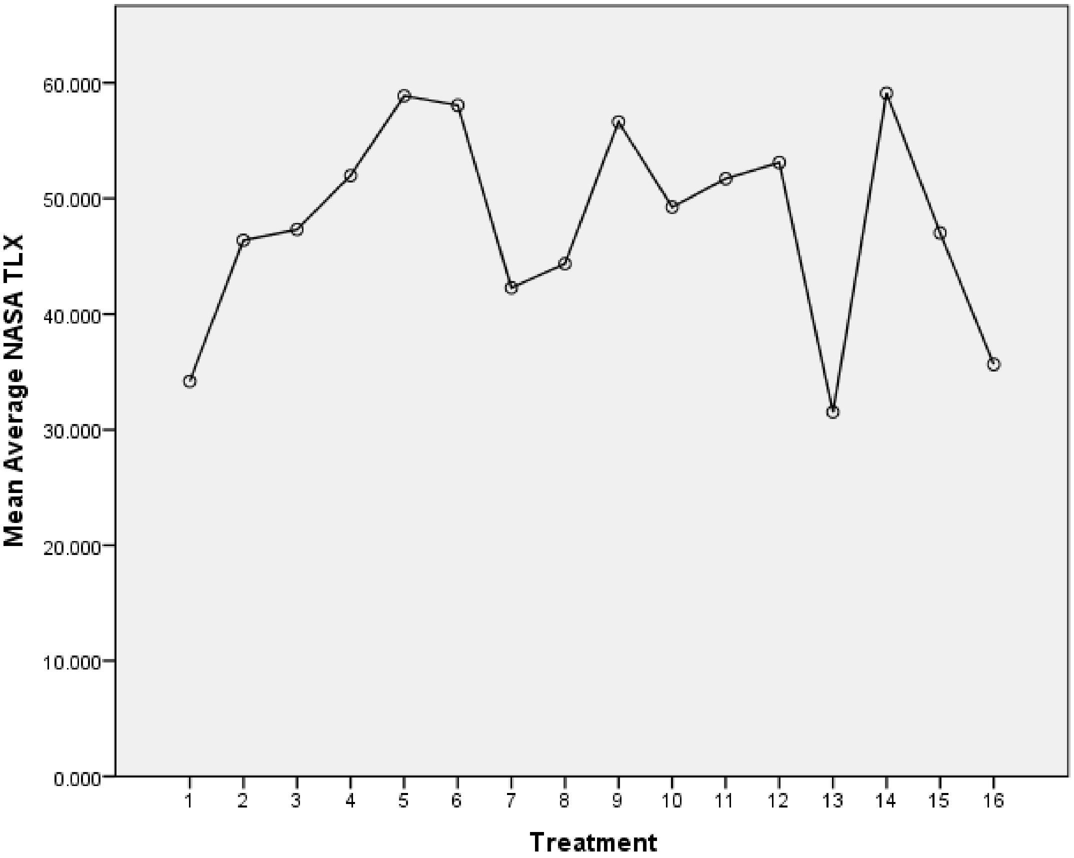


Figure 9. Workload index by treatments

Galvanic Skin Resistance

Measurements for GSR are given by the difference in values for skin resistance (KOhms) between the beginning and at the end of the task. High positive differences are an indicator of decrease in skin resistance. Skin resistance is inversely proportional to conductance according to Ohm’s Law, therefore a positive value for resistance differential, defined as the difference of the average measurements for 1 minute at the beginning and the end of the task is a possible indicator for stress. Figure 10 shows trends for GSR mean difference and also total GSR averages by treatments.

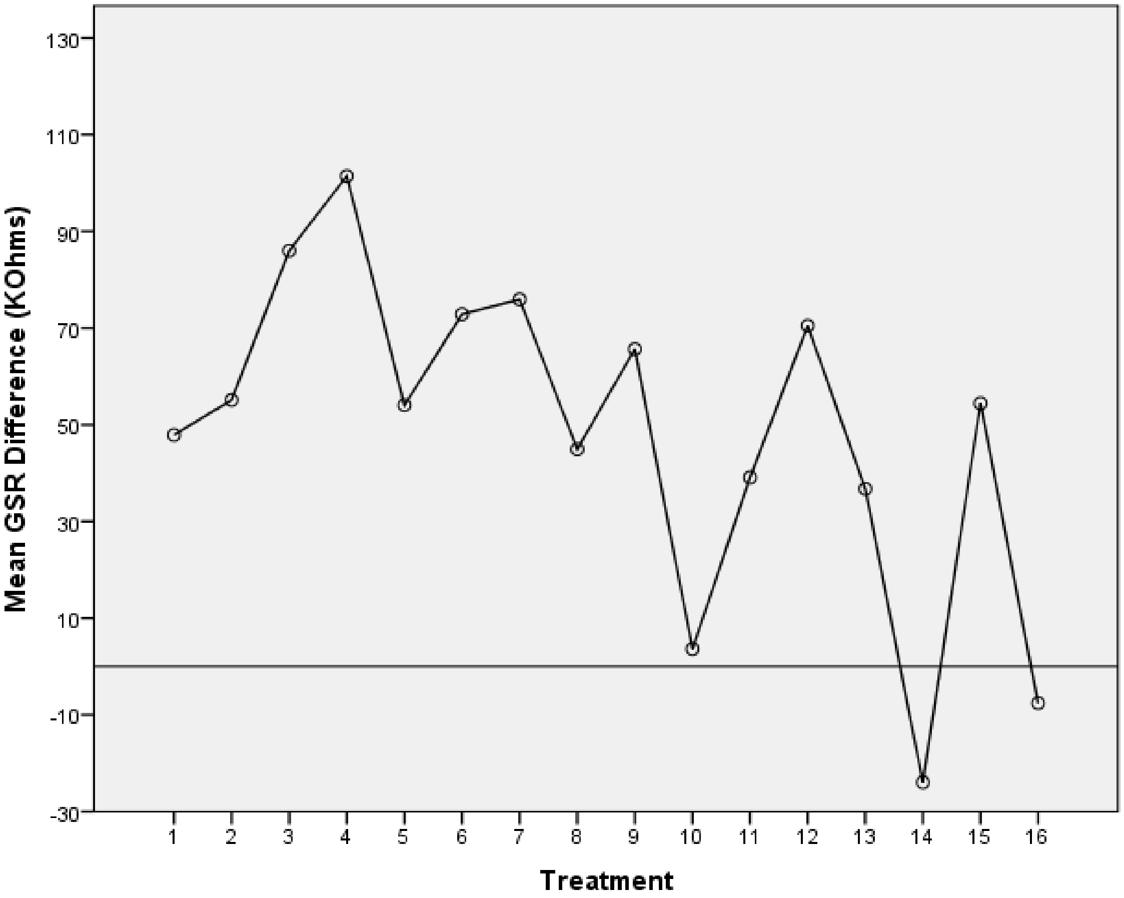


Figure 10. Galvanic skin resistance differentials by treatments

Finger Tip Temperature

Finger tip temperature was taken continuously during the task. Differentials in finger tip temperature are calculated to evidence physiological responses to stress. A decrease or change in finger tip temperature is an indicator of stress. Figure 11 shows differentials of finger tip temperature per treatments. Negative values correspond to those treatments with high temperature, while positive values correspond to treatments with low temperature. It should be noted that treatment 5 shows the smallest difference when temperature is high.

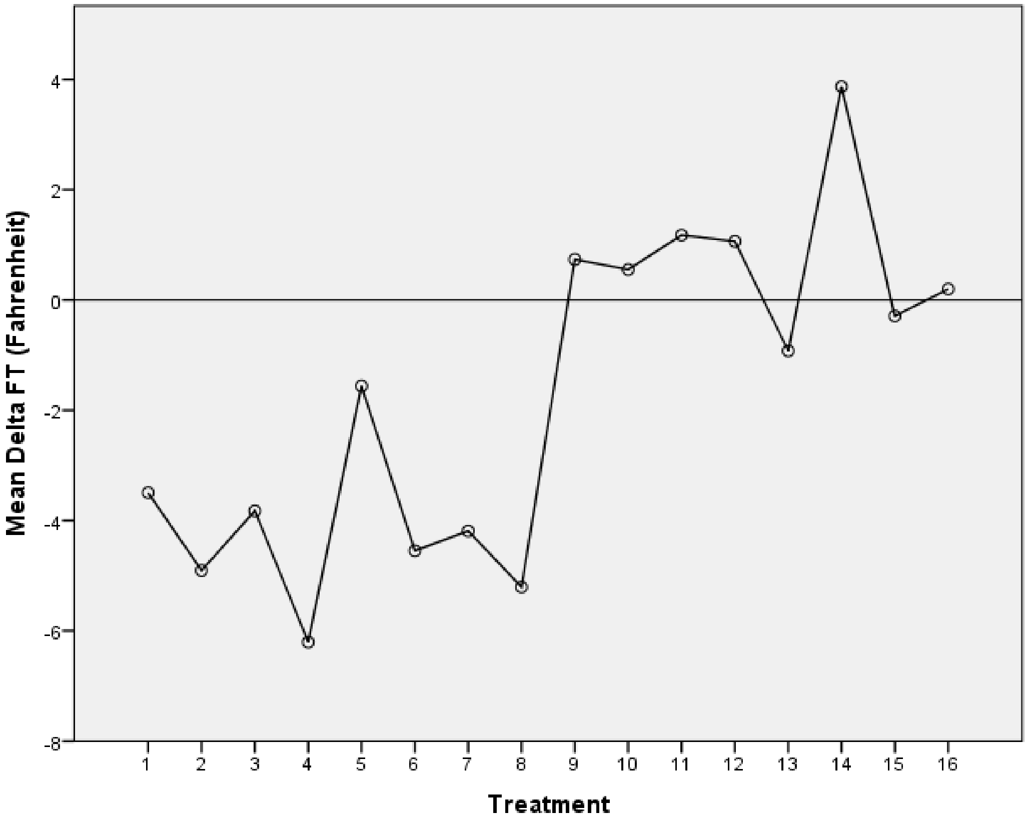


Figure 11. Mean differential for finger tip temperature

Cortisol Difference

Samples of salivary cortisol were taken before and after each task. A differential was calculated to determine changes in cortisol level. Mean levels of cortisol associated with each treatment are shown in table 12.

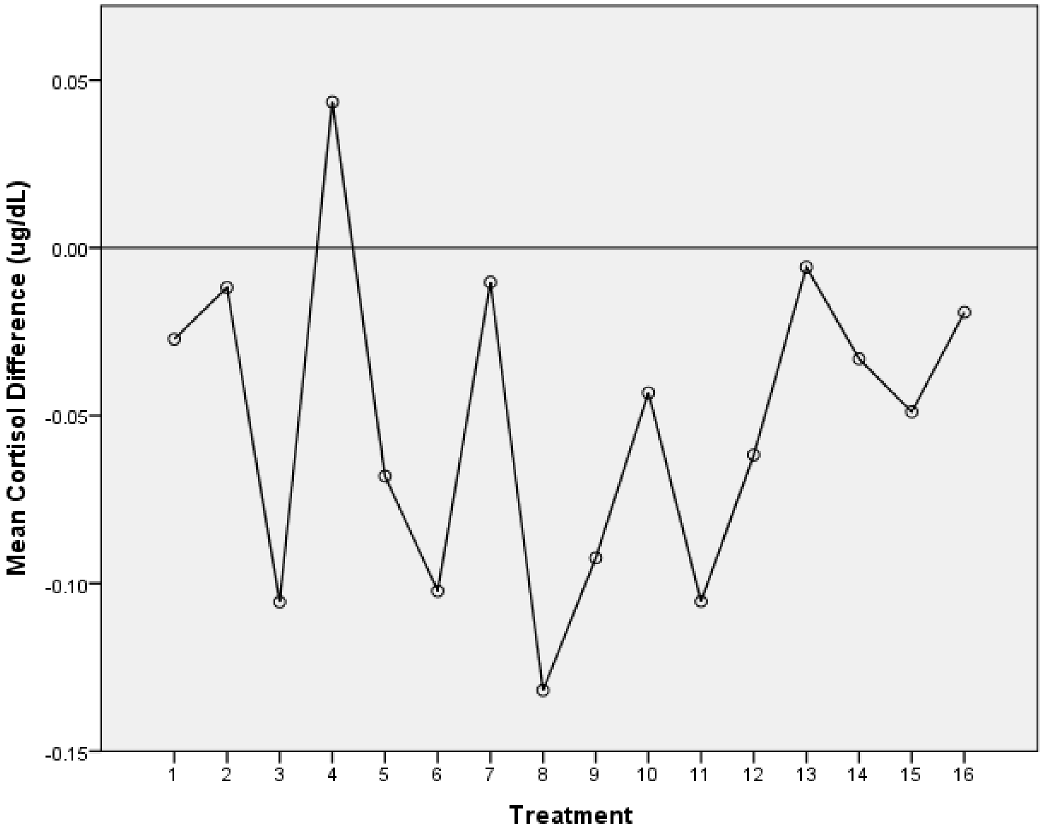


Figure 12. Differential of cortisol levels by treatments

Percentage of Maximum Heart Rate

Maximum heart rate was calculated for each participant and the corresponding percentage of maximum heart rate is calculated. Figure 13 shows the average percentage of maximum heart rate values for participants during various treatments.

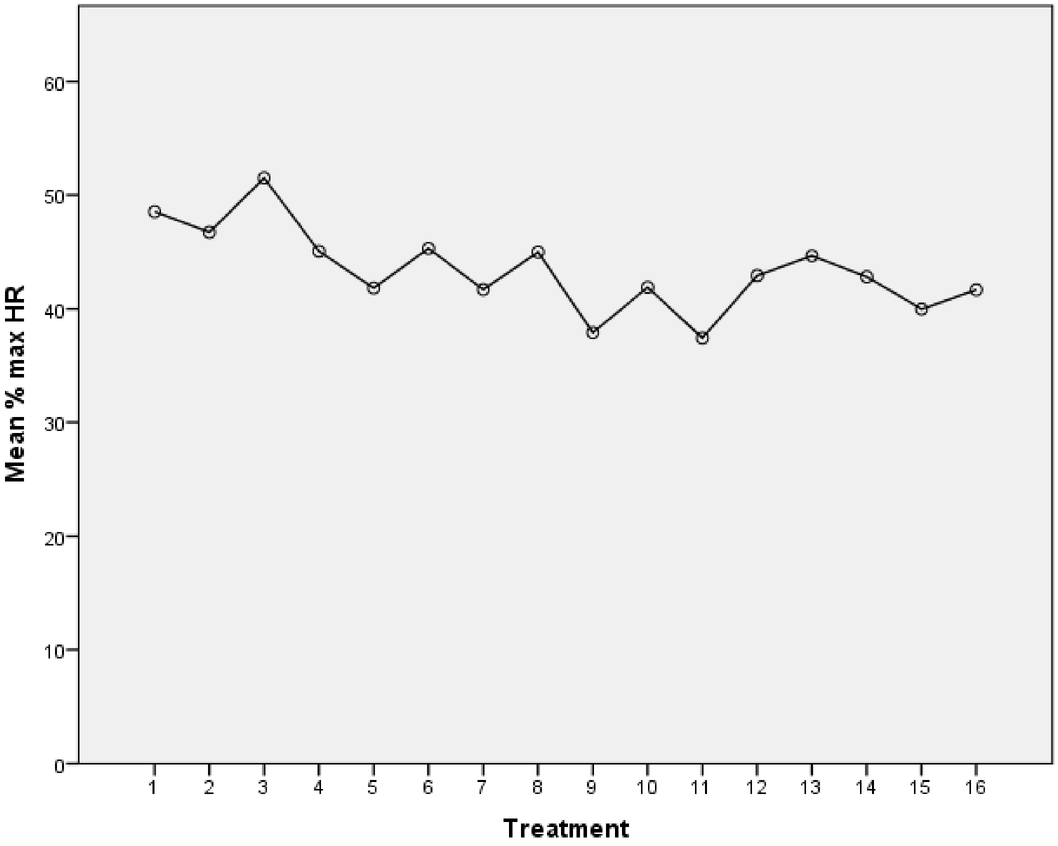


Figure 13. Mean percentage of maximum heart rate per treatment

Number of Misses and False Alarms

Task performance measures are collected in number of misses and false alarms. Figure 14 presents these instances according to treatment. Figure 14 also presents score values for misses and false alarms per treatments.

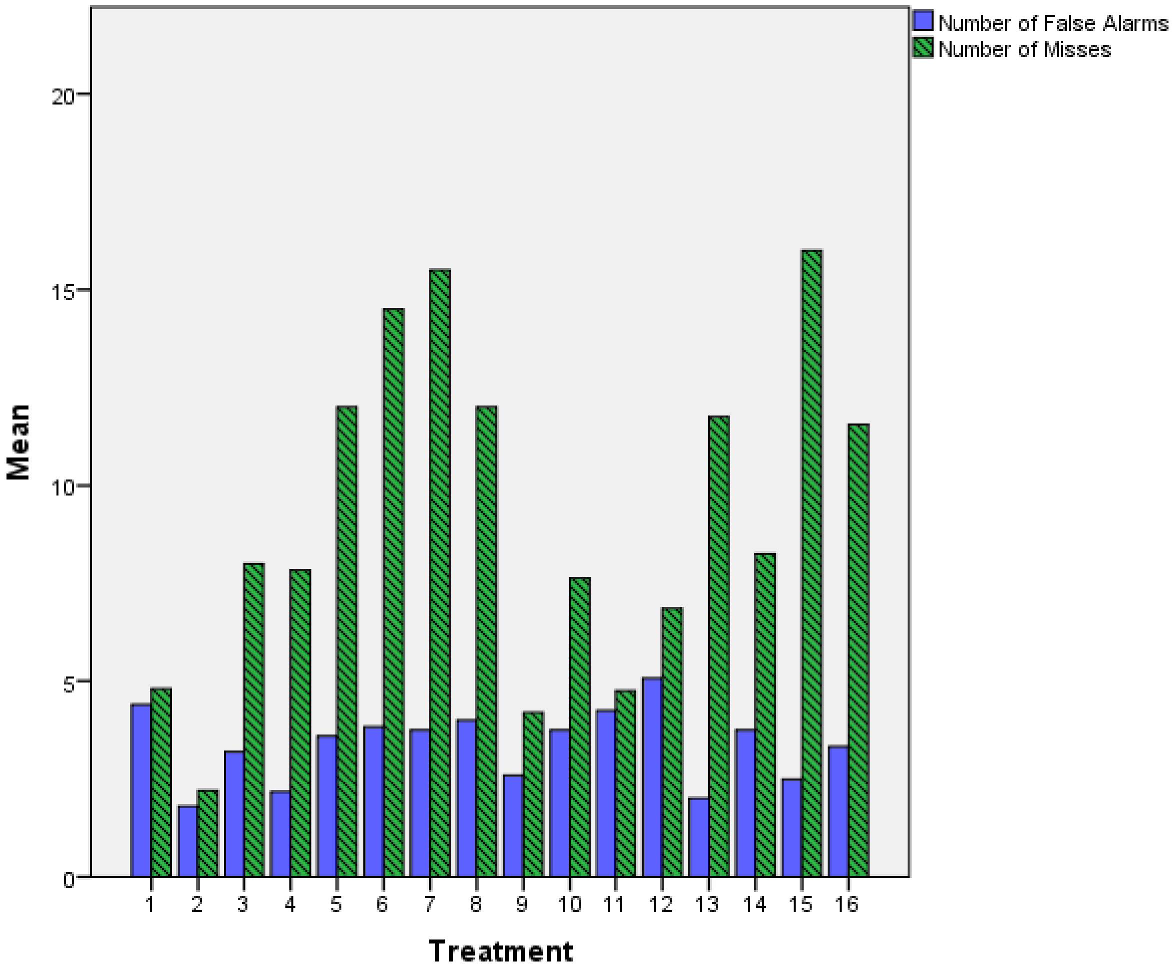


Figure 14. Number of misses and false alarms according to treatments

Reaction Times

Another task performance measure used in this study was reaction times. Mean time to react before missing a signal and after missing a signal were collected and presented in Figure 15.

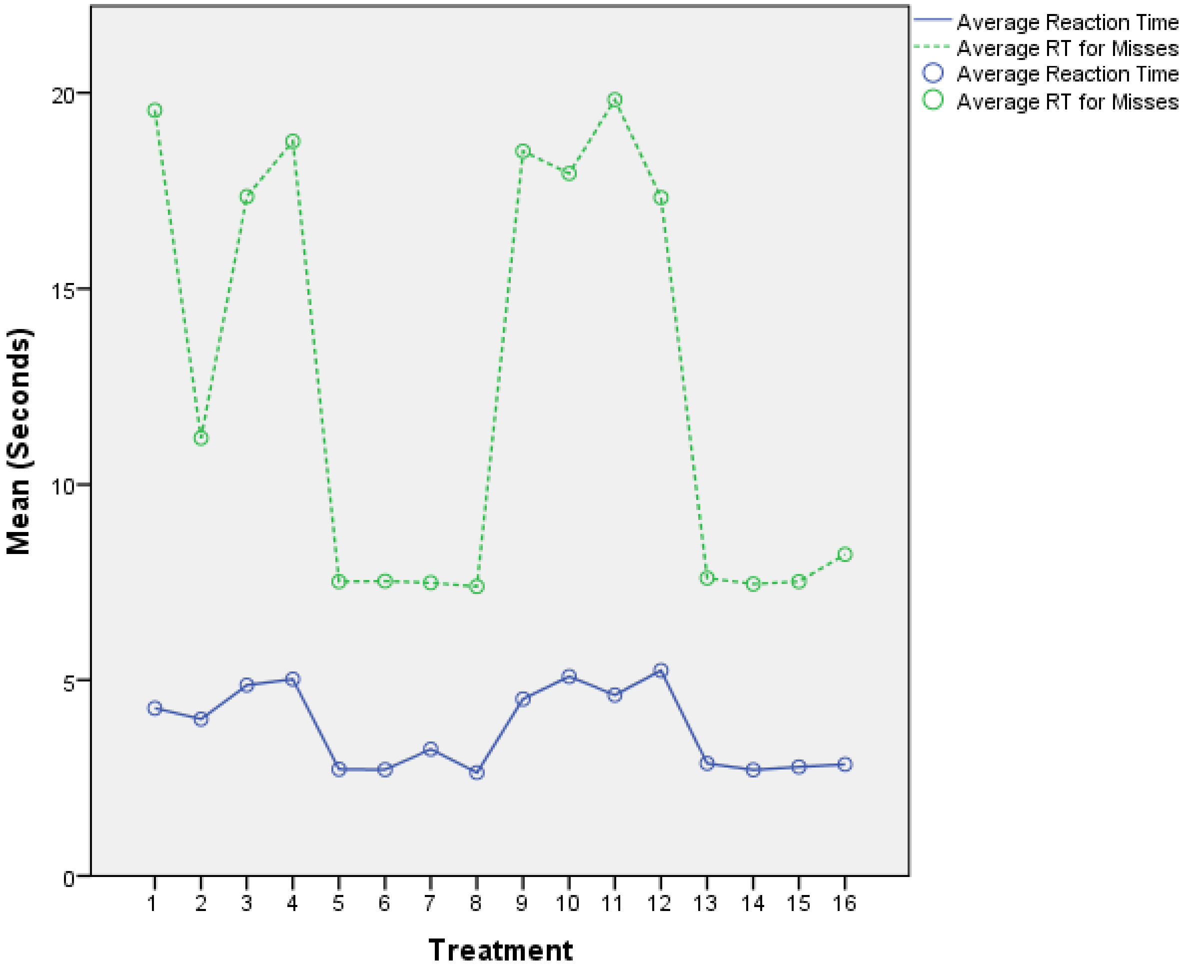


Figure 15. Reaction times by treatment

Deviation from Target

The last task performance measure recorded was deviation from target. The root mean squared error for deviation was calculated and trend results are shown in Figure 16 according to treatments.

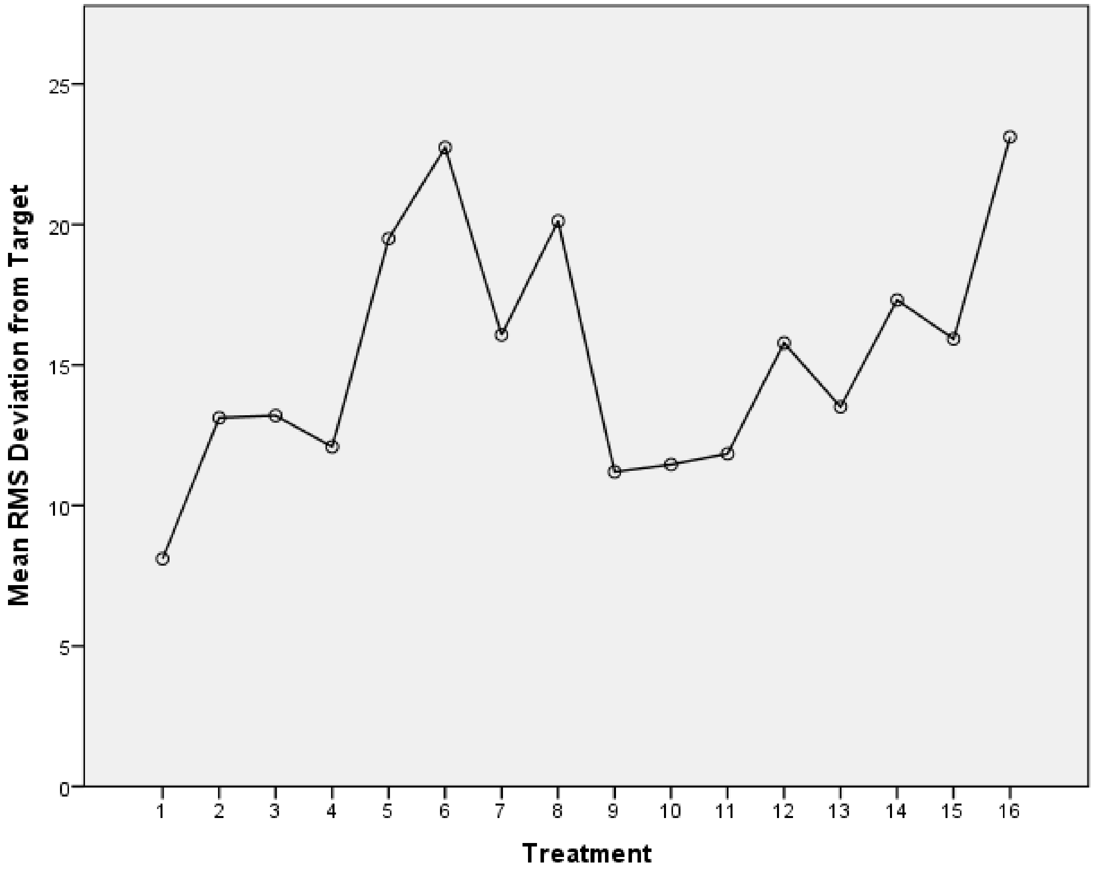


Figure 16. Deviation error from target according to treatments

4.2.2. Multivariate Analysis of Variance

Response variables were tested for statistical significance. A mixed analysis of variance (ANOVA) for a full factorial experimental design: 2 (Noise) x 2 (Temperature) x 2 (Time Awareness) x 2 (Workload) was performed at α=0.05. The analysis revealed statistical significant differences on certain dependent variables for main and interactions effects. ANOVA results for significant responses are shown below. ANOVA analysis was performed with 77 participants due to missing data for certain measurements on 19 participants. Complete results from this statistical analysis can be found in Appendix D.

Stress Arousal Checklist

Stress difference was found to be statistically significant for the main effect related to the factor *Time Awareness*, *F* (1,76) = 6.639, *p*=0.012. The *Noise x Temperature x Workload* interaction was also found to be marginally statistically significant *F*(1,76) = 3.778, *p*=0.057.

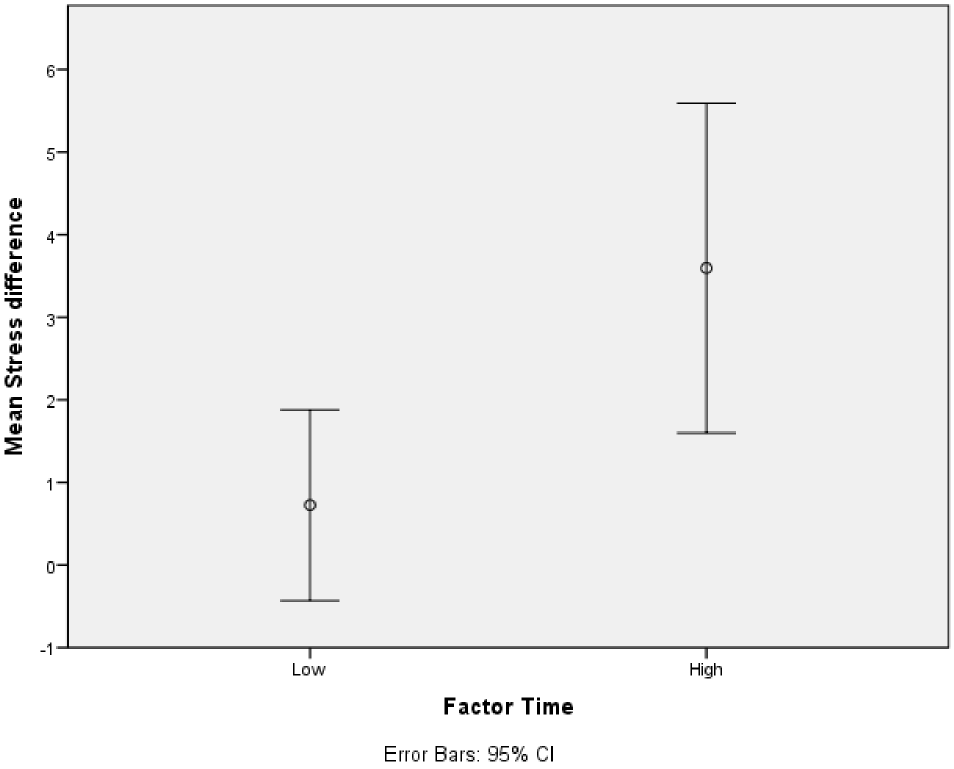


Figure 17. Mean stress difference for stress level dimension for main effect Time Awareness

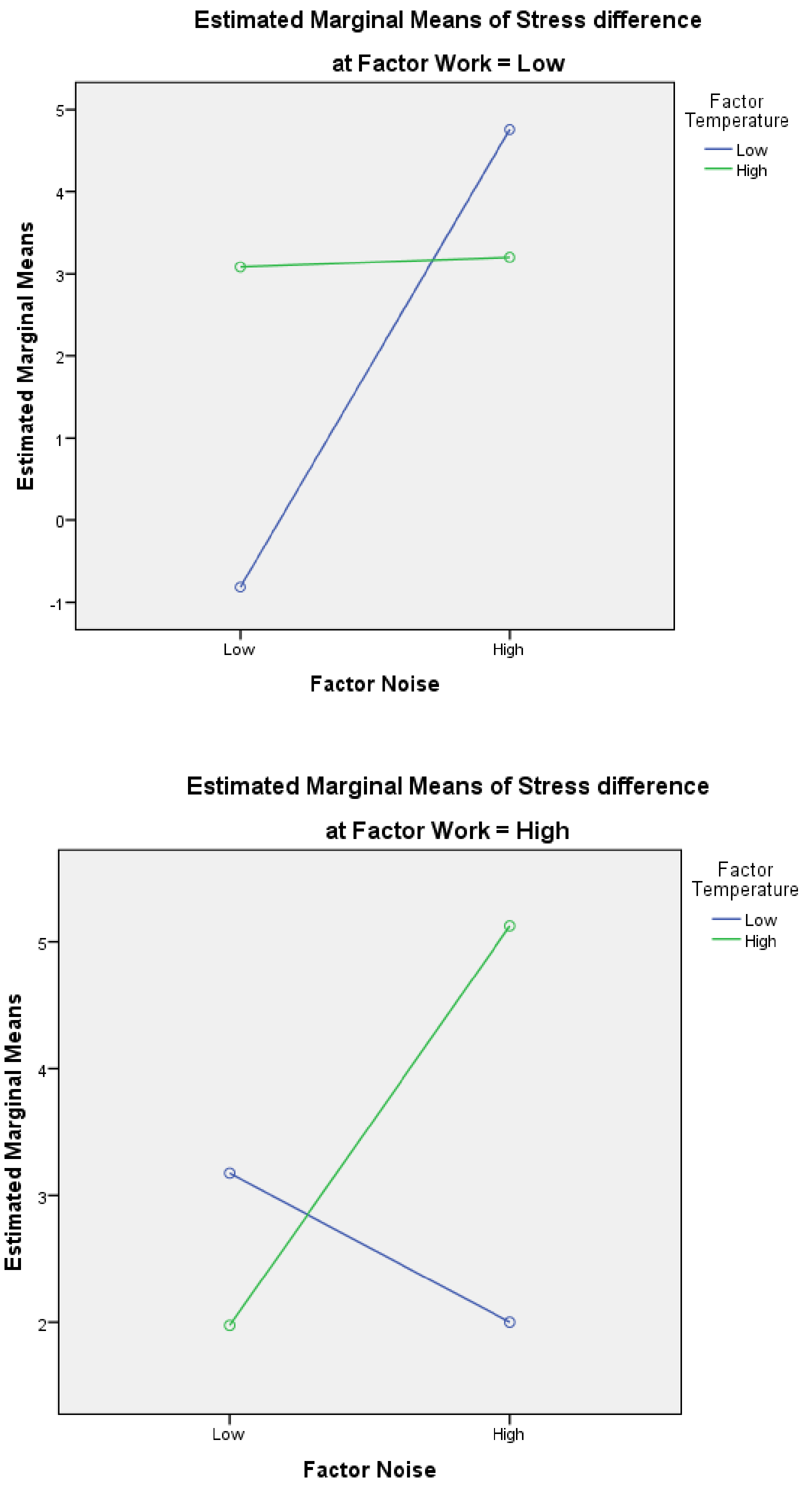


Figure 18. Mean stress difference for three way interaction Noise x Temperature x Workload

NASA TLX Workload Index

Significant differences were found for the *Noise* and *Workload* main effects. For the main effect *Noise F* (1,76) = 10.561, *p*=0.002. For the main effect *Workload*, *F* (1,76) = 5.818, *p*=0.019. The NASA TLX Workload index is also statistically significant at the *Noise x Time Awareness* interaction with *F* (1, 76)= 5.876, *p*=0.018.

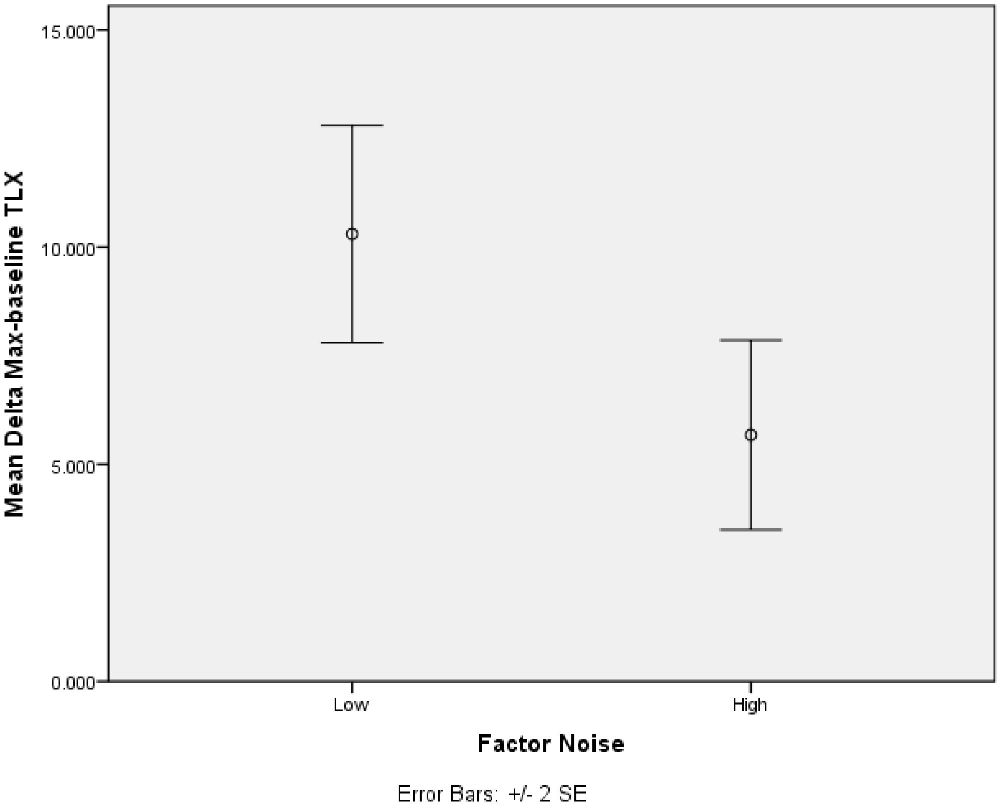


Figure 19. Mean NASA TLX workload index difference for main effect Noise

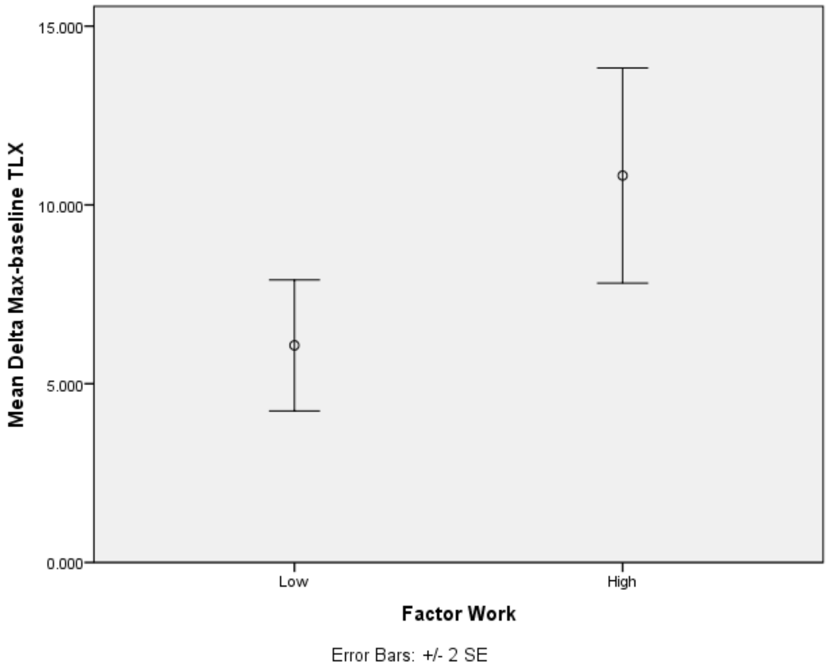


Figure 20. Mean NASA TLX workload index difference for main effect Workload

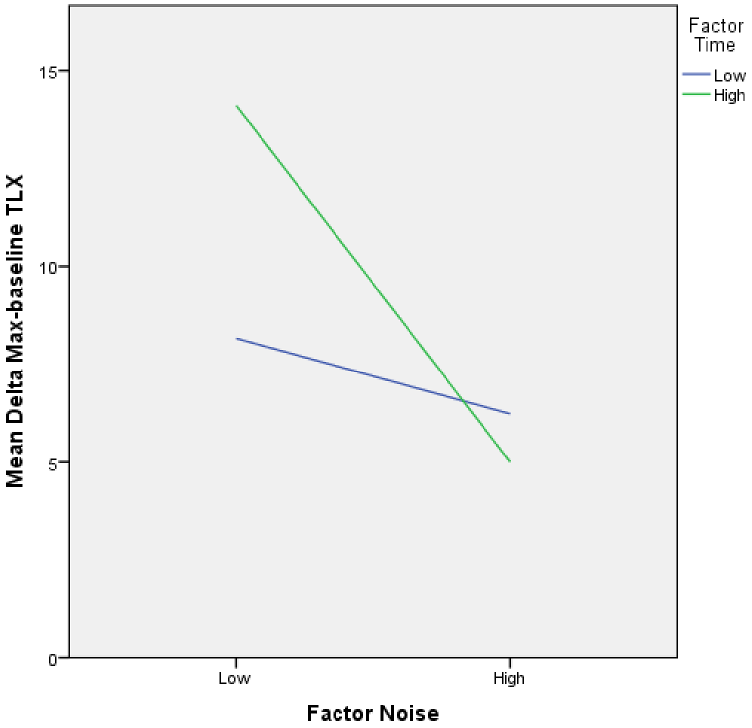


Figure 21. Mean NASA TLX workload index difference for two way interaction Noise x Time Awareness

Galvanic Skin Resistance

Galvanic skin resistance differences are statistically significant for the main effects *Noise F* (1,76)=5.249, *p*=0.025 and *Temperature F*(1,76)=4.068, *p*=0.048.

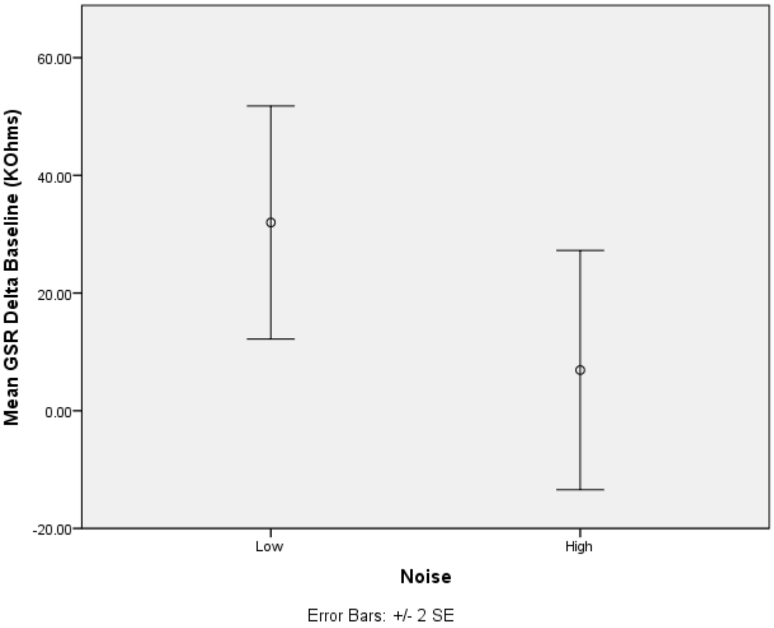


Figure 22. Mean GSR difference for main effect Noise

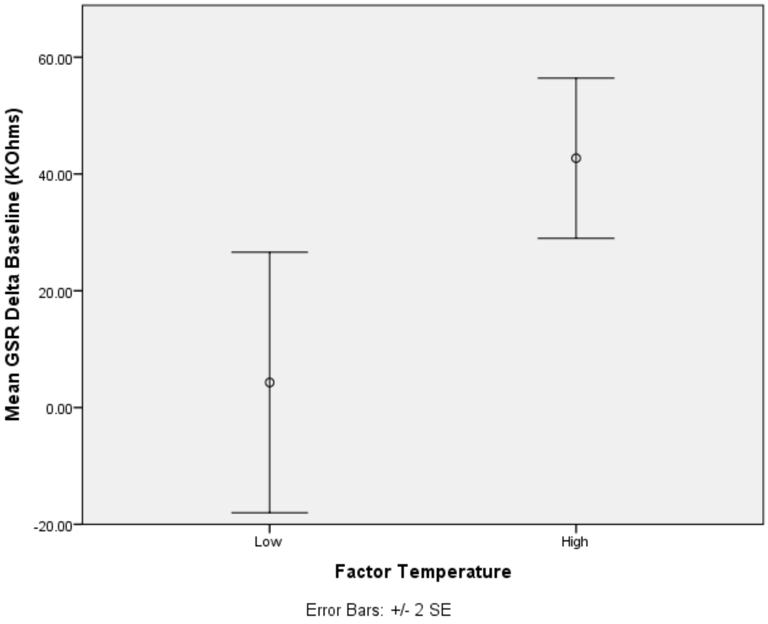


Figure 23. Mean GSR difference for main effect Temperature

Finger Tip Temperature

Statistical significant differences are found for main effect *Temperature F* (1,76)=28.812, *p*=0.000 and two-way effect *Temperature x Time Awareness F*(1,76)=5.788, *p*=0.019.

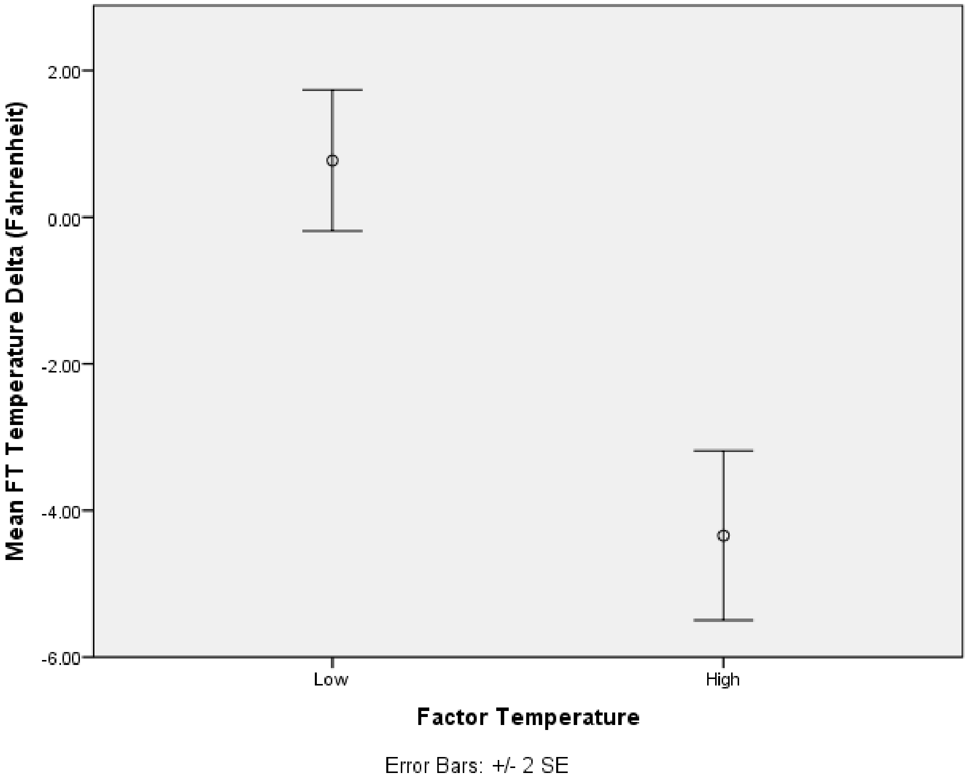


Figure 24. Mean finger tip temperature difference for main effect Temperature

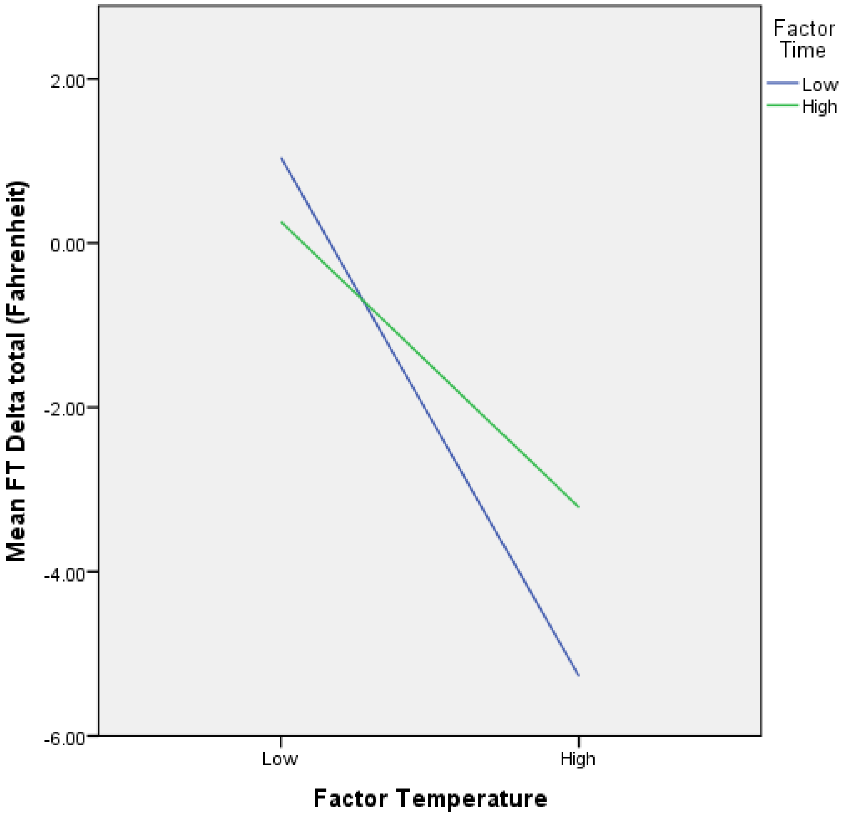


Figure 25. Mean finger tip temperature difference for two way interaction Temperature x Time Awareness

Cortisol difference

Statistical significant difference was obtained at the two way effect for *Temperature x Workload* *F* (1,76)= 5.047, *p*=0.028 and *Time Awareness x Workload*, *F* (1,76)=4.299, *p*=0.042.

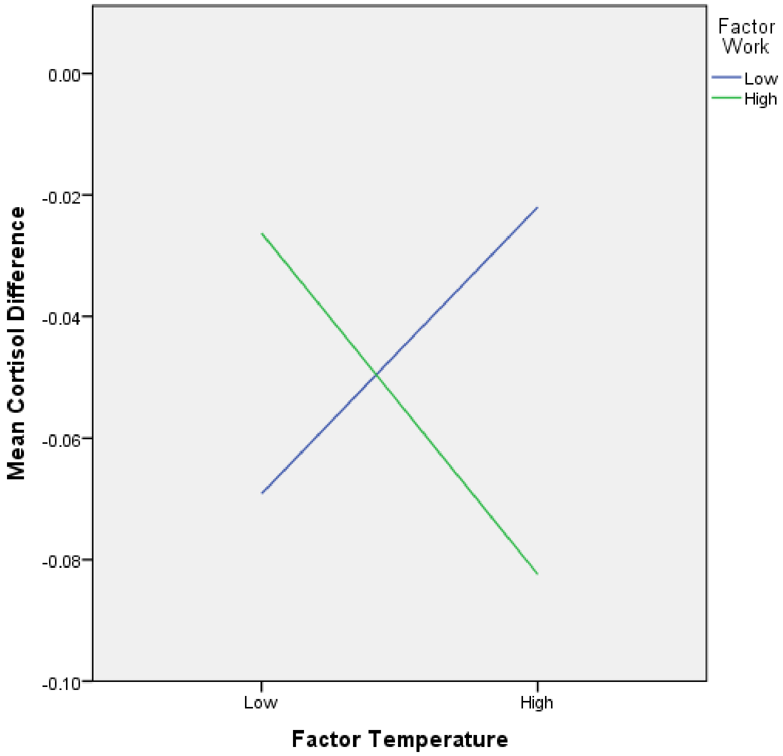


Figure 26. Mean cortisol concentration difference for two-way interaction Temperature x Workload

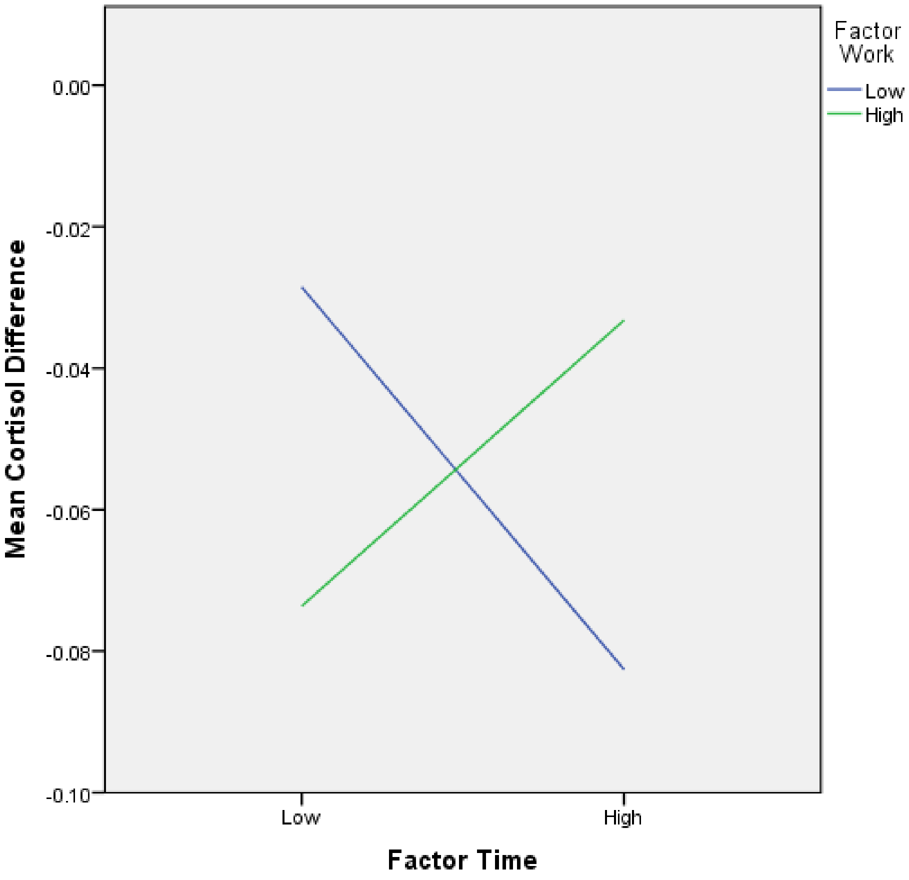


Figure 27. Mean cortisol concentration difference for two-way interaction Time Awareness X Workload

Percentage of Maximum Heart Rate

This experimental response has statistical significance for the main effect *Temperature*, *F* (1, 76) = 10.451, *p*=0.002 and the two way interaction effect for *Temperature x Workload F* (1, 76) = 4.311, *p*=0.042. Additionally, statistical significance is found at the three way interaction effect for *Temperature x Time Awareness x Workload*, *F* (1, 76) = 5.153, *p*=0.027.

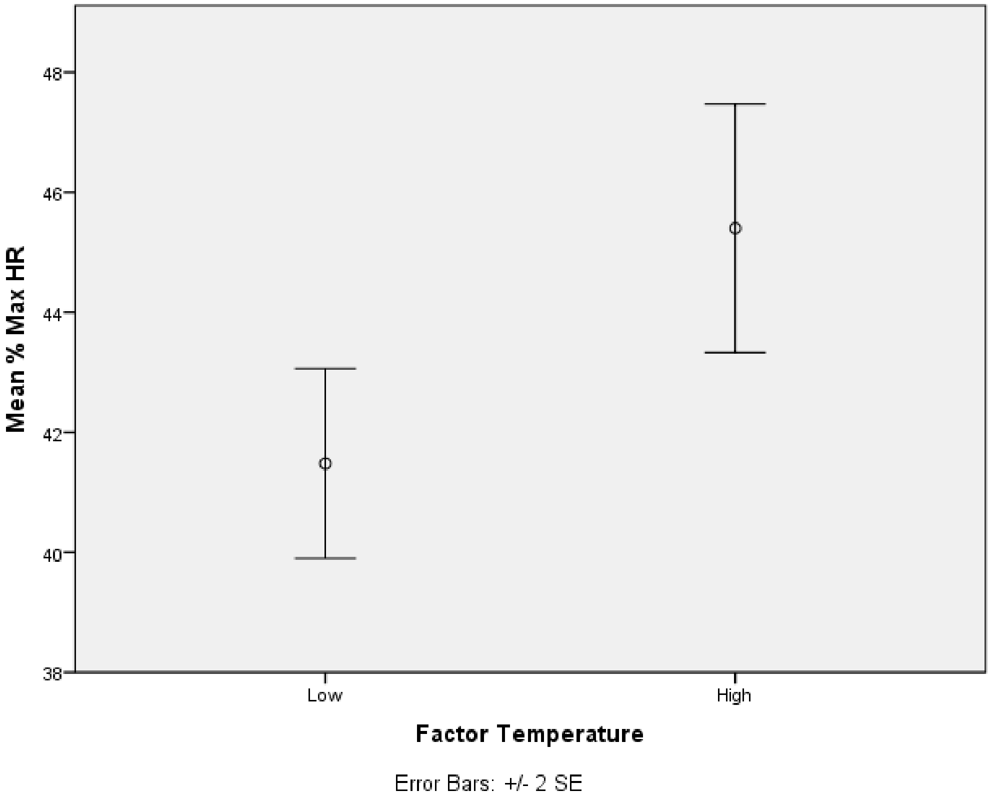


Figure 28. Mean percentage of maximum heart rate for main effect Temperature

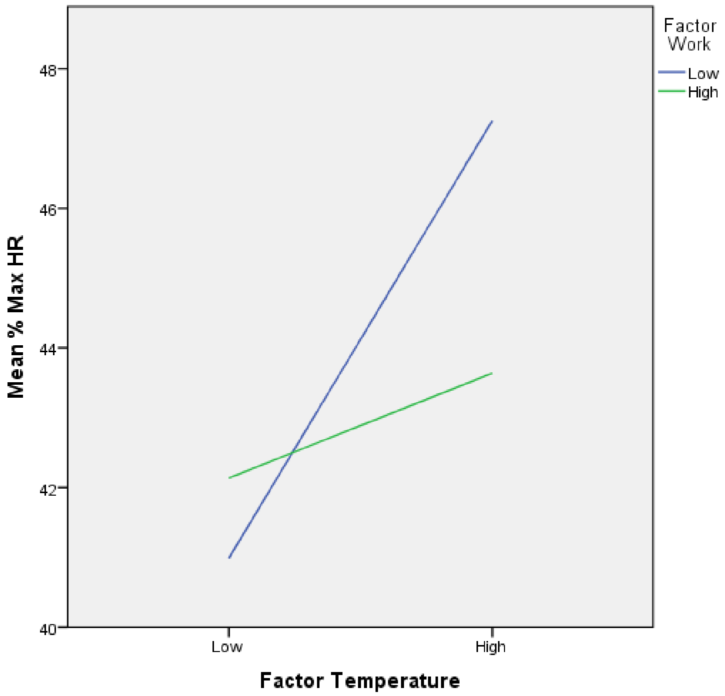


Figure 29. Mean percentage of maximum heart rate for main effect Temperature

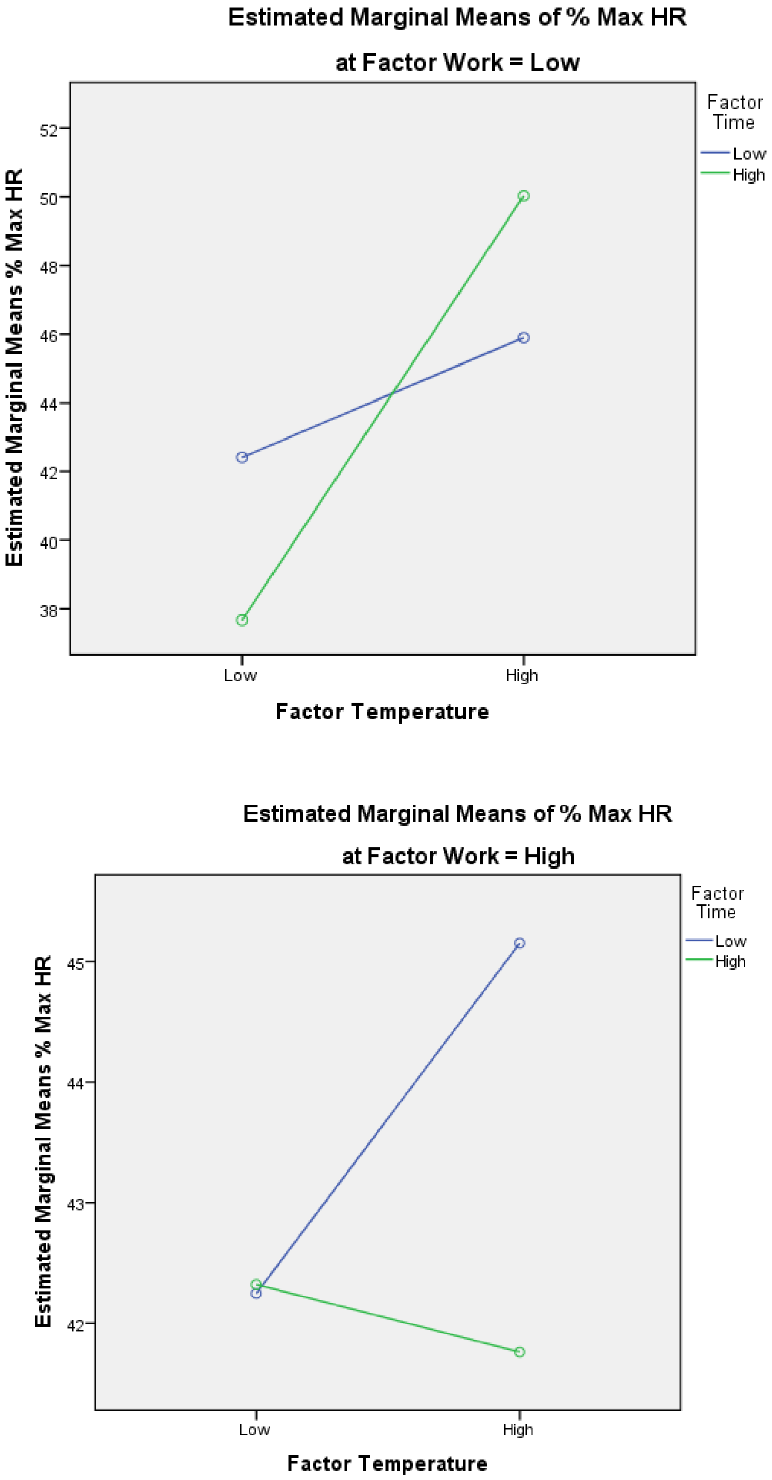


Figure 30. Mean percentage of maximum heart rate for three way interaction Temperature x Time Awareness x Workload

Number of Misses

This performance response was statistically significant for the main effect *Workload*, *F* (1, 76) = 28.054, *p* = 0.000. Additionally, there was statistical significance for the three way interaction *Noise x Temperature x Workload*, *F* (1, 76) = 4.033, *p*= 0.049.

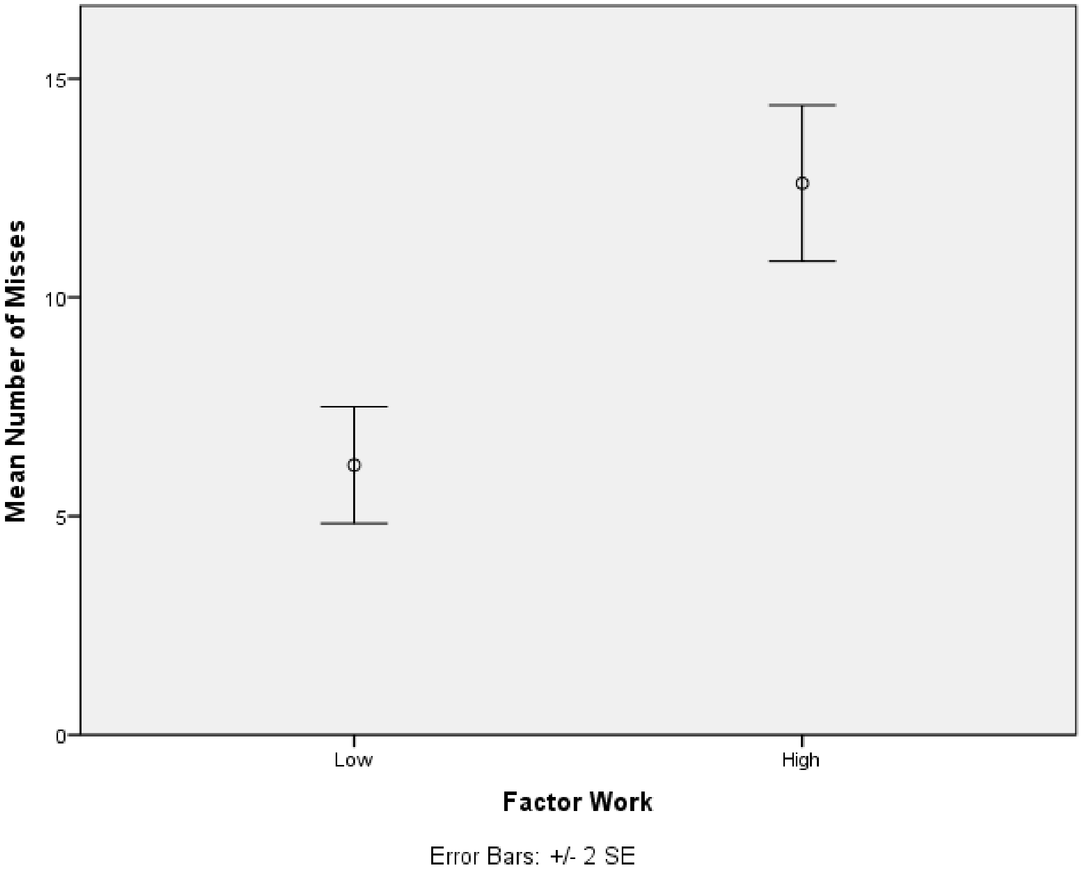


Figure 31. Mean number of misses for main effect Work

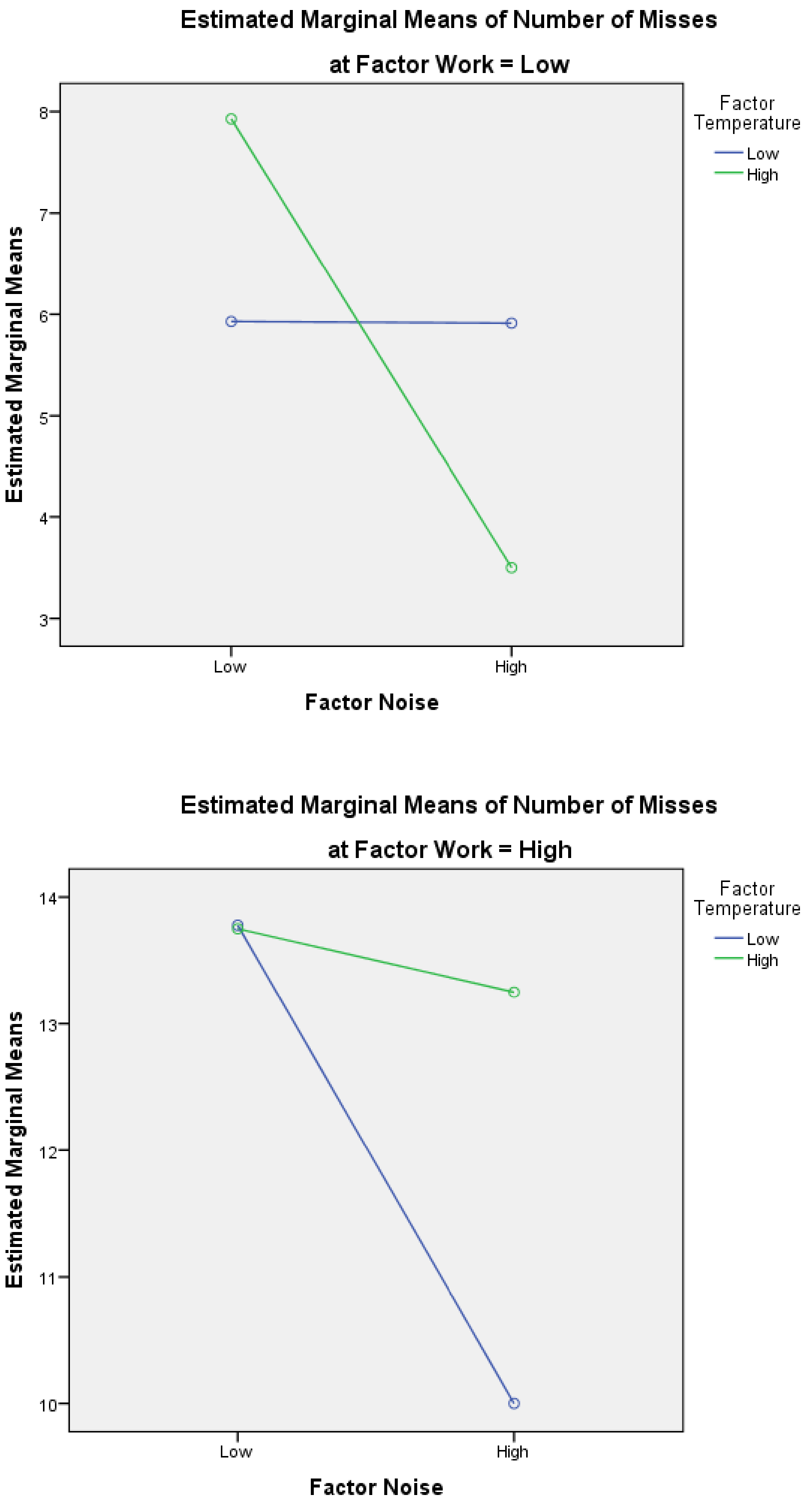


Figure 32. Mean number of misses for three way interaction Noise x Temperature x Workload

Reaction Time

Statistical significance was found at the main effect *Work*, *F* (1, 76) = 145.741, *p*= 0.000.

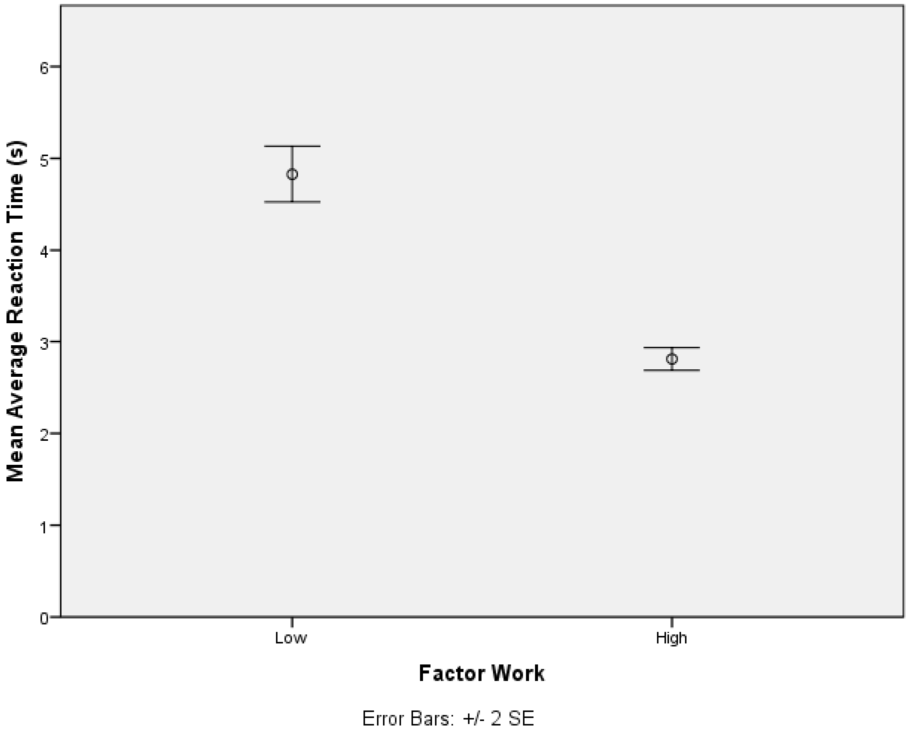


Figure 33. Mean reaction time for main effect Workload

Reaction Time for Misses

As previous performance measure, statistical significance was found at the main effect *Workload, F* (1, 76) = 75.815, *p*= 0.000.

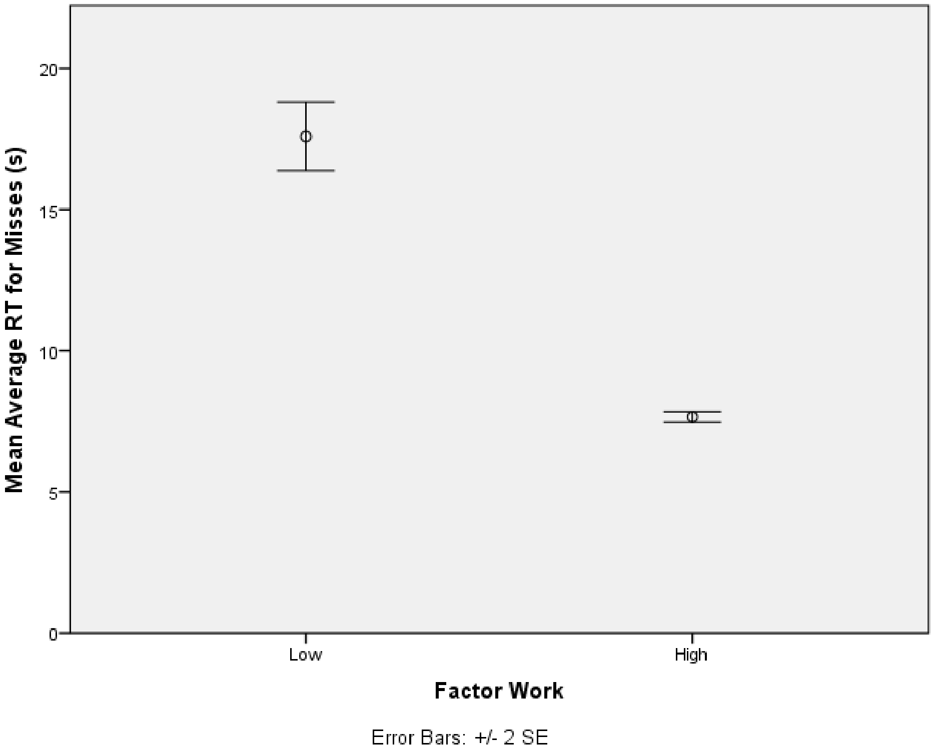


Figure 34. Mean reaction time (misses) for main effect Workload

Deviation from Target

For this performance measure, statistical significance was found at the main effect *Time*, *F* (1, 76) = 4.211, *p*= 0.044. In addition, statistical significance was found at the main effect *Workload*, *F* (1, 76) = 13.876, *p*= 0.000.

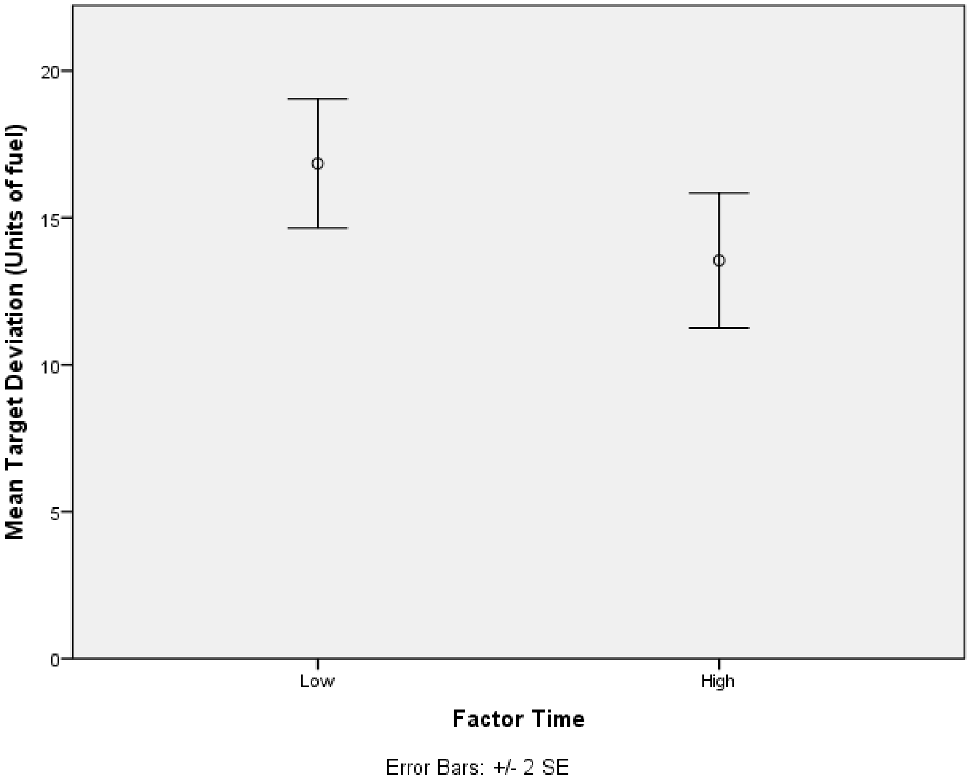


Figure 35. Mean target deviation for main effect Time

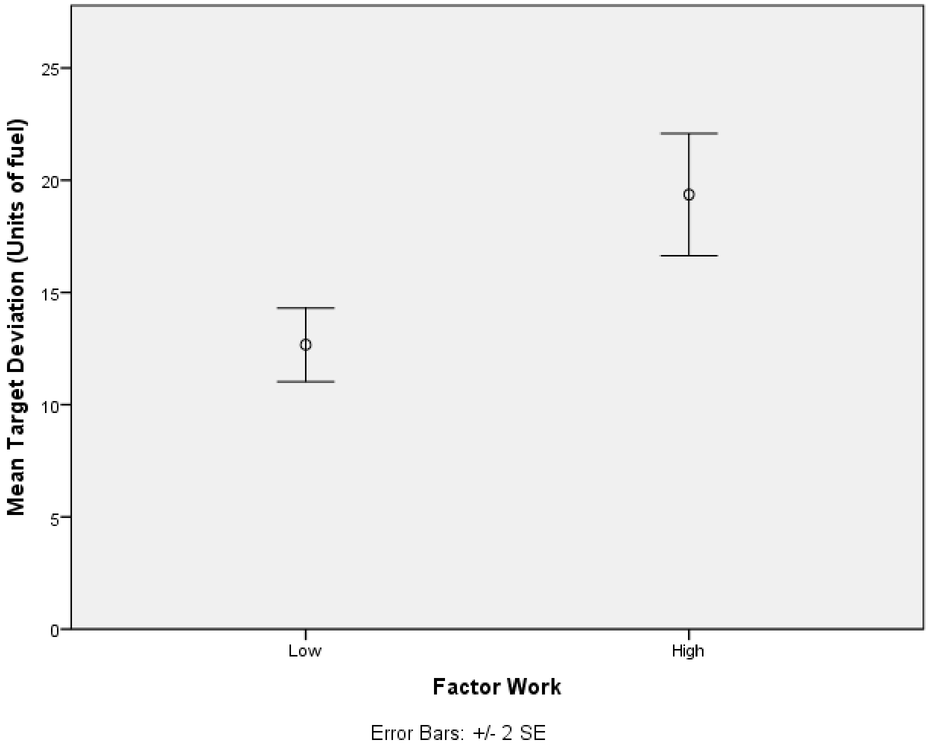


Figure 36. Mean target deviation for main effect Workload

From the ANOVA analysis we can reject the null hypothesis for the following tested hypotheses:

1. Test for main and interaction effect on physiological measurements.

   H_o: There are no significant differences of mean physiological responses between the stress conditions.

   H_a: There are significant differences of mean physiological responses between the stress conditions.

2. Test for main and interaction effect on cognitive measurements

   H_o: There are no significant differences of mean cognitive responses between the stress conditions.

H_a: There are significant differences of mean cognitive responses between the stress conditions.

3. Test for main and interaction effect on behavioral measurements

   H_o: There are no significant differences of mean behavioral responses between the stress conditions.

4. H_a: There are significant differences of mean behavioral responses between the stress conditions

5. Test for main and interaction effect on performance measurements

   H_o: There are no significant differences of mean performance responses between the stress conditions.

   H_a: There are significant differences of mean performance responses between the stress conditions.

In addition to the traditional analysis of variance for a factorial design, a multiple comparison of treatments means (Bonferroni for unequal sample size) was performed. Such pairwise comparisons show sufficient evidence to conclude that the population means for specific response variables differ at $\alpha = 0.05$. Complete tables with results for pairwise comparisons between conditions for main effect test can be found in Appendix D after ANOVA tables.

4.3. Fuzzy Modeling

4.3.1. Membership Functions

For the construction of the model and its membership function only those variables that have statistical significance are used for the development of the fuzzy model. The following are the membership functions for each of these variables.

4.3.1.1. Stress Arousal Level

Membership function for this self-report scale is developed based on the nature of the scoring instrument. The stress arousal checklist has a maximum score of 18 to evidence highest level of stress and zero to indicate no stress. Because the SACL score is found to be directly proportional to the level of stress and the scalar nature of the measurement a linear function is most appropriate.

$$y(x) = \frac{x}{18}$$

Where:

x = represents the score obtained for the stress dimension in the Stress Arousal Checklist (SACL)

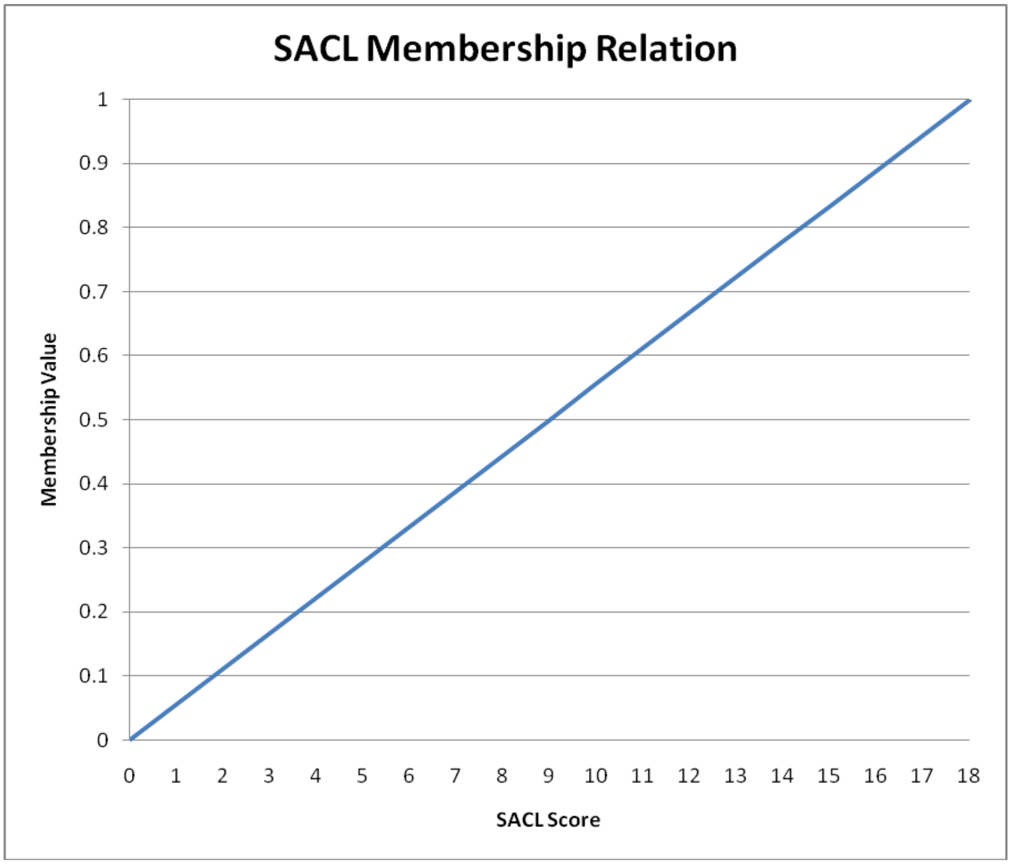


Figure 37. SACL-Stress membership function

4.3.1.2. Workload Index (NASA TLX)

As the previous variable, the NASA TLX workload index is a self-reported instrument to assess levels of workload. The scale for such instrument is represented in percentages, describing highest level of workload with 100% rating. This workload rating instrument has been used extensively in research and associated to stress. Workload ratings have been found positively correlated to stress, therefore a simple linear curve can be used to describe the membership relation. The expression for this membership function is:

$$y(x) = \frac{x}{100}$$

Where:

x = represents the score in percentage obtained for workload

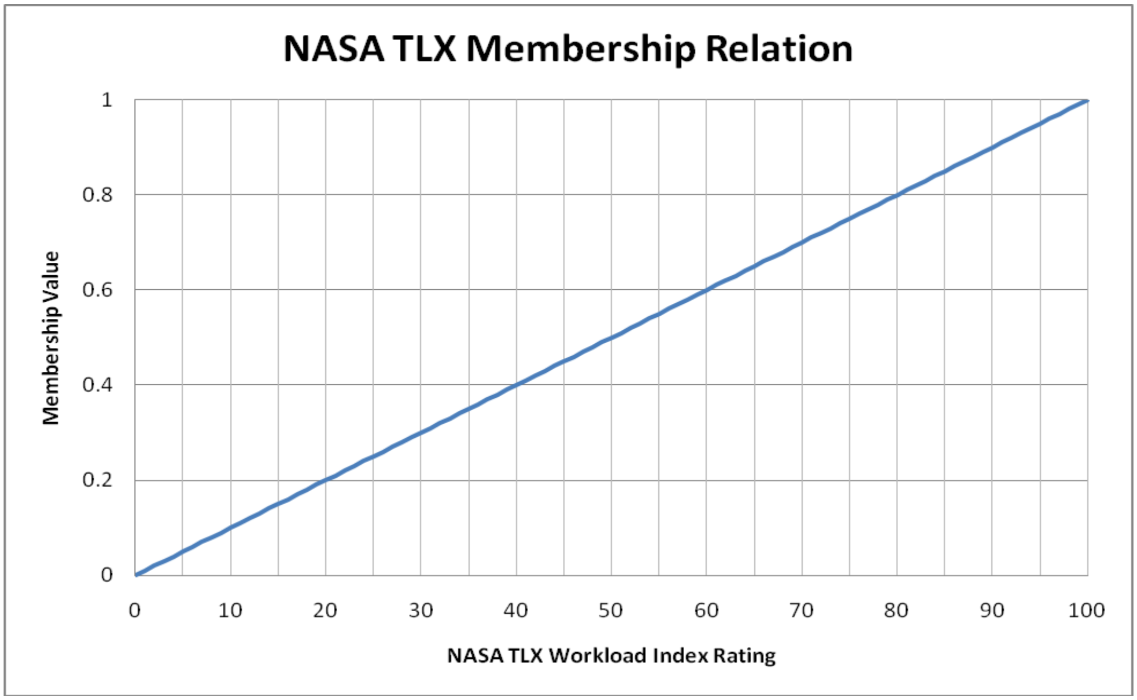


Figure 38. Workload index membership function

4.3.1.3. Galvanic Skin Resistance

Changes in galvanic skin resistance can be described through a decreasing sigmoid curve. Low levels of skin resistance (high levels of electricity conductance are associated with stress) are attributed to high stress conditions. Galvanic skin resistance levels can vary from a maximum of 500 KOhms to almost a minimum of cero. From the literature review it was found that a sigmoid curve fits this physiological measure and it is contained within the minimum and maximum values observed. The form of the membership function has the following expression:

$$y(x) = \frac{1}{1+e^{(\alpha(x-T_o))}}$$

Where:

α = represents the amplitude of the curve and describe the growing rate 0.05 (Base 100)

T_o = corresponds to the mean value for the mean GSR (250)

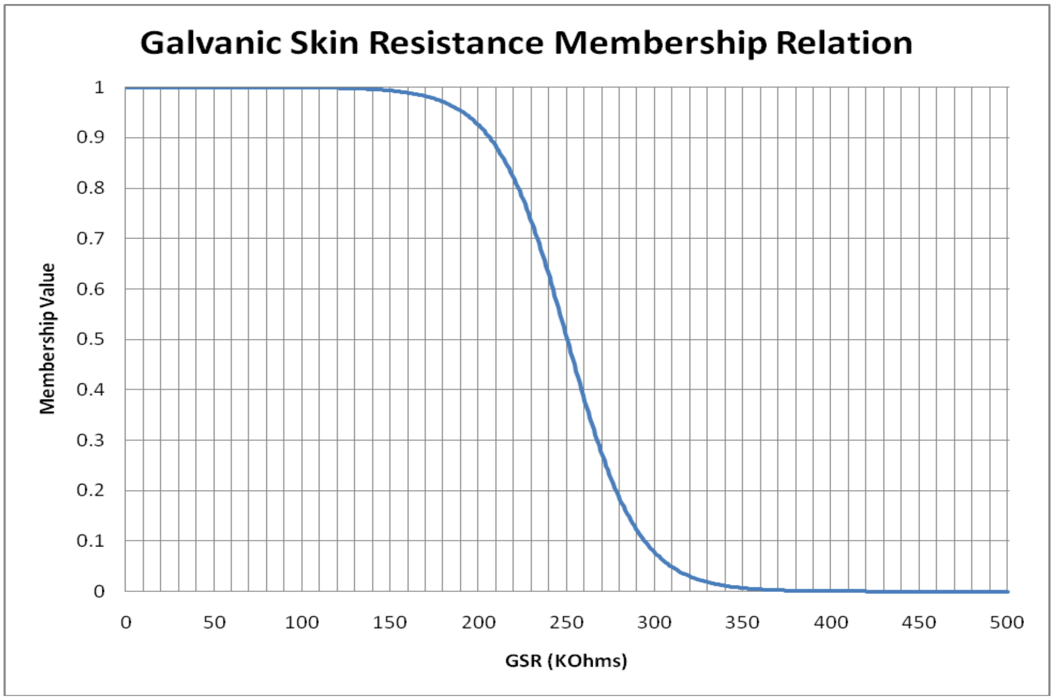


Figure 39. Galvanic Skin Resistance (GSR) membership function

4.3.1.4. Finger Tip Temperature

Decreases on finger tip temperature are the result of vascular constriction or reduction of blood to distal extremities. As the previous objective physiological measurements, the function selected to relate this phenomena to stress has the shape of a sigmoid curve. This curve is contained within the minimum and maximum values observed. The form of the membership function has the following expression:

$$y(x) = \frac{1}{1 + e^{(-\alpha(x - T_o))}}$$

Where:

α = represents the amplitude of the curve and describe the growing rate 0.5

T_o = corresponds to the mean value for the difference in temperature (7 ^{o} F)

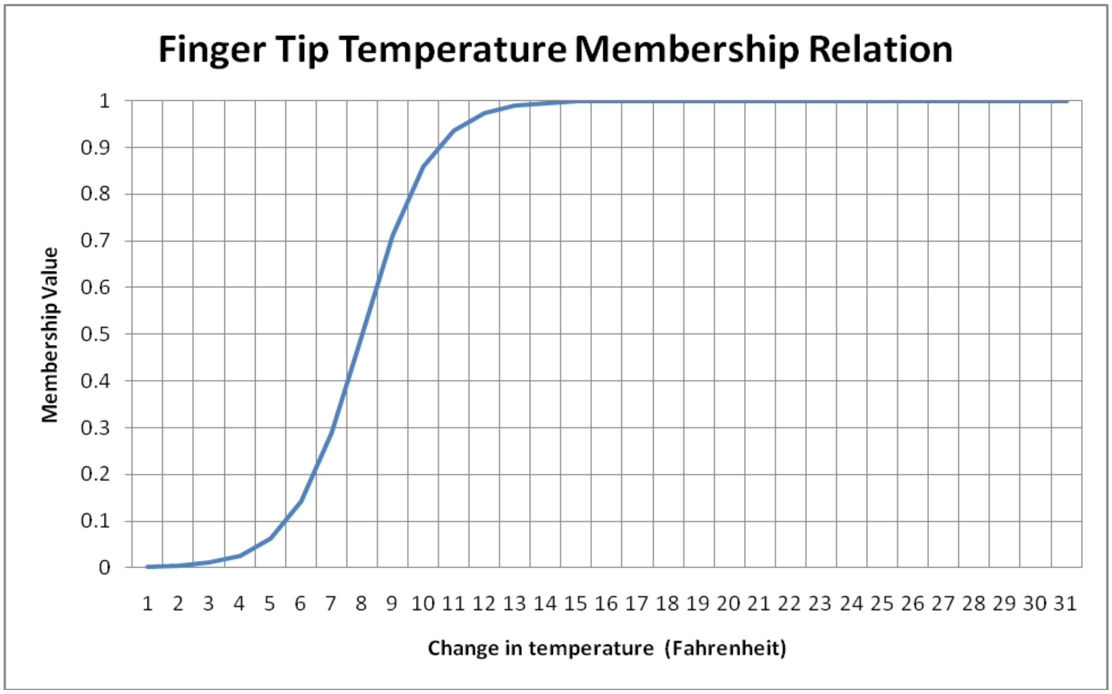


Figure 40. Finger tip temperature membership function

4.3.1.5. Percentage of Maximum Heart Rate

This physiological variable describes the changes in percentage of maximum heart rate. Heart rate has been represented in previous studies with a linear membership function (Mital, A., & Karwowski, W., 1986). Because, this measurement is a percentage of maximum heart rate a linear model can be equally used. Additionally, percentages of maximum heart rate are proportionally associated to physiological stress. A fuzzy representation of this variable has the following expression:

$$y(x) = \frac{x}{100}$$

Where:

x = represents the percentage of maximum heart rate.

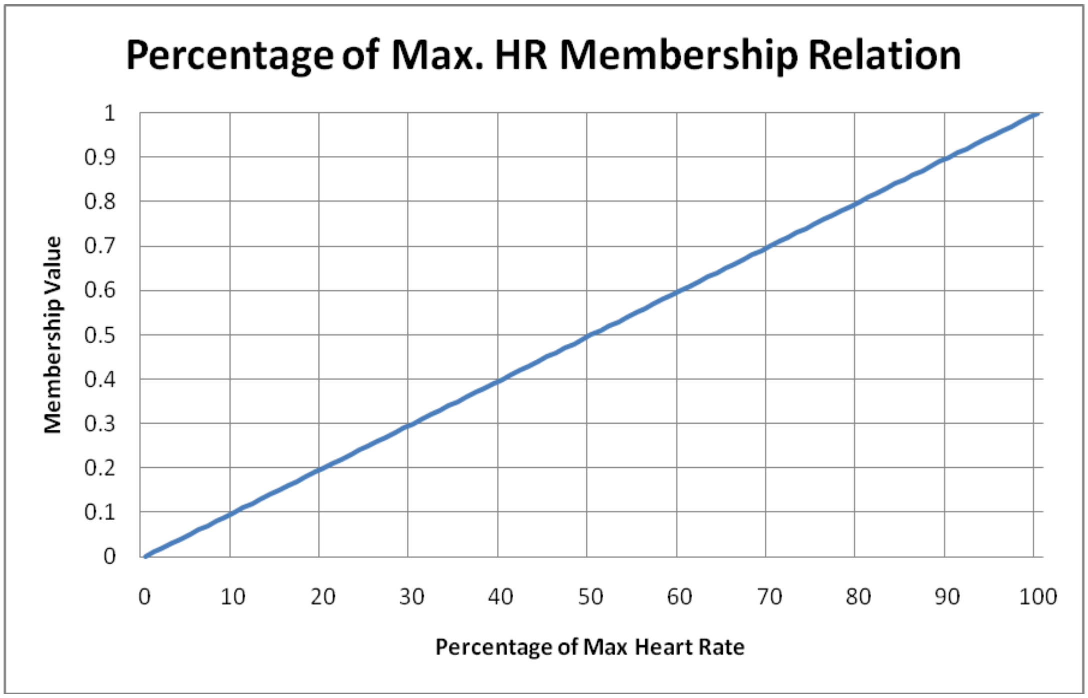


Figure 41. Percentage of maximum heart rate membership function

4.3.1.6. Cortisol Level

This physiological variable describes the changes in cortisol levels. Cortisol levels are tightly associated to stress. Because, this measurement is directly proportional to the level of stress a linear curve is selected. However, for the purpose of this research cortisol levels are taken after the diurnal peak. A fuzzy representation of this variable has the following expression:

$$y(x) = \frac{x}{0.6}$$

Where:

x = represents the cortisol levels in μg/dL.

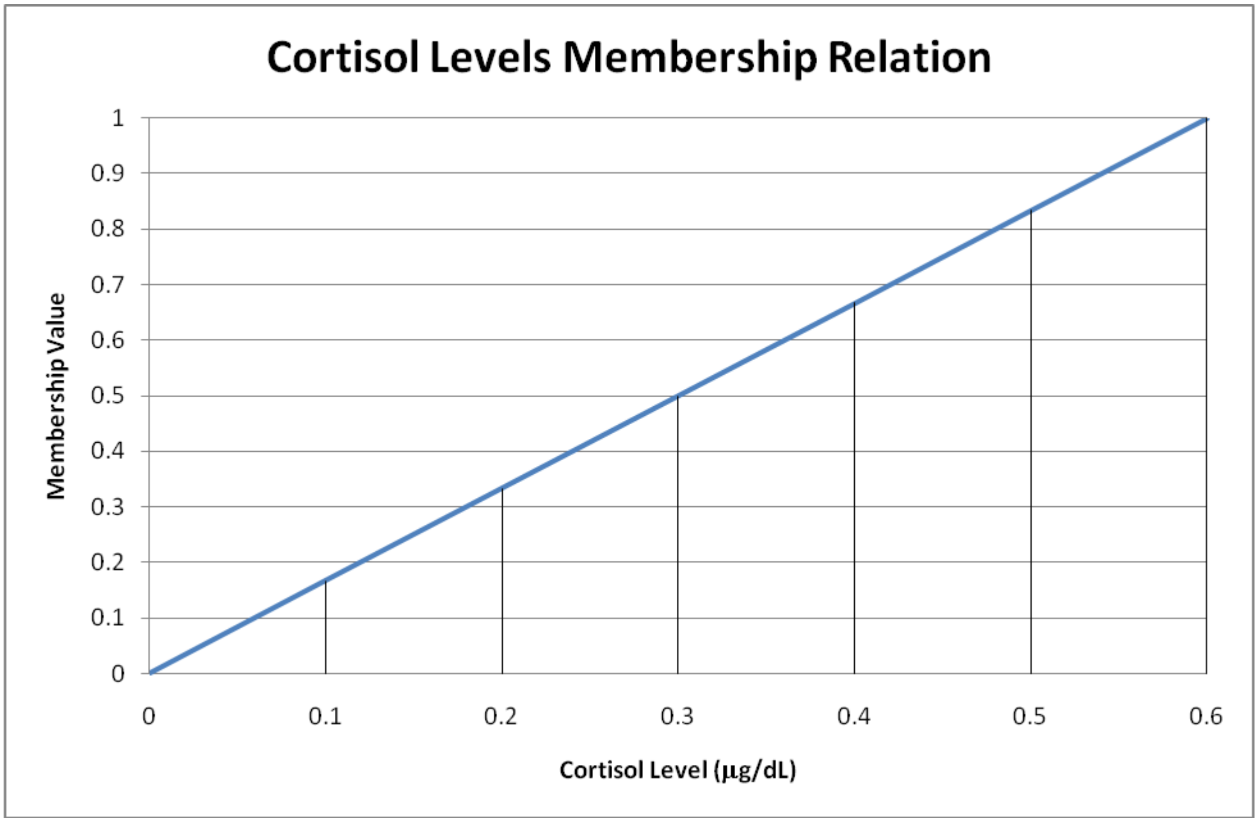


Figure 42. Cortisol levels membership value

4.3.1.7. Number of Misses

This performance variable describes the numbers of times a warning signal was missed. This measurement grows in time and is highly dependent on workload and other stressors. Because of the nature of the variable a sigmoid curve is selected to describe the membership relation with the fuzzy set stress. The curve is contained within the minimum and maximum values observed. This form of membership function has the following expression:

$$y(x) = \frac{1}{1 + e^{(-\alpha(x - T_o))}}$$

Where:

α = represents the amplitude of the curve and describe the growing rate 0.5

T_o = corresponds to the mean value for the number of misses (9)

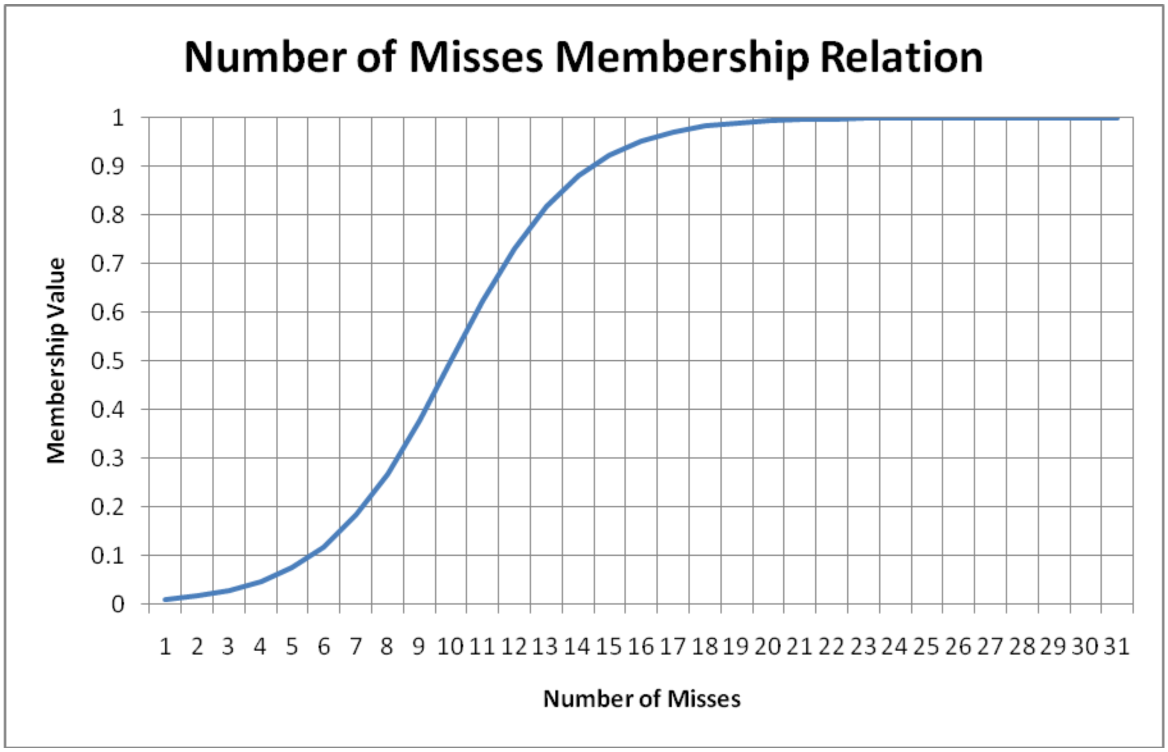


Figure 43. Number of misses membership function

4.3.1.8. Target Deviation

This performance variable describes the deviation error from a target. This measurement grows in time and is highly dependent on workload and other stressors. Because of the nature of the variable, a sigmoid curve is selected to describe the membership relation with the fuzzy set stress. The curve is contained within the minimum and maximum values observed. This form of membership function has the following expression:

$$y(x) = \frac{1}{1+e^{(-\alpha(x-T_o))}}$$

Where:

α = represents the amplitude of the curve and describe the growing rate 0.5

T_o = corresponds to the mean value for the deviation error (15)

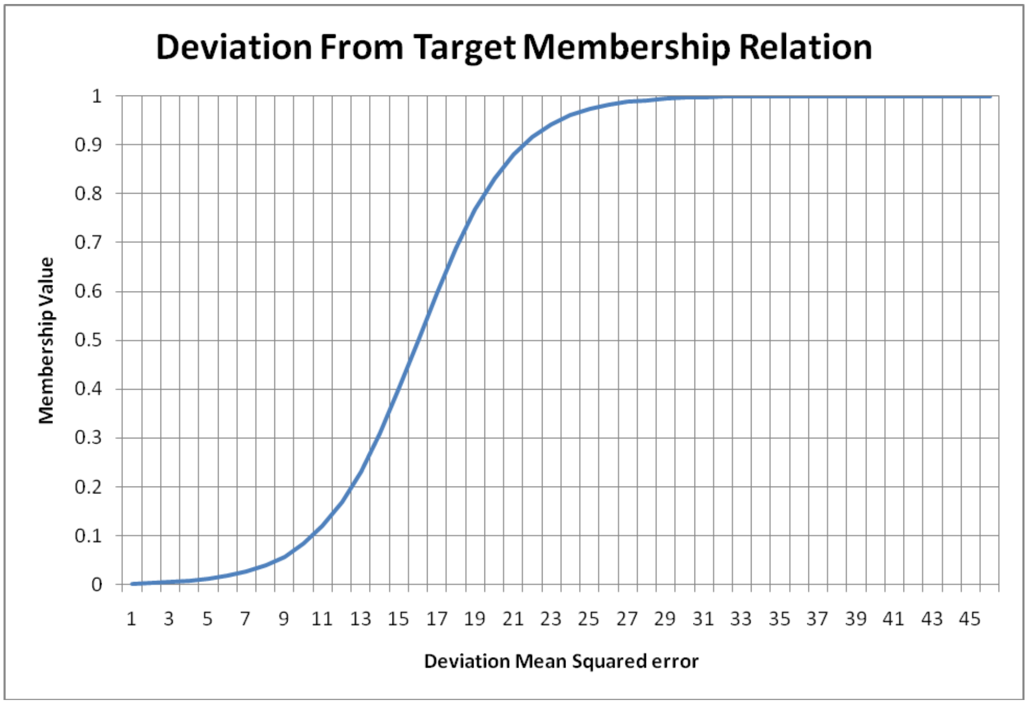


Figure 44. Deviation error membership function

4.3.1.9. Competitiveness

Membership function for this self-report scale was developed based on the scoring instrument. The Competitiveness index has a converted maximum score of 20 to evidence highest level of competitiveness and 8 for low levels. It is assumed, based on the literature, that lowest levels of competitiveness trait bring higher levels of stress. The form of the membership function has the following expression.

$$y(x) = -\frac{x}{12} + 1.66667$$

Where:

x = represents the score obtained in the competitiveness scale instrument.

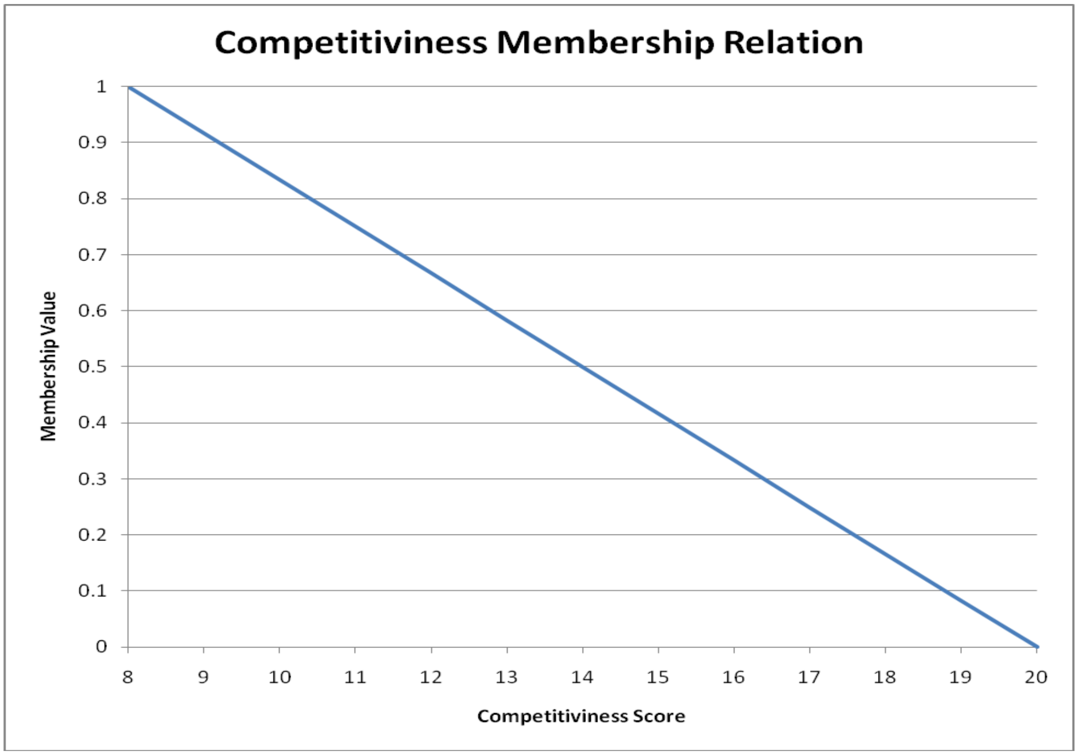


Figure 45. Competitiveness membership function

4.3.1.10. Motivation

Membership function for this self-report scale was developed based on the scoring instrument. The Ray's achievement motivation scale has a maximum score of 42 for highest level of motivation and 14 for low levels. The form of the membership function has the following expression.

$$y(x) = \frac{x}{28} - 0.5$$

Where:

x = represents the score obtained in the Ray's achievement motivation scale.

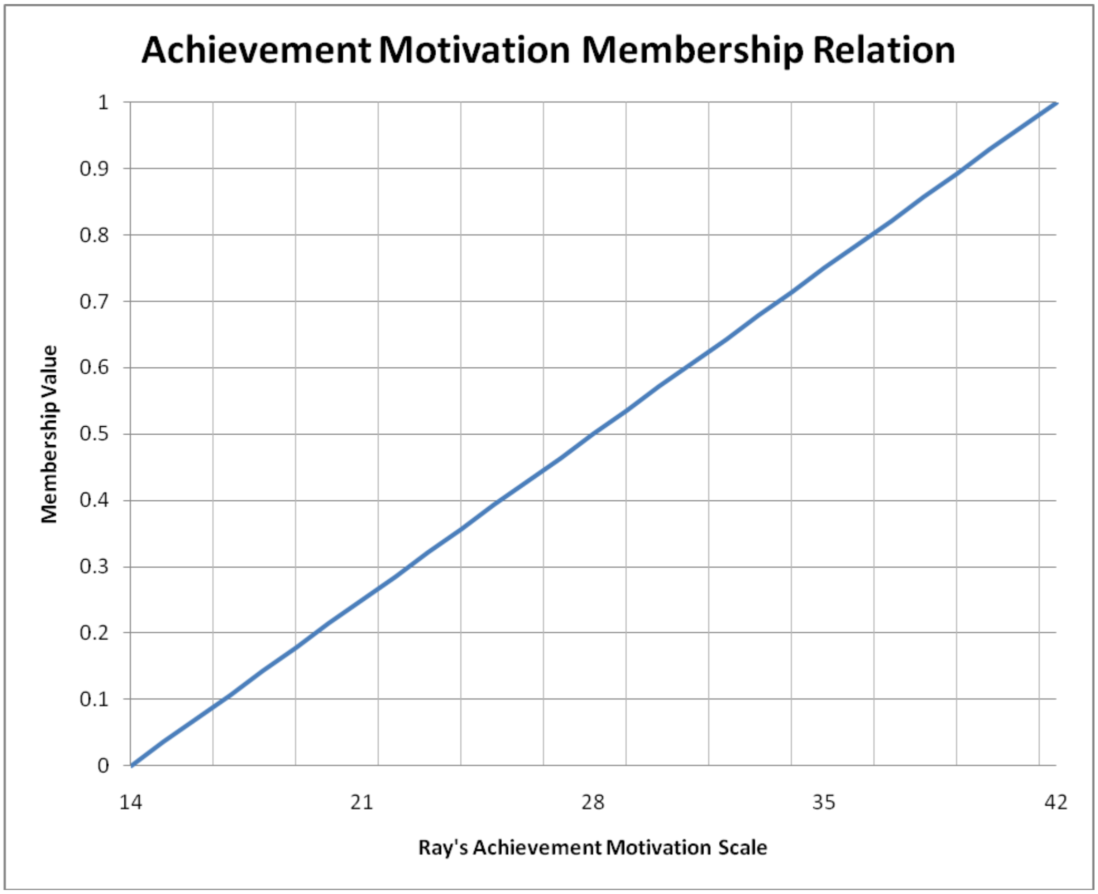


Figure 46. Motivation membership function

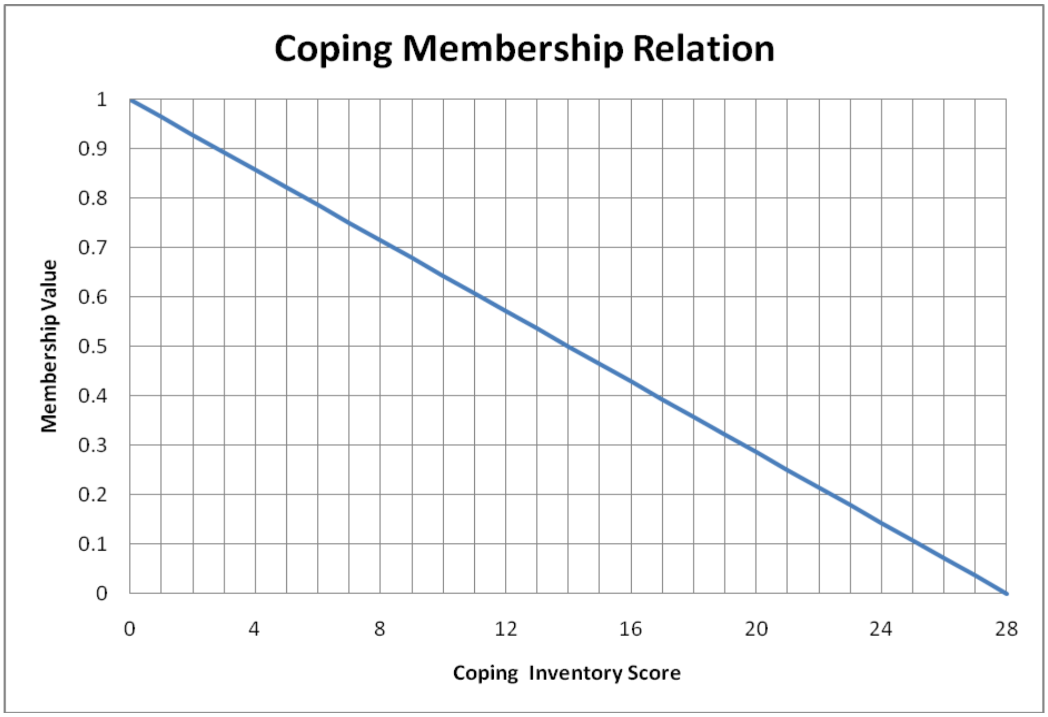
4.3.1.11. Coping

Values for this variable are obtained through a self-reported instrument. Parameters for this curve are developed based on scores from the instrument. Three dimensions for coping technique are assessed with this instrument: task focus, emotion focus and avoidance. Each dimension has a maximum value of 28 and a minimum value zero. Because coping is a mechanism that reduces stress, the curve has a negative slop and intersects the highest membership value (1) at its origin, when coping score is minimum. The form of the membership function has the following expression.

$$y(x) = -\frac{x}{28} + 1$$

Where:

x = represents the score obtained in the Coping Inventory scale



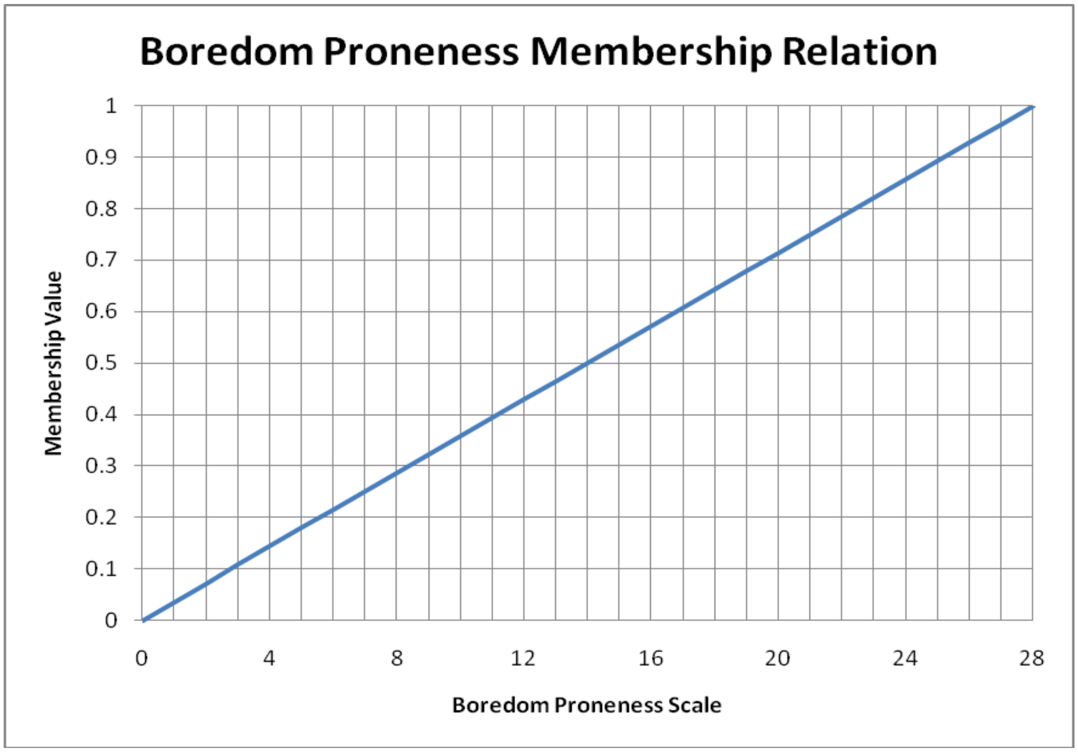
4.3.1.12. Boredom Proneness

Membership function for this self-report scale is developed based on the scoring instrument. The Boredom Proneness scale has a maximum score of 28 to indicate highly prone to boredom and 0 for the opposite condition. Study shows that the tendency to become bore, as a personal trait, is proportionally associated to levels of stress. Thus, a linear function is most appropriate to define the membership function. The form of the membership function follows the expression:

$$y(x) = \frac{x}{28}$$

Where:

x = represents the score obtained in the Boredom proneness scale.



4.3.2. Calculation of Variables Weights (ω)

Variables weights for the fuzzy model are calculated through an analytical hierarchy process (AHP). Four pair-wise comparisons for variables involved in the model are developed and rated by four subject matter experts (SME). Appendix C shows pair-wise comparison tables used for the analytical hierarchy process. All calculations are performed through Expert Choice®. Levels of inconsistency are noted for validation purposes.

4.3.2.1. Weights for Physiological Responses

The following figure presents results obtained from the pair wise comparison that compares physiological responses. The inconsistency ratio for this model is 0.07. Weights are acceptable since the consistency ratio among SMEs is high.

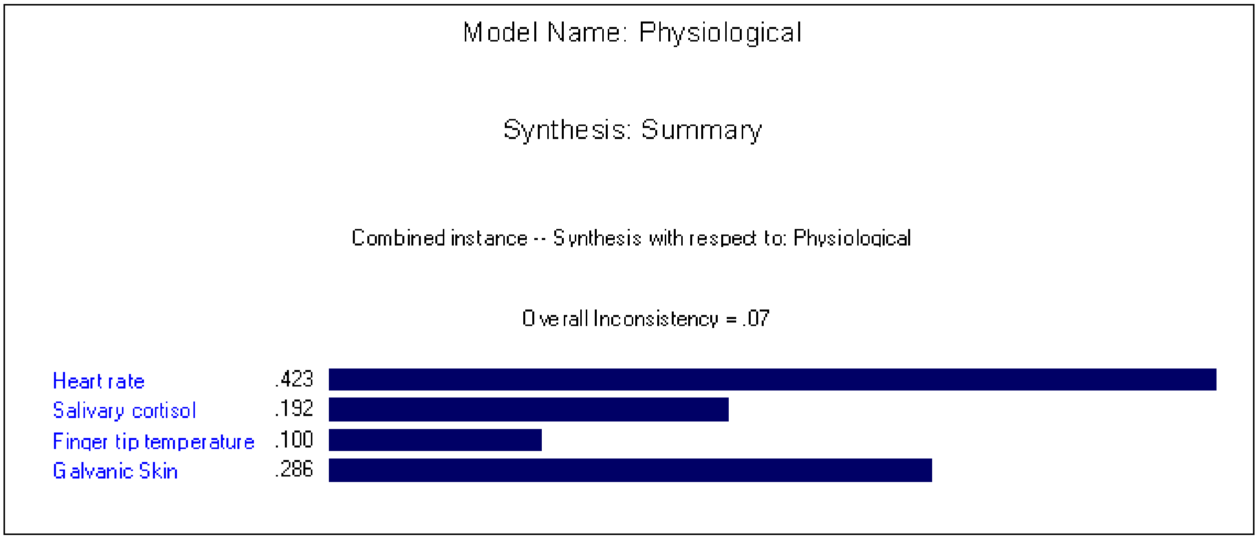
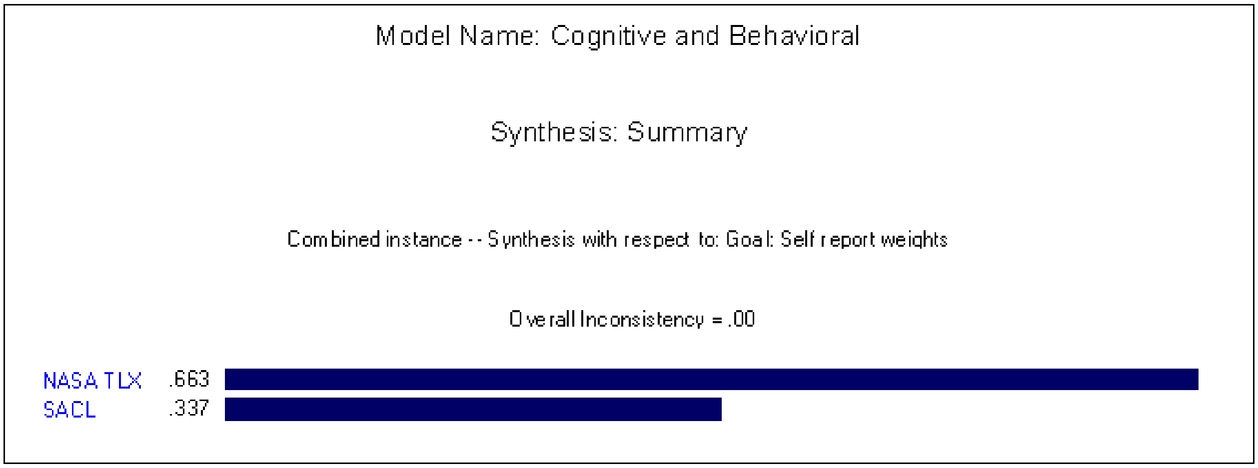


Figure 47. Weights obtained for physiological responses

4.3.2.2. Weights for Cognitive and Behavioral Responses

Figure 48 below presents results obtained from the pair wise comparison that compares cognitive and behavioral responses. The inconsistency ratio for this model is 0.00. Therefore weights are acceptable since the consistency ratio among SMEs is high.



Model Name: Cognitive and Behavioral

Synthesis: Summary

Combined instance -- Synthesis with respect to: Goal: Self report weights

Overall Inconsistency = .00

Figure 48. Weights values obtained for cognitive and behavioral responses

4.3.2.3. Weights for Mediators

The following figure presents results obtained from the pair wise comparison that compares mediators. The inconsistency ratio for this model is 0.04. This value indicates high consistency among SME’s pair wise comparisons.

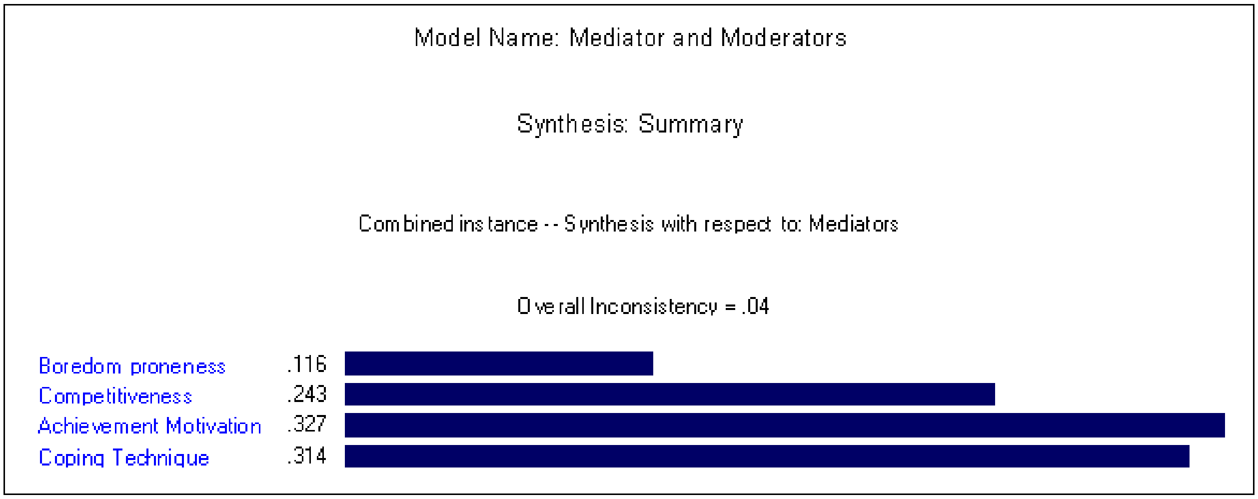


Figure 49. Weights obtained for mediators

4.3.2.4. Physiological Vs. Cognitive and Behavioral

The last pair wise comparison corresponds to the model physiological vs. cognitive and behavioral responses. The inconsistency value for this pair wise comparison is the lowest 0.00.

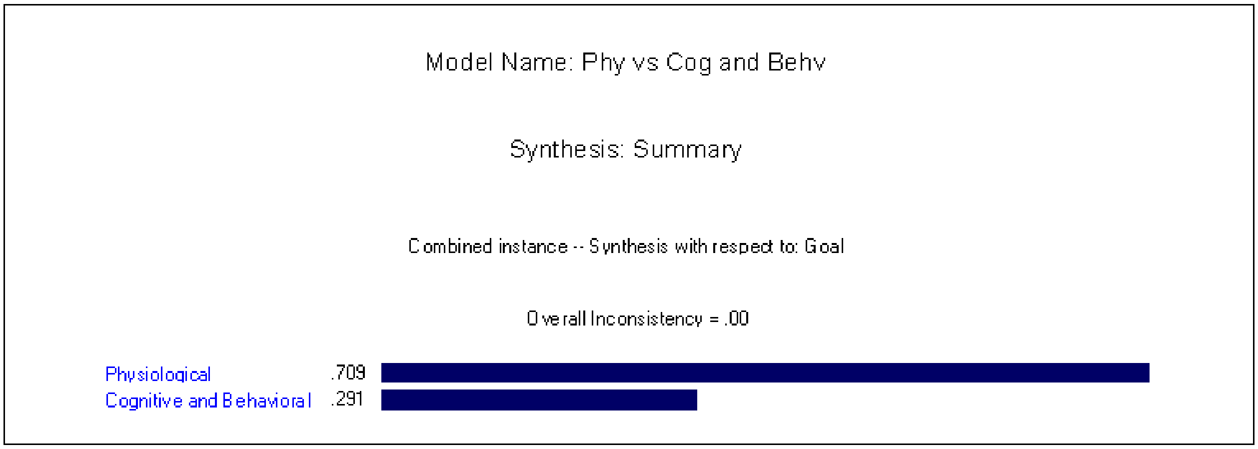


Figure 50. Weights obtained for physiological vs. cognitive and behavioral responses

Table 7 shows a summary of results for the pair wise comparison conducted through analytical hierarchy process AHP using ExpertChoice software.

Table 7. Summary of variables weights

Physiological Response Variable	Individual Weight	Inconsistency Ratio	Overall weight
Heart Rate	0.423	0.07	0.709
Salivary Cortisol	0.192		
Finger Tip Temperature	0.100		
Galvanic Skin Resistance	0.286		
Cognitive and Behavioral Response Variable	**Weight**		
Workload Index(NASA TLX)	0.663	0.0	0.291
Stress and Arousal Checklist (SACL)	0.337		
Mediator Variable	**Weight**		
Boredom Proneness	0.116	0.04	Distributed multiplicative among both physiological and self-reported variables
Competitiveness	0.243		
Achievement Motivation	0.327		
Coping Technique	0.314		

4.4. Model Results and Validation

After membership functions and weights were built and selected the model can be expressed as follows:

$$SI = \ 0.709\, f(\mathrm{Y}) + 0.291 f(\mathrm{X}) \ \times (\, f(\mathrm{N})$$

Physiological, self-report and mediator singletons for this model are:

1. Physiological

$$f(Y) = \left(\frac{0.423 f(y_1)}{1} + \frac{0.192 f(y_2)}{1} + \frac{0.100 f(y_3)}{1} + \frac{0.286 f(y_4)}{1} \right)$$

Where:

$f(y_1)$= *Maximum heart rate*

$f(y_2)$= *Salivary cortisol*

$f(y_3)$= *Finger tip temperature*

$f(y_4)$= *Galvanic skin resistance*

2. For Cognitive and Behavioral

$$f(X)=\left(\frac{0.663\,f(x_1)}{1}+\frac{0.337\,f(x_2)}{1}\right)$$

Where:

$f(x_1)$= *Workload Index NASA TLX*

$f(x_2)$= *Stress arousal checklist*

3. For Mediators

$$f(N)=\left(\frac{0.116\,f(n_1)}{1}+\frac{0.243\,f(n_2)}{1}+\frac{0.327\,f(n_3)}{1}+\frac{0.327\,f(n_4)}{1}\right)$$

Where:

$f(n_1)$= *Boredom Proneness*

$f(n_2)$= *Competitiveness*

$f(n_3)$= *Achievement Motivation*

$f(n_4)$= *Coping Technique*

Once membership functions and weights were completed, the next step was testing for validation. The first step of this process was completed through an analysis of variance. Significant statistical differences have been found across factors. As it was described in Chapter Three in the validation section, a second step on validation takes place during development of the membership functions. Membership functions are developed based on observed data and previous research. Consistent values and parameters to describe the relation between membership functions to stress levels were found. A third step on the validation occurs during the AHP analysis. The consistency of pair-wise judgments provided by the SME is calculated. The highest inconsistency obtained was 0.07, therefore the pair-wise comparisons are considered to be satisfactory.

Additional validation was obtained through use of special cases (maximum, median and minimum cases). It was found that the output (Stress Index) follows theoretical assumptions regarding stress and human performance. The model also reflects the common knowledge on human performance when exposed to stressors. Analysis of variance of the Stress Index (SI) was performed to determine if its results show statistical significance for the four factors. Appendix E contains complete tables of these results. Significant difference was only found for the factor temperature F (1, 68) = 11.783, p=0.001 (Table 9). Additionally, pair wise comparison shows mean values of the SSI for the different treatments being consistent with the phenomena. Table 10 shows pairwise comparisons for the main effects of temperature on the treatments.

Table 8. Estimates for SI (Temperature)

Estimates

Dependent Variable:Stress Index

Factor Noise	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Low	.185	.012	.161	.209
High	.208	.012	.184	.233

Table 9. ANOVA test for SI (Temperature)

Univariate Tests

Dependent Variable:Stress Index

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	.068	1	.068	11.783	.001	.148	11.783	.923
Error	.390	68	.006					

The F tests the effect of Factor Temperature. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Table 10. SI pairwise comparison for Temperature

Pairwise Comparisons

Dependent Variable:Stress Index

(I) Factor Temperature	(J) Factor Temperature	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
Low	High	-.059*	.017	.001	-.094	-.025
High	Low	.059*	.017	.001	.025	.094

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

This difference is graphically presented in Figure 51, which shows mean SI vs. the low and high conditions for this stressor. Additionally, Figure 52 shows mean SI values by treatments

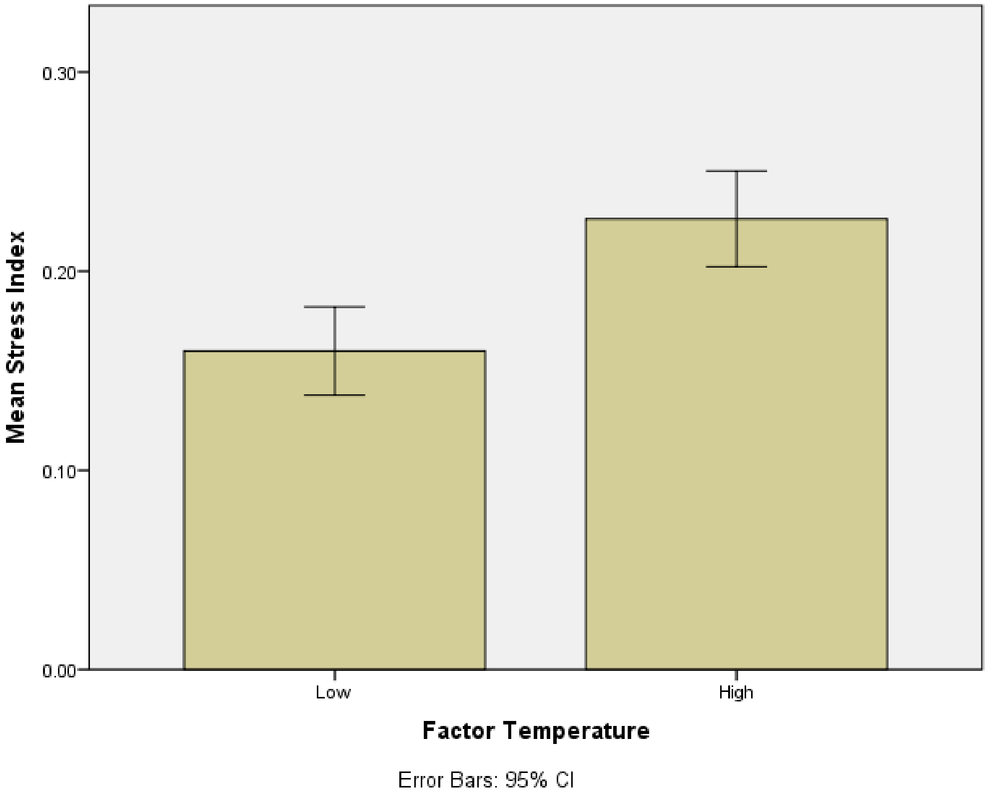


Figure 51. Mean Stress Index for Temperature

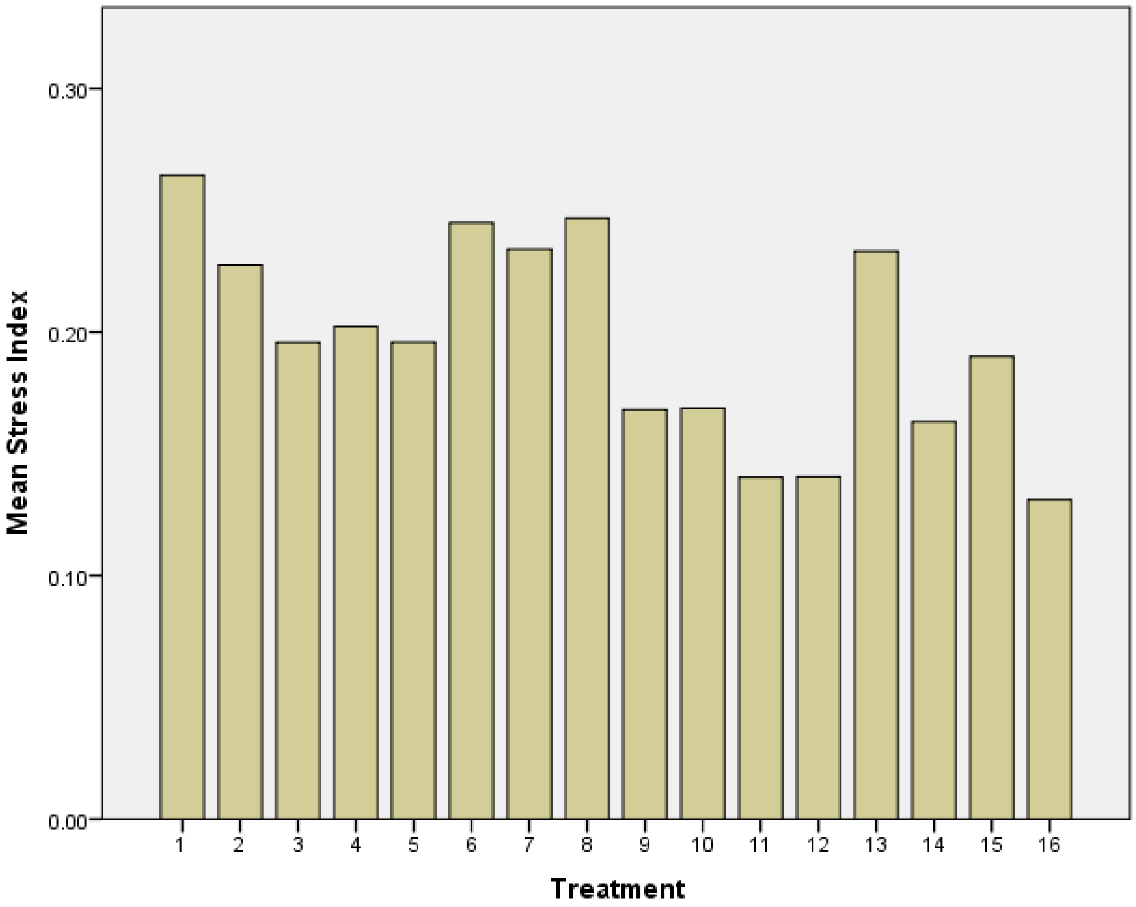


Figure 52. Mean Stress Index by treatments

It should be noted that the lowest demand treatment (treatment 12 with noise, temperature, time awareness and workload at lowest level) displays the lowest value for stress 0.14 after treatment 16 (Noise=Low, Temperature=Low, Time Awareness=Low, Workload=High) with a SI value of 0.13.

In addition to the SI model a performance index (PI) model was also developed. This performance index was modeled using the same procedure as the SI model. However, the relative weights for this fuzzy singleton are assumed to be equally distributed since all measurements are equally important and there was no difference on importance among measurements. Therefore relative weights are evenly distributed according to the number of variables involved. Based on the ANOVA analysis performed and discussed in section 4.2.2, and membership function from section 4.3.1, the PI model is then expressed as follows:

$$Performance\_Index = \left(\frac{0.5 f(z_1)}{1} + \frac{0.5 f(z_2)}{1} \right)$$

Where

Performance Index (PI)= value in the domain [0,1]

$f(z_1)$= Number of warning missed

$f(z_2)$= Deviation from target

Although there were other performance measures such as reaction time, these are not used in the performance index model because they are confounded with the factor Work. The times for the warning lights to automatically turn off and on were controlled; therefore reactions times are directly conditioned to this factor.

Validation of the Performance Index model (PI) was conducted using a similar approach as the SI model. Analysis of variance of the PI model was performed to determine if its results show statistical significance for factors. Appendix E contains complete tables of these results. Significant difference was found for the factor Time Awareness F (1,68) = 6.13, p=0.016 (Table 12) and for factor workload F (1,68) = 13.890, p=0.000 (Table 15). Additionally, pair wise comparison shows mean values of the PI for the different treatments being consistent with the phenomena. Table 13 shows pair wise comparison for main effect time and Table 16 for the main effect work.

Table 11. Performance Index estimates for factor Time Awareness

Estimates

Dependent Variable:Performance Miss and Dev

			95% Confidence Interval	
Factor Time	Mean	Std. Error	Lower Bound	Upper Bound
Low	.721	.026	.670	.772
High	.820	.031	.759	.882

Table 12. ANOVA test for PI (Time Awareness)

Univariate Tests

Dependent Variable:Performance Miss and Dev

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	.188	1	.188	6.133	.016	.083	6.133	.685
Error	2.079	68	.031					

The F tests the effect of Factor Time. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Table 13. PI pairwise comparison for Time Awareness

Pairwise Comparisons

Dependent Variable:Performance Miss and Dev

					95% Confidence Interval for Difference[a]	
(I) Factor Time	(J) Factor Time	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
Low	High	-.099[*]	.040	.016	-.179	-.019
High	Low	.099[*]	.040	.016	.019	.179

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 14. Performance Index estimates for factor Workload

Estimates

Dependent Variable:Performance Miss and Dev

Factor Work	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Low	.845	.028	.790	.901
High	.696	.029	.639	.753

Table 15.ANOVA test for PI (Workload)

Pairwise Comparisons

Dependent Variable:Performance Miss and Dev

(I) Factor Work	(J) Factor Work	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Low	High	.149*	.040	.000	.069	.229
High	Low	-.149*	.040	.000	-.229	-.069

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 16. PI pairwise comparison for Workload

Univariate Tests

Dependent Variable:Performance Miss and Dev

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	.425	1	.425	13.890	.000	.170	13.890	.957
Error	2.079	68	.031					

The F tests the effect of Factor Work. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Figure 53 displays difference of means PI by treatment levels for the factor Time Awareness, while Figure 54 displays these means for the factor Workload.

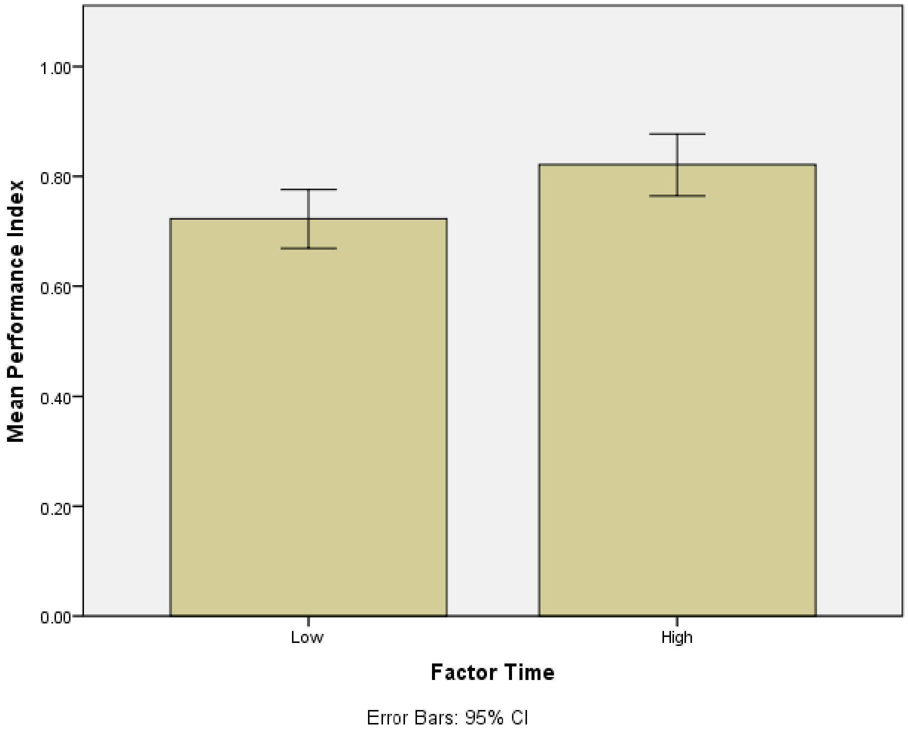


Figure 53. Mean Performance Index for factor Time Awareness

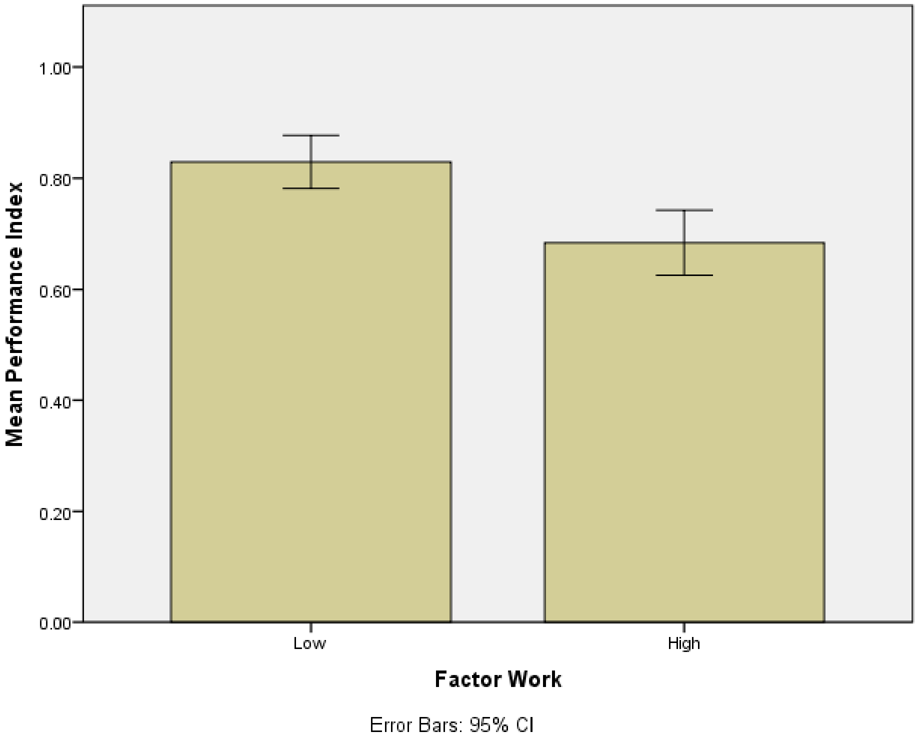


Figure 54. Mean Performance Index for factor Workload

Figure 55 shows Performance Index by treatments. It is noticed that highest performance values are obtained on the first 8 treatments where temperature is at high level. However there were not significant differences for means at this particular factor.

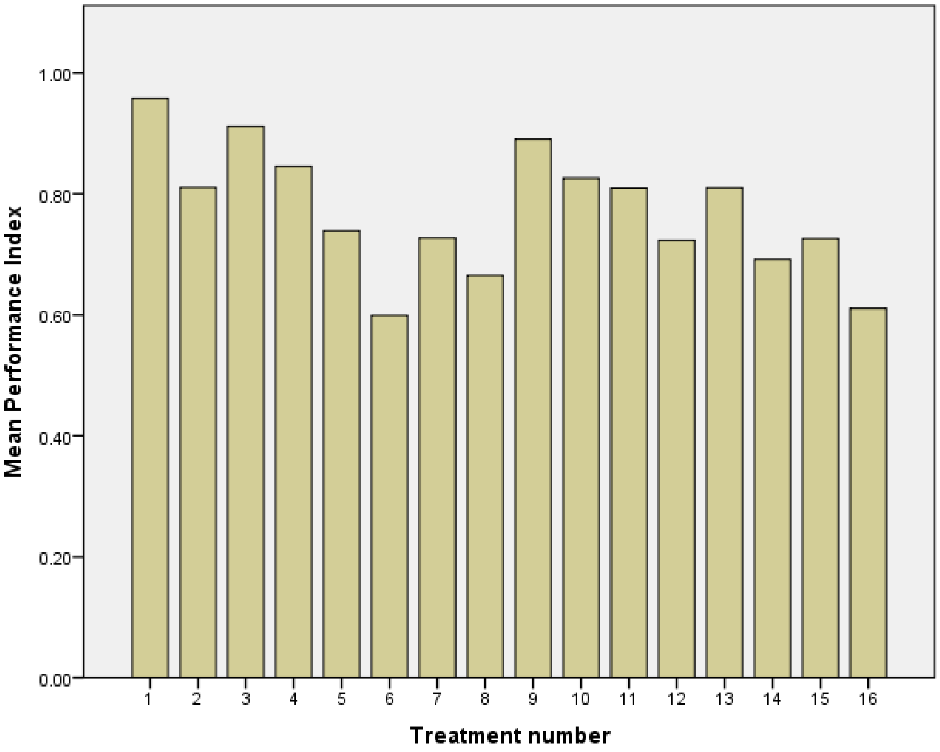


Figure 55. Mean Performance Index by treatments

Finally, Figure 56 display mean values for both SI and PI while Figure 57 shows the relationship between SI vs PI and task demands for each factor.

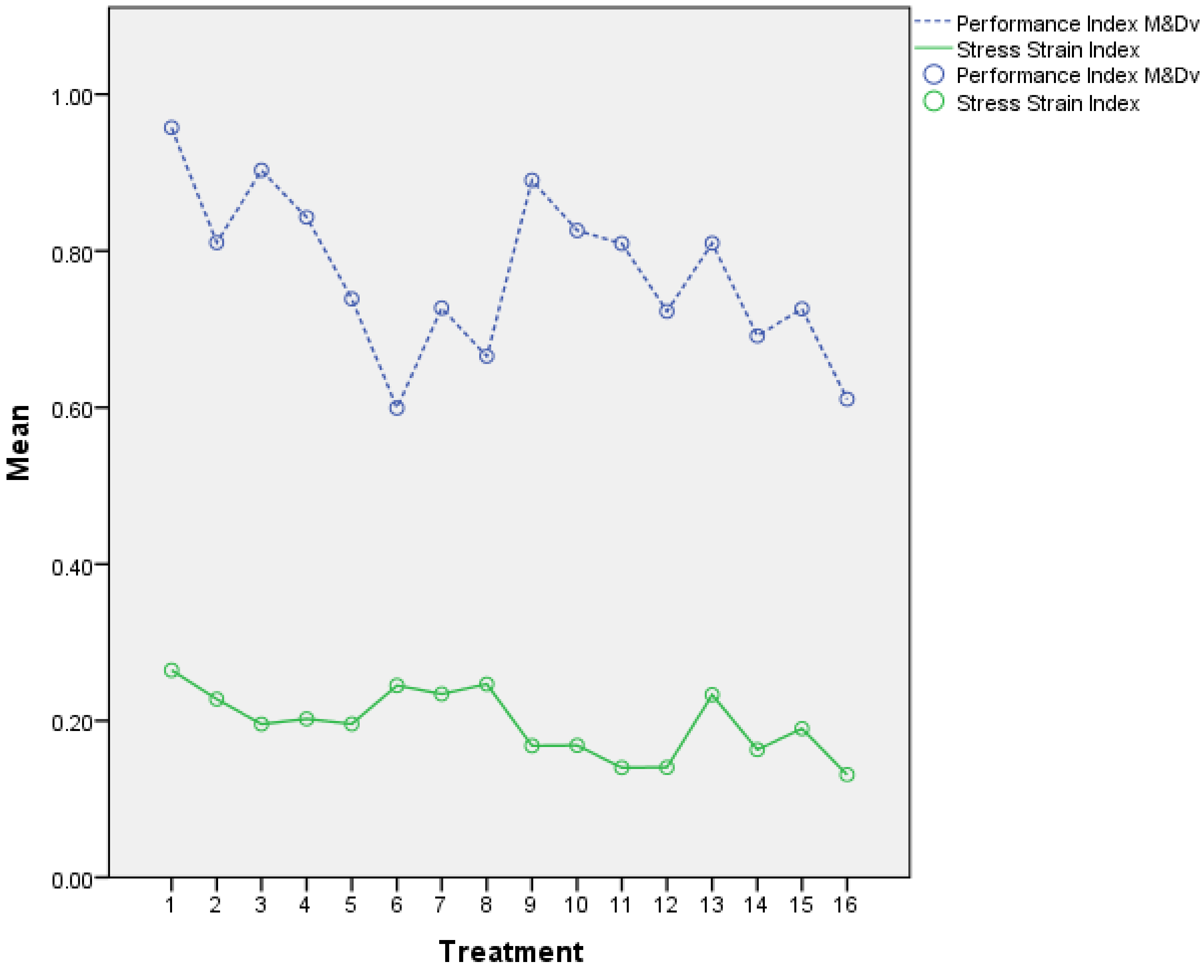


Figure 56. Means for Stress Index (SI) and Performance Index (PI)

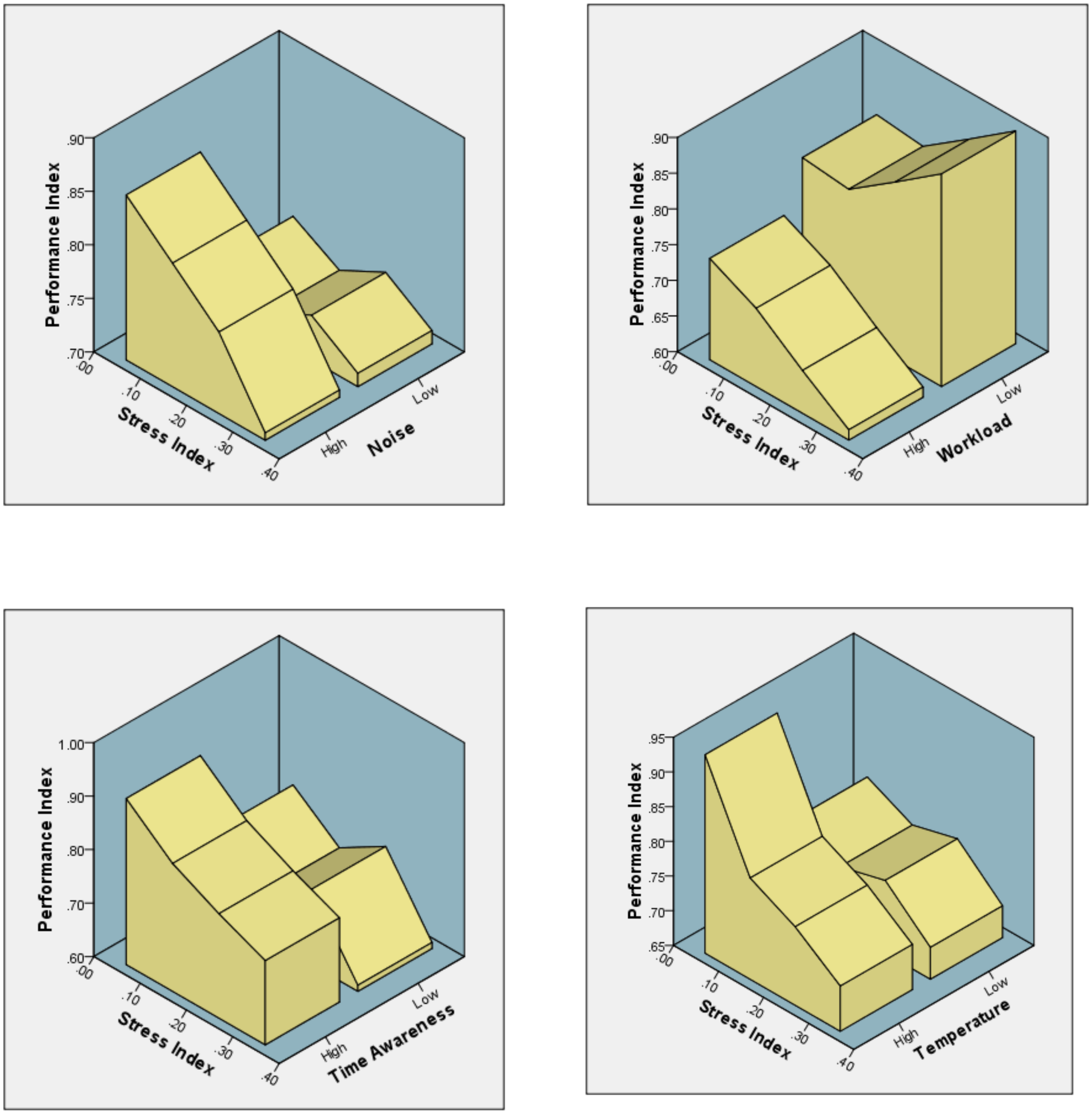


Figure 57. Stress Index Vs. Performance Index Vs. Task Demand for each factor

CHAPTER 5: DISCUSSION

A variety of physiological, cognitive and behavioral response variables were evaluated to described the acute stress level of humans while performing job tasks. However, only the response variables that showed statistical significance were included in the development of the Stress Index (SI) model. Statistical techniques were used to determine the most reliable response measures to characterize stress. Results, from this analysis also confirmed that stressor such as Noise, Temperature, Time Awareness and Workload over varying levels (i.e., High and Low) triggered significant physiological, cognitive and behavioral performance responses to stress, thus rejecting the null hypotheses of this research study as shown bellow.

Research Hypothesis # 1. Effect on physiological measurements.

> H_o: There are no significant differences of mean physiological responses between the stress conditions.
> H_a: There are significant differences of mean physiological responses between the stress conditions.

Research Hypothesis # 2. Effect on cognitive measurements

> H_o: There are no significant differences of mean cognitive responses between the stress conditions.
> H_a: There are significant differences of mean cognitive responses between the stress conditions.

Research Hypothesis # 3. Effect on behavioral measurements

> H_o: There are no significant differences of mean behavioral responses between the stress conditions.
> H_a: There are significant differences of mean behavioral responses between the stress conditions.

Research Hypothesis # 4. Effect on performance measurements

> H_o: There are no significant differences of mean performance responses between the stress conditions.

H_a: There are significant differences of mean performance responses between the stress conditions.

Cognitive and Behavioral Measurements

In this research study, the Stress Arousal Checklist (SACL) was administered before and after the task. This instrument is designed to assess one's experience in response to the external environment. Differences between the SACL scores collected before and after the task was completed were calculated for each research participant. Thus, positive values of this difference indicated an increase in stress and arousal. Research findings showed that greater score differences were found on those treatments where stressors were set at the high level condition. Smaller score differences were found in experimental treatments with stressors at low level conditions. Statistically significant differences were found in testing conditions involving time awareness as a stressor and those including the interactions of workload, temperature and noise factors. Higher SACL scores were found in the high level conditions of time awareness (i.e., awareness of time remaining on the task). Results for three-way interactions also showed that higher levels of stress are produced when the noise factor is at a high level (i.e., sound pressure level >90 dB) regardless of the Workload level at all temperature levels. These results are consistent SACL results presented in the research literature.

The NASA TLX Workload Index instrument was administered randomly during the task. This instrument is designed to assess workload ratings in response to the external environment. Differences between the maximum rating obtained during the task and the initial rating (i.e., baseline) were calculated for each research participant. Thus, positive values of this difference indicated an increase in NASA TLX workload ratings. Statistically significant differences were found in testing conditions involving noise. Research findings showed that score differences for the workload index were greater when participants were not exposed to noise (i.e., low level condition). Greater scores differences were found in high level conditions of workload. These results are consistent with results presented in the literature review. Additionally, research findings show a marginal interaction effect between noise and time awareness. Score differences are significantly smaller in testing conditions involving high levels of time awareness and noise. However, NASA TLX scores were indifferent in testing conditions involving low levels of time awareness (i.e., no awareness of time remaining in task) and high level of noise (>90dB). This finding suggests that knowledge of time remaining on the task reduces perceived levels of workload.

Reaction times were not included in the Stress Index model because, even though there was statistically significance, these measurements were confounded with the workload factor settings. Workload was increased and set at the high level for the testing condition by reducing times to react to warnings at the monitoring task. Reaction times were already conditioned to the workload factor. Therefore, this measurement shows a direct parallel relation with workload levels.

Physiological Measurements

Galvanic skin resistance (GSR) was continuously measured during the task. Because each person has different skin resistance levels, difference in tonic skin resistance (i.e., response over time) is observed rather than specific values for phasic skin resistance (i.e., discrete environmental stimuli). Differences for this physiological response measurement were obtained from averaging the first and last minute of GSR values for each participant. Positive value differences indicated that GSR at the beginning of the task was greater than at the end. Statistically significant differences were found for main the effects noise and temperature. Research findings showed that GSR value differences are smaller under low levels of noise (i.e., no noise) than under high level of noise (> 90dB). This finding can be explained as the result of the continuous phasic skin response throughout the task due to the uninterrupted noise stimuli. In contrast, statistically significant mean differences were found in testing conditions involving temperature as the main factor. This finding can be explained as the result of the skin's tonic response to temperature.

Finger tip temperature was measured continuously during the task. Initial and final values for temperature were subtracted to obtain a difference value for finger tip temperature. Research findings showed changes in finger tip temperature to be statistically significant in testing conditions involving temperature. However, results were contradictory with common knowledge of finger tip temperature and stress. This finding can be attributed to thermodynamic effects. Skin exposed to high temperature (i.e., 107^{o} F and 17% humidity) warms rapidly due to heat convection. Under high temperature levels, physiological mechanisms to reduce skin's temperature are triggered only when homeostasis has been disturbed and this mechanism does not appear instantly. Trend analysis graph for this physiological measurement (Figure 11) showed that treatments involving high temperature levels (i.e., treatments 1-8) displayed negative values for finger tip temperature and treatments involving low temperature conditions (i.e., 72° F and 54% humidity) showed positive values. Trend analysis also showed that treatment 5 involving all high level conditions had the smaller negative difference value for finger tip temperature. This finding is an indicator that despite the skin's high temperature, a change in peripheral blood flow occurs as a result of stress. Additionally, treatments 9-12 displayed the lowest positive difference values (close to zero) for this physiological measurement while treatment 14 involving conditions of high level of noise and workload had the highest positive difference value which evidenced the change in peripheral blood flow.

Finger tip temperature was measured continuously during the task. Initial and final values for temperature were subtracted to obtain a difference value for finger tip temperature. Research findings showed changes in finger tip temperature to be statistically significant in testing conditions involving temperature. However, results were contradictory with common knowledge of finger tip temperature and stress. This finding can be attributed to thermodynamic effects. Skin exposed to high temperature (i.e., 107° F and 17% humidity) warms rapidly due to heat convection. Under high temperature levels, physiological mechanisms to reduce skin's temperature are triggered only when homeostasis has been disturbed and this mechanism does not appear instantly. Trend analysis graph for this physiological measurement (Figure 11) showed that treatments involving high temperature levels (i.e., treatments 1-8) displayed negative values for finger tip temperature and treatments involving low temperature conditions (i.e., 72° F and 54% humidity) showed positive values. Trend analysis also showed that treatment 5 involving all high level conditions had the smaller negative difference value for finger tip temperature. This finding is an indicator that despite the skin's high temperature, a change in

peripheral blood flow occurs as a result of stress. Additionally, treatments 9-12 displayed the lowest positive difference values (close to zero) for this physiological measurement while treatment 14 involving conditions of high level of noise and workload had the highest positive difference value which evidenced the change in peripheral blood flow.

Cortisol levels were measured 10 min after participants' arrival and 5 minutes after task completion. The time interval between the two occurrences was about 45 minutes. Collection of salivary samples was conducted following appropriate protocol including sample collection after the early-morning hours (i.e., after 10:00 am) due to cortisol natural peak level as a result of body awakening. Changes or differences in cortisol levels were calculated by subtracting final sample level and initial sample level for each research participant. Research findings showed that differences in cortisol levels were mostly negative, indicating that cortisol levels from samples collected after task completion were smaller than those from samples collected before the task. These results contradict physiological effects of activation of the hypothalamic-pituitary-adrenal axis (HPA axis), which increases glucocorticoid secretion from the adrenal cortex. This result can be attributed to participants experiencing a long period of relaxation after arriving to the experimental room. Nevertheless, levels of cortisol after task completion were used as a valid measurement in the model because these were still above normal values for diurnal cortisol levels which have been extensively documented.

Percentage of maximum heart rate was calculated from average heart rate for each research participant. Maximum heart rate was obtained using corresponding formulas for female and male. This type of measurement does not require a difference value because it is automatically normalized. Statistically significant difference was found in testing conditions involving temperature. Greater values for maximum heart rate percentage were found in high level conditions of temperature (i.e., 107^{o} F and 17% humidity) which is consistent with results of heart rate changes presented in the literature review. Additionally, statistical significant differences were found for the two-way interaction for workload and temperature. Research findings showed that high level conditions of workload for this type of task reduces maximum heart rate values when temperature is at high level.

Performance Measures

One of the two performance measures used to construct the Performance Index (PI) model was the number of misses. This metric counts the number of warnings not detected by the research participant. Statistically significant difference was found for the main effect workload. Higher numbers of warning misses occurred in testing conditions involving high levels of workload. However, for the three way interaction Noise x Temperature x Workload, a significant decrease of the number of misses occurs under high level of noise, high level of temperature and low level of workload conditions. The same results are obtained when participants are exposed to high level of noise, low level of temperature and high level of workload. This finding indicates that the presence of at least one condition on a low level setting is sufficient to increase performance for this metric.

The other performance measure assessed in this research was deviation from target. This metric is a measure of accuracy and participants were asked to reach and maintain a level of fuel in a dynamic system as close as possible to 2500 (±300) units. Mean Squared Root (MSR) error was calculated for this measurement because the system was comprised of two tanks and the 2500 target has to be reached and maintained on both tanks. Statistically significant differences for MSR deviation was found for two main factors; time awareness and workload. Research finding showed that deviation from target was slightly lower for the high level of time awareness condition (i.e., knowledge of time remaining) vs. low level (i.e., no knowledge of time remaining). Awareness of time remaining on task showed a positive effect on performance for the resource management task. Higher values for deviation from target were found in high level conditions of workload.

Stress Index and Performance Index

The main goal of this research was the development of a Stress Index model that considers physiological, cognitive and behavioral responses to stress. Multivariate analysis of variance tests were conducted to find and select those response variables that showed statistical significant differences under the testing conditions, thus they can be used to construct the fuzzy model for stress index.

The use of fuzzy set theory to aggregate different response variables is only possible through membership functions. These membership functions also known as characteristic functions were built through data analysis and parameter estimation with the purpose of describing each response variable within a universe of discourse contained in the interval [0,1]. In this universe of discourse zero (0) represents no stress and one (1) represents the presence of stress. This representation of the response variable establishes a relation between response variables (i.e., physiological, cognitive, behavioral) and levels of stress.

Physiological, cognitive and behavioral response variables are aggregated because they represent states of stress while mediators are multiplicatively associated to the model because these mediate the relation between human's perception of stressors and physiological, cognitive and behavioral responses to stress. However, because each individual may have different responses, a weighting factor was necessary to complete the model. These weighting factors were obtained through analytical hierarchy process (AHP) and pairwise comparisons.

Analysis of the Stress Index model output reveled that it follows normality assumptions and levels of stress index calculated are consistent with the task and stressors used in the research study. The task was not physically demanding and the highest level of stress index was found to be 0.39 for high temperature levels followed by 0.37 for high workload levels. Trend analysis (Figure 52) showed higher stress index for those treatments with temperature at high level (treatments 1-8). Statistically significant differences between low and high temperature conditions were also found F (1, 68) = 11.783, p=0.001. This finding indicates that the stressor with the greatest impact on human responses is temperature.

Aggregation of cognitive, physiological and behavioral measurements is possible under fuzzy set theory. Previous studies have showed how variables can be aggregated to construct a fuzzy model (McCauley-Bell & Crumpton-Young, 1997; Karwowsky and Mital, 1986; McCauley-Bell & Badiru, 1996). However, under these studies the aggregation of variables under a fuzzy set model occurs only with variables within the same spectrum of body responses or maximum two (i.e., physiological or cognitive) while the present research associates variables across different type of body responses; physiological, cognitive including behavioral responses and mediating variables.

The performance index model was built using the same approach as the Stress Index but considering only performance measurements variables; number of warning misses and deviation from target. These two performance measure were found to be statistically significant in testing conditions involving time awareness F (1,68) = 6.13, p=0.016 and workload F (1,68) = 13.890, p=0.000 as stressors. Additionally, trend analysis (Figure 55) showed that performance index values are greater in testing conditions involving high level conditions of time awareness, which indicates that time awareness, might function as factor to enhance performance. Research findings showed that highest performance values were obtained on treatments involving high levels of temperature (treatments 1-8). However, there were not significant differences for means at this particular factor.

Finally, relationship between Stress Index and Performance index can be observed in Figure 57. Trend analysis shows increases on performance index values on selected treatments where stress index decreases and vice versa. This behavior is consistent with current stress and performance theories.

CHAPTER 6: CONCLUSIONS

The objective of this research was to characterize human responses to stress for the development of a Stress Index model (SI). A fuzzy set modeling approach was implemented to aggregate physiological, cognitive and behavioral responses to stress as well as individual factors such as competitiveness, coping technique, motivation and proneness to boredom into the mathematical model.

In order to develop the SI model an experiment was developed to find validity on possible physiological responses to stress as well as self-report instruments. The experiment revealed statistically significant differences in physiological and self-report responses to stressors (i.e., noise, temperature, time awareness and workload).

The approach used to produce a stress index was fuzzy set modeling because a variety of variables that lack linearity can be integrated into one mathematical expression. Consequently, this research successfully considers the impact of variables that are not traditionally included in stress prediction models. In addition, this research study developed a model that mathematically describes the relationship between stress, performance and task demands.

The resulting model was able to identify levels of stress and performance from a variety of physiological, cognitive and behavioral responses to stress. Stress and performance index ratings obtained through the model were consistent with theoretical assumptions regarding stress and human performance. The resulting SI model predictions are consistent with theoretical models found in the literature review that hypothesize changes in human performance resulting from exposure to stressors. The Stress Index model produced low values of stress for conditions with low task demands and higher values for those conditions with high task demands. However, statistical significant difference p=0.001 was only obtained for the model when the stressor is temperature (Low =72^{o} F with 54% Humidity and High =107^{o} F with 17% humidity).

From analysis of the results obtained with the Performance Index model the following conclusion were reached:

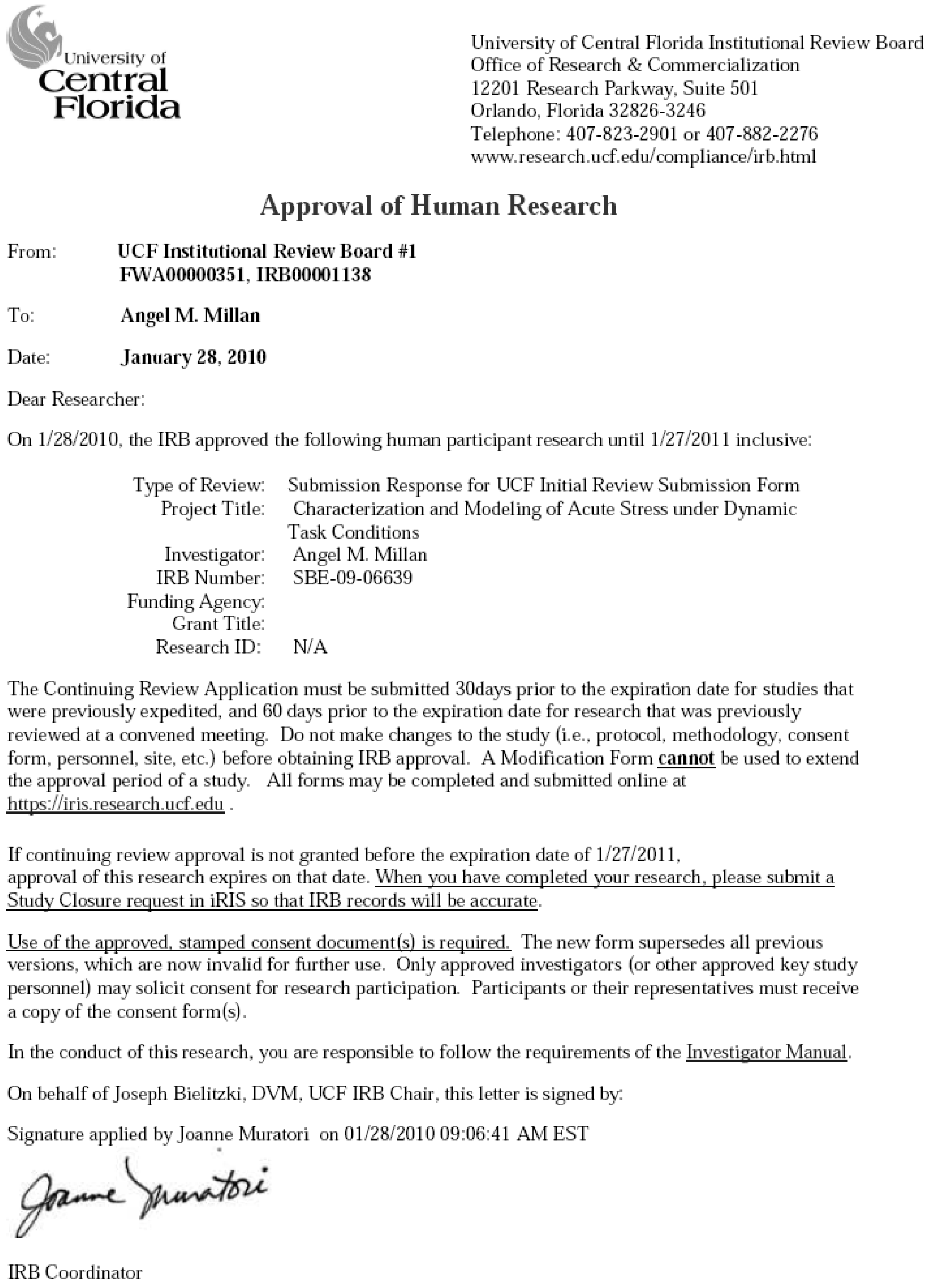
- Individuals appear to perform significantly better when they have knowledge of time remaining to complete a task.
- Individuals performed better when testing conditions for workload demands were low.

6.1. Future Research

Additional research on evaluating the impact of individual differences on acute stress could increase reliability of the Stress Index model. There are a variety of individual traits that could be included in the future such as personality, level of education, training level. Testing the model with other types of tasks specifically those that are physically demanding in nature is recommended to enhance validation of the SI model. Likewise, the model should be tested with different stressor conditions to extend its reliability. The use of neural networks and neuro-fuzzy could help to understand significant relationships among the variables involved in the calculation of the Stress Index model. Additionally, neural networks can be used to calculate membership functions to increase the models' reliability.

Because the performance index involves common performance measurements from a monitoring (misses) and resource management task (accuracy), performance curves could be constructed for tasks with these two specific performance measurements.

APPENDIX A: IRB APPROVAL OF HUMAN RESEARCH



University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Angel M. Millan**

Date: **January 28, 2010**

Dear Researcher:

On 1/28/2010, the IRB approved the following human participant research until 1/27/2011 inclusive:

Type of Review:	Submission Response for UCF Initial Review Submission Form
Project Title:	Characterization and Modeling of Acute Stress under Dynamic Task Conditions
Investigator:	Angel M. Millan
IRB Number:	SBE-09-06639
Funding Agency:	
Grant Title:	
Research ID:	N/A

The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 1/27/2011, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Joseph Bielitzki, DVM, UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 01/28/2010 09:06:41 AM EST

Joanne Muratori

IRB Coordinator

APPENDIX B: INSTRUMENTS

Competitiveness Index[1]

Circle "TRUE" for sentences that are true for you or "FALSE" for sentences that are false for you.

TRUE FALSE 1. I get satisfaction from competing with others.

TRUE FALSE 2. It's usually not important to me to be the best.

TRUE FALSE 3. Competition destroys friendships.

TRUE FALSE 4. Games with no clear cut winners are boring.

TRUE FALSE 5. I am a competitive individual.

TRUE FALSE 6. I will do almost anything to avoid an argument.

TRUE FALSE 7. I try to avoid competing with others.

TRUE FALSE 8. I would like to be on a debating team.

TRUE FALSE 9. I often remain quiet rather than risk hurting another person.

TRUE FALSE 10. I find competitive situations unpleasant.

TRUE FALSE 11. I try to avoid arguments.

TRUE FALSE 12. In general, I will go along with the group rather than create conflict.

TRUE FALSE 13. I don't like competing against other people.

TRUE FALSE 14. I don't like games that are winner-take-all.

TRUE FALSE 15. I dread competing against other people.

TRUE FALSE 16. I enjoy competing against an opponent.

TRUE FALSE 17. When I play a game I like to keep scores.

TRUE FALSE 18. I often try to outperform others.

TRUE FALSE 19. I like competition.

TRUE FALSE 20. I don't enjoy challenging others even when I think they are wrong.

---

[1] Houston, J. M., Farese, D., & La Du, T. J. (1992). Assessing Competitiveness: A validation study of the Competitiveness Index. ***Personality and Individual Differences, 13***, 10, 1153-1156.

[1] Smither, R. D., & Houston, J. M. (1992). The nature of competitiveness: The development and validation of the Competitiveness Index. ***Educational and Psychological Measurement***, 52, 407-418.

Boredom Proneness Scale[2]

The statements can be answered using a true-false response.

TRUE FALSE 1. It is easy for me to concentrate on my activities.

TRUE FALSE 2. Frequently when I am working I find myself worrying about other things.

TRUE FALSE 3. Time always seems to be passing slowly.

TRUE FALSE 4. I often find myself at "loose ends", not knowing what to do.

TRUE FALSE 5. I am often trapped in situations where I have to do meaningless things.

TRUE FALSE 6. Having to look at someone's home movies or travel slides bores me tremendously

TRUE FALSE 7. I have projects in mind all the time, things to do.

TRUE FALSE 8. I find it easy to entertain myself.

TRUE FALSE 9. Many things I have to do are repetitive and monotonous.

TRUE FALSE 10. It takes more stimulation to get me going than most people.

TRUE FALSE 11. I get a kick out of most things I do.

TRUE FALSE 12. I am seldom excited about my work.

TRUE FALSE 13. In any situation I can usually find something to do or see to keep me interested.

TRUE FALSE 14. Much of the time I just sit around doing nothing.

TRUE FALSE 15. I am good at waiting patiently.

TRUE FALSE 16. I often find myself with nothing to do, time on my hands.

TRUE FALSE 17. In situations where I have to wait, such as a line I get very restless.

TRUE FALSE 18. I often wake up with a new idea.

TRUE FALSE 19. It would be very hard for me to find a job that is exciting enough.

TRUE FALSE 20. I would like more challenging things to do in life.

TRUE FALSE 21. I feel that I am working below my abilities most of the time.

TRUE FALSE 22. Many people would say that I am a creative or imaginative person.

TRUE FALSE 23. I have so many interests, I don't have time to do everything.

TRUE FALSE 24. Among my friends, I am the one who keeps doing something the longest.

TRUE FALSE 25. Unless I am doing something exciting, even dangerous, I feel half-dead and dull.

TRUE FALSE 26. It takes a lot of change and variety to keep me really happy.

TRUE FALSE 27. It seems that the same things are on television or the movies all the time; it's getting old.

TRUE FALSE 28. When I was young, I was often in monotonous and tiresome situations.

---

[2] Farmer, R., & Sundberg, N.D. (1986). Boredom proneness: The development and correlates of a new scale. *Journal of Personality Assessment*, 50, 4-17

Ray's Achievement Motivation Index[3]

Response options are "Yes", (scored 3), "?" (scored 2), "No" (scored 1). Items marked "R" are to be reverse-scored (e.g. "1" becomes "3") before addition to get the overall score.

1. Is being comfortable more important to you than getting ahead? R
2. Are you satisfied to be no better than most other people at your job? R
3. Do you like to make improvements to the way the organization you belong to functions?
4. Do you take trouble to cultivate people who may be useful to you in your career?
5. Do you get restless and annoyed when you feel you are wasting time?
6. Have you always worked hard in order to be among the best in your own line? (school, organization, profession).
7. Would you prefer to work with a congenial but incompetent partner rather than with a difficult but highly competent one? R
8. Do you tend to plan ahead for your job or career?
9. Is "getting on in life" important to you?
10. Are you an ambitious person?
11. Are you inclined to read of the successes of others rather than do the work of making yourself a success? R
12. Would you describe yourself as being lazy? R
13. Will days often go by without your having done a thing? R
14. Are you inclined to take life as it comes without much planning? R

---

[3] *Australian Psychologist*, Vol. 14 No. 3, November, 1979, 337-344.
A Quick Measure of Achievement Motivation - Validated in Australia and Reliable in Britain and South Africa
J.J. Ray, *University of New South Wales*

Stress Arousal Checklist (SACL)[4]

The words shown below describe different feelings and moods. Please use this list to describe your feelings *at this moment*.

- If the word *definitely* describes your feelings, circle the double plus (++).
- If the word *more* or *less* describes your feelings circle the plus (+).
- If you do not understand the word, or *you cannot decide* whether or not it describes how you feel, circle the question mark (?).
- If the word does not describe the way you feel, circle the minus (-).

First reactions are most reliable; therefore do not spend too long thinking about each word. Please be as honest and accurate as possible.

1	Tense	++	+	?	-
2	Relaxed	++	+	?	-
3	Restful	++	+	?	-
4	Active	++	+	?	-
5	Apprehensive	++	+	?	-
6	Worried	++	+	?	-
7	Energetic	++	+	?	-
8	Drowsy	++	+	?	-
9	Bothered	++	+	?	-
10	Uneasy	++	+	?	-
11	Dejected	++	+	?	-
12	Nervous	++	+	?	-
13	Distress	++	+	?	-
14	Vigorous	++	+	?	-
15	Peaceful	++	+	?	-
16	Tired	++	+	?	-
17	Idle	++	+	?	-
18	Up-tight	++	+	?	-
19	Alert	++	+	?	-
20	Lively	++	+	?	-
21	Cheerful	++	+	?	-
22	Contented	++	+	?	-
23	Jittery	++	+	?	-
24	Sluggish	++	+	?	-
25	Pleasant	++	+	?	-
26	Sleepy	++	+	?	-
27	Comfortable	++	+	?	-
28	Calm	++	+	?	-
29	Stimulated	++	+	?	-
30	Activated	++	+	?	-

---

[4] Mackay. C., Cox, T., Burrows, G., and Lazzerini, T. (1978). An inventory for the measurement of self-reported stress and arousal, *British Journal of Social and Clinical Psychology*, 17, 283-284.

Coping Inventory For Task Stress (CITS)[5]

Think about how you dealt with any difficulties or problems which arose while you were performing the task. Below are listed some options for dealing with problems such as poor performance or negative reactions to doing the task. Please indicate how much you used each option, specifically as a **deliberately chosen way of dealing with problems**. To answer circle one of the following answers:

Extremely = 4 Very much = 3 Somewhat = 2 A little bit = 1 Not at all = 0

1. Worked out a strategy for successful performance	0	1	2	3	4
2. Worried about what I would do next	0	1	2	3	4
3. Stayed detached or distanced from the situation	0	1	2	3	4
4. Decided to save my efforts for something more worthwhile	0	1	2	3	4
5. Blamed myself for not doing better	0	1	2	3	4
6. Became preoccupied with my problems	0	1	2	3	4
7. Concentrated hard on doing well	0	1	2	3	4
8. Focused my attention on the most important parts of the task	0	1	2	3	4
9. Acted as though the task wasn't important	0	1	2	3	4
10. Didn't take the task too seriously	0	1	2	3	4
11. Wished that I could change what was happening	0	1	2	3	4
12. Blamed myself for not knowing what to do	0	1	2	3	4
13. Worried about my inadequacies	0	1	2	3	4
14. Made every effort to achieve my goals	0	1	2	3	4
15. Blamed myself for becoming too emotional	0	1	2	3	4
16. Was single-minded and determined in my efforts to overcome any problems	0	1	2	3	4
17. Gave up the attempt to do well	0	1	2	3	4
18. Told myself it wasn't worth getting upset	0	1	2	3	4
19. Was careful to avoid mistakes	0	1	2	3	4
20. Did my best to follow the instructions for the task	0	1	2	3	4
21. Decided there was no point in trying to do well	0	1	2	3	4

---

[5] Matthews, G., & Campbell, S.E. (1998). Task-induced stress and individual differences in coping. In *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting* (pp. 821-825). Santa Monica, CA: Human Factors and Ergonomics Society.

NASA TLX Weights

For each of the following pair-wise comparison, circle the word that contributed more to the workload of the task.

Effort or Performance	Temporal Demand or Frustration	Temporal Demand or Effort
Physical Demand or Frustration	Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand	Frustration or Effort
Performance or Mental Demand	Performance or Temporal Demand	Mental Demand or Effort
Mental Demand or Physical Demand	Effort or Physical Demand	Frustration or Mental Demand

Note: NASA TLX ratings were captured using the computerized version embedded on the software utilized for the experiment.

APPENDIX C: AHP PAIRWISE COMPARISON TABLES

Pairwise Comparisons Instructions

For these Pairwise comparisons, use the following intensity for relative importance scale to rate each of the 4 factor comparison regarding its impact on the specified goal or outcome:

1/9 = variable **A** is ***Extremely More Important*** than variable **B**
1/7 = variable **A** is ***Very Strongly More Important*** than variable **B**
1/5 = variable **A** is ***Strongly More Important*** than variable **B**
1/3 = variable **A** is ***Moderately More Important*** than variable **B**
1 = variable **A** is ***Equally Important*** as variable **B**
3 = variable **B** is ***Moderately More Important*** than variable **A**
5 = variable **B** is ***Strongly More Important*** than variable **A**
7 = variable **B** is ***Very Strongly More Important*** than variable **A**
9 = variable **B** is ***Extremely More Important*** than variable **A**

Example

The example below asks for preference/importance on three types of drinks

Comparison 1: If comparing Wine (variable B) to Coffee (variable A), you consider that B is *Very Strongly More Important* than A; then, you would write on the corresponding cell a value of 7.

Comparison 2: If comparing Tea (variable B) to Coffee (variable A), you consider that A is *Strongly More Important* than B; then, you would write on the corresponding cell a value of 1/5.

Comparison 3: If comparing Tea (variable B) to Wine (variable A), you consider that B is *Equally Important* as A; then, you would write on the corresponding cell a value of 1.

		A		
		Coffee	Wine	Tea
B	Coffee	1	*	*
	Wine	7	1	*
	Tea	1/5	1	1

Which factor from each of the given pairs of physiological responses is more important as a predictor for levels of acute stress and what is the intensity or strength of the comparison?

		A				
		Heart rate	Salivary Cortisol	Finger tip temperature	Heart sounds	Galvanic Skin Resistance
B	Heart rate	1	*	*	*	*
	Salivary Cortisol		1	*	*	*
	Finger tip temperature			1	*	*
	Heart sounds				1	*
	Galvanic Skin Resistance					1

Which factor from each of the given pairs of self-report instruments is more important to assess acute stress or its effects on a task and what is the intensity or strength of the comparison?

		A		
		NASA TLX	Stress Arousal Checklist	Perceived Stress Scale
B	NASA TLX	1	*	*
	Stress Arousal Checklist (SACL)		1	*
	Perceived Stress Scale (PSS)			1

Which of the given pair of responses provides better evidence to the presence of acute stress and what is the intensity or strength of the comparison?

		A	
		Physiological	Self-report
B	Physiological	1	*
	Self-report		1

Which factor of the given pairs of attitude and demographics is more important to mediate or moderate responses to acute stress and what is the intensity or strength of the comparison?

		A						
		Boredom proneness	Competitiveness	Achievement Motivation	Coping technique	Personality	Level of Education	Age
B	Boredom proneness	1	*	*	*	*	*	*
	Competitiveness		1	*	*	*	*	*
	Achievement Motivation			1	*	*	*	*
	Coping technique				1	*	*	*
	Personality					1	*	*
	Level of Education						1	*
	Age							1

APPENDIX D: EXPERIMENTAL RESPONSES ANOVA TABLES

Between-Subjects Factors

		Value Label	N
Noise	1	Low	40
	2	High	37
Temperature	1	Low	42
	2	High	35
Time Awareness	1	Low	46
	2	High	31
Workload	1	Low	43
	2	High	34

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power[b]
Intercept	Pillai's Trace	.989	373.621[a]	12.000	50.000	.000	4483.448	1.000
	Wilks' Lambda	.011	373.621[a]	12.000	50.000	.000	4483.448	1.000
	Hotelling's Trace	89.669	373.621[a]	12.000	50.000	.000	4483.448	1.000
	Roy's Largest Root	89.669	373.621[a]	12.000	50.000	.000	4483.448	1.000
Noise	Pillai's Trace	.309	1.866[a]	12.000	50.000	.062	22.396	.829
	Wilks' Lambda	.691	1.866[a]	12.000	50.000	.062	22.396	.829
	Hotelling's Trace	.448	1.866[a]	12.000	50.000	.062	22.396	.829
	Roy's Largest Root	.448	1.866[a]	12.000	50.000	.062	22.396	.829
Temperature	Pillai's Trace	.507	4.293[a]	12.000	50.000	.000	51.517	.998
	Wilks' Lambda	.493	4.293[a]	12.000	50.000	.000	51.517	.998
	Hotelling's Trace	1.030	4.293[a]	12.000	50.000	.000	51.517	.998
	Roy's Largest Root	1.030	4.293[a]	12.000	50.000	.000	51.517	.998
Time	Pillai's Trace	.269	1.531[a]	12.000	50.000	.144	18.374	.728
	Wilks' Lambda	.731	1.531[a]	12.000	50.000	.144	18.374	.728
	Hotelling's Trace	.367	1.531[a]	12.000	50.000	.144	18.374	.728

	Roy's Largest Root	.367	1.531[a]	12.000	50.000	.144	18.374	.728
Work	Pillai's Trace	.843	22.356[a]	12.000	50.000	.000	268.268	1.000
	Wilks' Lambda	.157	22.356[a]	12.000	50.000	.000	268.268	1.000
	Hotelling's Trace	5.365	22.356[a]	12.000	50.000	.000	268.268	1.000
	Roy's Largest Root	5.365	22.356[a]	12.000	50.000	.000	268.268	1.000
Noise * Temperature	Pillai's Trace	.126	.603[a]	12.000	50.000	.830	7.231	.295
	Wilks' Lambda	.874	.603[a]	12.000	50.000	.830	7.231	.295
	Hotelling's Trace	.145	.603[a]	12.000	50.000	.830	7.231	.295
	Roy's Largest Root	.145	.603[a]	12.000	50.000	.830	7.231	.295
Noise * Time	Pillai's Trace	.171	.861[a]	12.000	50.000	.590	10.335	.429
	Wilks' Lambda	.829	.861[a]	12.000	50.000	.590	10.335	.429
	Hotelling's Trace	.207	.861[a]	12.000	50.000	.590	10.335	.429
	Roy's Largest Root	.207	.861[a]	12.000	50.000	.590	10.335	.429
Noise * Work	Pillai's Trace	.111	.520[a]	12.000	50.000	.892	6.236	.253
	Wilks' Lambda	.889	.520[a]	12.000	50.000	.892	6.236	.253
	Hotelling's Trace	.125	.520[a]	12.000	50.000	.892	6.236	.253
	Roy's Largest Root	.125	.520[a]	12.000	50.000	.892	6.236	.253
Temperature * Time	Pillai's Trace	.192	.987[a]	12.000	50.000	.474	11.849	.493
	Wilks' Lambda	.808	.987[a]	12.000	50.000	.474	11.849	.493
	Hotelling's Trace	.237	.987[a]	12.000	50.000	.474	11.849	.493
	Roy's Largest Root	.237	.987[a]	12.000	50.000	.474	11.849	.493
Temperature * Work	Pillai's Trace	.214	1.132[a]	12.000	50.000	.357	13.584	.563
	Wilks' Lambda	.786	1.132[a]	12.000	50.000	.357	13.584	.563
	Hotelling's Trace	.272	1.132[a]	12.000	50.000	.357	13.584	.563

	Roy's Largest Root	.272	1.132[a]	12.000	50.000	.357	13.584	.563
Time * Work	Pillai's Trace	.200	1.040[a]	12.000	50.000	.429	12.485	.519
	Wilks' Lambda	.800	1.040[a]	12.000	50.000	.429	12.485	.519
	Hotelling's Trace	.250	1.040[a]	12.000	50.000	.429	12.485	.519
	Roy's Largest Root	.250	1.040[a]	12.000	50.000	.429	12.485	.519
Noise * Temperature * Time	Pillai's Trace	.122	.581[a]	12.000	50.000	.847	6.972	.284
	Wilks' Lambda	.878	.581[a]	12.000	50.000	.847	6.972	.284
	Hotelling's Trace	.139	.581[a]	12.000	50.000	.847	6.972	.284
	Roy's Largest Root	.139	.581[a]	12.000	50.000	.847	6.972	.284
Noise * Temperature * Work	Pillai's Trace	.247	1.368[a]	12.000	50.000	.212	16.420	.666
	Wilks' Lambda	.753	1.368[a]	12.000	50.000	.212	16.420	.666
	Hotelling's Trace	.328	1.368[a]	12.000	50.000	.212	16.420	.666
	Roy's Largest Root	.328	1.368[a]	12.000	50.000	.212	16.420	.666
Noise * Time * Work	Pillai's Trace	.106	.495[a]	12.000	50.000	.908	5.940	.241
	Wilks' Lambda	.894	.495[a]	12.000	50.000	.908	5.940	.241
	Hotelling's Trace	.119	.495[a]	12.000	50.000	.908	5.940	.241
	Roy's Largest Root	.119	.495[a]	12.000	50.000	.908	5.940	.241
Temperature * Time * Work	Pillai's Trace	.240	1.318[a]	12.000	50.000	.238	15.816	.646
	Wilks' Lambda	.760	1.318[a]	12.000	50.000	.238	15.816	.646
	Hotelling's Trace	.316	1.318[a]	12.000	50.000	.238	15.816	.646
	Roy's Largest Root	.316	1.318[a]	12.000	50.000	.238	15.816	.646
Noise * Temperature * Time * Work	Pillai's Trace	.235	1.279[a]	12.000	50.000	.260	15.344	.629
	Wilks' Lambda	.765	1.279[a]	12.000	50.000	.260	15.344	.629
	Hotelling's Trace	.307	1.279[a]	12.000	50.000	.260	15.344	.629

	Roy's Largest Root	.307	1.279[a]	12.000	50.000	.260	15.344	.629

a. Exact statistic

b. Computed using alpha = .05

c. Design: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
Stress Difference	1.871	15	61	.045
Arousal Difference	1.580	15	61	.106
Delta Max-baseline TLX	1.737	15	61	.067
GSR Delta Baseline	1.484	15	61	.140
FT Delta total	1.185	15	61	.308
Cortisol Difference	1.853	15	61	.047
% Max HR	1.133	15	61	.348
Number of Misses	1.425	15	61	.165
Number of False Alarms	1.134	15	61	.347
Average Reaction Time	2.755	15	61	.003
Average RT for Misses	6.665	15	61	.000
Target Deviation 2	2.784	15	61	.002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

Tests of Between-Subjects Effects

Source	Dependent Variable	Type IV Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[b]
Corrected Model	Stress Difference	642.942[a]	15	42.863	1.534	.121	23.012	.806
	Arousal Difference	149.444[c]	15	9.963	.720	.755	10.796	.408
	Delta Max-baseline TLX	1945.251[d]	15	129.683	2.105	.022	31.578	.933
	GSR Delta Baseline	77251.072[e]	15	5150.071	1.534	.121	23.010	.806
	FT Delta total	616.275[f]	15	41.085	3.120	.001	46.796	.993
	Cortisol Difference	.158[g]	15	.011	1.115	.363	16.728	.632
	% Max HR	791.578[h]	15	52.772	1.536	.121	23.036	.806
	Number of Misses	1284.671[i]	15	85.645	2.892	.002	43.379	.988
	Number of False Alarms	115.090[j]	15	7.673	.244	.998	3.663	.142
	Average Reaction Time	90.612[k]	15	6.041	6.536	.000	98.047	1.000
	Average RT for Misses	2160.339[l]	15	144.023	11.354	.000	170.315	1.000
	Target Deviation 2	1556.813[m]	15	103.788	1.788	.057	26.815	.876
Intercept	Stress Difference	558.378	1	558.378	19.986	.000	19.986	.993
	Arousal Difference	206.643	1	206.643	14.928	.000	14.928	.967
	Delta Max-baseline TLX	6247.771	1	6247.771	101.421	.000	101.421	1.000
	GSR Delta Baseline	44620.884	1	44620.884	13.291	.001	13.291	.948
	FT Delta total	232.700	1	232.700	17.670	.000	17.670	.985
	Cortisol Difference	.189	1	.189	19.984	.000	19.984	.993
	% Max HR	130840.372	1	130840.372	3807.699	.000	3807.699	1.000

	Number of Misses	6364.042	1	6364.042	214.895	.000	214.895	1.000
	Number of False Alarms	849.008	1	849.008	27.020	.000	27.020	.999
	Average Reaction Time	1031.807	1	1031.807	1116.476	.000	1116.476	1.000
	Average RT for Misses	11184.043	1	11184.043	881.716	.000	881.716	1.000
	Target Deviation 2	16436.793	1	16436.793	283.111	.000	283.111	1.000
Noise	Stress Difference	64.817	1	64.817	2.320	.133	2.320	.323
	Arousal Difference	.086	1	.086	.006	.937	.006	.051
	Delta Max-baseline TLX	650.571	1	650.571	10.561	.002	10.561	.892
	GSR Delta Baseline	17623.115	1	17623.115	5.249	.025	5.249	.616
	FT Delta total	25.949	1	25.949	1.970	.165	1.970	.282
	Cortisol Difference	.003	1	.003	.352	.555	.352	.090
	% Max HR	18.207	1	18.207	.530	.469	.530	.111
	Number of Misses	86.932	1	86.932	2.935	.092	2.935	.392
	Number of False Alarms	3.602	1	3.602	.115	.736	.115	.063
	Average Reaction Time	2.391	1	2.391	2.587	.113	2.587	.353
	Average RT for Misses	13.150	1	13.150	1.037	.313	1.037	.171
	Target Deviation 2	64.571	1	64.571	1.112	.296	1.112	.180
Temperature	Stress Difference	20.092	1	20.092	.719	.400	.719	.133
	Arousal Difference	2.050	1	2.050	.148	.702	.148	.067
	Delta Max-baseline TLX	20.784	1	20.784	.337	.563	.337	.088

	GSR Delta Baseline	13658.242	1	13658.242	4.068	.048	4.068	.510
	FT Delta total	379.430	1	379.430	28.812	.000	28.812	1.000
	Cortisol Difference	.002	1	.002	.164	.687	.164	.068
	% Max HR	359.110	1	359.110	10.451	.002	10.451	.889
	Number of Misses	16.159	1	16.159	.546	.463	.546	.112
	Number of False Alarms	.305	1	.305	.010	.922	.010	.051
	Average Reaction Time	.133	1	.133	.144	.706	.144	.066
	Average RT for Misses	9.110	1	9.110	.718	.400	.718	.133
	Target Deviation 2	17.747	1	17.747	.306	.582	.306	.085
Time	Stress Difference	185.501	1	185.501	6.639	.012	6.639	.718
	Arousal Difference	3.301	1	3.301	.238	.627	.238	.077
	Delta Max-baseline TLX	133.653	1	133.653	2.170	.146	2.170	.305
	GSR Delta Baseline	66.007	1	66.007	.020	.889	.020	.052
	FT Delta total	10.733	1	10.733	.815	.370	.815	.144
	Cortisol Difference	.006	1	.006	.627	.431	.627	.122
	% Max HR	.600	1	.600	.017	.895	.017	.052
	Number of Misses	8.306	1	8.306	.280	.598	.280	.082
	Number of False Alarms	3.612	1	3.612	.115	.736	.115	.063
	Average Reaction Time	.002	1	.002	.002	.964	.002	.050
	Average RT for Misses	40.425	1	40.425	3.187	.079	3.187	.420
	Target Deviation	244.496	1	244.496	4.211	.044	4.211	.524

	2							
Work	Stress Difference	4.641	1	4.641	.166	.685	.166	.069
	Arousal Difference	.165	1	.165	.012	.913	.012	.051
	Delta Max-baseline TLX	358.384	1	358.384	5.818	.019	5.818	.661
	GSR Delta Baseline	2199.968	1	2199.968	.655	.421	.655	.125
	FT Delta total	.064	1	.064	.005	.945	.005	.051
	Cortisol Difference	.001	1	.001	.102	.750	.102	.061
	% Max HR	35.475	1	35.475	1.032	.314	1.032	.170
	Number of Misses	830.818	1	830.818	28.054	.000	28.054	.999
	Number of False Alarms	.981	1	.981	.031	.860	.031	.053
	Average Reaction Time	70.065	1	70.065	75.815	.000	75.815	1.000
	Average RT for Misses	1848.636	1	1848.636	145.741	.000	145.741	1.000
	Target Deviation 2	805.588	1	805.588	13.876	.000	13.876	.956
Noise * Temperature	Stress Difference	1.414	1	1.414	.051	.823	.051	.056
	Arousal Difference	12.230	1	12.230	.884	.351	.884	.152
	Delta Max-baseline TLX	126.732	1	126.732	2.057	.157	2.057	.292
	GSR Delta Baseline	2157.565	1	2157.565	.643	.426	.643	.124
	FT Delta total	.035	1	.035	.003	.959	.003	.050
	Cortisol Difference	.001	1	.001	.090	.765	.090	.060
	% Max HR	18.878	1	18.878	.549	.461	.549	.113
	Number of Misses	4.439	1	4.439	.150	.700	.150	.067
	Number of False	1.563	1	1.563	.050	.824	.050	.056

	Alarms							
	Average Reaction Time	1.729	1	1.729	1.871	.176	1.871	.270
	Average RT for Misses	10.228	1	10.228	.806	.373	.806	.143
	Target Deviation 2	136.160	1	136.160	2.345	.131	2.345	.326
Noise * Time	Stress Difference	22.658	1	22.658	.811	.371	.811	.144
	Arousal Difference	14.591	1	14.591	1.054	.309	1.054	.173
	Delta Max-baseline TLX	361.979	1	361.979	5.876	.018	5.876	.665
	GSR Delta Baseline	381.193	1	381.193	.114	.737	.114	.063
	FT Delta total	.278	1	.278	.021	.885	.021	.052
	Cortisol Difference	.002	1	.002	.237	.628	.237	.077
	% Max HR	2.434	1	2.434	.071	.791	.071	.058
	Number of Misses	32.436	1	32.436	1.095	.299	1.095	.178
	Number of False Alarms	.363	1	.363	.012	.915	.012	.051
	Average Reaction Time	.323	1	.323	.349	.557	.349	.090
	Average RT for Misses	11.884	1	11.884	.937	.337	.937	.159
	Target Deviation 2	29.154	1	29.154	.502	.481	.502	.107
Noise * Work	Stress Difference	15.228	1	15.228	.545	.463	.545	.112
	Arousal Difference	.000	1	.000	.000	.995	.000	.050
	Delta Max-baseline TLX	62.022	1	62.022	1.007	.320	1.007	.167
	GSR Delta Baseline	5214.448	1	5214.448	1.553	.217	1.553	.232
	FT Delta total	2.757	1	2.757	.209	.649	.209	.074

	Cortisol Difference	.000	1	.000	.042	.838	.042	.055
	% Max HR	17.552	1	17.552	.511	.478	.511	.108
	Number of Misses	.251	1	.251	.008	.927	.008	.051
	Number of False Alarms	.284	1	.284	.009	.925	.009	.051
	Average Reaction Time	1.454	1	1.454	1.574	.214	1.574	.235
	Average RT for Misses	12.945	1	12.945	1.021	.316	1.021	.169
	Target Deviation 2	.236	1	.236	.004	.949	.004	.050
Temperature * Time	Stress Difference	8.436	1	8.436	.302	.585	.302	.084
	Arousal Difference	15.267	1	15.267	1.103	.298	1.103	.179
	Delta Max-baseline TLX	41.897	1	41.897	.680	.413	.680	.128
	GSR Delta Baseline	10664.034	1	10664.034	3.176	.080	3.176	.419
	FT Delta total	76.093	1	76.093	5.778	.019	5.778	.658
	Cortisol Difference	.001	1	.001	.119	.731	.119	.063
	% Max HR	37.134	1	37.134	1.081	.303	1.081	.176
	Number of Misses	1.044	1	1.044	.035	.852	.035	.054
	Number of False Alarms	34.505	1	34.505	1.098	.299	1.098	.178
	Average Reaction Time	1.118	1	1.118	1.210	.276	1.210	.191
	Average RT for Misses	6.767	1	6.767	.534	.468	.534	.111
	Target Deviation 2	6.260	1	6.260	.108	.744	.108	.062
Temperature * Work	Stress Difference	.193	1	.193	.007	.934	.007	.051
	Arousal	14.802	1	14.802	1.069	.305	1.069	.175

	Difference							
	Delta Max-baseline TLX	118.746	1	118.746	1.928	.170	1.928	.277
	GSR Delta Baseline	404.880	1	404.880	.121	.730	.121	.063
	FT Delta total	.096	1	.096	.007	.932	.007	.051
	Cortisol Difference	.048	1	.048	5.047	.028	5.047	.599
	% Max HR	148.118	1	148.118	4.311	.042	4.311	.533
	Number of Misses	8.480	1	8.480	.286	.595	.286	.082
	Number of False Alarms	11.481	1	11.481	.365	.548	.365	.091
	Average Reaction Time	.397	1	.397	.430	.515	.430	.099
	Average RT for Misses	6.791	1	6.791	.535	.467	.535	.111
	Target Deviation 2	63.119	1	63.119	1.087	.301	1.087	.177
Time * Work	Stress Difference	33.585	1	33.585	1.202	.277	1.202	.190
	Arousal Difference	4.545	1	4.545	.328	.569	.328	.087
	Delta Max-baseline TLX	49.650	1	49.650	.806	.373	.806	.143
	GSR Delta Baseline	312.841	1	312.841	.093	.761	.093	.060
	FT Delta total	2.416	1	2.416	.183	.670	.183	.071
	Cortisol Difference	.041	1	.041	4.299	.042	4.299	.532
	% Max HR	1.914	1	1.914	.056	.814	.056	.056
	Number of Misses	12.423	1	12.423	.420	.520	.420	.098
	Number of False Alarms	4.370	1	4.370	.139	.710	.139	.066
	Average Reaction Time	.377	1	.377	.408	.525	.408	.096

	Average RT for Misses	34.612	1	34.612	2.729	.104	2.729	.369
	Target Deviation 2	9.636	1	9.636	.166	.685	.166	.069
Noise * Temperature * Time	Stress Difference	6.901	1	6.901	.247	.621	.247	.078
	Arousal Difference	.920	1	.920	.066	.797	.066	.057
	Delta Max-baseline TLX	9.300	1	9.300	.151	.699	.151	.067
	GSR Delta Baseline	7978.654	1	7978.654	2.377	.128	2.377	.329
	FT Delta total	18.610	1	18.610	1.413	.239	1.413	.216
	Cortisol Difference	.001	1	.001	.154	.696	.154	.067
	% Max HR	5.711	1	5.711	.166	.685	.166	.069
	Number of Misses	5.310	1	5.310	.179	.673	.179	.070
	Number of False Alarms	.002	1	.002	.000	.994	.000	.050
	Average Reaction Time	.151	1	.151	.164	.687	.164	.068
	Average RT for Misses	33.703	1	33.703	2.657	.108	2.657	.361
	Target Deviation 2	14.594	1	14.594	.251	.618	.251	.078
Noise * Temperature * Work	Stress Difference	105.555	1	105.555	3.778	.057	3.778	.481
	Arousal Difference	39.318	1	39.318	2.840	.097	2.840	.382
	Delta Max-baseline TLX	4.701	1	4.701	.076	.783	.076	.059
	GSR Delta Baseline	326.849	1	326.849	.097	.756	.097	.061
	FT Delta total	1.629	1	1.629	.124	.726	.124	.064
	Cortisol Difference	3.085E-5	1	3.085E-5	.003	.955	.003	.050
	% Max HR	33.050	1	33.050	.962	.331	.962	.162

	Number of Misses	119.446	1	119.446	4.033	.049	4.033	.507
	Number of False Alarms	2.133	1	2.133	.068	.795	.068	.058
	Average Reaction Time	.949	1	.949	1.026	.315	1.026	.169
	Average RT for Misses	9.347	1	9.347	.737	.394	.737	.135
	Target Deviation 2	17.240	1	17.240	.297	.588	.297	.084
Noise * Time * Work	Stress Difference	2.218	1	2.218	.079	.779	.079	.059
	Arousal Difference	10.350	1	10.350	.748	.391	.748	.136
	Delta Max-baseline TLX	10.617	1	10.617	.172	.679	.172	.069
	GSR Delta Baseline	732.191	1	732.191	.218	.642	.218	.075
	FT Delta total	.481	1	.481	.036	.849	.036	.054
	Cortisol Difference	.013	1	.013	1.417	.239	1.417	.216
	% Max HR	26.483	1	26.483	.771	.383	.771	.139
	Number of Misses	7.907	1	7.907	.267	.607	.267	.080
	Number of False Alarms	1.790	1	1.790	.057	.812	.057	.056
	Average Reaction Time	5.543E-6	1	5.543E-6	.000	.998	.000	.050
	Average RT for Misses	10.407	1	10.407	.820	.369	.820	.145
	Target Deviation 2	31.129	1	31.129	.536	.467	.536	.111
Temperature * Time * Work	Stress Difference	101.988	1	101.988	3.650	.061	3.650	.468
	Arousal Difference	6.461	1	6.461	.467	.497	.467	.103
	Delta Max-baseline TLX	91.606	1	91.606	1.487	.227	1.487	.225

	GSR Delta Baseline	251.434	1	251.434	.075	.785	.075	.058
	FT Delta total	5.092	1	5.092	.387	.536	.387	.094
	Cortisol Difference	.009	1	.009	.972	.328	.972	.163
	% Max HR	177.059	1	177.059	5.153	.027	5.153	.608
	Number of Misses	90.798	1	90.798	3.066	.085	3.066	.407
	Number of False Alarms	11.961	1	11.961	.381	.540	.381	.093
	Average Reaction Time	.513	1	.513	.555	.459	.555	.114
	Average RT for Misses	6.234	1	6.234	.491	.486	.491	.106
	Target Deviation 2	63.199	1	63.199	1.089	.301	1.089	.177
Noise * Temperature * Time * Work	Stress Difference	8.967	1	8.967	.321	.573	.321	.086
	Arousal Difference	48.241	1	48.241	3.485	.067	3.485	.451
	Delta Max-baseline TLX	7.967	1	7.967	.129	.720	.129	.064
	GSR Delta Baseline	2110.543	1	2110.543	.629	.431	.629	.122
	FT Delta total	28.476	1	28.476	2.162	.147	2.162	.304
	Cortisol Difference	.023	1	.023	2.379	.128	2.379	.330
	% Max HR	23.451	1	23.451	.682	.412	.682	.129
	Number of Misses	35.914	1	35.914	1.213	.275	1.213	.192
	Number of False Alarms	.027	1	.027	.001	.977	.001	.050
	Average Reaction Time	.312	1	.312	.338	.563	.338	.088
	Average RT for Misses	34.144	1	34.144	2.692	.106	2.692	.365
	Target Deviation	2.514	1	2.514	.043	.836	.043	.055

	2							
Error	Stress Difference	1704.279	61	27.939				
	Arousal Difference	844.374	61	13.842				
	Delta Max-baseline TLX	3757.730	61	61.602				
	GSR Delta Baseline	204792.212	61	3357.249				
	FT Delta total	803.326	61	13.169				
	Cortisol Difference	.577	61	.009				
	% Max HR	2096.086	61	34.362				
	Number of Misses	1806.498	61	29.615				
	Number of False Alarms	1916.729	61	31.422				
	Average Reaction Time	56.374	61	.924				
	Average RT for Misses	773.748	61	12.684				
	Target Deviation 2	3541.525	61	58.058				
Total	Stress Difference	2768.000	77					
	Arousal Difference	1200.000	77					
	Delta Max-baseline TLX	11690.473	77					
	GSR Delta Baseline	331032.824	77					
	FT Delta total	1636.687	77					
	Cortisol Difference	.924	77					
	% Max HR	144288.001	77					
	Number of Misses	9473.000	77					
	Number of False	3050.000	77					

	Alarms							
	Average Reaction Time	1358.410	77					
	Average RT for Misses	16063.209	77					
	Target Deviation 2	23284.112	77					
Corrected Total	Stress Difference	2347.221	76					
	Arousal Difference	993.818	76					
	Delta Max-baseline TLX	5702.981	76					
	GSR Delta Baseline	282043.283	76					
	FT Delta total	1419.601	76					
	Cortisol Difference	.736	76					
	% Max HR	2887.664	76					
	Number of Misses	3091.169	76					
	Number of False Alarms	2031.818	76					
	Average Reaction Time	146.985	76					
	Average RT for Misses	2934.087	76					
	Target Deviation 2	5098.338	76					

a. R Squared = .274 (Adjusted R Squared = .095)

b. Computed using alpha = .05

c. R Squared = .150 (Adjusted R Squared = -.059)

d. R Squared = .341 (Adjusted R Squared = .179)

e. R Squared = .274 (Adjusted R Squared = .095)

f. R Squared = .434 (Adjusted R Squared = .295)

g. R Squared = .215 (Adjusted R Squared = .022)

h. R Squared = .274 (Adjusted R Squared = .096)

i. R Squared = .416 (Adjusted R Squared = .272)

j. R Squared = .057 (Adjusted R Squared = -.175)

k. R Squared = .616 (Adjusted R Squared = .522)

l. R Squared = .736 (Adjusted R Squared = .671)

m. R Squared = .305 (Adjusted R Squared = .135)

Estimated Marginal Means

1. Grand Mean

			95% Confidence Interval	
Dependent Variable	Mean	Std. Error	Lower Bound	Upper Bound
Stress Difference	2.812	.629	1.554	4.070
Arousal Difference	1.711	.443	.825	2.596
Delta Max-baseline TLX	9.407	.934	7.539	11.275
GSR Delta Baseline	25.141	6.896	11.351	38.930
FT Delta total	-1.816	.432	-2.679	-.952
Cortisol Difference	-.052	.012	-.075	-.029
% Max HR	43.050	.698	41.655	44.445
Number of Misses	9.494	.648	8.199	10.790
Number of False Alarms	3.468	.667	2.134	4.802
Average Reaction Time	3.823	.114	3.594	4.052
Average RT for Misses	12.586	.424	11.739	13.434
Target Deviation 2	15.259	.907	13.445	17.072

Noise

Estimates

Dependent Variable	Noise	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Stress Difference	Low	1.854	.895	.065	3.643
	High	3.771	.885	2.002	5.540
Arousal Difference	Low	1.746	.630	.487	3.005
	High	1.676	.623	.431	2.921
Delta Max-baseline TLX	Low	12.443	1.328	9.787	15.099
	High	6.372	1.314	3.745	8.999
GSR Delta Baseline	Low	40.940	9.807	21.330	60.550
	High	9.341	9.698	-10.051	28.733
FT Delta total	Low	-2.422	.614	-3.650	-1.194
	High	-1.209	.607	-2.424	.005
Cortisol Difference	Low	-.059	.016	-.092	-.026
	High	-.045	.016	-.077	-.012
% Max HR	Low	42.542	.992	40.559	44.526
	High	43.558	.981	41.596	45.520
Number of Misses	Low	10.604	.921	8.762	12.446
	High	8.385	.911	6.564	10.206
Number of False Alarms	Low	3.694	.949	1.797	5.591
	High	3.242	.938	1.366	5.118
Average Reaction Time	Low	4.007	.163	3.682	4.332
	High	3.639	.161	3.317	3.961
Average RT for Misses	Low	13.018	.603	11.813	14.223
	High	12.155	.596	10.963	13.347
Target Deviation 2	Low	16.215	1.290	13.636	18.794
	High	14.302	1.275	11.752	16.852

Pairwise Comparisons

Dependent Variable	(I) Noise	(J) Noise	Mean Difference (I-J)	Std. Error	Sig.[a]
Stress Difference	Low	High	-1.916	1.258	.133
	High	Low	1.916	1.258	.133
Arousal Difference	Low	High	.070	.886	.937
	High	Low	-.070	.886	.937
Delta Max-baseline TLX	Low	High	6.071*	1.868	.002
	High	Low	-6.071*	1.868	.002
GSR Delta Baseline	Low	High	31.599*	13.792	.025
	High	Low	-31.599*	13.792	.025
FT Delta total	Low	High	-1.213	.864	.165
	High	Low	1.213	.864	.165
Cortisol Difference	Low	High	-.014	.023	.555
	High	Low	.014	.023	.555
% Max HR	Low	High	-1.016	1.395	.469
	High	Low	1.016	1.395	.469
Number of Misses	Low	High	2.219	1.295	.092
	High	Low	-2.219	1.295	.092
Number of False Alarms	Low	High	.452	1.334	.736
	High	Low	-.452	1.334	.736
Average Reaction Time	Low	High	.368	.229	.113
	High	Low	-.368	.229	.113
Average RT for Misses	Low	High	.863	.848	.313
	High	Low	-.863	.848	.313
Target Deviation 2	Low	High	1.913	1.814	.296
	High	Low	-1.913	1.814	.296

Pairwise Comparisons

Dependent Variable	(I) Noise	(J) Noise	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
Stress Difference	Low	High	-4.432	.600
	High	Low	-.600	4.432
Arousal Difference	Low	High	-1.701	1.841

	High	Low	-1.841	1.701
Delta Max-baseline TLX	Low	High	2.336	9.807
	High	Low	-9.807	-2.336
GSR Delta Baseline	Low	High	4.020	59.178
	High	Low	-59.178	-4.020
FT Delta total	Low	High	-2.940	.515
	High	Low	-.515	2.940
Cortisol Difference	Low	High	-.060	.033
	High	Low	-.033	.060
% Max HR	Low	High	-3.806	1.774
	High	Low	-1.774	3.806
Number of Misses	Low	High	-.371	4.810
	High	Low	-4.810	.371
Number of False Alarms	Low	High	-2.216	3.120
	High	Low	-3.120	2.216
Average Reaction Time	Low	High	-.090	.826
	High	Low	-.826	.090
Average RT for Misses	Low	High	-.832	2.558
	High	Low	-2.558	.832
Target Deviation 2	Low	High	-1.714	5.539
	High	Low	-5.539	1.714

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.309	1.866[a]	12.000	50.000	.062
Wilks' lambda	.691	1.866[a]	12.000	50.000	.062
Hotelling's trace	.448	1.866[a]	12.000	50.000	.062
Roy's largest root	.448	1.866[a]	12.000	50.000	.062

Multivariate Tests

	Noncent. Parameter	Observed Power[b]
Pillai's trace	22.396	.829
Wilks' lambda	22.396	.829
Hotelling's trace	22.396	.829
Roy's largest root	22.396	.829

Each F tests the multivariate effect of Noise. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Univariate Tests

Dependent Variable		Sum of Squares	df	Mean Square	F	Sig.
Stress Difference	Contrast	64.817	1	64.817	2.320	.133
	Error	1704.279	61	27.939		
Arousal Difference	Contrast	.086	1	.086	.006	.937
	Error	844.374	61	13.842		
Delta Max-baseline TLX	Contrast	650.571	1	650.571	10.561	.002
	Error	3757.730	61	61.602		
GSR Delta Baseline	Contrast	17623.115	1	17623.115	5.249	.025
	Error	204792.212	61	3357.249		
FT Delta total	Contrast	25.949	1	25.949	1.970	.165
	Error	803.326	61	13.169		
Cortisol Difference	Contrast	.003	1	.003	.352	.555
	Error	.577	61	.009		
% Max HR	Contrast	18.207	1	18.207	.530	.469
	Error	2096.086	61	34.362		
Number of Misses	Contrast	86.932	1	86.932	2.935	.092
	Error	1806.498	61	29.615		
Number of False Alarms	Contrast	3.602	1	3.602	.115	.736
	Error	1916.729	61	31.422		
Average Reaction Time	Contrast	2.391	1	2.391	2.587	.113

	Error	56.374	61	.924		
Average RT for Misses	Contrast	13.150	1	13.150	1.037	.313
	Error	773.748	61	12.684		
Target Deviation 2	Contrast	64.571	1	64.571	1.112	.296
	Error	3541.525	61	58.058		

Univariate Tests

Dependent Variable		Noncent. Parameter	Observed Power[a]
Stress Difference	Contrast	2.320	.323
	Error		
Arousal Difference	Contrast	.006	.051
	Error		
Delta Max-baseline TLX	Contrast	10.561	.892
	Error		
GSR Delta Baseline	Contrast	5.249	.616
	Error		
FT Delta total	Contrast	1.970	.282
	Error		
Cortisol Difference	Contrast	.352	.090
	Error		
% Max HR	Contrast	.530	.111
	Error		
Number of Misses	Contrast	2.935	.392
	Error		
Number of False Alarms	Contrast	.115	.063
	Error		
Average Reaction Time	Contrast	2.587	.353
	Error		
Average RT for Misses	Contrast	1.037	.171
	Error		
Target Deviation 2	Contrast	1.112	.180
	Error		

The F tests the effect of Noise. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Temperature

Estimates

Dependent Variable	Temperature	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Stress Difference	Low	2.279	.868	.543	4.015
	High	3.346	.911	1.525	5.167
Arousal Difference	Low	1.540	.611	.319	2.762
	High	1.881	.641	.599	3.163
Delta Max-baseline TLX	Low	8.865	1.289	6.287	11.442
	High	9.950	1.352	7.246	12.654
GSR Delta Baseline	Low	11.231	9.516	-7.797	30.259
	High	39.050	9.983	19.087	59.013
FT Delta total	Low	.503	.596	-.689	1.695
	High	-4.134	.625	-5.384	-2.884
Cortisol Difference	Low	-.056	.016	-.088	-.024
	High	-.047	.017	-.081	-.014
% Max HR	Low	40.795	.963	38.870	42.720
	High	45.306	1.010	43.286	47.325
Number of Misses	Low	9.016	.894	7.229	10.803
	High	9.973	.938	8.098	11.848
Number of False Alarms	Low	3.534	.921	1.693	5.374
	High	3.402	.966	1.471	5.333
Average Reaction Time	Low	3.866	.158	3.551	4.182
	High	3.780	.166	3.448	4.111
Average RT for Misses	Low	12.946	.585	11.776	14.115
	High	12.227	.614	11.000	13.454
Target Deviation 2	Low	15.760	1.251	13.258	18.262
	High	14.757	1.313	12.132	17.382

Pairwise Comparisons

Dependent Variable	(I) Temperature	(J) Temperature	Mean Difference (I-J)	Std. Error	Sig.[a]
Stress Difference	Low	High	-1.067	1.258	.400
	High	Low	1.067	1.258	.400
Arousal Difference	Low	High	-.341	.886	.702
	High	Low	.341	.886	.702
Delta Max-baseline TLX	Low	High	-1.085	1.868	.563
	High	Low	1.085	1.868	.563
GSR Delta Baseline	Low	High	-27.818*	13.792	.048
	High	Low	27.818*	13.792	.048
FT Delta total	Low	High	4.637*	.864	.000
	High	Low	-4.637*	.864	.000
Cortisol Difference	Low	High	-.009	.023	.687
	High	Low	.009	.023	.687
% Max HR	Low	High	-4.511*	1.395	.002
	High	Low	4.511*	1.395	.002
Number of Misses	Low	High	-.957	1.295	.463
	High	Low	.957	1.295	.463
Number of False Alarms	Low	High	.132	1.334	.922
	High	Low	-.132	1.334	.922
Average Reaction Time	Low	High	.087	.229	.706
	High	Low	-.087	.229	.706
Average RT for Misses	Low	High	.718	.848	.400
	High	Low	-.718	.848	.400
Target Deviation 2	Low	High	1.003	1.814	.582
	High	Low	-1.003	1.814	.582

Pairwise Comparisons

Dependent Variable	(I) Temperature	(J) Temperature	95% Confidence Interval for Difference[a]	
			Lower Bound	Upper Bound
Stress Difference	Low	High	-3.583	1.449
	High	Low	-1.449	3.583
Arousal Difference	Low	High	-2.112	1.430
	High	Low	-1.430	2.112
Delta Max-baseline TLX	Low	High	-4.821	2.651
	High	Low	-2.651	4.821
GSR Delta Baseline	Low	High	-55.397	-.240
	High	Low	.240	55.397
FT Delta total	Low	High	2.909	6.364
	High	Low	-6.364	-2.909
Cortisol Difference	Low	High	-.056	.037
	High	Low	-.037	.056
% Max HR	Low	High	-7.301	-1.721
	High	Low	1.721	7.301
Number of Misses	Low	High	-3.547	1.633
	High	Low	-1.633	3.547
Number of False Alarms	Low	High	-2.537	2.800
	High	Low	-2.800	2.537
Average Reaction Time	Low	High	-.371	.544
	High	Low	-.544	.371
Average RT for Misses	Low	High	-.977	2.414
	High	Low	-2.414	.977
Target Deviation 2	Low	High	-2.624	4.629
	High	Low	-4.629	2.624

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.507	4.293[a]	12.000	50.000	.000
Wilks' lambda	.493	4.293[a]	12.000	50.000	.000
Hotelling's trace	1.030	4.293[a]	12.000	50.000	.000
Roy's largest root	1.030	4.293[a]	12.000	50.000	.000

Multivariate Tests

	Noncent. Parameter	Observed Power[b]
Pillai's trace	51.517	.998
Wilks' lambda	51.517	.998
Hotelling's trace	51.517	.998
Roy's largest root	51.517	.998

Each F tests the multivariate effect of Temperature. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Univariate Tests

Dependent Variable		Sum of Squares	df	Mean Square	F	Sig.
Stress Difference	Contrast	20.092	1	20.092	.719	.400
	Error	1704.279	61	27.939		
Arousal Difference	Contrast	2.050	1	2.050	.148	.702
	Error	844.374	61	13.842		
Delta Max-baseline TLX	Contrast	20.784	1	20.784	.337	.563
	Error	3757.730	61	61.602		
GSR Delta Baseline	Contrast	13658.242	1	13658.242	4.068	.048
	Error	204792.212	61	3357.249		
FT Delta total	Contrast	379.430	1	379.430	28.812	.000
	Error	803.326	61	13.169		
Cortisol Difference	Contrast	.002	1	.002	.164	.687
	Error	.577	61	.009		

% Max HR	Contrast	359.110	1	359.110	10.451	.002
	Error	2096.086	61	34.362		
Number of Misses	Contrast	16.159	1	16.159	.546	.463
	Error	1806.498	61	29.615		
Number of False Alarms	Contrast	.305	1	.305	.010	.922
	Error	1916.729	61	31.422		
Average Reaction Time	Contrast	.133	1	.133	.144	.706
	Error	56.374	61	.924		
Average RT for Misses	Contrast	9.110	1	9.110	.718	.400
	Error	773.748	61	12.684		
Target Deviation 2	Contrast	17.747	1	17.747	.306	.582
	Error	3541.525	61	58.058		

Univariate Tests

Dependent Variable		Noncent. Parameter	Observed Power[a]
Stress Difference	Contrast	.719	.133
	Error		
Arousal Difference	Contrast	.148	.067
	Error		
Delta Max-baseline TLX	Contrast	.337	.088
	Error		
GSR Delta Baseline	Contrast	4.068	.510
	Error		
FT Delta total	Contrast	28.812	1.000
	Error		
Cortisol Difference	Contrast	.164	.068
	Error		
% Max HR	Contrast	10.451	.889
	Error		
Number of Misses	Contrast	.546	.112
	Error		
Number of False Alarms	Contrast	.010	.051
	Error		
Average Reaction Time	Contrast	.144	.066

	Error		
Average RT for Misses	Contrast	.718	.133
	Error		
Target Deviation 2	Contrast	.306	.085
	Error		

The F tests the effect of Temperature. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Time Awareness

Estimates

				95% Confidence Interval	
Dependent Variable	Time Awareness	Mean	Std. Error	Lower Bound	Upper Bound
Stress Difference	Low	1.191	.812	-.432	2.815
	High	4.433	.961	2.511	6.355
Arousal Difference	Low	1.495	.571	.352	2.637
	High	1.927	.677	.574	3.280
Delta Max-baseline TLX	Low	8.031	1.205	5.621	10.442
	High	10.783	1.427	7.929	13.637
GSR Delta Baseline	Low	24.174	8.899	6.380	41.967
	High	26.107	10.537	5.037	47.178
FT Delta total	Low	-2.205	.557	-3.320	-1.091
	High	-1.426	.660	-2.745	-.106
Cortisol Difference	Low	-.043	.015	-.072	-.013
	High	-.061	.018	-.096	-.026
% Max HR	Low	42.958	.900	41.158	44.758
	High	43.142	1.066	41.011	45.274
Number of Misses	Low	9.151	.836	7.480	10.823
	High	9.838	.990	7.859	11.816
Number of False Alarms	Low	3.694	.861	1.973	5.415
	High	3.242	1.019	1.203	5.280
Average Reaction Time	Low	3.818	.148	3.523	4.113
	High	3.828	.175	3.479	4.178

Average RT for Misses	Low	11.830	.547	10.736	12.924
	High	13.343	.648	12.048	14.638
Target Deviation 2	Low	17.120	1.170	14.780	19.460
	High	13.398	1.386	10.627	16.168

Pairwise Comparisons

Dependent Variable	(I) Time Awareness	(J) Time Awareness	Mean Difference (I-J)	Std. Error
Stress Difference	Low	High	-3.242*	1.258
	High	Low	3.242*	1.258
Arousal Difference	Low	High	-.432	.886
	High	Low	.432	.886
Delta Max-baseline TLX	Low	High	-2.752	1.868
	High	Low	2.752	1.868
GSR Delta Baseline	Low	High	-1.934	13.792
	High	Low	1.934	13.792
FT Delta total	Low	High	-.780	.864
	High	Low	.780	.864
Cortisol Difference	Low	High	.018	.023
	High	Low	-.018	.023
% Max HR	Low	High	-.184	1.395
	High	Low	.184	1.395
Number of Misses	Low	High	-.686	1.295
	High	Low	.686	1.295
Number of False Alarms	Low	High	.452	1.334
	High	Low	-.452	1.334
Average Reaction Time	Low	High	-.010	.229
	High	Low	.010	.229
Average RT for Misses	Low	High	-1.513	.848
	High	Low	1.513	.848
Target Deviation 2	Low	High	3.722*	1.814
	High	Low	-3.722*	1.814

Pairwise Comparisons

Dependent Variable	(I) Time Awareness	(J) Time Awareness	Sig.[a]
Stress Difference	Low	High	.012
	High	Low	.012
Arousal Difference	Low	High	.627
	High	Low	.627
Delta Max-baseline TLX	Low	High	.146
	High	Low	.146
GSR Delta Baseline	Low	High	.889
	High	Low	.889
FT Delta total	Low	High	.370
	High	Low	.370
Cortisol Difference	Low	High	.431
	High	Low	.431
% Max HR	Low	High	.895
	High	Low	.895
Number of Misses	Low	High	.598
	High	Low	.598
Number of False Alarms	Low	High	.736
	High	Low	.736
Average Reaction Time	Low	High	.964
	High	Low	.964
Average RT for Misses	Low	High	.079
	High	Low	.079
Target Deviation 2	Low	High	.044
	High	Low	.044

Pairwise Comparisons

Dependent Variable	(I) Time Awareness	(J) Time Awareness	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
Stress Difference	Low	High	-5.758	-.726
	High	Low	.726	5.758
Arousal Difference	Low	High	-2.203	1.338
	High	Low	-1.338	2.203
Delta Max-baseline TLX	Low	High	-6.488	.984
	High	Low	-.984	6.488
GSR Delta Baseline	Low	High	-29.513	25.645
	High	Low	-25.645	29.513
FT Delta total	Low	High	-2.507	.947
	High	Low	-.947	2.507
Cortisol Difference	Low	High	-.028	.065
	High	Low	-.065	.028
% Max HR	Low	High	-2.975	2.606
	High	Low	-2.606	2.975
Number of Misses	Low	High	-3.276	1.904
	High	Low	-1.904	3.276
Number of False Alarms	Low	High	-2.216	3.120
	High	Low	-3.120	2.216
Average Reaction Time	Low	High	-.468	.447
	High	Low	-.447	.468
Average RT for Misses	Low	High	-3.209	.182
	High	Low	-.182	3.209
Target Deviation 2	Low	High	.095	7.349
	High	Low	-7.349	-.095

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.269	1.531[a]	12.000	50.000	.144
Wilks' lambda	.731	1.531[a]	12.000	50.000	.144
Hotelling's trace	.367	1.531[a]	12.000	50.000	.144
Roy's largest root	.367	1.531[a]	12.000	50.000	.144

Multivariate Tests

	Noncent. Parameter	Observed Power[b]
Pillai's trace	18.374	.728
Wilks' lambda	18.374	.728
Hotelling's trace	18.374	.728
Roy's largest root	18.374	.728

Each F tests the multivariate effect of Time Awareness. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Univariate Tests

Dependent Variable		Sum of Squares	df	Mean Square	F	Sig.
Stress Difference	Contrast	185.501	1	185.501	6.639	.012
	Error	1704.279	61	27.939		
Arousal Difference	Contrast	3.301	1	3.301	.238	.627
	Error	844.374	61	13.842		
Delta Max-baseline TLX	Contrast	133.653	1	133.653	2.170	.146
	Error	3757.730	61	61.602		
GSR Delta Baseline	Contrast	66.007	1	66.007	.020	.889
	Error	204792.212	61	3357.249		
FT Delta total	Contrast	10.733	1	10.733	.815	.370
	Error	803.326	61	13.169		
Cortisol Difference	Contrast	.006	1	.006	.627	.431
	Error	.577	61	.009		
% Max HR	Contrast	.600	1	.600	.017	.895
	Error	2096.086	61	34.362		

Number of Misses	Contrast	8.306	1	8.306	.280	.598
	Error	1806.498	61	29.615		
Number of False Alarms	Contrast	3.612	1	3.612	.115	.736
	Error	1916.729	61	31.422		
Average Reaction Time	Contrast	.002	1	.002	.002	.964
	Error	56.374	61	.924		
Average RT for Misses	Contrast	40.425	1	40.425	3.187	.079
	Error	773.748	61	12.684		
Target Deviation 2	Contrast	244.496	1	244.496	4.211	.044
	Error	3541.525	61	58.058		

Univariate Tests

Dependent Variable		Noncent. Parameter	Observed Power[a]
Stress Difference	Contrast	6.639	.718
	Error		
Arousal Difference	Contrast	.238	.077
	Error		
Delta Max-baseline TLX	Contrast	2.170	.305
	Error		
GSR Delta Baseline	Contrast	.020	.052
	Error		
FT Delta total	Contrast	.815	.144
	Error		
Cortisol Difference	Contrast	.627	.122
	Error		
% Max HR	Contrast	.017	.052
	Error		
Number of Misses	Contrast	.280	.082
	Error		
Number of False Alarms	Contrast	.115	.063
	Error		
Average Reaction Time	Contrast	.002	.050
	Error		
Average RT for Misses	Contrast	3.187	.420

	Error		
Target Deviation 2	Contrast	4.211	.524
	Error		

The F tests the effect of Time Awareness. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Workload

Estimates

				95% Confidence Interval	
Dependent Variable	Workload	Mean	Std. Error	Lower Bound	Upper Bound
Stress Difference	Low	2.556	.868	.820	4.292
	High	3.069	.911	1.248	4.890
Arousal Difference	Low	1.759	.611	.537	2.981
	High	1.662	.641	.381	2.944
Delta Max-baseline TLX	Low	7.154	1.289	4.577	9.732
	High	11.660	1.352	8.956	14.365
GSR Delta Baseline	Low	30.723	9.516	11.695	49.751
	High	19.558	9.983	-.405	39.521
FT Delta total	Low	-1.846	.596	-3.037	-.654
	High	-1.785	.625	-3.036	-.535
Cortisol Difference	Low	-.055	.016	-.087	-.024
	High	-.048	.017	-.082	-.015
% Max HR	Low	43.759	.963	41.834	45.684
	High	42.341	1.010	40.322	44.361
Number of Misses	Low	6.064	.894	4.277	7.851
	High	12.925	.938	11.050	14.800
Number of False Alarms	Low	3.586	.921	1.745	5.427
	High	3.350	.966	1.419	5.281
Average Reaction Time	Low	4.819	.158	4.504	5.135
	High	2.827	.166	2.496	3.158
Average RT for Misses	Low	17.704	.585	16.534	18.873

	High	7.469	.614	6.242	8.696
Target Deviation 2	Low	11.881	1.251	9.378	14.383
	High	18.637	1.313	16.011	21.262

Pairwise Comparisons

Dependent Variable	(I) Workload	(J) Workload	Mean Difference (I-J)	Std. Error	Sig.[a]
Stress Difference	Low	High	-.513	1.258	.685
	High	Low	.513	1.258	.685
Arousal Difference	Low	High	.097	.886	.913
	High	Low	-.097	.886	.913
Delta Max-baseline TLX	Low	High	-4.506*	1.868	.019
	High	Low	4.506*	1.868	.019
GSR Delta Baseline	Low	High	11.165	13.792	.421
	High	Low	-11.165	13.792	.421
FT Delta total	Low	High	-.060	.864	.945
	High	Low	.060	.864	.945
Cortisol Difference	Low	High	-.007	.023	.750
	High	Low	.007	.023	.750
% Max HR	Low	High	1.418	1.395	.314
	High	Low	-1.418	1.395	.314
Number of Misses	Low	High	-6.861*	1.295	.000
	High	Low	6.861*	1.295	.000
Number of False Alarms	Low	High	.236	1.334	.860
	High	Low	-.236	1.334	.860
Average Reaction Time	Low	High	1.992*	.229	.000
	High	Low	-1.992*	.229	.000
Average RT for Misses	Low	High	10.234*	.848	.000
	High	Low	-10.234*	.848	.000
Target Deviation 2	Low	High	-6.756*	1.814	.000
	High	Low	6.756*	1.814	.000

Pairwise Comparisons

Dependent Variable	(I) Workload	(J) Workload	95% Confidence Interval for Difference[a]	
			Lower Bound	Upper Bound
Stress Difference	Low	High	-3.029	2.003
	High	Low	-2.003	3.029
Arousal Difference	Low	High	-1.674	1.868
	High	Low	-1.868	1.674
Delta Max-baseline TLX	Low	High	-8.242	-.770
	High	Low	.770	8.242
GSR Delta Baseline	Low	High	-16.414	38.743
	High	Low	-38.743	16.414
FT Delta total	Low	High	-1.787	1.667
	High	Low	-1.667	1.787
Cortisol Difference	Low	High	-.054	.039
	High	Low	-.039	.054
% Max HR	Low	High	-1.372	4.208
	High	Low	-4.208	1.372
Number of Misses	Low	High	-9.451	-4.271
	High	Low	4.271	9.451
Number of False Alarms	Low	High	-2.432	2.904
	High	Low	-2.904	2.432
Average Reaction Time	Low	High	1.535	2.450
	High	Low	-2.450	-1.535
Average RT for Misses	Low	High	8.539	11.930
	High	Low	-11.930	-8.539
Target Deviation 2	Low	High	-10.383	-3.129
	High	Low	3.129	10.383

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.843	22.356[a]	12.000	50.000	.000
Wilks' lambda	.157	22.356[a]	12.000	50.000	.000
Hotelling's trace	5.365	22.356[a]	12.000	50.000	.000
Roy's largest root	5.365	22.356[a]	12.000	50.000	.000

Multivariate Tests

	Noncent. Parameter	Observed Power[b]
Pillai's trace	268.268	1.000
Wilks' lambda	268.268	1.000
Hotelling's trace	268.268	1.000
Roy's largest root	268.268	1.000

Each F tests the multivariate effect of Workload. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Univariate Tests

Dependent Variable		Sum of Squares	df	Mean Square	F	Sig.
Stress Difference	Contrast	4.641	1	4.641	.166	.685
	Error	1704.279	61	27.939		
Arousal Difference	Contrast	.165	1	.165	.012	.913
	Error	844.374	61	13.842		
Delta Max-baseline TLX	Contrast	358.384	1	358.384	5.818	.019
	Error	3757.730	61	61.602		
GSR Delta Baseline	Contrast	2199.968	1	2199.968	.655	.421
	Error	204792.212	61	3357.249		
FT Delta total	Contrast	.064	1	.064	.005	.945
	Error	803.326	61	13.169		
Cortisol Difference	Contrast	.001	1	.001	.102	.750
	Error	.577	61	.009		

% Max HR	Contrast	35.475	1	35.475	1.032	.314
	Error	2096.086	61	34.362		
Number of Misses	Contrast	830.818	1	830.818	28.054	.000
	Error	1806.498	61	29.615		
Number of False Alarms	Contrast	.981	1	.981	.031	.860
	Error	1916.729	61	31.422		
Average Reaction Time	Contrast	70.065	1	70.065	75.815	.000
	Error	56.374	61	.924		
Average RT for Misses	Contrast	1848.636	1	1848.636	145.741	.000
	Error	773.748	61	12.684		
Target Deviation 2	Contrast	805.588	1	805.588	13.876	.000
	Error	3541.525	61	58.058		

Univariate Tests

Dependent Variable		Noncent. Parameter	Observed Power[a]
Stress Difference	Contrast	.166	.069
	Error		
Arousal Difference	Contrast	.012	.051
	Error		
Delta Max-baseline TLX	Contrast	5.818	.661
	Error		
GSR Delta Baseline	Contrast	.655	.125
	Error		
FT Delta total	Contrast	.005	.051
	Error		
Cortisol Difference	Contrast	.102	.061
	Error		
% Max HR	Contrast	1.032	.170
	Error		
Number of Misses	Contrast	28.054	.999
	Error		
Number of False Alarms	Contrast	.031	.053
	Error		
Average Reaction Time	Contrast	75.815	1.000

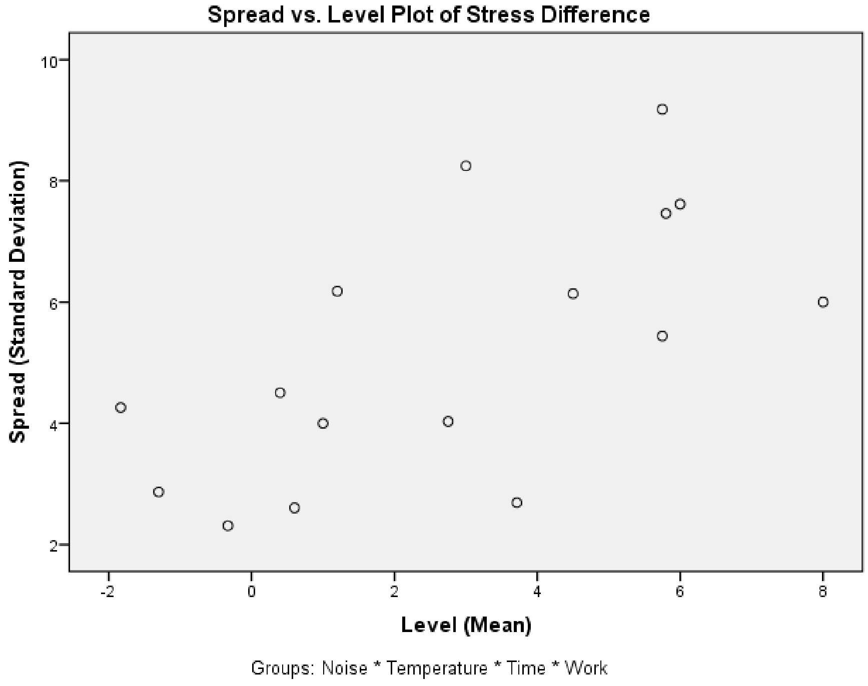
	Error		
Average RT for Misses	Contrast	145.741	1.000
	Error		
Target Deviation 2	Contrast	13.876	.956
	Error		

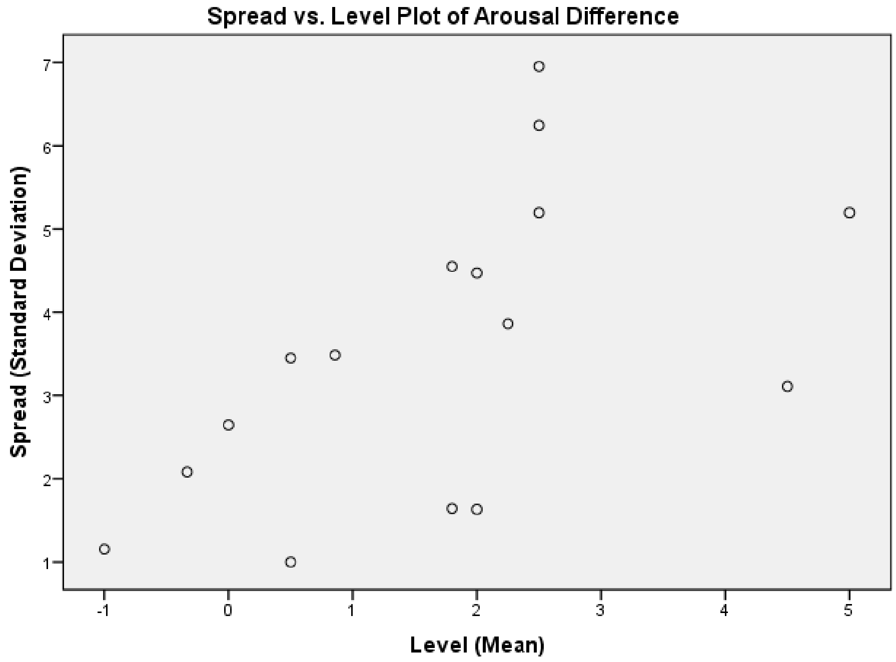
The F tests the effect of Workload. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

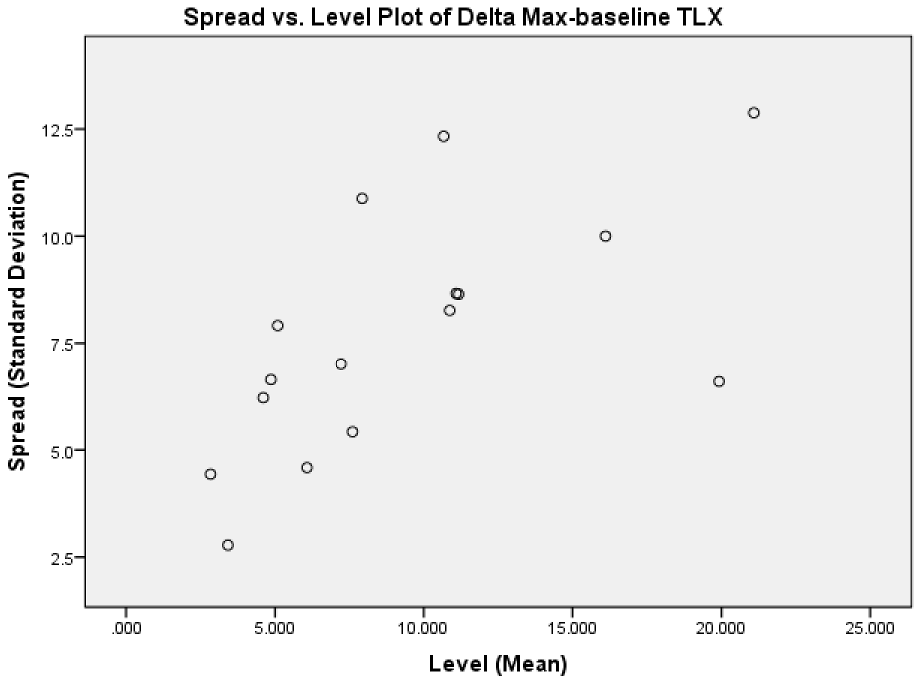
Spread-versus-Level Plots

Standard Deviations versus Means

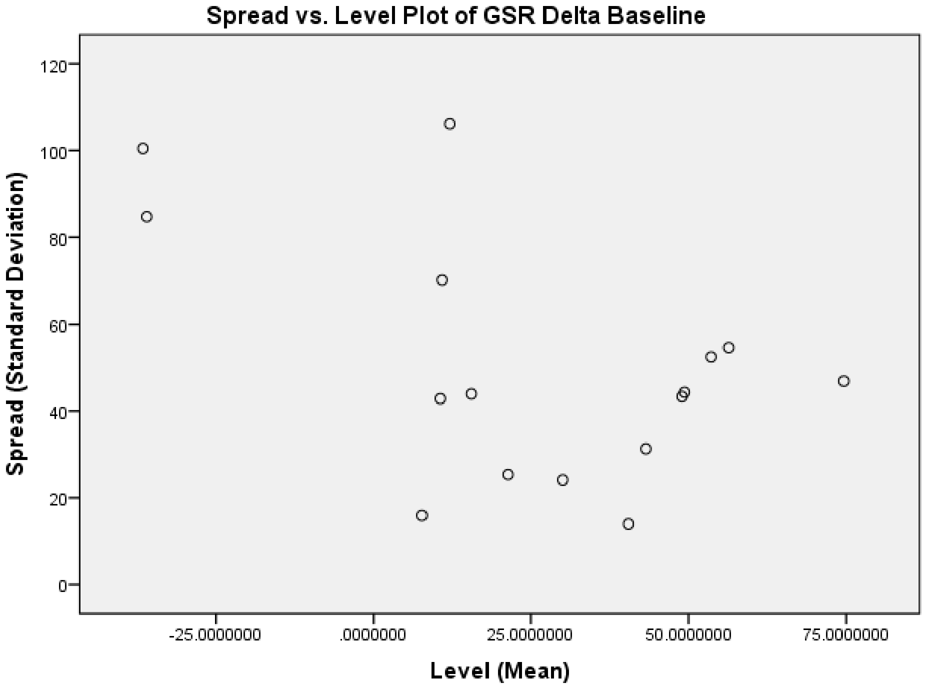




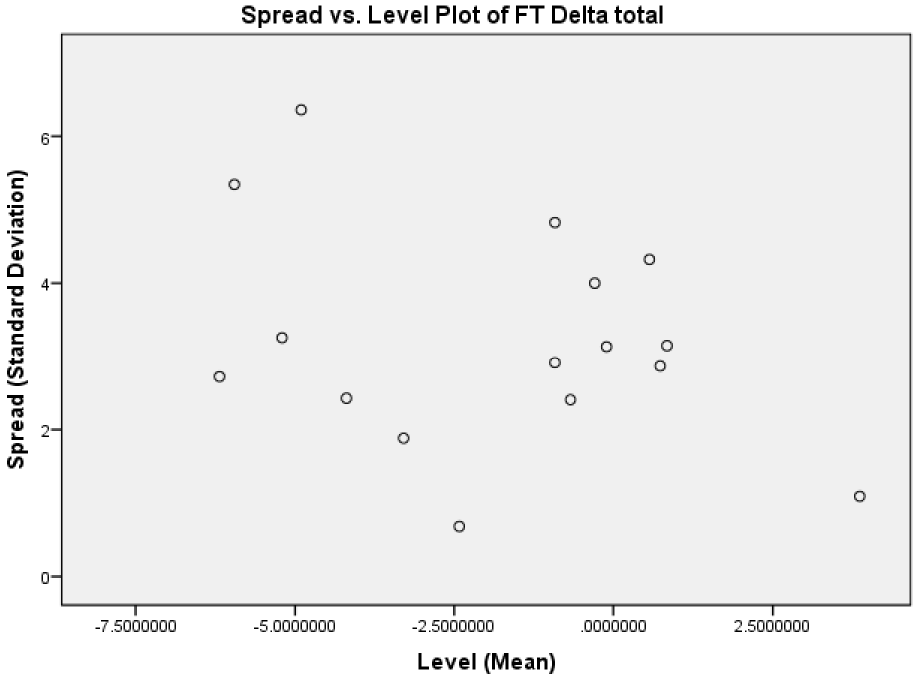
Groups: Noise * Temperature * Time * Work



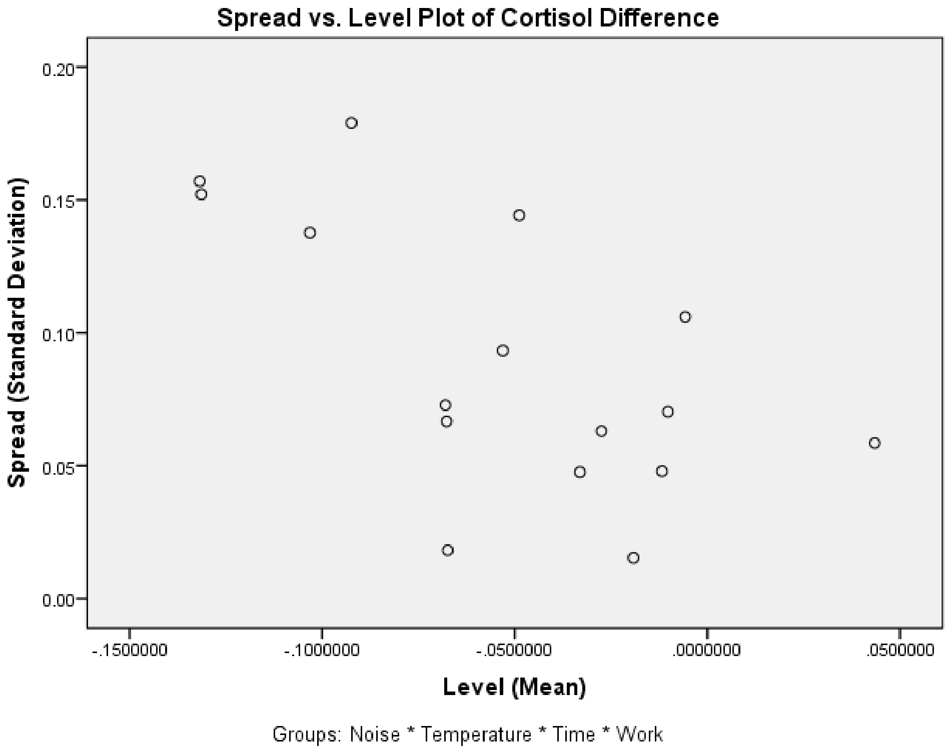
Groups: Noise * Temperature * Time * Work

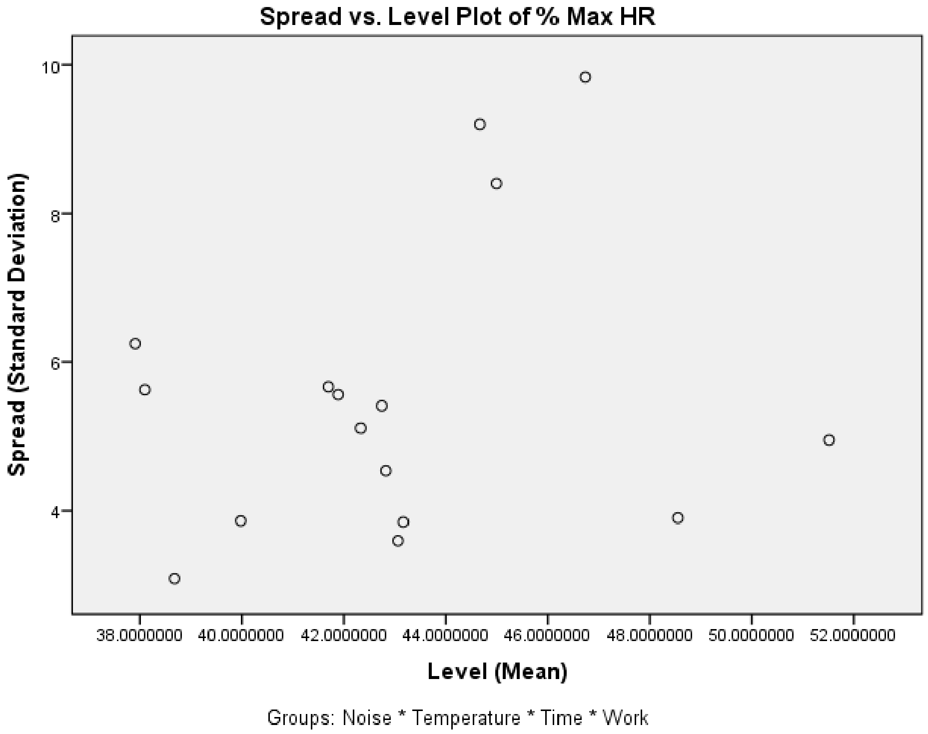

Spread vs. Level Plot of GSR Delta Baseline

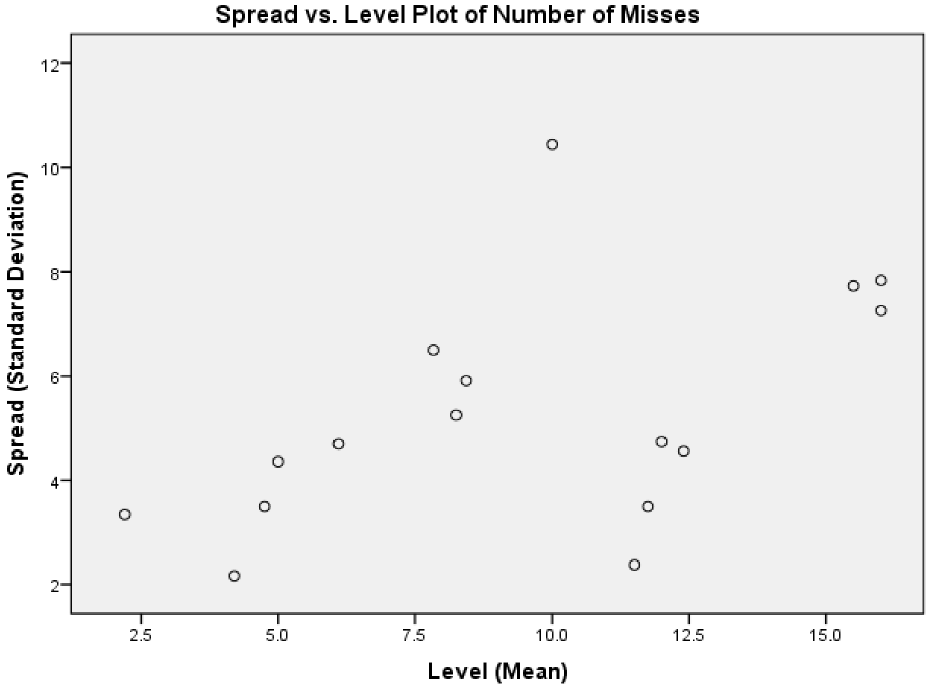
Groups: Noise * Temperature * Time * Work


Spread vs. Level Plot of FT Delta total

Groups: Noise * Temperature * Time * Work

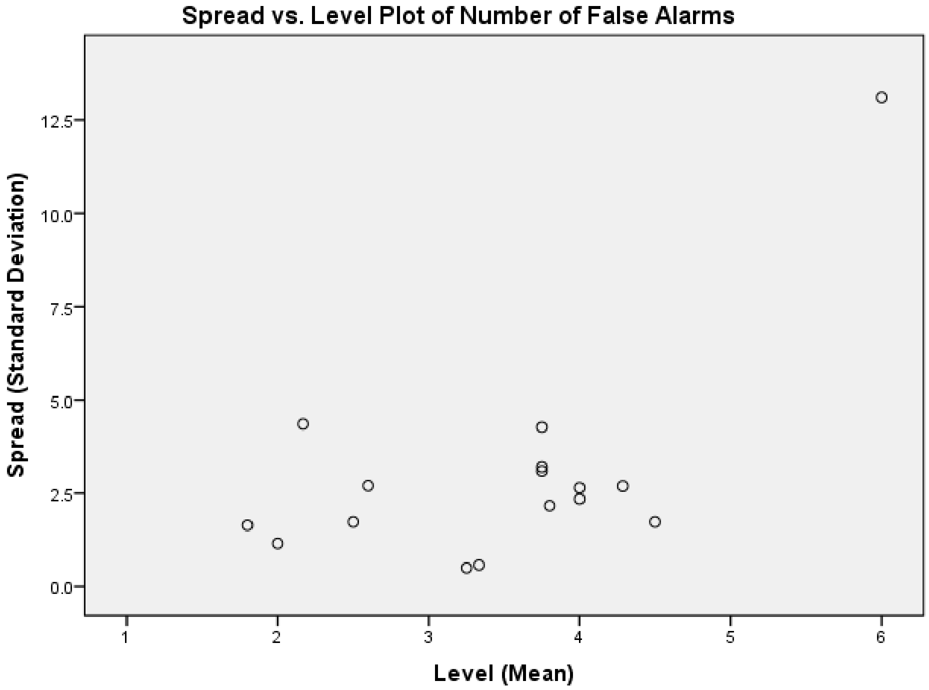

Spread vs. Level Plot of Cortisol Difference
Spread (Standard Deviation)
0.20
0.15
0.10
0.05
0.00
-.1500000
-.1000000
-.0500000
.0000000
.0500000
Level (Mean)
Groups: Noise * Temperature * Time * Work


Spread vs. Level Plot of % Max HR
Spread (Standard Deviation)
10
8
6
4
38.0000000
40.0000000
42.0000000
44.0000000
46.0000000
48.0000000
50.0000000
52.0000000
Level (Mean)
Groups: Noise * Temperature * Time * Work



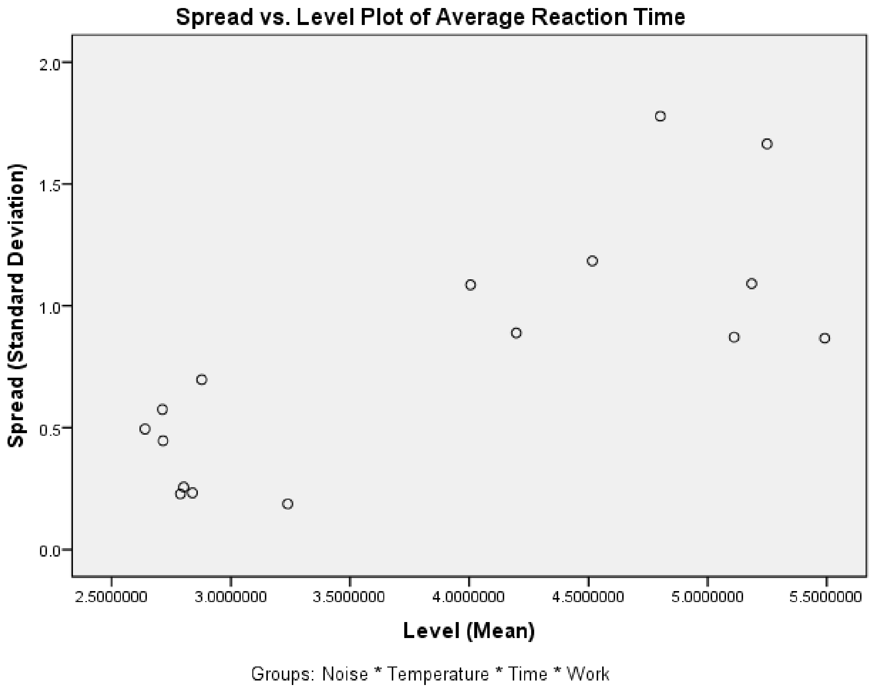
Spread vs. Level Plot of Number of Misses

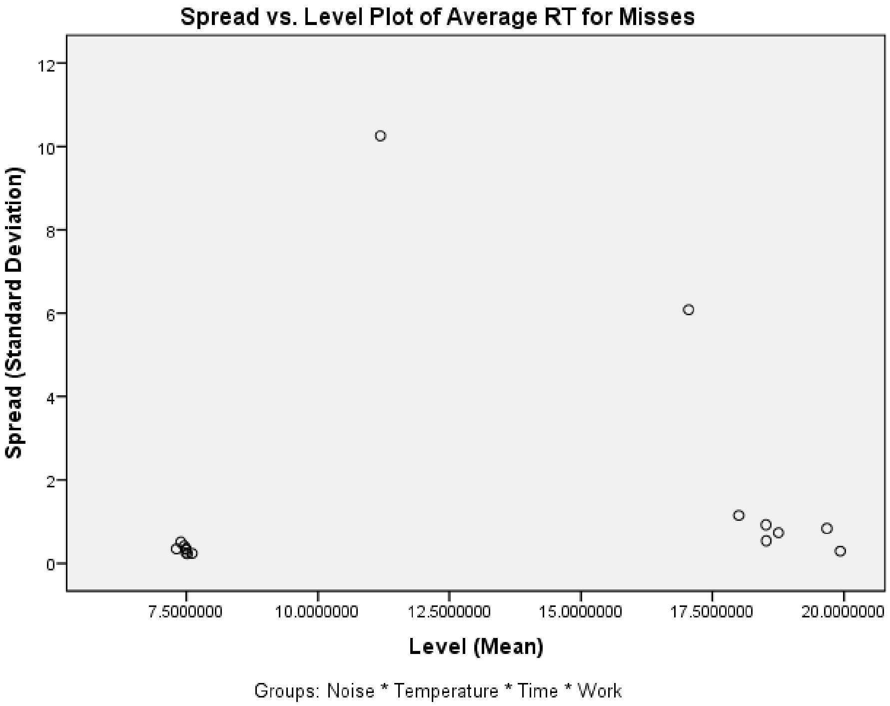
Groups: Noise * Temperature * Time * Work

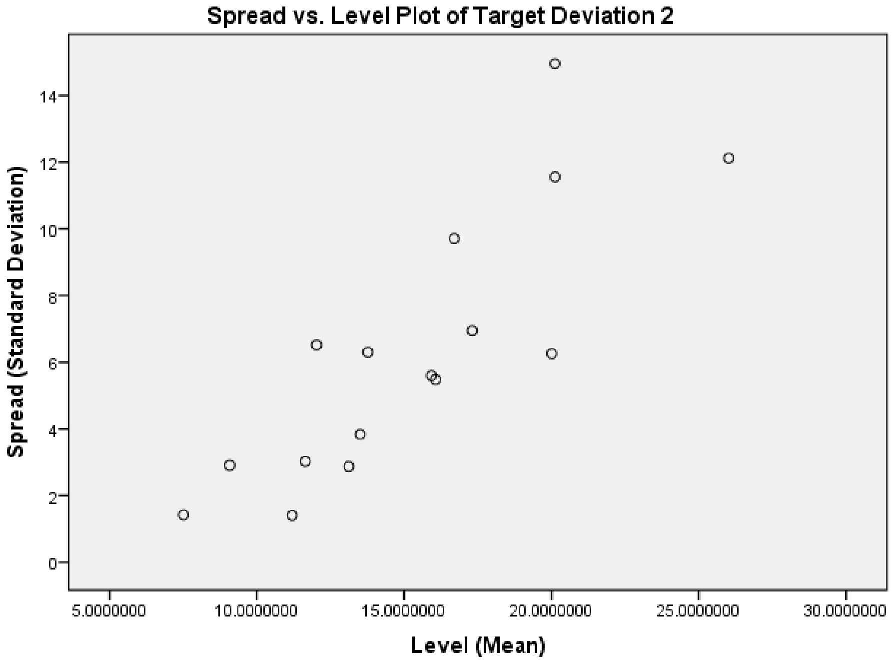


Spread vs. Level Plot of Number of False Alarms

Groups: Noise * Temperature * Time * Work

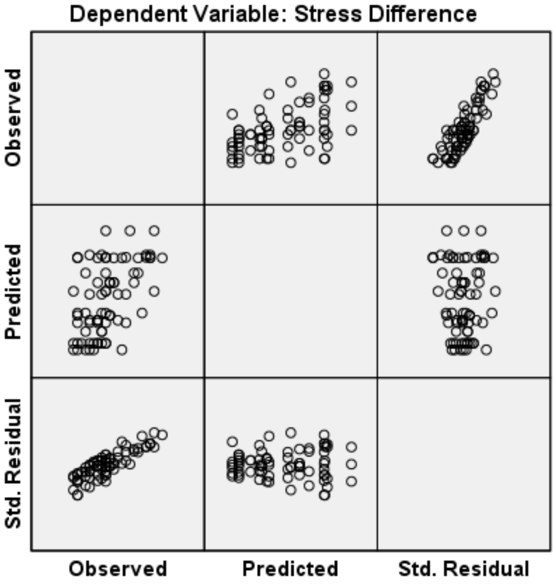

Spread vs. Level Plot of Average Reaction Time
Spread (Standard Deviation)
2.0
1.5
1.0
0.5
0.0
2.5000000
3.0000000
3.5000000
4.0000000
4.5000000
5.0000000
5.5000000
Level (Mean)
Groups: Noise * Temperature * Time * Work


Spread vs. Level Plot of Average RT for Misses
Spread (Standard Deviation)
12
10
8
6
4
2
0
7.5000000
10.0000000
12.5000000
15.0000000
17.5000000
20.0000000
Level (Mean)
Groups: Noise * Temperature * Time * Work

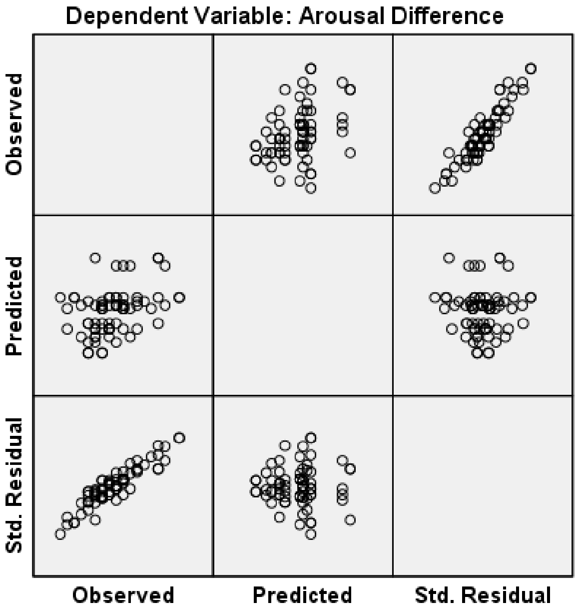


Groups: Noise * Temperature * Time * Work

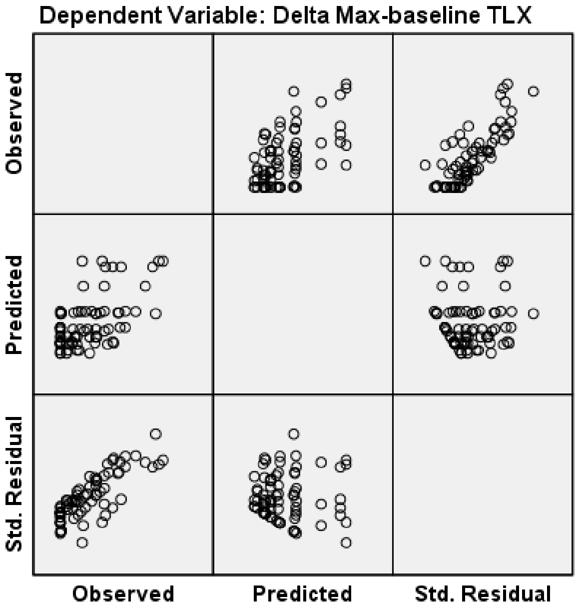
Observed * Predicted * Std. Residual Plots



Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

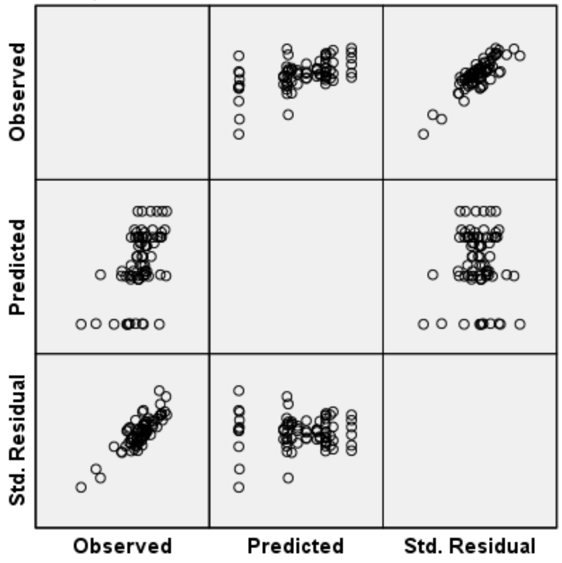

Dependent Variable: Arousal Difference

Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work


Dependent Variable: Delta Max-baseline TLX

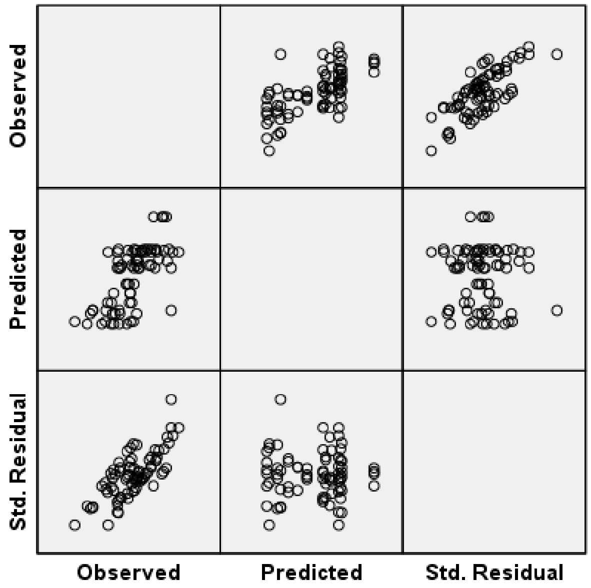
Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

Dependent Variable: GSR Delta Baseline

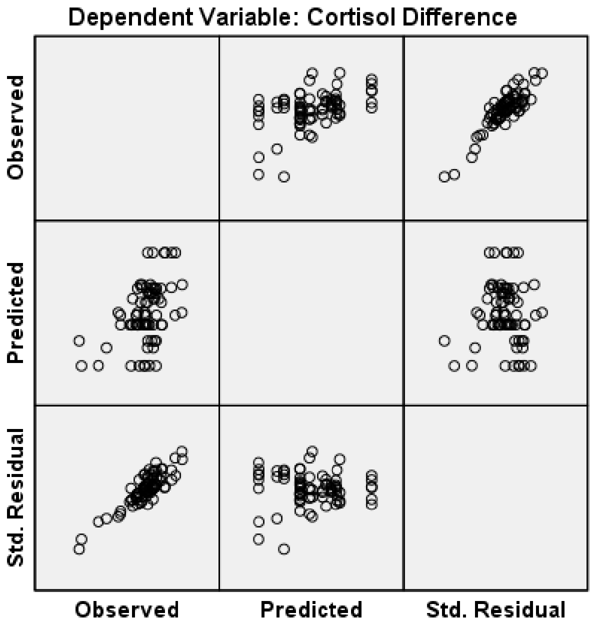


Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

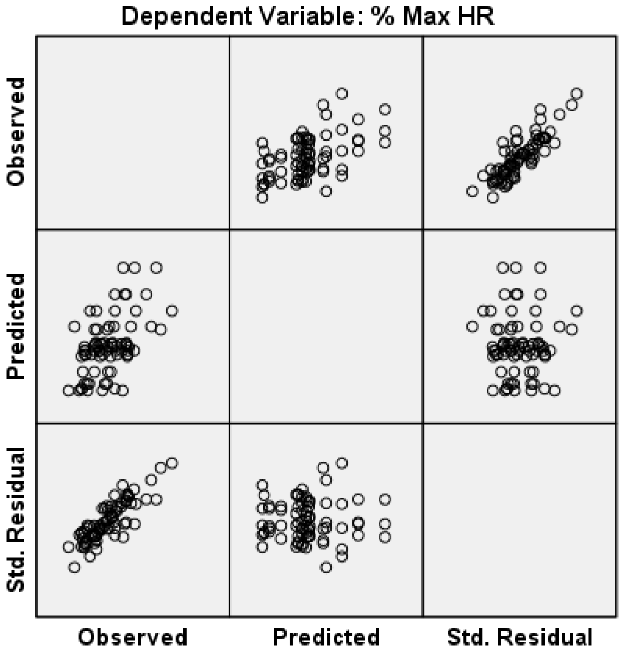
Dependent Variable: FT Delta total



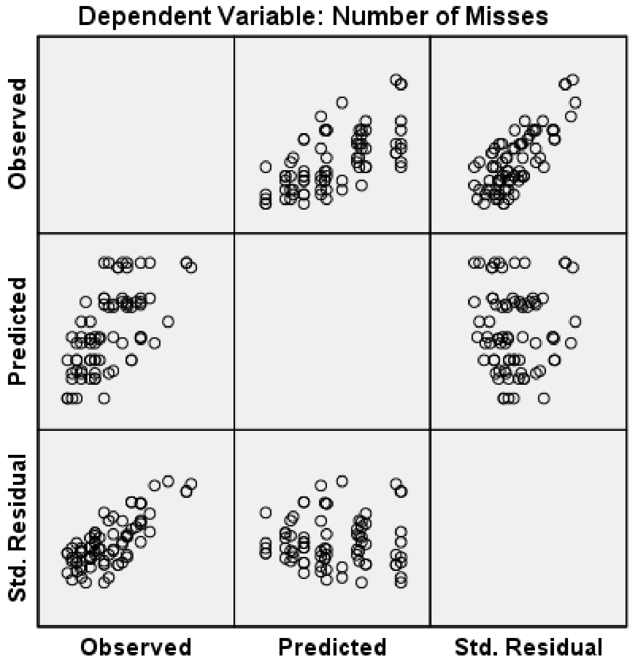
Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work



Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

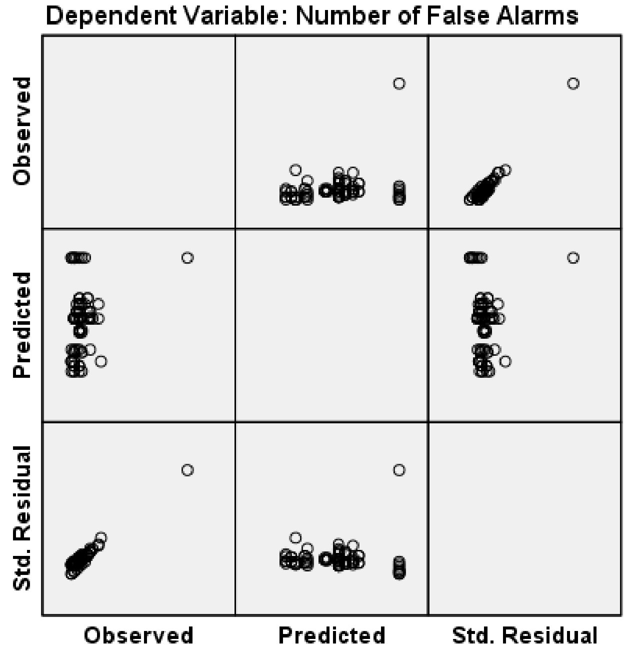


Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work



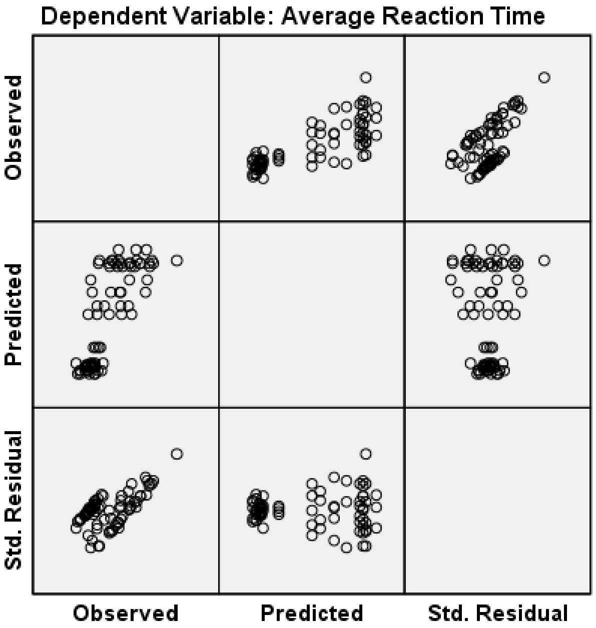
Dependent Variable: Number of Misses

Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work



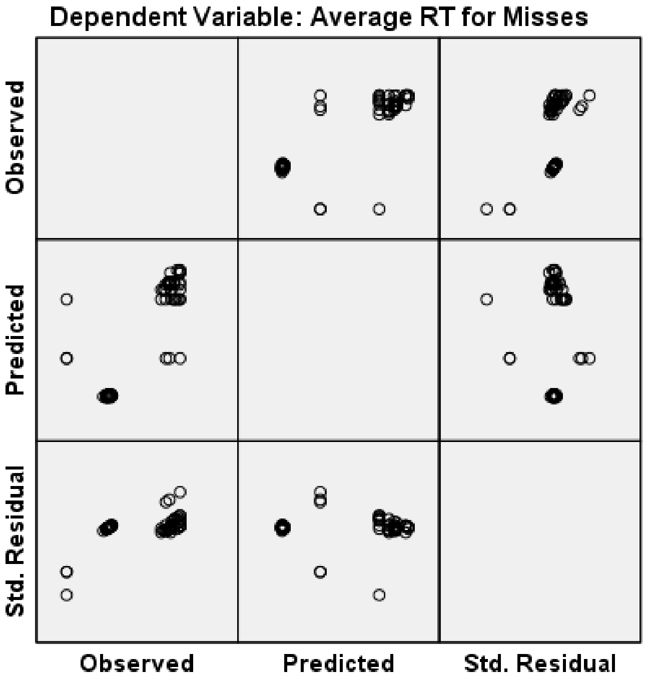
Dependent Variable: Number of False Alarms

Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work



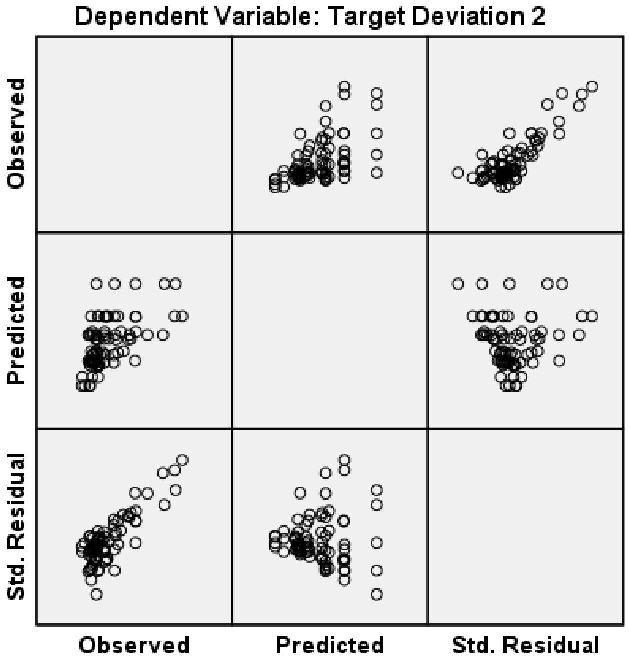
Dependent Variable: Average Reaction Time

Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work



Dependent Variable: Average RT for Misses

Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work



Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

APPENDIX E: STRESS INDEX AND PERFORMANCE INDEX ANOVA TABLES

Between-Subjects Factors

		Value Label	N
Factor Noise	1	Low	45
	2	High	39
Factor Temperature	1	Low	47
	2	High	37
Factor Time	1	Low	51
	2	High	33
Factor Work	1	Low	44
	2	High	40

Descriptive Statistics

Dependent Variable:Stress Index

Factor Noise	Factor Temperature	Factor Time	Factor Work	Mean	Std. Deviation	N
Low	Low	Low	Low	.14062150	.065068198	10
			High	.13123344	.065676686	9
			Total	.13617453	.063696213	19
		High	Low	.14034225	.037046674	4
			High	.18993575	.062787565	4
			Total	.16513900	.054593607	8
		Total	Low	.14054171	.056990164	14
			High	.14929569	.068237888	13
			Total	.14475659	.061586679	27
	High	Low	Low	.20233233	.073297155	6
			High	.24670320	.084325755	5
			Total	.22250091	.077894210	11
		High	Low	.19571633	.118180269	3
			High	.23401900	.067779290	4
			Total	.21760357	.085858670	7
		Total	Low	.20012700	.082827426	9
			High	.24106578	.072958001	9
			Total	.22059639	.078593498	18
	Total	Low	Low	.16376306	.072685647	16

			High	.17247264	.090216692	14
			Total	.16782753	.080004766	30
		High	Low	.16407400	.078853256	7
			High	.21197738	.064912686	8
			Total	.18962247	.073372639	15
		Total	Low	.16385770	.072787217	23
			High	.18683800	.082591439	22
			Total	.17509251	.077714794	45
High	Low	Low	Low	.16870157	.084249870	7
			High	.16324150	.077698216	4
			Total	.16671609	.077958430	11
		High	Low	.16820480	.097977011	5
			High	.23315175	.108818225	4
			Total	.19707011	.102039065	9
		Total	Low	.16849458	.085804716	12
			High	.19819663	.095176635	8
			Total	.18037540	.088446147	20
	High	Low	Low	.22752240	.019631590	5
			High	.24487540	.077862720	5
			Total	.23619890	.054308610	10
		High	Low	.26432100	.101304958	4
			High	.19584760	.056868617	5
			Total	.22628022	.082267375	9
		Total	Low	.24387733	.066463217	9
			High	.22036150	.069278732	10
			Total	.23150058	.067145863	19
	Total	Low	Low	.19321025	.070208253	12
			High	.20859367	.084535900	9
			Total	.19980314	.075036254	21
		High	Low	.21092311	.105898342	9
			High	.21242722	.080275168	9
			Total	.21167517	.091161999	18
		Total	Low	.20080148	.085308383	21
			High	.21051044	.079996140	18
			Total	.20528254	.081958517	39

Total	Low	Low	Low	.15218388	.072430917	17
			High	.14108208	.067980129	13
			Total	.14737310	.069556060	30
		High	Low	.15582144	.074364395	9
			High	.21154375	.085428582	8
			Total	.18204371	.082339726	17
		Total	Low	.15344304	.071626300	26
			High	.16792462	.080972122	21
			Total	.15991353	.075444212	47
	High	Low	Low	.21378236	.054894922	11
			High	.24578930	.076523124	10
			Total	.22902376	.066408868	21
		High	Low	.23491900	.105506471	7
			High	.21281267	.061192480	9
			Total	.22248419	.081104898	16
		Total	Low	.22200217	.076248567	18
			High	.23016879	.069844817	19
			Total	.22619584	.072122809	37
	Total	Low	Low	.17638329	.071857709	28
			High	.18660696	.087937442	23
			Total	.18099396	.078849355	51
		High	Low	.19042663	.095101653	16
			High	.21221553	.071172886	17
			Total	.20165121	.083033744	33
		Total	Low	.18148995	.080273978	44
			High	.19749060	.081269664	40
			Total	.18910931	.080662767	84

Levene's Test of Equality of Error Variances[a]

Dependent Variable:Stress Index

F	df1	df2	Sig.
1.386	15	68	.180

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

Tests of Between-Subjects Effects

Dependent Variable:Stress Index

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	.150[a]	15	.010	1.749	.062	.278	26.229	.874
Intercept	2.952	1	2.952	515.149	.000	.883	515.149	1.000
Noise	.010	1	.010	1.780	.187	.026	1.780	.260
Temperature	.068	1	.068	11.783	.001	.148	11.783	.923
Time	.003	1	.003	.483	.490	.007	.483	.105
Work	.005	1	.005	.896	.347	.013	.896	.154
Noise * Temperature	.002	1	.002	.311	.579	.005	.311	.085
Noise * Time	9.726E-5	1	9.726E-5	.017	.897	.000	.017	.052
Noise * Work	.004	1	.004	.682	.412	.010	.682	.129
Temperature * Time	.008	1	.008	1.321	.254	.019	1.321	.205
Temperature * Work	.001	1	.001	.242	.625	.004	.242	.077
Time * Work	.000	1	.000	.073	.788	.001	.073	.058
Noise * Temperature * Time	4.580E-6	1	4.580E-6	.001	.978	.000	.001	.050
Noise * Temperature * Work	.007	1	.007	1.219	.273	.018	1.219	.193
Noise * Time * Work	.001	1	.001	.243	.624	.004	.243	.077
Temperature * Time * Work	.015	1	.015	2.547	.115	.036	2.547	.350
Noise * Temperature * Time * Work	.002	1	.002	.433	.513	.006	.433	.099
Error	.390	68	.006					
Total	3.544	84						
Corrected Total	.540	83						

a. R Squared = .278 (Adjusted R Squared = .119)

b. Computed using alpha = .05

Pair wise Comparison: Factor Noise

Estimates

Dependent Variable:Stress Index

Factor Noise	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Low	.185	.012	.161	.209
High	.208	.012	.184	.233

Pairwise Comparisons

Dependent Variable:Stress Index

(I) Factor Noise	(J) Factor Noise	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Low	High	-.023	.017	.187	-.058	.011
High	Low	.023	.017	.187	-.011	.058

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable:Stress Index

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	.010	1	.010	1.780	.187	.026	1.780	.260
Error	.390	68	.006					

The F tests the effect of Factor Noise. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Pair wise Comparison: Temperature

Estimates

Dependent Variable:Stress Index

Factor Temperature	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Low	.167	.012	.143	.190
High	.226	.013	.201	.252

Pairwise Comparisons

Dependent Variable:Stress Index

(I) Factor Temperature	(J) Factor Temperature	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Low	High	-.059*	.017	.001	-.094	-.025
High	Low	.059*	.017	.001	.025	.094

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable:Stress Index

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	.068	1	.068	11.783	.001	.148	11.783	.923
Error	.390	68	.006					

The F tests the effect of Factor Temperature. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Pair wise Comparison: Factor Time

Estimates

Dependent Variable:Stress Index

Factor Time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Low	.191	.011	.169	.213
High	.203	.013	.176	.229

Pairwise Comparisons

Dependent Variable:Stress Index

(I) Factor Time	(J) Factor Time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Low	High	-.012	.017	.490	-.047	.023
High	Low	.012	.017	.490	-.023	.047

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable:Stress Index

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	.003	1	.003	.483	.490	.007	.483	.105
Error	.390	68	.006					

The F tests the effect of Factor Time. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

Pair wise Comparison: Factor Time

Estimates

Dependent Variable:Stress Index

Factor Work	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Low	.188	.012	.164	.213
High	.205	.012	.180	.230

Pairwise Comparisons

Dependent Variable:Stress Index

(I) Factor Work	(J) Factor Work	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Low	High	-.016	.017	.347	-.051	.018
High	Low	.016	.017	.347	-.018	.051

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

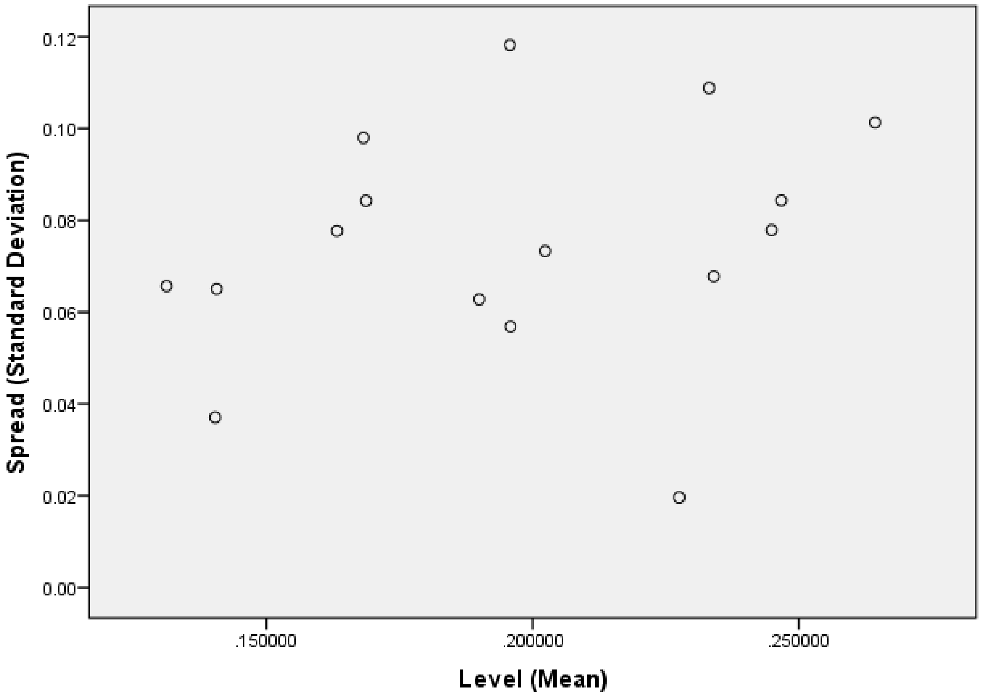
Univariate Tests

Dependent Variable:Stress Index

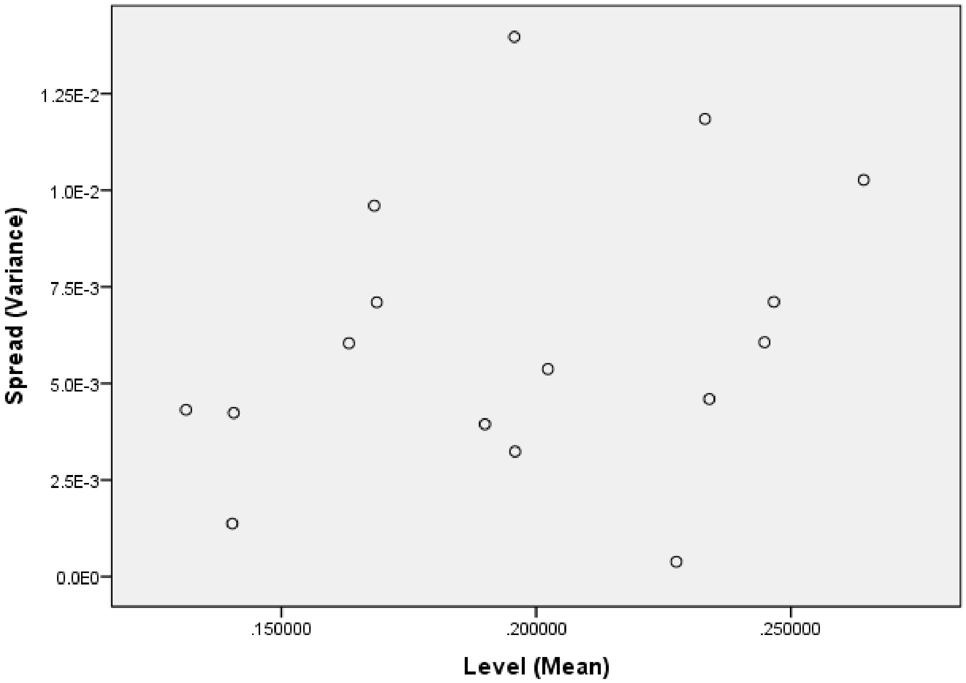
	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Contrast	.005	1	.005	.896	.347	.013	.896	.154
Error	.390	68	.006					

The F tests the effect of Factor Work. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

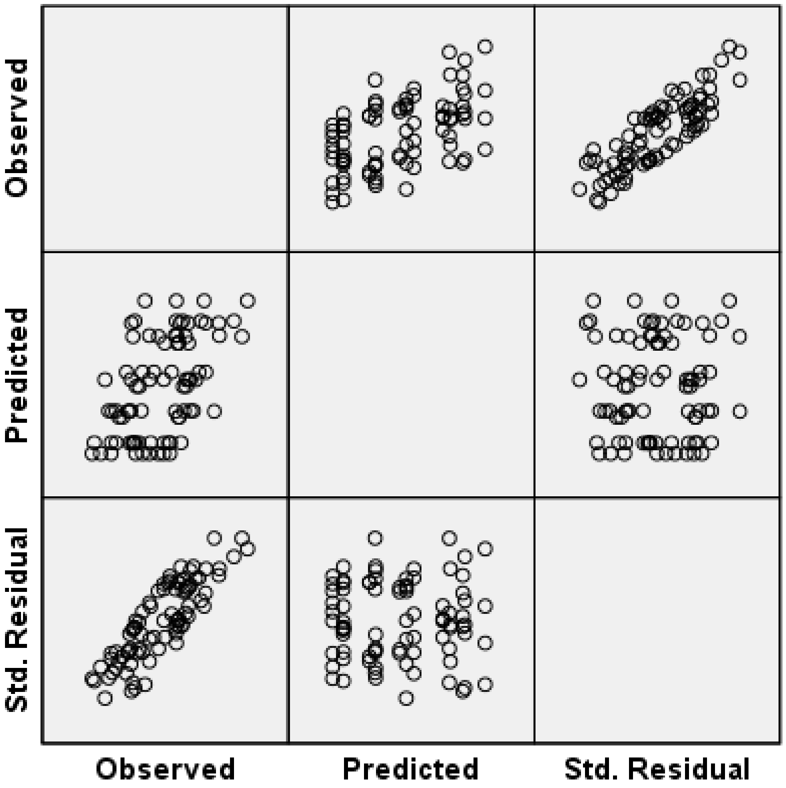

Spread vs. Level Plot of Stress Strain Index

Groups: Noise * Temperature * Time * Work


Spread vs. Level Plot of Stress Strain Index

Groups: Noise * Temperature * Time * Work

Dependent Variable: Stress Strain Index



Model: Intercept + Noise + Temperature + Time + Work + Noise * Temperature + Noise * Time + Noise * Work + Temperature * Time + Temperature * Work + Time * Work + Noise * Temperature * Time + Noise * Temperature * Work + Noise * Time * Work + Temperature * Time * Work + Noise * Temperature * Time * Work

LIST OF REFERENCES

APA Help Center From the American Psychological Association. Retrieved on April 16, 2007 from http://www.apa.org/helpcenter/stress-kinds.aspx

Babski, Kari & Crumpton, Lesia L. (1999) An Evaluation of Total Body Fatigue. Proceedings of the Eighth Annual Institute of Industrial Engineering Research Conference, p. G2.

Baron, R. A. & Kenny, D. A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*: 1173-1182.

Bandura, A., Reese, L., & Adams, N.E. (1982). Microanalysis of action and fear arousal as a function of differential levels of perceived self-efficacy. *Journal of Personality and Social Psychology, 43*, 5-21

Cannon-Bowers, J. A., Salas, E., & Grossman, J. D. (1991). Improving tactical decision making under stress: Research directions and applied implications. Paper presented at the International Applied Military Psychology Symposium, Stockholm, Sweden.

Combs, A. W., & Taylor, C. (1952). The effect of the perception of mild degrees of threats on performance. *Journal of Abnormal and Social Psychology*, 47, 420-424.

Cohen, E. L. (1952). The influence of varying degrees of psychological stress on problem solving rigidity. *Journal of Abnormal and Social Psychology, 47,* 512-519.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24,* 386-396.

Cohen, S. (1978). Environmental load and the allocation of attention. In A. Baum, J. E. Singer, & S. Valins (eds.), Advances in environmental psychology (Vol. 1, pp- 1-29). Hillsdale, NJ: Lawerence Erlbaum Associates.

Cohen, S. (1980). Aftereffects of stress on human performance and social behavior: A review of research and theory. *Psychological Bulletin*, 88, 82-108.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior, 24,* 386-396.

Cox, T. (1985). Repetitive work: occupational stress and health, in C. L. Cooper & M. J. Smith (Eds), Job Stress and Blue Collar Work, Chichester, UK: Wiley, pp. 85-111

Cox, T., Thirlaway, M., & Cox, S. (1984). Occupational well-being: sex differences at work, *Ergonomics*, 27:449-510

Crocker, J., M. (1997) Noise, in Handbook of Human factors and Ergonomics 2nd edition. (Ed. Gavriel Salvendy). John Wiley & Sons, Inc.

Dewe, P.J. & Guest, D. E. (1990). Methods of coping with stress at work: a conceptual analysis and empirical study of measurement issues. *Journal of Organizational Behavior,* 11:135-150.

Dorner, D. (1990). The logic of failure. In D. E. Broadbent, J. Reason, and A. Baddeley (eds.). *Human Factors in hazardous situations.* (pp-463-473). Oxford. England: Clarendon Press

Driskell, J. E., & Salas, E., (1991). Overcoming the effects of stress on military performance: Human factors, training, and selection strategies. In R. Gal & A. D. Mangelsdorff (Eds.), Handbook of military psychology (pp. 183-193). Chichester, New York: John Wiley & Sons.

Driskell, J.,E., Carson, R., & Moskal, P.,J. (1988). Stress and human performance. Naval Training Systems Center, Orlando Florida.

Driskell, J. E., Salas, E., & Johnston, J. (1995). Does stress lead to a loss of team perspective? Paper presented at the 10th Annual Conference of the Society for Industrial and Organizational Psychology, Orlando, FL

Driskell. J., E., & Salas, E. Eds. (1996). Stress and Human Performance. Lawrence Erlbaum Associates, Inc. NJ

Eastbrooke, J.A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Physiological Review*, 66, 183-201.

Edland, A. (1989). On cognitive processes under time stress: A selective review of the literature on time stress and related stress. Reports from the Department of Psychology. University of Stockholm.

Edwards, Julian. A; Guppy, Andrew & Cockerton, Tracey (2007). A longitudinal study exploring the relationships between occupational stressors, non-work stressors, and work performance. *Work & Stress,* 21(2), pp. 99–116.

Evans, G. W. & Carrere, S. (1991). Traffic congestion, perceived control, and psycho-physiological stress among urban bus drivers. *Journal of Applied Psychology 76,* 5, 658-663.

Farmer, R. & Sundberg N. (1986). Boredom Proneness-The development and correlates of a new scale. *Journal of Personality Assessment*. 50(1), 4-17

Fischer, J., Corcoran, K., & Corcoran, K. (2007). *Measures for clinical practice and research: A sourcebook*. Oxford: Oxford University Press

Fletcher, T., D., Major, D., A., & Davis, D., D. (2008). The interactive relationship of competitive climate and trait competitiveness with workplace attitudes, stress, and performance. *Journal of Organizational Behavior*,.29, 899–922. DOI: 10.1002/job.503

Folkman, S. & Lazarus, R. S. (1980). An analysis of coping in a middle-aged community sample. *Journal of Health and Social Behavior*, 21:219-239

Folkman, S. (1984). Personal control and stress and coping processes: A theoretical analysis. *Journal of Personality and Social Psychology*, 46, 839-852.

Fried, Y. (1988). Physiological assessment of stress at work, in C. L. cooper and R. Payne (eds.), *Causes and Consequences of Coping with Stress at Work*. Chichester, UK: Wiley, pp. 343-373.

Greiner, B. A., Ragland, N.K., Syme, L. S., Fisher, J. M. (1997). Objective measurement of occupational stress factors-An example with san francisco urban transit operators. *Journal of Occupational Health Psychology 2*, 4, 325-342.

Gulati, M., Shaw, J. L., Thisted, A. R., Black, R. H., Merz, B. N., Arnsdorf, F. M. (2010). Heart rate response to exercise stress testing in asymptomatic women. *Circulation*. 122, 130-137. Doi:10.1161/CIR.0b013e3181e8e9b9

Hancock, P.A., & Warm, J.,S. (1989). A dynamic model of stress and sustained attention. *Human Factors*. 3,(15). 519-537

Hancock, P.A., & Vasmatzids, I. (1998). Human occupational and performance limits under stress: The thermal environment as a prototypical example. Ergonomics, 41 (8), 1169-1191.

Hancock, P. A., & Desmond, P. A. (Eds.). (2001). *Stress, workload, and fatigue*. Mahwah, NJ: Erlbaum.

Hancock, P.A., Ganey, H.C.N., & Szalma, J.L. (2003). Stress and performance: Contrasting different descriptive relationships. Proceedings of the 15th Triennial Congresses of the International Ergonomics Association, Seoul, Korea.

Hancock, P.A., & Szalma, J.L. (2003). Operator stress and display design. *Ergonomics in Design*, 11, (2). 13-18.

Hart, S. G., & Hauser, J. R. (1987). In-flight application of three pilot workload measurement techniques. *Aviation, Space and Environmental Medicine*, 58, 402-410.

Hart, S.G., Staveland, L.E., 1988. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In: Hancock, P.A., Meshkati, N. (Eds.), Human Mental Workload. Elsevier Science Publishers, North-Holland, Amsterdam, pp. 139–183.

Hockey, G. R. J. (1986). Changes in operator efficiency as a function of environmental stress, fatigue and circadian rhythms. In K. R. Boff, L. Kaufamn, & J. P. Thomas (Eds.) Handbook of perception and human performance (Vol. 2) New York: Wiley.

Houston, J. M., McIntire, S. A., Kinnie, J., & Terry, C. (2002). A factorial analysis of scales measuring competitiveness. Educational and Psychological Measurement, 62, 284–298.

Ivancevich, J.M., & Matterson, M. T. (1980). Stress and work. Glenview, IL: Scott, Foreseman.

Israel, B. A., Baker, E. A., Goldenhar, L. M., Heaney, C. A., & Schurman, S. J. (1996). Occupational stress, safety, and health: conceptual framework and principle for effective preventive interventions. *Journal of Occupational Health Psychology*, 3: 261-286.

Jamal, M. (1984). Job stress and job performance controversy: an empirical assessment. *Organizational Behavior and Human Performance*, 33:1-21

Jex, M. E. (1998). Stress and job performance: Theory, research, and implications for managerial practice. Advanced Topics in Organizational Behavior Series. Sage Publications Inc. CA.

Johnston, J. A., Smith-Jentsch, K. A., & Cannon-Bowers, J. A. (1997). Performance measurement tools for enhancing team decision making. In M. T. Brannick, E. Salas, & C. Prince (eds.), Team performance assessment and measurement: Theory, methods, and applications (pp. 311-327). Mahwah, NJ: LEA.

Jones, J. W. (1983). The human factor inventory. St Paul, MN: The St Paul Insurance Companies.

Karson C. N. (1988) Physiology of normal and abnormal blinking. *Advances in Neurology* 49, 25–37.

Koslowsky, M. (1998). Modeling the stress-strain relationship in work settings. London ; New York, Routledge.

Larsson, G. (1987). Routinization of mental training in organizations: Effects on performance and well-being. *Journal of Applied Psychology*, 72(1), 88-96.

Lazarus, R.S., & Folkman, S. (1984). Stress, appraisal and coping. New York: Springer.

Lazarus, R., DeLongis, A., Folkman, S., & Gruen, R. (1985). Stress and adaptational outcomes. *American Psychologist, 40 (7)*, 770-779.

Lichacz, 2005, J.M.F. (2005). Examining the effects of combined stressors on dynamic task performance. *International Journal Aviation Psychology, 15*(1), 45-66.

Locke, E. A., Frederick, E, Lee, C., & Bobko, P. (1984). Effects of self efficacy, goals, and task strategies on task performance. *Journal of Applied Psychology, 69*, 241-251.

Mackay. C., Cox, T., Burrows, G., & Lazzerini, T. (1978). An inventory for the measurement of self-reported stress and arousal, *British Journal of Social and Clinical Psychology*, 17, 283-284.

MacDonald, W. (2003). *Impact of Job Demands and Workload on Stress and Fatigue.* Australian Psychologist, Vol. 38, No. 2, pgs 102-117.

Matthews, G. & Campbell, S. E. (1998). Task-induced stress and individual differences in coping. Proceedings of the human factors and ergonomics society 42nd annual meeting. Pp:821-825

Matthews, G. & Campbell, S. E. (2009). Sustained performance under overload: personality and individual differences in stress and coping. *Theoretical Issues in Ergonomics Science*, Vol 10(5), Sep 2009, 417-442. Doi: 10.1080/14639220903106395

Matthews, G., Campbell, S. E, Falconer, S., Joyner, L. A,, Huggins, J., Gilliland, K., Grier, R., & Warm, J. S. (2002). Fundamental dimensions of subjective state in performance settings: task engagement, distress, and worry. *Emotion*, *2*(4), 315-40.

Matuszek, P., Nelson, D. L., & Quick, J. C. (1995). Gender differences is distress: are we asking all the right questions?. *Journal of Social Behavior and Personality*, 10:99-120.

McCauley-Bell & Crumpton, (1997). A Fuzzy Linguistic Model for the Prediction of Carpal Tunnel Syndrome Risks in an Occupational Environment. *Ergonomics* Vol. 40, 790-799.

McCauley-Bell, P. & Badiru, A. (1996) Fuzzy Modeling and Analytic Hierarch Processing—Means to Quantify Risk Levels Associated with Occupational Injuries—Part I: The Development of a Fuzzy Linguistic Risk Levels. *IEEE Transactions on Fuzzy Systems*, Vol 4, No 2

McCauley-Bell, P. & Badiru, A. (1996) Fuzzy Modeling and Analytic Hierarch Processing—Means to Quantify Risk Levels Associated with Occupational Injuries—Part II: The

Development of a Fuzzy Rule-Based Model for the Prediction of Injury. IEEE *Transactions on Fuzzy Systems*, Vol 4, No 2.

McGrath, J.E. (1976). Stress and behavior in organizations. In M.D. Dunnette (Ed.) *Handbook of industrial and organizational psychology* (pp.1351-1395). Chicago: Rand-McNally

McGrath, J.E. (Ed.). (1970). Social and psychological factors in stress. New York: Holt Rinehart & Winston.

McNair. D. M., Lorr, M. & Droppleman. L. F. (1992). *Profile of mood states* (Revised ed.). San Diego, CA: Educational and Industrial Testing Service.

Meichenbaum, D. (1996). Stress inoculation training for coping with stressors. *The Clinical Psychologist, 49,* 4-7

Melamed, S., Ben-Avi, I., Luz, J., & Green, M., S. (1995). Objective and subjective work monotony: effects on job satisfaction, psychological distress, and absenteeism in blue collar workers. *Journal of Applied Psychology*, 80:29-42

Michela, J. L., Lukaszewski, M. P., & Allegrante, J. P. (1995). Organizational climate and work stress: a general framework applied to inner-city school-teachers, in S.S. Sauter and L. R. Murphy (Eds), *Organizational Risk Factors for Job Stress*, Washington, DC: American Psychological Association, pp. 61-80

Mital, A. & Karwowski, W., 1986, Towards the Development of Human Work-Performance Standards in Human-machine Systems: A Fuzzy Modeling Approach, Fuzzy Sets and Systems, 19 (2), 133-147.

Moos, R. H. (1981). Work environment scale manual, palo Alto, Ca.: Consulting Psychology Press, Inc.

Murphy, K. (1989). Is the relationship between cognitive ability and job performance stable over time? *Human Performance, 2*, 183-200.

Reisman, S. (1997). Measurement of physiological stress. Bioengineering Conference. Proceedings of the IEEE 1997 23rd Northeast. Durham, NH Doi: 10.1109/NEBC.1997.594939

Rubio,S., Díaz, E., Martín, J, & Puente, J. (2004). Evaluation of Subjective Mental Workload: A Comparison of SWAT, NASA-TLX, and Workload Profile Methods. *Applied psychology: an international review*, 2004, *53* (1), 61–86

Siegel, A. I., Pfeiffer, M. G., Kopstein, F. F., Wolf, J. J.& Ozkaptan, H. (1980). *Human performance in continuous operations: Volume III*, Technical documentation. Wayne, PA: Applied Psychological Service.

Singer, J. A., Neale, M. S., & Schwartz, G. E. (1987). The nuts and bolts of assessing occupational stress: a collaborative effort with labor, in L. R. Murphy and T. F. Schoenborn (eds.), Stress Management in Work settings, Washington, DC: US Public Health Service, pp 3-29.

Selye, H. (1976). *The Stress of Life*. McGraw-Hill: New York.

Shipley, P., & Baranski, J.,V. (2002). Police officer performance under stress: A pilot study on the effects of visual-motor behavior rehearsal. *International Journal of Stress Management.* 9 (2), April. 71-80

Smith, R. E. (1980). A cognitive-affective approach to stress management training for athletes. In C. H. Nadeau, W. R. Halliwell, K. M. Newell, and G. C. Roberts (Eds.), *Psychology of motor behavior and sport.* Champaign, IL: Human Kinetics Press

Soga, C. & Wada, C., (2004). Quantitative assessment of physiological stress effects correlated with mood states. Proceeding of the Society of Instruments and Control Engineers (SICE) Annual Conference in Sapporo, August 4-6. 2261-2265.

Soh, Tzer-Nan, Crumpton, Lesia L., & McCauley-Bell, Pamela. (1996). The Use of Fuzzy Logic to Develop a Mathematical Model to Quantify Fatigue. Advances in Occupational Ergonomics and Safety I. pp. 123-128.

Spaccarelli, S. (1994). Stress appraisal, and coping in child sexual abuse: a theoretical and empirical review. Psychological bulletin, 116: 340-362.

Spence, J. T., & Helmreich, R. L. (1983). Achievement-related motives and behaviors. In J. T. Spence (Ed.), Achievement and achievement motives: Psychological and sociological approaches (pp. 7–74). San Francisco: W.H. Freeman and Company

Spielberger, C. D. & Reheirser, E. C. (1994). The job stress survey: measuring gender differences in occupational stress. *Journal of Social Behavior and Personality*, 9: 199-218.

Stokes, A. F., Belger, A., & Zhang, K. (1990). Investigation of factors comprising a model of pilot decision making: Part II. Anxiety and cognitive strategies in expert and novice aviators. University of Illinois Institute of Aviation Tech. Rep. (ARL-90-8/SCEEE-90-2). Savoy, IL; Aviation Research Laboratory.

Stokes A, Kite K. (1994). Flight Stress: stress, fatigue, and performance in aviation. Brookfield, VT: Ashgate Publishing Co.

Spence, J. T., & Helmreich, R. L. (1983). Achievement-related motives and behaviors. In J. T. Spence (Ed.), Achievement and achievement motives: Psychological and sociological approaches (pp. 7–74). San Francisco: W.H. Freeman and Company.

Stranks, J. (2005). *Stress at Work*. Elsevier: Massachusetts.

Svenson, O., & Maule, A. J. (1993). Time pressure and stress in human judgment and decision making. NewYork: Plenum.

Takakuwa, E. (1971). Maintaining concentration (TAF) as a measure of mental stress. *Ergonomics*, 14 (1): 145-158.

Tanaka, H., Monahan, D. K., & Seals, R. D. (2001). Age-predicted maximal heart rate revisited. *Journal of the American college of cardiology*. 37, 153-156.

Warburton, D. (1979). Physiological aspects of information processing and stress. In V. Hamilton & D. Warburton (Eds.) *Human stress and cognition* (pp. 33-65). New York: Wiley.

Wellens, B.T. Smith, A.P. (2006). Exposure to a combination of workplace stressors and cumulative effects on mood, physiology and performance efficiency. *Work and Stress. 20*, 1-14. ISSN 0267-8373.

Wray, R. E. & Laird, J. E. (2003). Variability in human behavior modeling for military simulations). Behavior Representation in Modeling & Simulation Conference. May, 2003.

Worchel, S., & Yohai, S.M.L. (1979). The role of attribution in the experience of crowding. *Journal of Experimental Social Psychology, 15*, 91-104.

Wright, P. (1974). The harassed decision maker: Time pressure, distraction and use of evidence. *Journal of Applied Psychology*, 59, 555-561.

Yerkes & Dodson, (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative neurology and Psychology*. 18, 459-482.

Zadeh, L. A. (1965). Fuzzy Sets. *Information and control*. 8, 338-353.