EFFECTS OF PHYSICAL AND MENTAL TASKS ON HEART RATE VARIABILITY

A Thesis
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science in Industrial Engineering
In
The Department of Construction Management & Industrial Engineering

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B.Tech (Electronics and Communication Engineering)
Kakatiya University, India, 2007.
December, 2009

ACKNOWLEDGEMENTS

I am indebted to my advisor Dr. Laura Ikuma for her exemplary patience, guidance and support. She taught me how to approach problems in research and inspired me to be patient when progress was slow and to overcome all obstacles on my way towards completing my thesis. I would also like to extend my gratitude to my committee members Dr. Fereydoun Aghazadeh and Dr. Bhaba Sarker for their valuable suggestions and kind support. I thank the Dept. of Construction Management and Industrial Engineering for supporting me financially from the first day in the department, helping me concentrate on my research without any deviations.

I also want to convey my sincere thanks to Lauren Thomas and Brandon Pitts for their time and effort spent towards the successful completion of this study.

I wish to thank all the participants for their time and patient participation in the experimental sessions. I want to thank all my friends who assisted me in my endeavors, especially to Pradeep Rayaprolu for his invaluable assistance rendered during the progress of this thesis.

I wish to endow my earnest gratitude to my father Paritala Subba Rao and my uncle Paritala Narasimha Rao, who believed in me and have been thorough all the rough times with me. I also want to express special thanks to my entire family for their affection, support, and compassion.

Finally, I dedicate this thesis to my mother “Shailaja”, without whose blessings this would not have been a reality. I am the person I am today solely due to her upbringing.

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ABSTRACT

Demands at work are associated with an increased risk of cardio vascular diseases, but little is known about its underlying connection. The purpose of this study was to evaluate the effects of physical and mental tasks that induced stress, on Heart Rate Variability (HRV). Another aim was to observe the trends in subjective workload ratings in conjunction with the physiological response of the heart and also to assess the comfort level of the participants while wearing the heart rate monitor and performing tasks. Heart rate was recorded while at rest and while performing the tasks. Subjective workload ratings were obtained from NASA-TLX and the comfort scores from a comfort questionnaire for each task. The power spectral components HF, LF, LF/HF and the time domain RMSSD, were used as the components of HRV in the analysis. The results indicated that all the components of HRV examined were sensitive to physical and mental demands. The HF and RMSSD components decreased with increase in demands from the baseline values. The LF and the LF/HF ratio increased with increase in demands. Overall results indicated reduction in HRV when demanding physical and mental tasks were performed. Subjective workload ratings changed in accordance with the physiological response. Subjective workload rating was high for both the tasks. Overall comfort score indicated that the participants were comfortable while wearing the heart rate monitor and performing the tasks. The evidence from this study suggested that these simulated work factors (physical and mental demands) influence risk factors that may increase risk for CVDs in work places. It is recommended that future research be conducted in the field to quantify HRV and the workplace/tasks be redesigned to reduce excessive physical and mental demands.

1. INTRODUCTION

Cardiovascular diseases are the highest cause of death in the industrialized world (Chandola, Britton, Brunner et al., 2008), and many of these deaths may be work related. Stress at work is associated with an increased risk of cardiovascular disease (CVD) but little is known about the mechanisms that underlie this connection (Chandola, Britton, Brunner et al., 2008). There is substantial evidence that environmental tobacco smoke, extreme heat, and extreme cold are risk factors for cardiovascular disease (Kamath and Fallen, 1993), and while the linkages are not yet understood, numerous studies also show a relationship between exposure to stress at work and heart disease (NIOSH, 2007). In addition, shift work, which disrupts circadian rhythms, has been linked to heart disease, although there again, the data are far from conclusive (NIOSH, 2007). Physical activity at work, either too much or too little, can also be a risk factor for heart disease (Kamath, Fallen, and McKelvie, 1991). While in general, more physical activity results in less heart disease, heavy lifting (in occupational and non occupational settings) has been associated with increased risk of heart attack (NIOSH, 2007). Further epidemiologic research into areas associated with risk of CVDs is warranted (NIOSH, 2007). Heart disease has been associated with excessive work demands (physical, mental, psychological), so monitoring heart rate activity can assist in assessing occupational risks (Astrand and Rodahl, 2003).

As mentioned above heavy lifting has been associated with risk of heart attack. Heavy lifting and physical activity are often seen in manual material handling activities. Manual material handling involves heavy lifting in both symmetric and asymmetric planes. When a manual material handling job requires highly repetitive, fast paced or forceful exertions, physical work capacity (PWC) and fatigue must be considered. Each person has a unique PWC, which is a measurement of maximum aerobic capacity, or metabolic expenditure capabilities. PWC is affected by age (decreases with age), fitness, gender (men typically have a higher PWC than women), maximum heart rate, and the energy demands of the job (repetition, exertion levels, and duration/length of time spent per forming the job (Astrand and Rodahl, 2003). If a lifting task is repetitive in nature and takes place over an extended period of time, it will probably require sustained strength and endurance. The body responds to this demand by increasing the heart rate and by breathing more heavily to take in more oxygen (Randall and Jeter, 2003). When physiological limits are exceeded, fatigue occurs, and in severe cases, a person's cardiovascular system may be stressed to the point of heart failure (Astrand and Rodahl, 2003).

Current jobs include tasks which are a combination of physical exertion as well as mental exertion. This may be the case in manual material handling where a person needs to move heavy materials from one room to the other, at the same time the individual may also have to do checklists, data entry etc. The influence of mental stress on various physiological functions is well documented using biomarkers of stress like blood pressure, heart rate and catecholamine and cortisol secretion (Krantz, Forsman and Lundberg, 2004). However, these responses do not only serve the role of stress indicators, but are also of interest as a possible link between psychosocial stress and various physical health outcomes (Krantz, Forsman and Lundberg, 2004). Most research has focused on physiological stress in causing cardiovascular disease (Belkic, Landsbergis, Schnall et al., 2004; Collins, Karasek and Costas, 2005). This shows that any kind of stressful work environment is associated with increased heart disease risk. Therefore real time heart rate measures may be useful as occupational disease risk indicators (Astrand and Rodahl, 2003), and heart rate variability (HRV) can be used to assess levels of mental stress (Backs, 1998). Research has been done to assess the cardiovascular disease risk based on job strain (Belkic, Landsbergis, Schnall et al., 2004; Collins, Karasek and Costas, 2005; Karasek, 1979), computer work (Hjortskov, Rissen, Blansted et al., 2004) and mental workload (Backs, Lenneman, and Sicard, 1999). Heart rate has been shown to increase during manual material handling (Ciriello, Snook, Blick et al., 1990; Straker, Stevenson and Twomey, 1997) which included lifting tasks both symmetric and asymmetric (Garg and Banaag, 1988; Garg and Saxena, 1979).

Clinicians are often called upon to assess the cardiovascular work fitness of patients. As they attempt to make an informed judgment, a fundamental question arises from ergonomics: Is the work environment fit, or conducive, to cardiovascular health of the worker? With technological advances, jobs characterized *purely* by heavy physical demands have become progressively less common. New types of work related challenges and burdens primarily affecting the higher nervous system of humans (i.e., psychosocial stressors) are more frequently encountered. Yet most of the clinical guidelines relevant to the interface between the workplace and the patient’s cardiovascular system continue to focus upon levels of physical exertion (Belkic, Landsbergis, Schnall et al., 2004). More complex analysis involving the power spectral components of heart rate can be used to predict risk of cardiovascular diseases. These components were used to predict risk due to job strain (Collins, Karasek and Costas, 2005), mortality after acute myocardial infarction (Quintana, Storckt, Lindbald et al., 1997), effects of exercise on heart rate (Kamath, Ghista, Fallen et al., 1987; Pagani, Lombardi, Guzzetti et al., 1986), cardiac regulatory response (Kamath, Fallen and McKelvie, 1991) and changes due to smoking (Hayano, Yamada, Sakakibara et al., 1990).

The importance of heart rate measures have been recognized historically, and traditionally electrocardiogram machines were used to monitor heart rate. However, these machines are not practical for use in work environments. A current research trend is the use of a portable and wireless physiological measurement device to monitor soldiers and medical patients remotely. This can be extended to use in work environments to monitor heart rates and other occupational disease risk factors such as chronic stress. It is easier to use these portable monitors in real time work environments as they are relatively non-intrusive compared to the traditional ECG or EKG machines and also have a user-friendly interface with computer. The feasibility of portable HR monitors in sports was also studied (Kingsley, Lewis and Marson, 2005), which gave insight into the usability of the device to measure heart rate. A few studies compared various heart rate monitors for their reliability (Sandercock, Bromley and Brodie, 2004) and validity (Gamelin, Berthoin, Bosquet, 2006) and found that they can be used in real time.

However there is not much research done on how work related physical and mental activities can affect heart rate, when performed one after the other or on psychometric properties like sensitivity and repeatability and level of comfort experienced by the wearer of portable wireless HR monitors. This study intends to use the power spectral components of heart rate variability to analyze heart rate during physically and mentally demanding activities and see if there are any pronounced changes due to the physical and mental activity.

Therefore the goals of this study were:

- To determine if portable and wireless HR monitors can be feasibly used in real time to accurately measure occupational risk factors.
- To evaluate the effects of physical and mental activity on HRV.
- To see if there are potential changes in HRV due to the trial order of the tasks.
- To assess the overall level of comfort a person experiences, while wearing the heart rate monitor and performing the mental or physical tasks.

1.1 Scope of the Study

Although many factors (physical, psychological and individual) contribute to the development of cardiovascular diseases, this study focused only on the effects of mental and physical activity on response of the heart. Both of these factors are thought to increase stress. Mental and physical demands were achieved here by designing the tasks in such a way that they induced stress. The outcome measures were limited to the frequency domain and time domain values although other studies had proposed examining other physiological responses, such as hormone excretion (Krantz, Forsman and Lundberg, 2004) and oxygen uptake (Astrand and Rodahl, 2003). The workload rating and the comfort levels were the individual subjective factors studied. Other individual factors like age, ethnicity and gender were recorded but not considered. The tasks were simulated in the laboratory and may vary from actual working conditions. The current study only related the changes in heart rate variability with different kinds of activities. Changes in HRV could possibly be used to analyze the root causes for CVDs. This study did not directly attribute CVDs to the variability in HR, but instead investigated potential risk factors in work environments that could lead to CVDs.

2. LITERATURE REVIEW

Stress can be defined as a phenomenon that occurs when people feel they are unable to manage the demands placed on them (Bongers, De Winter, Kompier et al., 1993). It occurs when the demands of a situation outweighs the body's ability to cope with it (Astrand and Rodahl, K., 2003). Research suggests that certain segments of the working population is at a higher risk of cardiovascular diseases due to physical and mental stress induced by higher job demands placed on them (Collins, Karasek and Costas, 2005; Karasek, 1979). These high levels of physical and mental strain could lead to adverse physiological conditions such as elevated blood pressure levels, increased heart rate, excessive sweating and higher intake of oxygen. A repetitive physical task requires sustained strength and endurance. The body responds by increasing the heart rate such that any kind of task that goes on for an extended period of time can cause stress to the level of heart failure. It is of interest to the ergonomics field to see how physical and mental demands in a work place can affect heart rate and if certain components of heart rate measurements, such as power spectral components of HRV, can be used to predict risk of disease. Examples of daily job scenarios where physical stress is induced are repetitive motions for a long period of time and postural distortions during manual material handling, long work hours requiring patient transfers in health care etc. Mental stress could be induced by cognitive work immediately after manual work, impossible deadlines, lack of sleep etc. Some industries with high job demands (mental and physical) are health care industry, fire fighting, military, software industry, call centers, any activity requiring manual material handling (MMH), etc. Since heart rate is extremely sensitive to different kinds of stress, measuring heart rate and monitoring it can be a good way to assess risk of cardiovascular diseases (Chandola, Britton, Brunner et al., 2008).

2.1 Autonomic Nervous System and Heart

The ANS (Autonomic Nervous System) regulates all the major organs, most importantly the heart. All the components of heart rate are markers of parasympathetic or sympathetic activity. Parasympathetic (PSMP) and sympathetic (SMP) systems constitute the ANS. Heart rate contributes to the ANS by being a part of the SMP and the PSMP to regulate all major organs of the body. Diagnostic tests to assess the integrity of ANS and its modulating effects on the heart have been developed to subject the ANS to a known stressor that activates a reflex and measure the response of the heart(Kamath and Fallen, 1993). The heart rate response to stressors like change of position, deep breathing and lower body negative pressure are used as an index of autonomic nervous system response.

2.2 Heart Rate Variability (HRV)

HRV refers to the beat to beat alterations in heart rate. Under resting conditions, the Electrocardiogram (ECG) of healthy people exhibit variation in the RR interval (duration between two consecutive R-waves of the ECG) periodically. A study by Backs (1998) focused on the fact that heart rate response may be due to different patterns of autonomic nervous system activity. The diagnosticity of heart rate is restricted by several factors like environmental stressors and physical demands that may be associated with a task. These tasks may have different physiological consequences and change in heart rate may depend on these factors more than mental workload. Backs (1998) focused on the fact that observed heart rate could be caused by different underlying patterns of autonomic nervous system activity. If different information processing demands affect the heart via different modes of autonomic control, it could increase diagnosticity of heart rate (Backs, 1998). Backs' study addressed the validity of the autonomic component, using data from a large study, in which many central and peripheral psychophysiological measures were collected simultaneously while performing single and dual tasks which had different physical demands. The measures collected were the residual heart rate, parasympathetic and sympathetic activity, respiratory sinus arrhythmia (RSA), and THM (Traube-Hering-Mayer) wave using principle component analysis (PCA), image factoring, impedance cardiogram (ZKG) and electrocardiogram (EKG). The sympathetic and parasympathetic systems were examined for independence. Their objective was to verify if factors extracted using residual heart rate as a marker variable validly reflected cardiac sympathetic activity and if the solutions obtained from raw and baseline corrected data were in compliance with each other. From the study, the PCA factors computed on raw EKG data provided useful information like different autonomic modes of control were found that were not evident in heart period. This information about the underlying autonomic activity may increase the diagnosticity of heart rate.

2.3 Components of Heart Rate

HRV was originally assessed by calculating the mean beat to beat heart rate commonly called the RR interval, and its standard deviation measured on short term ECG. To date about 26 different types of arithmetic manipulations of RR intervals have been used (Macarthur and Macarthur, 2000). Variable of interest for the study was the RMSSD index. The RMSSD index is defined as the root mean square of the differences of the successive RR intervals. MAX-MIN or peak-valley quantification of HRV is the difference between the shortest RR interval during inspiration and longest during expiration. RMSSD is a time domain measure of HRV. Recently spectral analysis of HRV has been developed which transforms the signal from time domain to frequency domain. The power spectrum of heart rate and blood pressure yields three major bands. A low frequency peak ranging between .06 Hz to .15 Hz, a high frequency peak ranging between .15 Hz to .4 Hz and a very low frequency peak below .05 Hz constitute the power spectrum (Kamath and Fallen, 1993). The LF is associated with blood pressure control, reflecting sympathetic activity. The HF is correlated with respiratory sinus arrhythmia reflecting parasympathetic activity (Kamath and Fallen, 1993). The VLF is linked with vasomotor control or temperature control. The RR interval data obtained from ECG or other heart rate monitoring devices can be analyzed using any mathematical tool like Fourier transformation or moving average method (Quintana, Storckt, Lindbald et al., 1997). Statistical significance can be tested using standard tests after the frequency domain analysis. For the current study, in the first phase the raw data obtained from the heart rate monitor was analyzed using both the time domain and the frequency domain measures. The data further obtained from these analyses was tested for statistical significance using analysis of variance (ANOVA).

2.4 Factors That Influence the Power Spectrum of HRV

Several variables such as the age, posture, level of physical fitness, frequency of breaths, circadian cycle and mental fitness (a person's comprehension ability) - all influence ANS and heart mechanisms (Kamath and Fallen, 1993). Respiration has a strong influence on heart rate; this rhythmic phenomenon is known as respiratory sinus arrhythmia (RSA). In a previous study, when posture was changed from supine to standing, the power under the LF peak and the LF to HF ratio increased significantly upon standing (Kamath, Fallen and McKelvie, 1991). The LF peak increased when the person was standing compared to the supine position (Kamath, Fallen and McKelvie, 1991)). Exercise produces a change in autonomic balance. The HF power for trained individuals is more than for untrained individuals and mild levels of exercise and steady state exercise showed an increase in the LF component (Kamath, Ghista, Fallen et al., 1987; Pagani, Lombardi, Guzzetti et al., 1986; Yamamoto, Hughson and Peterson, 1991). A reduction in the standard deviation of the RR interval and reduction in the RMSSD values indicate reduction in HRV. For the current study the physical task has been designed such that it represents a work scene where the posture is changed continuously such as in manual material handling. RR interval variance decreased when age increased, while at rest and change of posture. This decrease in variance resulted in smaller HRV (Kamath and Fallen, 1993; Pagani, Lombardi, Guzzetti et al., 1986), but the LF/HF ratio remained the same. Also mental stress was seen to increase the HRV. In individuals who smoked cigarettes, the LF component increased implying reduction in cardiac vagal control (Hayano, Yamada, Sakakibara et al., 1990). The current study was aimed to check the impact of physical and mental activity on heart rate. All the previous studies have information on how heart rate components changed during physical exercise but there is no information on how they may change when tasks imitating real-time jobs were done or when one type of activity followed another.

2.5 Importance of HRV in Assessing Mental Stress and Job Strain

The demand control model of job strain suggest that jobs in which the demands are high and the control is low along with low social support are stressful i.e., when there is an imbalance between the job demand and the person’s ability to meet those demands (Karasek, Brisson, Kawakami et al., 1998). Decreased HRV has been associated with mental stress in lab experiments which indicated a lack of mental ability to respond by physiological variability and complexity (Hjortskov, Rissen, Blansted et al., 2004). If the condition is long lasting, it may lead to cardiovascular diseases (Hjortskov, Rissen, Blansted et al., 2004). Hjortskov (2004), evaluated cardio vascular and subjective stress responses to a combination of mental and emotional stressors during computer work sessions. The effect of rest periods in between sessions was also evaluated. HRV was relatively lower for the work periods and rest periods. This study was consistent with other studies stating that HRV is a sensitive indicator of mental stress during computer work. Resting had a positive effect on HRV and blood pressure. Intermittent rest periods between various physical and mental tasks showed an improvement in HRV.

Regulatory limitations of control of nervous system may be an important pathway by which psychosocial risks contribute to cardiovascular illness. Sudden cardiac death which results from defective control of cardiac rhythms, accounted for around 50% of cardiac mortality among the working population (Collins, Karasek and Costas, 2005). Defective cardiac regulation (irregular or sudden changes in HRV), a pathway to cardiovascular disease implicated by job strain can be monitored by a Holter ECG monitor. HRV provides an assessment of the autonomic nervous system as it influences heart rate. A study by Collins et al (2005) measured job strain using the job content questionnaire, 8 day diary reports, autonomic regulation which utilized HRV and its spectral components. The LF/HF ratio, residual heart rate increased in the high strain group on work days. This may explain elevated blood pressure during and after work. The study showed that there was autonomic deregulation under job strain conditions, which can give a good explanation of heart diseases related to work. It could not be proved implicitly that defective cardiac regulation measured by HRV can serve as a final cardio vascular disease pathway for job stress.

2.6 Summary: Heart Rate Measures

Important information on the heart rate components can be summarized from the past literature as follows:

- All the components of HRV are markers of the sympathetic and parasympathetic activity.

- The low frequency component:

  - Is associated with blood pressure control / sympathetic activity.
  - Is high, when the person is in high strain conditions.
- The high frequency component :
  - Is an indicator of parasympathetic autonomic response
  - Is an indicator of respiratory sinus arrhythmia (RSA)
  - Is reduced during heavy exertions and awkward postures.
- The ratio of low to high frequency:
  - Is an estimate of mental stress
  - Is used as an index of parasympathetic and sympathetic balance.
  - Is correlated with high job strain, when high.
- The very low frequency is:
  - Linked with temperature control
  - Often seen as an unreliable measure.
  - Correlated with high ANS activity, when high.
  - High, then it implied high strain.
- Reduced HRV predicts sudden death and is a marker of fatal ventricular arrhythmia.
- This reduction in HRV can be examined from time domain components like the RMSSD.
- All of these components are responsible for the identification of increased cardiac reactivity in individuals under high stress.

2.7 Practical Applications of Heart Rate Monitors

HRV is sensitive to both physiological and psychophysical disorders. In recent years HRV has also been used as a tool to improve diagnosticity of heart rate in the general population which included both the working and non working population. Assessing the impact of physical and mental demands associated with tasks in a work place on the heart can help to predict cardiac diseases. Therefore it has become essential to measure HRV (Gamelin, Berthoin and Bosquet, 2006). Measurement of HRV in the past required a high-quality electrocardiogram (ECG), but the cost and complexity of the ECG equipment has made it difficult to perform HRV analysis particularly in the physical training field (Kingsley, Lewis, and Marson, 2005). To address these needs, several portable heart rate monitoring devices have been designed. The development of wireless heart rate monitoring (HRM) with elastic electrode belt allowing the detection of RR intervals with a resolution of 1ms represents an interesting alternative to classic fixed or ambulatory ECG for use outside of laboratory settings. Kingsley et al (2005) demonstrated that the R-R intervals and heart rate measurements obtained using Polar 810S and ambulatory ECG system are in good agreement with each other. Gamelin et al (2006) examined the validity of the Polar S810 monitor to measure RR intervals at rest. Narrow limits of agreement, good correlation and small effect sizes validate the monitor and measure RR intervals to make HRV analysis (Gamelin, Berthoin, and Bosquet, 2006). Sandercock et al (2004) measured the reliability of three commercially available HRV instruments using short term recordings. These recordings were made in three conditions: lying supine, standing, and lying supine with controlled breathing. Reliability was calculated using CV (coefficient of variation), ICC (intraclass correlation coefficient) and LoA (limits of agreement). The study showed supine condition is more reliable. On the whole the short term recordings less than five minutes were seen to be unreliable (Sandercock, Bromley, and Brodie, 2004). On the whole heart rate monitors pave a simple pathway to measure the heart rate in a feasible manner as they are affordable, portable, reliable for recordings more than 5 minutes and also easy to handle. For this study the Polar RS800 monitor (Polar Electro Inc., Lake Success, NY) was used to record the data. It has a chest strap and a watch which transmits data wirelessly.

Previous literature reviews showed that various heart rate monitors had been checked for their validity and reliability. But the comfort levels experienced while using the heart rate monitor had not been addressed. This is important because wearing a heart rate monitor in a real time situation during work should not affect the workers performance and should be as comfortable as possible. One of the purposes of this study was to see how comfortable the wearer feels while doing various tasks, so that the HR monitor can be used for real time recording. Also statistical consistency had not been tested thoroughly and there is little research on HRV during a physical or manual activity like moving something heavy. Earlier studies had shown that the heart rate increases when a manual material handling job is performed, but the spectral components had not been studied in association with predictability of diseases (Garg and Banaag, 1988). The aim of the current study was to address some of these shortcomings. The objectives were to study the changes in HRV during physical and mental activities, the potential changes in HRV when the order of the tasks is changed, and measure the level of comfort a person experienced while wearing the heart rate monitor.

3. METHODOLOGY

The purposes of this study were to see if a portable heart rate monitor is feasible for use in a work setting and to see if there were significant changes in heart rate variables while performing physical and mental tasks. This study was needed because the resultant heart rate measures may be indicators of cardiac risk factors in the workplace. The current study focused on heart rate and heart rate variability (HRV) in mental and physical work tasks simulated in the laboratory. The following data were collected for the study:

1. Heart rate (beat to beat data) recorded using a heart rate monitor during mental task performance.
2. Heart rate (beat to beat data) recorded using a heart rate monitor during physical task performance.
3. Subjective workload ratings, derived from the NASA TLX for both mental and physical tasks.
4. Level of comfort of the participants measured with a comfort questionnaire submitted after each task.

3.1 Study Population

To meet the above objectives twenty four individuals from the university community (aged between 18 and 30) were recruited to participate in the study (a minimum sample size of 20 was needed to obtain a power of 0.8). The complete demographic information is summarized in Table 1. All the participants did not have the following conditions: sedentary lifestyle, any history of cardiovascular or musculoskeletal disorders, currently under medications that may affect heart rate, or pregnancy. The participants were asked to avoid any strenuous exercise, consumption of alcohol, nicotine or caffeine on the days they did the experiment. A flier was posted on the notice boards in various places all over the university, asking students to volunteer who had the required health conditions. The participants were required to sign the consent form (Appendix 1) before doing the experiment.

Table 1 Demographic Summary of Participants

Demographic Variable	Mean (Std. Deviation) or count
Gender	19 Males, 5 Females
Age	22.1(2.0)
Ethnicity	10 Caucasian 7 Asian 3 Middle Eastern 2 Hispanic 1 African 1 Cajun
First Language	12 native English speakers 12 Non-native English speakers
No. of Hours of exercise/week	6.7 (5.3)
No. of years of exercise	1.8 (2.2)

3.2 Procedures

3.2.1 Pre-test Procedure

The Institutional Review Board (IRB) approved the study (Appendix 2). A consent form explaining the study procedures, benefits risks and exclusion criteria was provided to the individuals prior to the experiment. They were required to sign it in order to participate. Also clear verbal instructions were given on how to wear the heart rate monitor and how the experiment would be performed. After that a Physical Activity Readiness Questionnaire (PAR-Q) (Hafen and Hoeger, 1994) was given. The PAR-Q (Appendix 3) was designed to identify a small number of adults for whom physical activity might be inappropriate or those with medical reasons concerning the suitable type of physical activity. Anyone who marked a “yes” on the PAR-Q could not participate in the study. Participants also filled out a demographics form (Appendix 4), which had information on age, gender, ethnicity and physical fitness.

3.2.2 Sequence of Procedures

Each participant performed this experiment twice, on separate days (2 – 14 days apart) using the same procedures (although the informed consent, and the demographic questionnaire was only conducted on the first day). Data obtained from the first of two sessions was used for the current study. The procedures were followed as shown:

1) The participants signed the consent form and filled out the demographics form.

2) An experimenter gave each individual verbal instruction on how to put on the heart rate monitor, which consists of a strap worn around the chest. An experimenter visually inspected the monitor's placement after the participant has put it on.

3) The HR monitor was turned on and the heart rate at rest for 5 minutes was recorded. During this time the participant was required to sit at rest without any major movement or mental unrest.

If the physical activity was done first go to step 4, If the mental task was done 1st go to step 9.

Physical task:

4) The NASA-TLX pair wise comparisons were done prior to the physical task.

5) Prior to the physical task, static strength was measured.

6) The physical task was performed for 12 minutes, while the HR monitor recorded heart rate.

7) The NASA-TLX work-load sheet was completed by the participant.

8) The comfort questionnaire was filled for the physical task section.

Mental Task:

9) The NASA-TLX pair-wise comparisons were done prior to the mental task.

10) The mental task lasted for 10 minutes. The mental task was done and the heart rate was recorded.

11) The NASA-TLX work-load sheet was completed by the participant.

12) The comfort questionnaire for the mental task was filled.

13) After the completion of both tasks the participant removed the HR monitor.

Note: Every individual needed to do both the tasks and each time the procedure described above was followed. A rest period of 5 minutes was allowed between the tasks. Half of the participants performed the physical task first and the mental task following it. The other half did the mental task first and the physical task followed. It was designed this way so as to examine any potential order effects. The experiment was terminated if the heart rate exceeded 85% of the maximum heart rate (220 - Age, from Eastman Kodak Company, 2004) at any point during the experiment, or participants could also stop at anytime without penalty. If abnormally higher or lower HR was observed during rest period for any participant, he/she was not allowed to do the experiment. Participants followed the same order in both the sessions.

3.3 Experimental Apparatus

The heart rate monitor used was the Polar RS800 (Polar Electro Inc., Lake Success, NY) (Figure 1), which is a portable wireless device. It included a watch, coded wear link chest transmitter and Polar ProTrainer 5.0 software which enabled data download via IrDA (an infra red USB) interface. The heart rate data was obtained directly in the form of beat to beat (RR) intervals, which is the time between the beats. This data was exported to Microsoft Excel.

Figure 1 Polar RS800 HR Monitor (http://www.polar-usa.us/polar-rs800.html)

For the static strength measurement a Dillon Load Cell (INC Camarillo, CA) was used to measure the static arm strength. The device consisted of a display unit (Figure 2) known as the Advanced Force Gauge (AFG) that displayed the arm strength readings in kilograms and a custom made 18 inch handle was connected to the load cell where force was applied. Furthermore, the equipment comprised of a platform with a chain support to which the handle was connected using the load cell, which in turn was connected to the Advanced Force gauge.

3.4 Tasks

To compare the heart rate under physical and mental demand, two main tasks of physical and mental activities were designed as follows.

Figure 2 Dillon Advanced Force Gauge (http://www.basicservice.com/dillon/afg.html)

3.4.1 Physical Activity

3.4.1.1 Static Strength Measurement

The participants' physical strength was measured by having them perform the static arm pull test using a static strength model (Aghazadeh and Ayoub, 1985). Strength was measured at elbow height. Measurement of static strength was necessary to determine the person's maximum strength and use weights equivalent to 20% of that maximum strength to perform the physical task. This was done as each person had an individual strength and the weight was arranged suitably so that the participant did not injure himself/herself. Weight equivalent to 20% of maximum strength was determined through a small pilot study having 3 participants try different weights starting at 50% of maximum strength and decreasing in amounts of 10%. They were comfortable with weights equivalent to 20% of maximum strength and could endure it for about 15 minutes. However, using this weight still increased heart rate sufficiently to create a physically demanding activity. The strength was measured at elbow height as the participant needed to carry the load at elbow height. The testing method involved adjustment of the handle of the equipment such that the forearms of the participant were flexed at 90° and the upper arms were vertical, parallel, and adjacent to the torso. The participant was required to stand erect with legs and back straight and with feet flat. The participant was required to hold sides of the handle bar connected to the load cell and exert force upward and vertically in the sagittal plane (Aghazadeh, Waly and Nason, 1997). The exerted force was generated by the arms only and shoulder movement was avoided. Each participant was asked to pull the handle gradually with maximum strength without jerking and the strength readings were displayed on the gauge in kilograms. They had to exert force for 5s, which was followed by a rest period of 45s each time. The procedure was repeated three times per participant and the coefficient of variation (CV) was calculated. If it was less than 0.1, the average was calculated. If the CV was greater, then a 4th trial was done for accuracy. 20% of the average maximum strength of each participant was used as the weight for the physical task.

3.4.1.2 Physical Task

The purpose of the physical task was to perform simple tasks that simulated a physically demanding job such as manual material handling to increase heart rates but not to bring any mental stress on the participants. Participants were instructed to discontinue the task if they felt discomfort, shortness of breath, or pain. Heart rate was checked once every 3 minutes to check if it exceeded 85% of their maximum. If that was the case, they were asked to discontinue. The task was modeled after previously developed methods that had been used to simulate physically demanding tasks in the laboratory setting. The current task was a combination of loading, unloading, moving while carrying the weights and asymmetric lifting, (Aghazadeh and Ayoub, 1985; Ciriello, Snook, Blick et al., 1990; Garg, and Banaag, 1988). The loading part involved free style bending (any position that is convenient for the participant) (Garg, and Saxena, 1979) and lifting of weights from ground height, one at a time and placing them in the box (20.32cm x 20.32cm x 20.32cm) placed at elbow height. The number of times the person had to bend was equal to the number of the weights, with six as the minimum number. This also served as a warm up for the carrying and lifting task. The moving part involved carrying the load at knuckle height and walking in the corridor for 3 min to reach the location indicated by the experimenter (a shelf in the laboratory with adjustable heights, that is adjusted to the person's shoulder height), and place it at ground level. The lifting task involved lifting the box with weights to the person's shoulder height in 90° lateral plane to the right, while the feet are in the sagittal plane (Garg and Banaag, 1988). The frequency of lifts was 12lifts/min, similar to the procedure used by Garg (1979). The timing was controlled using a stop watch. The person was asked to walk while holding the box for another 3 minutes then come back and do the lifting again. The lifts were scheduled for 1min each time between the walking. The same process was repeated three times. The box was then held at knuckle height and the participant was asked to move back to the original table. There he/she was asked to place the box on the table and unload it to ground height, removing one weight at a time. This served as a cool down process. The total task duration was 12 min, including the warm up and cool-down sessions. It should be noted that the warm up/cool down time was excluded from the heart rate analysis as it depended on the number of weights each person had. 20 seconds at the beginning and end of the physical task was removed for analysis.

3.4.2 Mental Task

The purpose of this task was to elicit high levels of mental demands by asking the participants to read passages and answer reading comprehension questions. This simulated a scenario where a worker is required to do checklists, look up information, read and comprehend that information accurately. The duration of the mental task was 10 minutes. The passages were taken from 29 CFR 1910 (OSHA Standards for General Industry). Passages and comprehension questions for the mental task can be found in Appendix 7. Participants were asked to look up specific safety regulations, read the regulations, and answer questions directly related to what they read. The questions were multiple-choice and required marking a response on the sheet with the questions. Participants were asked to work as quickly and accurately as possible to complete as much of the work as possible in the allotted time. They were advised not to read the entire article but rather use it as a reference to answer the multiple choice questions. Heart rate was recorded for the entire duration of the task.

3.5 Independent Variables

There were two independent variables.

- <u>Task type:</u> Physical task and mental task.
- <u>Trial order:</u> It was done in 2 ways, either the physical task was done 1st or the mental task was done 1st.

3.6 Dependent Variables

There were four categories of dependent variables.

- <u>Frequency domain output for R-R intervals during both the mental and physical tasks:</u>

There were 3 frequency domain variables that this study focused on. This included the power in LF (low frequency) and HF (high frequency) bands and the ratio of LF to HF. These components were obtained from the power spectral analysis of HRV. The high frequency component is an indicator of parasympathetic autonomic response or the respiratory sinus arrhythmia (RSA) (Collins, Karasek and Costas, 2005). The low frequency component is associated with blood pressure control or sympathetic activity (Kamath and Fallen, 1993). The ratio of low to high frequency is an estimate of mental stress (Collins, Karasek and Costas, 2005). These measures may be indicators of a person's heart response to various activities.

- Time domain output for both the tasks:

A root mean square difference of successive RR intervals (RMSSD) was the time domain value of interest. This measure was used to check the difference in RR interval data for the physical and mental tasks.

- Comfort questionnaire (Appendix 6):

A comfort questionnaire was developed to assess the level of comfort for each participant while wearing the watch and the chest strap. The participants completed this after the tasks. The questionnaire consisted of fourteen questions pertaining to the levels of comfort of the participant while wearing the heart rate monitor and performing the experimental tasks. Each question had five potential answer choices, but only one could be chosen. The choices were rated from the most positive comfort level to the most negative level of comfort, with neutral being the middle choice. The choices were assigned numerical values for the analysis. A '1' denoted the most negative or most uncomfortable level, a '2' denoted fairly negative or fairly uncomfortable, a '3' denoted neutrality, a '4' denoted fairly positive or comfortable, and a '5' denoted the most positive or most comfortable level. After all the participants finished the experiment and filled the comfort questionnaire, a comfort score was obtained by adding all the responses together.

- NASA- TLX (Appendix 5):

NASA-TLX is a subjective workload assessment tool that allows users to perform subjective workload assessments on operator(s) working with various human-machine systems. This is a set of six scales are weighted using pair-wise comparisons and combined to derive a sensitive and reliable estimate of workload (Hart, 1987). The six scales are physical demand, mental demand, performance demand, temporal demand, frustration and effort. The relative importance of the six scales to each subject's personal definition of workload was determined before the task was done. The member of each pair selected as most relevant to workload was recorded and the number of times each factor was selected was computed. The more important a factor is considered to be, the more weight the ratings of that factor is given in computing an average weighted workload score (WWL) for each experimental condition. This data was used as weights in combining the six pair-wise comparisons to produce a workload score that will equal the approximations that the individuals report to use.

3.7 Analysis

3.7.1 RR Interval Data

RR interval data was directly obtained from the heart rate monitor. The Polar Pro-Trainer software exported the data to Microsoft Excel. HRV analysis methods were divided into time-domain and frequency-domain.

3.7.1.1 Heart Rate Analysis Software

A Matlab based software package for event-related bio signal analysis was used for this study to obtain the frequency and time domain measures (Taraveinen, Karjaleinen and Ranta-aho, 2001). The software gave both the time domain and frequency domain values (parametric and non parametric) along with the Poincare plot for the RR data. The input was the raw RR interval data from an ASCII file in milliseconds. The output showed both the original signal and the detrended signal. For this study the following information was used from the software: absolute values and normalized units of LF, HF and LF/HF ratio of the frequency domain and RMSSD from the time domain.

3.7.1.2 Time Domain Analysis

The time-domain parameters were directly obtained from the raw RR interval data. The simplest time domain measures are the mean and standard deviation of the RR intervals. The square root of standard deviation of the differences between consecutive RR intervals (RMSSD) describes short-term variation. For the analysis here the RMSSD values obtained were used.

3.7.1.3 Frequency Domain Analysis

The power spectral density (PSD) estimation gives information about power distribution as a function of frequency. However the RR interval time series used here was an irregularly time-sampled signal. If the spectrum estimate was calculated with this raw interval data additional harmonic components would have been generated in the spectrum. Therefore, the RR interval signal was interpolated before the spectral analysis to obtain an evenly sampled signal from the raw data (Niskanen, 2004). This was called signal detrending. Detrending options included removal of the first or second order linear trend or the trend could be removed using the smoothness priors method(Taraveinen, Karjaleinen, and Ranta-aho, 2001). The PSD could be estimated using two ways, the traditional non-parametric method that uses Fast Fourier Transformation (FFT) and the parametric method based on auto regressive models. For this analysis the non-parametric analysis was used. The spectrum can be divided into components and the band powers were obtained as powers of these components. The frequency bands used were low frequency (LF, 0.04- 0.15 Hz) and high frequency (HF, 0.15-0.4 Hz) (Kamath and Fallen, 1993). The frequency domain parameters calculated were powers of LF and HF bands in absolute values, the normalized power of LF and HF bands, and the LF to HF ratio. For the current study HF, LF, LF/HF absolute values (natural logarithm transformed) and normalized units were used in the statistical analysis.

3.7.1.4 Comfort Questionnaire

The questionnaire consisted of fourteen questions pertaining to the levels of comfort of the participant while wearing the heart rate monitor and performing the experimental tasks. Each question had five potential answer choices, but only one could be chosen. The choices were rated from the most positive comfort level to the most negative level of comfort, with neutral being the middle choice. The choices were assigned numerical values for the analysis. A ‘1’ denoted the most negative or most uncomfortable level, a ‘2’ denoted fairly negative or fairly uncomfortable, a ‘3’ denoted neutrality, a ‘4’ denoted fairly positive or comfortable, and a ‘5’ denoted the most positive or most comfortable level.

Once each response is recorded, an overall number of responses for each comfort level for each participant and each task were added. The scores were anywhere between 0 and 75. If the score was between 0-13, then wearing the device is considered to be “very uncomfortable”, 15 - 28 then wearing the device was considered to be “uncomfortable”, if score was between 29 - 42 then wearing the device does not make any difference, if score was between 43-60 then it was considered to be comfortable, if score was between 61-75, then it was very comfortable.

3.7.1.5 NASA-TLX

An average of the six scales was weighted to reflect the contribution of each factor to the workload of a specific activity from the perspective of the rater and was the integrated measure of overall workload for the 2 types of tasks performed. The relative importance of the six scales to each subject's personal definition of workload was determined before the task was done. The member of each pair selected as most relevant to workload was recorded and the number of times each factor was selected was computed. The resulting values ranged from 0 to 100. For the current study the mental load, physical load and the overall work load were used. Ratings above 50 were considered high.

3.7.2 Statistical Analysis

There were 3 objectives for this study.

1) To see if the task type or order in which tasks are performed had a significant effect on heart rate variability.

The hypotheses were stated as:

Hypothesis 1: H0: Task type will NOT have any effect on the HF component.
H1: Task type will have effect on the HF component.

Hypothesis 2: H0: Trial order will NOT have any effect on the HF component.
H1: Trial order will have an effect on the HF component.

Hypothesis 3: H0: Task type will NOT have any effect on the LF component.
H1: Task type will have an effect on the LF component.

Hypothesis 4: H0: Trial order will NOT have any effect on the LF component.
H1: Trial order will have an effect on the LF component.

Hypothesis 5: H0: Task type will NOT have any effect on the LF/HF ratio.
H1: Task type will have an effect on the LF/HF ratio.

Hypothesis 6: H0: Trial order will NOT have any effect on the LF/HF ratio.
H1: Trial order will have an effect on the LF/HF ratio.

Hypothesis 7: H0: Task type will NOT have any effect on RMSSD.
H1: Task type will have an effect on RMSSD.

Hypothesis 8: H0: Trial order will NOT have any effect on RMSSD.

H1: Trial order will have an effect on the RMSSD.

2) To examine any differences present in the physical workload, metal workload and the overall workload experienced during the physical and mental task.

Hypothesis 9: H0: Physical workload will NOT be different due to the type of task.

H1: Physical workload will be different due to the type of task.

Hypothesis 10: H0: Physical workload will NOT be different due to the trial order.

H1: Physical workload will be different due to the trial order.

Hypothesis 11: H0: Mental workload will NOT be different due to the type of task.

H1: Mental workload will be different due to the type of task.

Hypothesis 11: H0: Mental workload will NOT be different due to trial order.

H1: Mental workload will be different due to the trial order.

Hypothesis 12: H0: Overall workload will NOT be different due to the type of task.

H1: Overall workload will be different due to the type of task.

3) To assess the level of comfort a person experienced wearing the HR monitor during both the tasks.

Hypothesis 13: H0: Overall workload will NOT be different due to the trial order.

H1: Overall workload will be different due to the trial order.

Hypothesis 14: H0: Participants are NOT comfortable wearing the monitor during physical task.

H1: Participants are comfortable wearing the monitor during physical task.

Hypothesis 15: H0: Participants are NOT comfortable wearing the monitor during mental task.

H1: Participants are comfortable wearing the monitor during mental task.

To test the hypotheses from 1 to 13, two-way analysis of variance was used. The two factors were the task type and the trial order which were both within-subjects factors. Each factor had two levels within it (2x2 factorial experiment). Levels of task type were physical task and mental task. Levels of trial order were 1. Physical task performed first, 2. Mental task performed first. Each of the dependant variables was used as the response variable and the ANOVA was run several times to test the factor level effects on each of the dependant variables. For hypotheses 1-8 the response variables were the power spectrum components (LF, HF, LF/HF ratio) and the RMSSD from time domain analysis. For hypotheses 9 - 13, the response variables were the mental and physical workload and the overall workload that was obtained from the NASA-TLX workload rating. T-test was used to test the significance of the comfort scores for both the tasks, to address hypotheses 14 and 15. The response variables were the average comfort levels for the physical and mental activities calculated from the comfort questionnaire. All the hypotheses were tested at a significance level of $\alpha=0.05$.

4. RESULTS

Twenty four university students (ages between 18-30 years) participated in the study. Twelve of the participants did the physical task first followed by the mental task (trial order 1) and another twelve of them did the mental task first followed by the physical task (trial order 2). Although the software generated the normalized units for each component, the absolute power values of each component are considered to describe completely the distribution of power in spectral components (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). Due to the skewness in the distribution, LF and HF power components (i.e., the absolute power values) were analyzed after natural logarithmic transformation. Complete means and standard deviations of each dependant variable are listed in Table 2.

Table 2 Averages and Standard Deviations for Dependant Variables

	Trial order 1		Trial order 2	
	Physical task	Mental task	Physical task	Mental task
Ln(Low Frequency(LF))	4.95 (1.25)	6.76 (0.99)	4.94 (1.62)	6.64 (1.01)
Ln(High Frequency(HF))	3.57 (1.37)	5.62 (1.25)	3.62 (1.74)	5.35 (1.36)
LF (n.u)	74.0 (10.9)	78.0 (15.6)	76.0 (10.7)	80.0 (6.64)
HF (n.u)	20.7 (10.2)	25.6 (11.5)	21.0 (6.2)	23.8 (10.6)
LF/HF Ratio	3.96 (2.12)	4.54 (2.79)	4.12 (1.81)	4.53 (2.82)
Root Means Square Standard Deviation	16.9 (9.7)	35.0 (24.6)	18.6 (20.3)	33.8 (25.5)
Overall Work Load	55.6 (10.5)	65.6 (14.1)	61.1 (10.3)	65.6 (18.6)
Physical Work Load	78.1 (11.3)	16.2 (11.4)	83.3 (16.0)	22.6 (17.5)
Mental Work Load	16.4 (15.0)	76.8 (18.9)	19.4 (17.0)	73.8 (19.1)
Comfort Score	46.5 (5.56)	51.5 (5.2)	49.0 (6.95)	48.4 (4.40)

All the above variables are included in the statistical analysis. ANOVA was performed on all the variables except for the comfort scores. The ANOVA p-values are listed in the Table 3 and the significant p-values are indicated by “*”. Trial order is not a significant factor for any of the dependant variables. Task type is not significant for two of the dependant variables, i.e., the ratio of LF to HF components and the overall work load.

Table 3 ANOVA P-Values.

Dependant variables	**Task Type**	**Trial Order**
Low Frequency(LF)	<.0001*	0.8452
High Frequency(HF)	<.0001*	0.7914
LF/HF Ratio	0.4848	0.9192
Root Mean Square Standard Deviation	0.0028*	0.9646
Physical Work Load	<.0001*	0.2570
Mental Work Load	<.0001*	0.9956
Overall Work Load	0.0749	0.4939

Based on the p-values the following conclusions have been made for each of the hypotheses as shown below:

Results for objective 1:

Hypothesis 1: H0: Task type will NOT have any effect on the HF component.

H1: Task type will have effect on the HF component.

The p-value for the HF component, is <0.0001 for the task type factor. Based on the significant p-value obtained the null hypothesis was rejected and the alternate hypothesis was concluded i.e., task type had an effect on the HF component.

Hypothesis 2: H0: Trial order will NOT have any effect on the HF component.

H1: Trial order will have an effect on the HF component.

The p–value obtained is 0.7914, which is not significant. The null hypothesis was concluded i.e. trial order did not affect HF component.

Hypothesis 3: H0: Task type will NOT have any effect on the LF component.

H1: Task type will have an effect on the LF component.

The p-value for the LF component, is <0.0001 for the task type factor. Based on the significant p-value obtained the null hypothesis was rejected and the alternate hypothesis was concluded i.e., task type did have an effect on the LF component.

Hypothesis 4: H0: Trial order will NOT have any effect on the LF component.

H1: Trial order will have an effect on the LF component.

The p–value obtained is 0.8542, which is not significant. The null hypothesis was concluded i.e. trial order did not affect HF component.

Hypothesis 5: H0: Task type will NOT have any effect on the LF/HF ratio.

H1: Task type will have an effect on the LF/HF ratio.

The p–value obtained is 0.4848 for the LF/HF ratio, which is not significant. The null hypothesis was concluded i.e. trial order did not affect LF/HF ratio.

Hypothesis 6: H0: Trial order will NOT have any effect on the LF/HF ratio.

H1: Trial order will have an effect on the LF/HF ratio.

The p–value obtained is 0.9192 for the LF/HF ratio, which is not significant. The null hypothesis was concluded i.e. trial order did not affect LF/HF ratio.

Hypothesis 7: H0: Task type will NOT have any effect on RMSSD.

H1: Task type will have an effect on RMSSD.

The p-value for the RMSSD component is .0028 for the task type factor. Based on the significant p-value obtained the null hypothesis was rejected and the alternate hypothesis was concluded i.e., task type had an effect on the RMSSD component.

Hypothesis 8: H0: Trial order will NOT have any effect on RMSSD.

H1: Trial order will have an effect on the RMSSD.

The p–value obtained is 0.9646, which is not significant. The null hypothesis was concluded i.e. trial order did not affect RMSSD component.

Results for objective 2:

Hypothesis 9: H0: Physical workload will NOT be different due to the type of task.

H1: Physical workload will be different due to the type of task.

The p-value for the physical workload is <0.0001 for the task type. Based on the significant p-value obtained the null hypothesis was rejected and the alternate hypothesis was concluded i.e., task type had an effect on the physical workload.

Hypothesis 10: H0: Physical workload will NOT be different due to the trial order.

H1: Physical workload will be different due to the trial order.

The p–value obtained is 0.257 for trial order, which is not significant. The null hypothesis was concluded i.e. trial order did not affect physical workload.

Hypothesis 11: H0: Mental workload will NOT be different due to the type of task.

H1: Mental workload will be different due to the type of task.

The p-value for the mental workload is <0.0001 for the task type. Based on the significant p-value obtained the null hypothesis was rejected and the alternate hypothesis was concluded i.e., task type had an effect on the mental workload.

Hypothesis 12: H0: Mental workload will NOT be different due to trial order.

H1: Mental workload will be different due to the trial order.

The p–value obtained is 0.995 for trial order, which is not significant. The null hypothesis was concluded i.e. trial order did not affect mental workload.

Hypothesis 13: H0: Overall workload will NOT be different due to the type of task.

H1: Overall workload will be different due to the type of task.

Hypothesis 14: H0: Overall workload will NOT be different due to the trial order.

H1: Overall workload will be different due to the trial order.

The p-values are 0.0749 and 0.4948 for the task type and trial order respectively. The null hypotheses were rejected and the alternate hypotheses were concluded, indicating that neither trial order nor task type affected the overall workload significantly.

Results for objective 3:

Hypothesis 15: H0: Participants are NOT comfortable wearing the monitor during physical task.

H1: Participants are comfortable wearing the monitor during physical task.

The p-value obtained from the t-test is 0.0012. The null hypothesis was rejected and the alternate hypothesis was concluded, indicating that the participant was comfortable wearing the monitor during the physical task.

Hypothesis 16: H0: Participants are NOT comfortable wearing the monitor during mental task.

H1: Participants are comfortable wearing the monitor during mental task.

The P-value obtained from the t-test is <0.0001. The null hypothesis was rejected and the alternate hypothesis was concluded, indicating that the participant was comfortable wearing the monitor during the mental task.

4.1 Power Spectral Components

Each component during the mental and physical activities was compared to those values during rest to give a clearer understanding of increase or decrease in the spectral component values depending on each kind of stress induced. The power of the power spectrum components considered is measured in ms^2, but it is presented here in normalized units (n.u) to give a better idea of how the LF and HF components are a part of the total power spectrum as the normalized units represent these components as a part of the total power by excluding the VLF component.

The HF component for both the tasks is lower compared to the values at rest, indicating that stress is induced on the participants by the tasks designed. The ratio and the LF component, both are significantly higher compared to the values at rest. The graphs shown as figures 3, 4, 5 and 6 illustrate this situation appropriately:

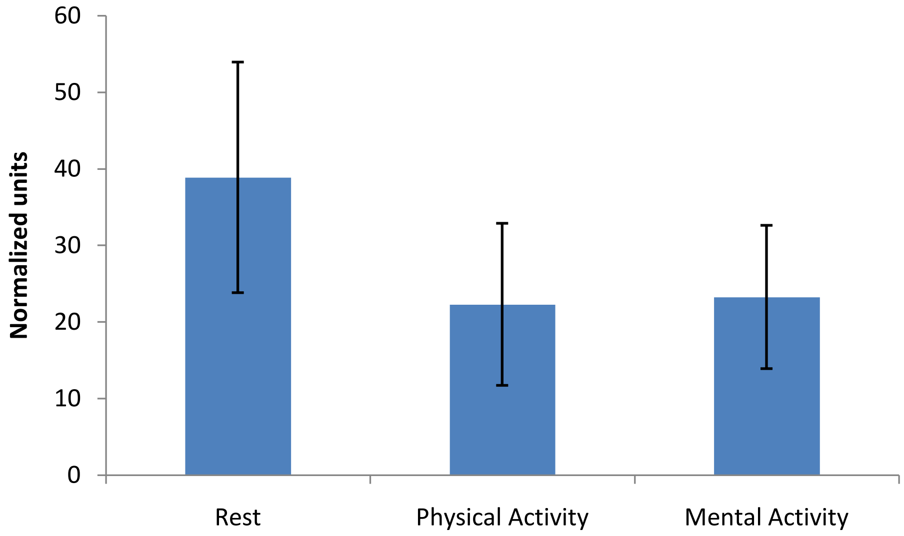

Figure 3 Mean (SD) of HF Components at Rest and While Performing Tasks

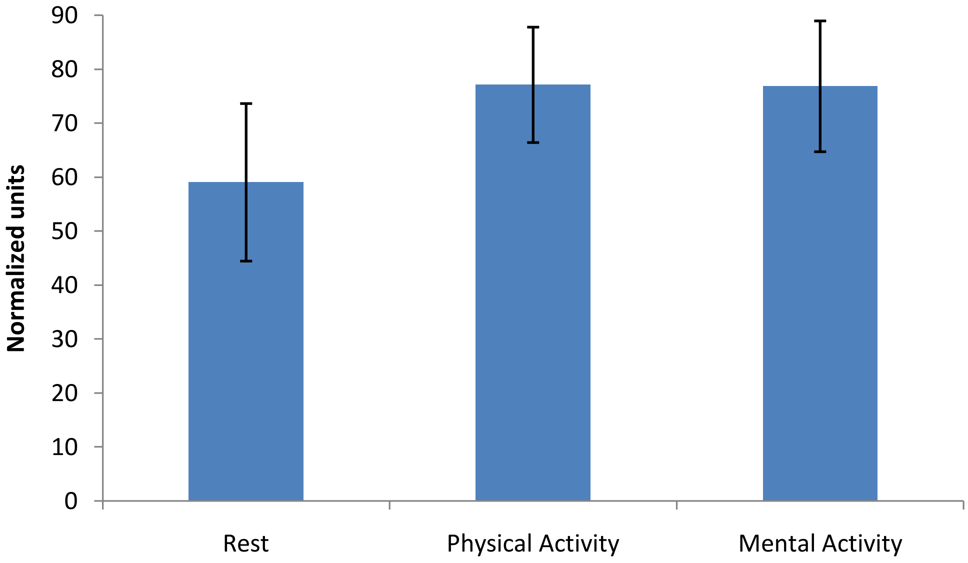

Figure 4 Mean (SD) of LF Components at Rest and While Performing Activities.

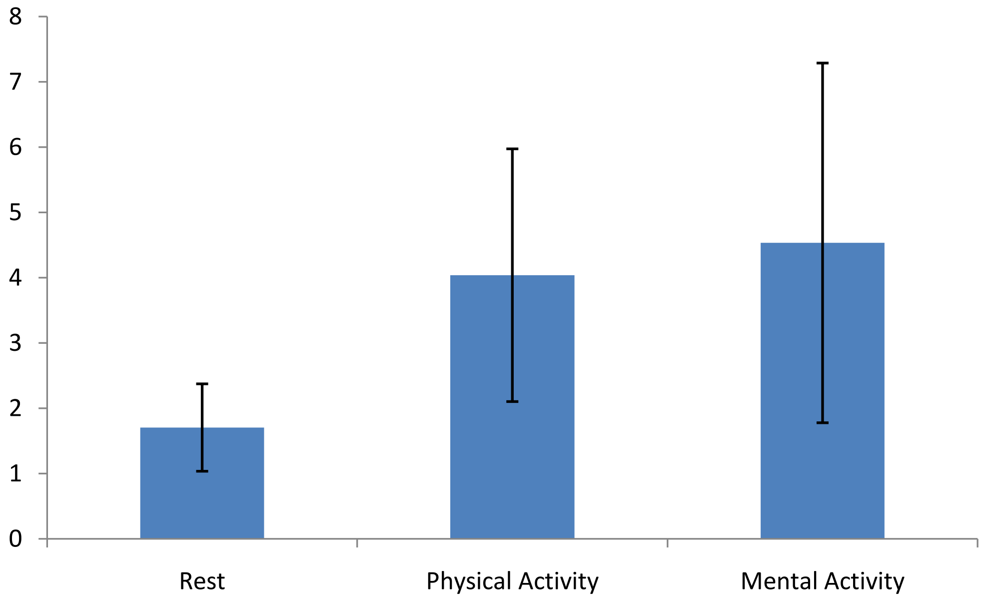

Figure 5 Mean (SD) of LF/HF Components at Rest and While Performing Activities

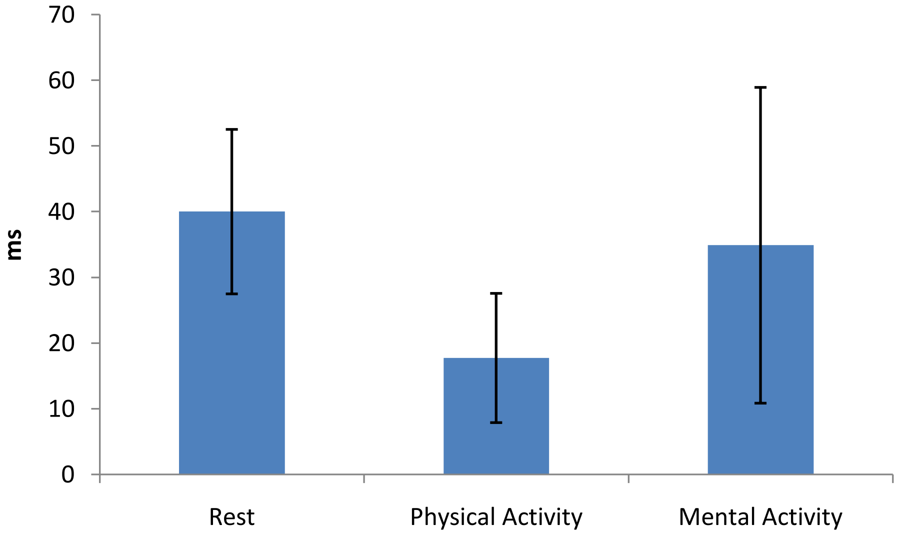

Figure 6 Mean (SD) of RMSSD Components at Rest and While Performing Activities

Figure 3 shows that the HF component for physical activity is lesser than mental activity, which shows high physical strain due to asymmetrical lifting and awkward postures which were included in the physical task. High LF component indicated strain for both the physical and mental activity cases but it is slightly higher for physical activity as depicted in Figure 4. Figure 5 shows that the LF/HF ratio was higher for the mental activity which is an estimate of mental stress. The LF component was higher for physical activity than for mental activity again indicating greater physical stress. Lower HRV was indicated for the physical task. Lower HF power indicated high physical stress during the physical activity. The RMSSD values for the physical activity were lower than for the mental task. This showed that there was reduced HRV during the physical activity than during mental task (Figure 6). The time domain measure RMSSD is analogous with the frequency domain measure of the HF component. Both these components were sensitive to physical stress and decreased when physical stress was induced.

4.2 NASA-TLX Results

Mean (SD) perceived workload for each demand when the physical task and mental task were performed is shown in the Table 4.

Table 4 Mean (SD) Perceived Workload for Each Demand for the Physical & Mental Tasks

	Physical Task	Mental task
Mental demand	18.1 (16.1)	73.6 (21.0)
Physical demand	80.7 (14.0)	11.9 (16.8)
Temporal demand	36.0 (23.0)	79.2 (27.1)
Performance	40.8 (20.0)	66.1 (27.5)
Frustration	27.5 (25.0)	55.8 (26.2)
Effort	63.5 (24.6)	64.5 (26.5)
Overall Workload	58.2 (10.6)	65.5 (16.1)

The physical workload for the physical task is 81 on a scale of 0-100, indicating that on average the participants felt they were under high physical stress. The same applies to the mental workload for the mental task. The overall workload for the mental task is higher than for the physical task (though not significantly higher). This can be attributed to the higher values of perceived temporal demand for the mental task. The average values of each demand obtained for both the tasks are plotted in a graph (Figure 7).

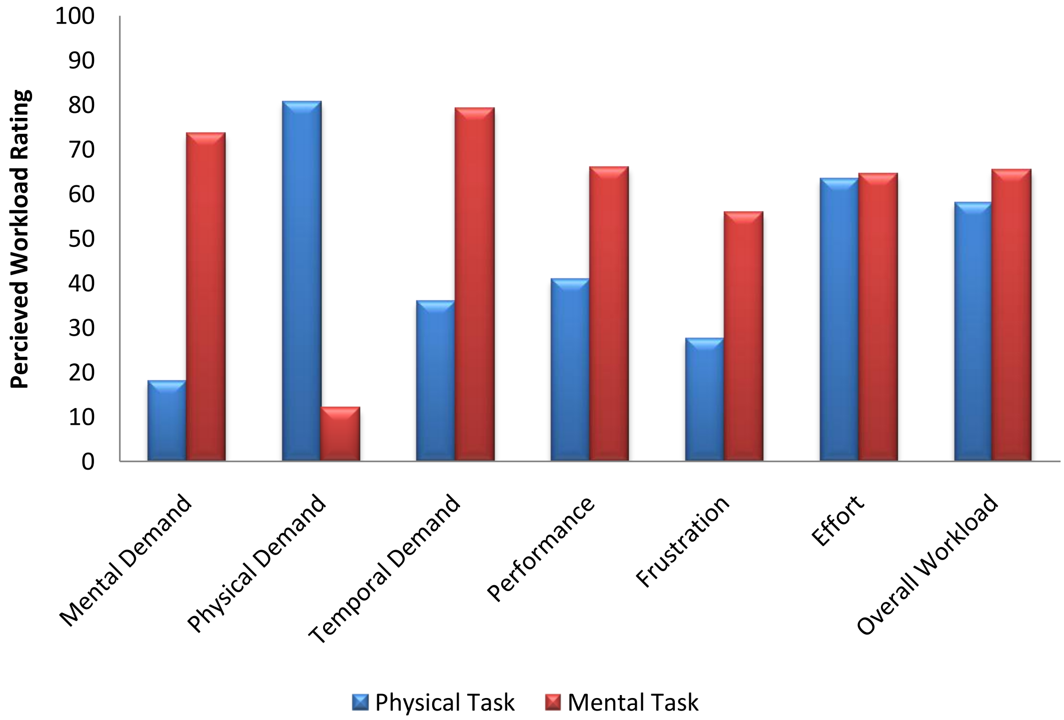

Figure 7 Mean of NASA-TLX Perceived Workload Ratings for Each Task

The graph (Figure 7) is indicating higher levels of physical demand (p-value <0.0001) which is justified by the nature of the lifts the participants have to perform. A higher level of mental demand (p-value <0.0001), performance standards (p-value 0.0006) and temporal demand (p-value <0.0001) is indicated for the mental activity, which is again justified by the type of task that is to be performed. The physical and mental workload perceived by the participants is also reflected by the fluctuation in the power spectral components obtained from the analysis of the RR interval data.

4.3 Comfort Questionnaire

As mentioned in the methodology section, the questionnaire consisted of fourteen questions pertaining to the levels of comfort of the participant while wearing the heart rate monitor and performing the experimental tasks. The scores were anywhere between 0 and 75. Anything over a score of 43 was considered comfortable. The average comfort score obtained for the physical task was 47.75 (6.29) and for the mental task it was 49.95 (4.98). There was no significant difference between the comfort levels for the different tasks. Both the average comfort scores are well above the cutoff value of 43. The results show that the average comfort levels the participant experienced while doing the both the tasks was “comfortable”. The comfort scores indicate that, on an average the participants were willing to wear the monitor on a normal working day.

5. DISCUSSION

The physical and mental tasks were conducted as described earlier to evaluate the effects of physical and mental tasks on HRV and to check for potential task and trial order effects on the HR variables. As expected the type of task performed did affect the power spectral components and the RMSSD. The general values of the standard measures of HRV recorded while the participants were lying down in supine position are given as: LF (n.u) is 54(4), HF (n.u) is 29(3). LF/HF is 1.5 – 2.0, RMSSD is 27(12)ms (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). The values obtained under rest conditions for this study are: LF (n.u) is 59 (14.6), HF (n.u) is 39 (15), LF/HF is 1.7 (0.5) and the RMSSD (ms) is 40 (12), which are in compliance with the standard values shown here. Although these readings are not recorded while the person was lying in a supine position, it was ensured that the participants were in a calm environment and were in a sitting position without any major movements or distractions. For the purpose of this study the power spectral components were compared in the form of normalized units (n.u) i.e., as a percentage of total power disregarding the VLF component. The normalization tends to minimize the effects of changes in total power on the values of LF and HF components as it excludes the less reliable VLF components from its estimates giving an idea of how LF and HF components change with respect to the total power (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). However it should be noted that normalized units in this study are only used to compare changes in each of the components with respect to the baseline values and the natural logarithm transformed values are used in the actual statistical analysis.

The HF component decreased significantly from the base line (rest) value for both the tasks, indicating the stress was induced in the participants. HF at rest was 38.8 (15) (n.u) and it decreased to 24.2 (9.3) (n.u) and 22.2 (10.5) (n.u) for the mental and physical tasks respectively. HF power represents the influence of respiration on heart rate and is assigned to parasympathetic activity (Vuksanovic and Gal, 2007) and is characterized by the respiratory sinus arrhythmia (RSA) (Kamath and Fallen, 1993). When highly frequent parasympathetic modulation occurs, it results in increased heart rate (Vuksanovic and Gal, 2007). This is what probably happened during the physical task and the mental task. The HF component decreased further for during the physical task as the breathing pattern changes owing to the awkward postures and the frequent lifting.

The LF component increased significantly from the baseline (59.0 (14.6)) to 76.8 (12.1) and 77.1 (10.6) for both the physical and mental tasks. A study by Kamath et.al (1993), showed that changes in posture increased the power under the LF frequency significantly. Also increased LF is observed during 90 degrees tilt of the head while the body is in supine position, standing, mental stress, moderate exercise in healthy subjects and physical activity (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). This explains the higher values of the LF component for both the physical and mental tasks. Contrary to this finding, it was also seen that the LF component decreased during steady state exercise (Kamath, Fallen and McKelvie, 1991; Pagani, Lombardi, Guzzetti et al., 1986), but the precise reasons for this reduction are unclear. The current findings of this study are justified as the physical task designed as it cannot be classified as steady state exercise.

The LF/HF ratio increased from the baseline from 1.7 (0.5) to 4.0 (1.9) and 4.5 (2.5) for the physical and mental tasks respectively, but was not affected by the type of task performed. Other studies also found LF/HF ratio increased 2.5 times higher than at rest after high intensity exercise (Perini and Veicsteinas, 2003). In a study by Collins (2005) et al., this ratio was used as a sympathetic measure and the HF power as parasympathetic activity to assess job strain. They found that the ratio was significantly elevated and the HF power demonstrated a significant reduction in the high strain group on workdays. It could be seen from this study also that the LF/HF ratio increased when the tasks were performed and the HF power decreased supporting the findings of Collins et al., (2005) Hjortskov et.al., (2004). During low intensity tasks some authors have stated that a shift of autonomic interaction occurred toward sympathetic dominance, as indicated by the reduced HF power, with a concomitant increase in LF power and thus an increase in the LF/HF ratio (Perini and Veicsteinas, 2003). Trial order was never a significant factor in influencing the HR variables as a rest period of 5 minutes was allowed between the tasks. This amount of rest period is chosen based on the observation that HRV spectral analysis showed that autonomic control of HR returned to control conditions within 5 minutes of recovery from sub maximal exercise (Perini and Veicsteinas, 2003).

The main finding of this study, that HRV indices i.e., HF, LF and the LF/HF ratio are sensitive indicators of mental and physical stress, agree with a number of other studies using either prolonged (Collins, Karasek and Costas, 2005; Pagani, Mazzuero, Ferrari et al., 1991) or short term exposure to psychosocial stressors (Hjortskov, Rissen, Blansted et al., 2004). Pagani (1991) et al, tested the hypothesis that psychological stress testing in the clinical laboratory provokes changes in the sympathetic and vagal activities regulating heart rate that can be assessed noninvasively using spectral analysis of RR variability. They found that the low-frequency component of RR variability, a marker of sympathetic activity, increased from 58 +/- 5 normalized units (n.u) to 68 +/- 3 NU with the mental task performed on the computer and to 76 +/- 3 n.u with the more stressful interview. The findings in this study indicated the same levels of increase in the LF power.

The time domain variable RMSSD is highly correlated with the HF power component (Kamath and Fallen, 1993; Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). This correlation was evident during 24 hour recordings but not with short term recordings. In this study the RMSSD decreased from a baseline value of 40 (12) ms to 17 (9.8) ms for the physical task and 34.8 (24) ms for the mental task. The decrease in RMSSD values was significant for both the tasks and very prominent for the physical task. The reason could be because the HF power is regulated by the respiratory sinus arrhythmia (Kamath and Fallen, 1993). Due to the way the physical task was designed, there might have been changes in breathing pattern reducing the HF and RMSSD components, indicating reduction in HRV. Although the recordings are short term (<15minutes), the RMSSD components showed a similar trend as the HF component.

Previous studies concentrated either on mental stress affecting heart rate (Backs, Lenneman and Sicard, 1999; Collins, Karasek, and Costas, 2005; Hjortskov, Rissen, Blansted et al., 2004; Vuksanovic and Gal, 2007) or changes in HRV due to different kinds of physical exercise ((Kamath, Fallen and McKelvie, 1991; Perini and Veicsteinas, 2003; Yamamoto, Hughson and Peterson 1991). This particular study attempted to create a realistic manual material handling job similar to the procedures developed by Straker (1997) et al, and a mental task which needs some cognitive ability. Theoretically HF component is more sensitive to physical movement and is lower for physical tasks, the LF component is sensitive to stress in general (either physical or mental, but in general is higher for mental stress), the LF/HF ratio indicates autonomic balance (for any kind of activity) and the RMSSD is similar to the HF component. The ANOVA results showed that difference in type of task performed make a significant difference to the LF and HF components. Therefore, for the current study it can be said that type of task can be identified easily based on the LF and HF spectrum estimates, but further research is need to extrapolate these conclusions to different kinds of physical activities or mental activities. All the power spectral components followed the expected trend that healthy people were to follow when subjected to stress. Allowing a rest period of 5 minutes in between the tasks minimized the chances of task interactions.

The NASA-TLX perceived workload rating for the mental task is 73.6 (21) and 80.7 (14) for the physical task. The overall workload (from all 6 scales) was 58.2 (10.6) for the physical task and 65.5 (16.1) for the mental task. The task load index scale revealed that physical and effort demands were essential components of workload for the physical task. Similarly mental, performance and temporal demands were essential components of workload for the mental task. The overall work load is slightly lower for the physical task owing to its nature i.e., there is no temporal or performance demands placed on the participant. The task was explained in advance to the participants and they also were given some practice. They were able to perform the task with ease with regard to the temporal and performance demand lowering the overall workload. Although there is no significant difference, the overall workload for the mental task is slightly higher owing to the higher temporal demand and the performance demand placed on the participant. Most of the participants could not finish 75% of the task before the allotted time of 10 minutes. Higher average performance demand also indicated that the participants were not satisfied with their performance in the mental task.

Various studies also showed that the NASA-TLX is sensitive to changes in mental and physical workload (Collet, Averty and Dittmar, 2009; DiDomenico and Nussbaum, 2008). Previous studies used the Borg's scale of perceived exertion while performing manual material handling tasks and also measured the heart rate while doing physical tasks (Straker, Stevenson and Twomey, 1997) and concluded that the magnitude of heart rate differences between tasks was similar to that for the perceived exertion, supporting the notion that perceived exertion is sensitive to the general body feeling. Another study on air traffic controllers by Collet (2009) et al, showed that the TLX subjective ratings and the instantaneous heart rate measured showed strong correlation. The study showed that the workload rating and the HR shared a linear relationship. Contrary to these findings, Miyake (2001) found that NASA-TLX did not co-vary much with the physiological responses recorded during task performance. One of the physiological responses used in that study was the LF/HF ratio. This discrepancy was justified by stating an example where in, if participants were to complete a very complex task, they would have a feeling of accomplishment. But if at the very end of the task if they encountered a problem, they may feel frustrated inflating the workload. However, the physiological responses recorded during the task period would have been similar because, in both cases, the participants performed their task in the same way except for the problem encountered at the end. The problem that occurred at the end of the task could not affect the responses during the task. Thus, even if the task is the same, the subjective workload scores rated after the task may be affected greatly by the task results, while the physiological responses recorded during the task are not (Miyake, 2001). Feelings of achievement are important in evaluating workload. However, the correlation between such feelings and the physiological responses during the task may be low (Miyake, 2001). This could have been the case with the mental activity here and explains the higher overall workload score. As the participants could not complete the reading comprehension on time, they could have felt that their performance was poor, which is also indicated by higher performance demand scores. In the current study, although correlation analysis was not done, general observation revealed that the subjective ratings given by the participants for the physical task were in agreement with the physiological responses recorded. The workload ratings for the mental task also follow the physiological responses recorded, but at this point we cannot be sure if they are significantly correlated or not.

With growing awareness on cardiac health care the usage of HR monitors is increasing. Various heart rate monitors are available, facilitating people to monitor their own heart rate. This study attempted to assess the comfort levels while wearing one such monitor and performing the tasks so as to see how feasible it is to wear the HR monitor in a real work setting on a work day. The average comfort scores obtained are 47.7 (6.29) and 49.9 (4.98) for the physical and mental tasks respectively on a scale of 0-75. Any value above 43 was considered to be the comfort zone. These average scores indicated that the participants were comfortable wearing the monitor and performing the tasks. In a study by Ahtinen et al. (2008), surveys and interviews from 860 active or former users of heart rate monitors were conducted and among the several factors that caused diminished usage, one of the factors stated was the ergonomics of the HRM belts which were thought of as impractical to wear. It was reported that wearing the heart rate belt began to feel uncomfortable, after the initial enthusiasm wore off. So far a number of reliability studies have been done (Gamelin, Berthoin and Bosquet, 2006; Kingsley, Lewis and Marson, 2005) but none of these studies assess comfort levels. The comfort scores obtained in this study look promising to be used in a real time work setting on a normal work day.

6. CONCLUSIONS

6.1 Limitations

There are several sources of potential limitations to this study which will be divided into data interpretation, equipment, personal differences, experimental setup and practical applications.

Different authors use different techniques to represent, analyze and interpret the power spectral components of the RR interval data. The current study used the natural logarithm transformed absolute power values and the normalized units. Perini et al (2003) used the HR power spectral components as a percentage of the total power and observed that the LF power did not change at all at medium intensity of exercise which is contrary to the majority of findings that LF does increase. This discrepancy was attributed to the differences in representing the data. Studies that reported increases in LF component represented the data in normalized units (n.u) or natural logarithmic transformed values of the absolute power of each component. A certain amount of caution must be exercised while comparing and interpreting data to other studies.

The heart rate monitor (HRM) used in this study is polar RS800, which was originally designed for cross training, running etc. but not specifically designed for general physical tasks. Although various studies assessed the reliability of Polar HRMs (Gamelin, Berthoin and Bosquet, 2006; Kingsley, Lewis and Marson, 2005; Laukkanen and Virtanen, 1998; Porto and Junqueira, 2009) and found that they are highly accurate and are correlated to the ECG recordings, there is still room for error because of the task type in the current study. These studies reported that limits of agreement of the polar devices in comparison with the conventional ECG machine were ±2beats/min (Kingsley, Lewis, and Marson, 2005) (which is sufficient for HRV analysis).

Although gender, age and ethnicity were recorded for each participant, they were not considered in the analysis for the current study. Individual differences in participants could affect the results of the HR variables and NASA-TLX subjective workload rating. All the participants were students and most of them completed the study around the time of final exams, which could potentially increase perceived stress ratings compared to any other time of the year. Gender, age and levels of physical fitness must also have affected the stress ratings as individuals differed from each other. Individuals also differed in levels of comprehension, meaning some of them found the reading comprehension hard to complete in the given time and some of them found it relatively easy. This also could have been another factor affecting perceived mental stress. The HR at rest was measured the participants were requested to sit quietly without major movements or disturbing thoughts, but in reality this could not be completely monitored as one's thought process was difficult to control.

The experimental setup was standardized between participants (20% of maximum weight, height of shelf's adjusted to one's shoulder height, fixed task time for all participants, adjustable seat height for mental task etc.). However, most of the participants were not comfortable with lifting frequently to shoulder height and complained of soreness after some time. This might have caused increased effort and physical demand rating as well as increase in heart rate. The strap of the heart rate monitor was adjustable, but some of the participants complained about how the HRM kept "slipping down" from its position making them uncomfortable during the physical task. This could be one of the reasons for the lower comfort score for the physical task compared to the mental task.

The experimental tasks were intended to simulate mental and physical stress, and the actual tasks were designed as closely as possible to a realistic work place situation. However, the physical task may not be very realistic for college students to perform as in regular life they do not do frequent lifting and carrying. It was intended to generate a general manual material handling task. In reality people who actually handle those jobs might be more accustomed to it and might have performed it with ease. The mental task also may not be a real time situation. A more realistic example of mental stress would be answering phones and greeting customers (stock exchanges, call centers etc.), working overtime (Fire fighters, health care), multi-tasking and rushing to meet deadlines (manual material handling, IT services or any corporate industry).

The participants answered a comfort questionnaire that was described earlier. The tasks performed were over a brief period of time only which is in contrast to a work place where a person works for a period of 8 hours. The comfort score might look positive due to the shorter duration of tasks in the laboratory. Nevertheless a majority of the participants answered that they would be willing to wear the HRM on a normal work day.

6.2 Future Directions

The present study examined only the effects of mental and physical activity on response of the heart, although many factors (physical, psychological and individual) contribute to the development of cardiovascular diseases. There are various physiological responses like blood pressure, heart rate and catecholamine and cortisol secretion to different kinds of stress induced on the human body in general. The current study examines only one such response i.e., the response of the heart to physical and mental stress induced in a laboratory setting. However, these responses do not only serve the role of stress indicators, but are also of interest as a possible link between psychosocial stress and various physical health outcomes. It may be that the culmination of various factors cause more pronounced effects on physiological outcomes than any single factor alone. It may be helpful to expand physical outcome levels to certain hormone levels like catecholamine and cortisol secretion.

As mentioned in the limitations section, the tasks used in the current study may not be an accurate representation of the tasks performed in workplaces. Future research should focus on real time field studies that monitor heart rate of workers over a period of time that could provide support for laboratory studies. A number of studies have been performed on patients with myocardial infarction (Belkic, Landsbergis, Schnall et al., 2004; Kamath, Ghista, Fallen et al., 1987; Quintana, Storckt, Lindbald et al., 1997) but to our knowledge there are no studies done over a period of time in a particular work place setting where there have been absences due to cardiac diseases. One real time application of heart rate monitors could be to monitor the heart rate of workers in regular intervals and look for any abnormalities that may help identify risk of heart diseases. Stress levels could always be kept at a minimum by redesigning the work place or decreasing the intensities of the tasks to be performed or by introducing rest periods in between the tasks. The current study only related the changes in heart rate variability with different kinds of activities. Future research should investigate how changes in HRV can possibly be used to analyze the root causes for CVDs. Also the design of the tasks is such that there are low and high intensities of required effort all over the duration of the tasks. In the current study HR was analyzed as a whole and not as a function of task intensity. Future studies could focus on how HR variables behave at different intensities of the tasks and in different positions. This study does not directly attribute to causes of CVDs in relation to the variability in HR, but instead investigates potential effects of physical and mental stress induced that could lead to CVDs. Future research is also warranted into how the perceived workload ratings are correlated with the heart rate variables.

6.3 Contributions

The outcomes of the current study can be summarized as follows:

- All the heart rate variables were sensitive to physical and mental stress.
- The HF component decreased with increase in demands. It was especially sensitive to physical demands and was lowered during the physical task.
- The LF component increased with increase in stress levels in general and was more sensitive to the mental task.
- The LF/HF ratio increased with increase in demands irrespective of the type of task performed.
- The RMSSD component varied in a similar fashion as the HF component and was a sensitive indicator of physical stress.
- The NASA-TLX work load scores closely varied in accordance with the physiological response.
- The comfort levels showed that participants were comfortable wearing the HRM while performing physically and mentally demanding tasks.

Previous studies have examined the effects of steady state exercise, low, moderate and high intensity exercise effects on heart rate variability. The current study examined the behavior of power spectral components when a mental task and a physical task that mimics a manual material handling task, were performed. The potential effects of task type and trial order were studied in the interest of how physical and mental tasks affect established biomarkers of stress i.e., the heart rate variables. The NASA-TLX tool has not been used earlier in conjunction with heart rate variables measured while performing these kind of physical and mental activities designed for this study. They provide insight into how the perceived work load levels vary along with the heart rate variables. It can be concluded that quantitative assessment of cardiac autonomic activities can be obtained from spectral analysis of HRV. To our knowledge, this is the first study that assesses the comfort level of the wearer of HRMs. This study assessed the overall comfort levels of the participants and concluded that it is feasible to use heart rate monitors in real time work places. The participants were wearing the monitor for duration of 50 minutes for each session and reported that they were comfortable. Although it may be impractical to use HRMs for 24hr recordings, it is feasible to use them for shorter recordings on a normal work day. This study provides evidence that physical and mental exertion produces significant changes in the heart rate variables, thus indicating a change in the parasympathetic and sympathetic nervous systems with regard to the stress induced. The evidence suggests that these responses of the HR variables to stress can be used as some of the sensitive indicators to predict risk of CVDs in work places. These responses could also be used in redesigning tasks and workplaces to minimize risk of CVDs.

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APPENDIX 1 INFORMED CONSENT

The Use of Portable Physiological Monitoring Device in Work Tasks to Assess Health Risks

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Purpose of the Study: The purpose of this research project is to determine if portable physiological measuring devices, specifically heart rate monitors, can be feasibly used to accurately and reliably measure occupational disease risk factors.

Subject Inclusion: Individuals, ages 18-30, who exhibit excellent health conditions and who are interested examining and analyzing their heart rate, may participate. Each participant must refrain from strenuous exercises, heavy alcohol consumption, and frequent smoking the day prior to the experiment. Each participant must also refrain from foods and beverages that contain caffeine (including energy drinks) and/or tobacco on the day of the test. It is recommended to receive a full eight hours of sleep, and to eat a light breakfast/lunch at least 2 hours prior to testing.

Exclusion criteria: Individuals that have the following conditions:

Cardiovascular diseases (including the use of a pacemaker or other electronic implant)

Musculoskeletal disorders

Currently taking medications that may affect heart rate

Pregnant women

Current pain that would affect the ability to perform lifting tasks

Sedentary lifestyle (no regular physical activity)

Any answers of “yes” on the PAR-Q (to be given after this form is signed)

Reading ability below 8th grade level

Number of Subjects: 30 (15 males, 15 females)

Study Procedures: You will first read this consent form and be given a verbal explanation of the experiment. If you agree to the terms of participation, you will sign the informed consent form and complete a demographics questionnaire and the PAR-Q (Physical Activity Readiness Questionnaire). You will wear a heart rate monitor which includes a watch and chest strap during the entire experiment. An experimenter will give you verbal instructions on how to put on the heart rate monitor, which consists of a strap worn around the chest. You will put on the heart rate monitor by yourself in the restroom. An experimenter will visually inspect the monitor's placement when you return and provide verbal instructions if you need to correct any problems with the monitor's placement. Please tell the experimenters if you would prefer a matched-gender experimenter to do this inspection (An experimenter will ask your preference, which will be maintained for all experiments.) When you return you will begin a five-minute period of sitting quietly to obtain resting heart rate. The experimenter will record your resting heart rate as the lowest rate during any 15-second increment during the five minutes. The experiment will be terminated if your heart rate exceeds 85% of your maximum heart rate (220 - Age, from Eastman Kodak Company, 2004) at any point during the experiment.

You will then perform an exercise to determine your maximum lifting strength and be trained on the experimental task. To determine the weight to be lifted during the physical demands task, a series of short static exertions will be conducted on a force platform to elicit maximum exertions. You will stand on a platform and hold a metal plate with hand grips at elbow height. The metal plate will be chained to the platform and adjusted such that there is no slack in the chain at elbow height. When instructed, pull up on the metal plate with as much exertion as possible for 4-5 seconds (the recording device emits a sound when the maximum is recorded and is the indication to relax.) This procedure will be repeated three times with a resting period of one minute between each exertion. The weight used in the subsequent task will be 20% of your maximum lifting ability.

You will perform two tasks, a physically demanding task and a mentally demanding task. Both are expected to change your heart rate with respect to your resting heart rate. Both tasks will be performed for fifteen minutes. The physical activity will include the lifting of a box containing weights at a percent of the participant's lifting capacity. Prior to performing the physical activity, you will be given instructions on the procedures and be allowed to practice with just the box (no weights in the box) for 3 minutes. This will also serve as a warm-up exercise. The mental activity will include the reading of a passage and the answering of questions related to the reading. You will be asked to complete 2 questionnaire measures after completing each task, and you will be given 5 minutes to rest between activities. The questionnaires will ask your perceived level of demands during each task and your comfort level with respect to the heart rate monitor.

If at any time you experience discomfort and would like to discontinue any activity, please tell the experimenter.

You will repeat these experimental procedures for a total of two sessions. The sessions must be 2-14 days apart.

Benefits: There are no direct benefits; however, this experiment may provide future information that is helpful in improving our understanding of work related non-fatal injuries and illnesses.

Risks/Discomforts: There may be a slight discomfort in the lifting process which may lead to fatigue and aching of the muscles. There is also the slight chance of muscle strain from performing maximal exertions. However, these exertions last no more than 5 seconds. The potential physical fatigue is not expected to be any greater than that experienced after exercising. Participants are encouraged to inform the experimenter if discomfort or pain occurs.

Right to Refuse: At any time during the experiment, you have the right to not participate or withdraw from the study. There will be no penalties for withdrawal.

Privacy: The LSU Institutional Review Board (which oversees university research with human subjects) may inspect and/or copy the study records.

Results of the study may be published, but no names or identifying information will be included in the publication.

Other than as set forth above, participant identity will remain confidential unless disclosure is legally compelled.

Financial Information: You will be compensated $8/hour for participation at the end of each experiment session.

Withdrawal: If you choose to no longer participate in the experiment, then you will be compensated for the amount of time in which you participated.

Removal: You are expected to comply with the investigators' instructions. If you fail to comply, you will be removed by an investigator from the experiment, and you will be compensated for the amount of time you participated.

Signatures:

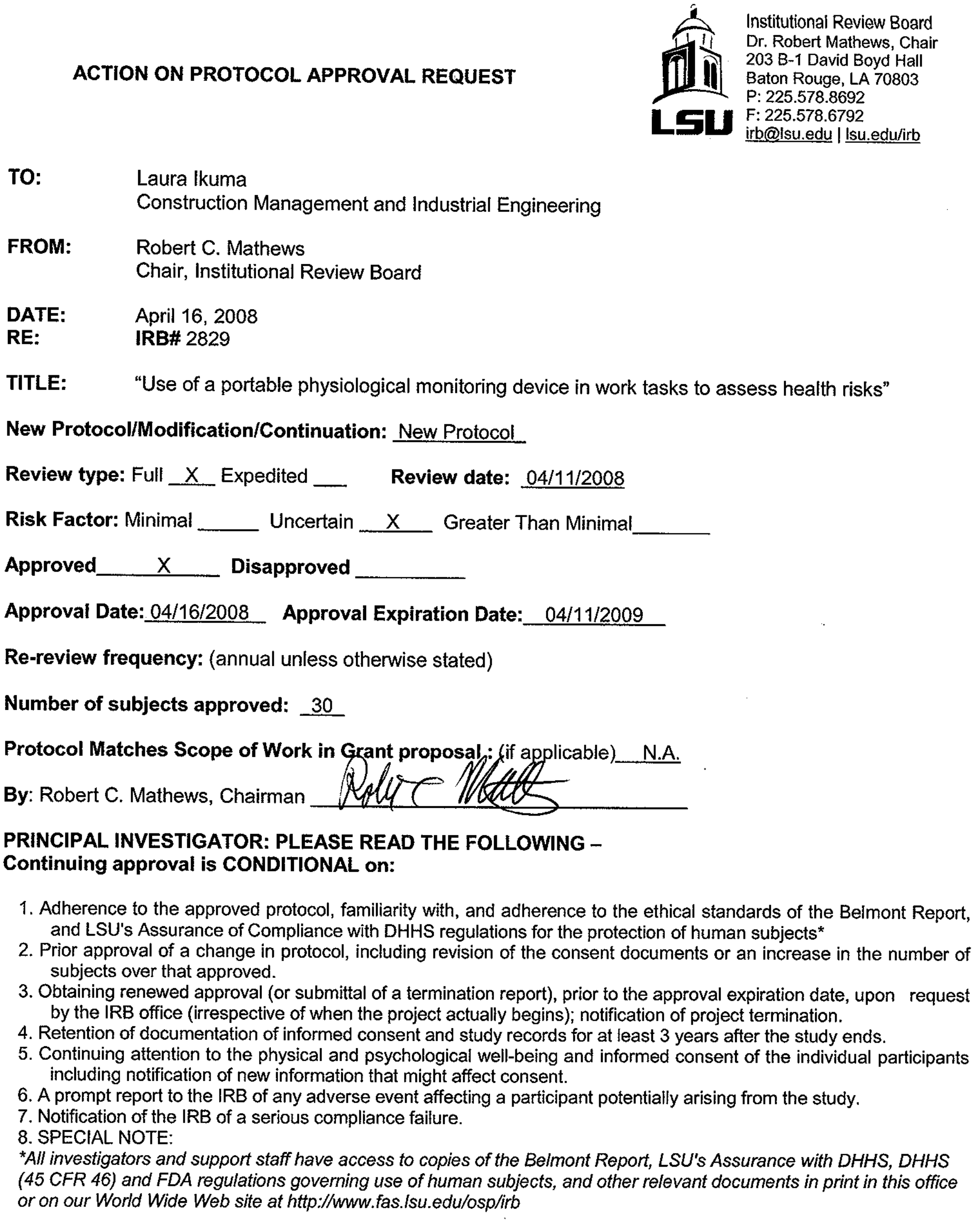
The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about participants' rights or other concern, I can contact Robert C. Mathews, Institutional Review Board, (225) 578-8692. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of the consent form.

______________________________________ ______________________________

Subject Signature Date

______________________________________print name

APPENDIX 2 IRB APPROVAL



ACTION ON PROTOCOL APPROVAL REQUEST

LSU
Institutional Review Board
Dr. Robert Mathews, Chair
203 B-1 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.6792
irb@lsu.edu | lsu.edu/irb

TO: Laura Ikuma
Construction Management and Industrial Engineering

FROM: Robert C. Mathews
Chair, Institutional Review Board

DATE: April 16, 2008
RE: **IRB#** 2829

TITLE: "Use of a portable physiological monitoring device in work tasks to assess health risks"

New Protocol/Modification/Continuation: New Protocol

Review type: Full _X_ Expedited ___ **Review date:** 04/11/2008

Risk Factor: Minimal _____ Uncertain _X_ Greater Than Minimal _____

Approved _X_ **Disapproved** _____

Approval Date: 04/16/2008 **Approval Expiration Date:** 04/11/2009

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 30

Protocol Matches Scope of Work in Grant proposal: (if applicable) N.A.

By: Robert C. Mathews, Chairman

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.fas.lsu.edu/osp/irb*

APPENDIX 3 PAR-Q

Physical Activity Readiness Questionnaire (PAR-Q)

For most people, physical activity should not pose any problem or hazard. This questionnaire has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the suitable type of activity.

1.	Has your doctor ever said you have heart trouble?	Yes	No
2.	Do you frequently suffer from chest pains?	Yes	No
3.	Do you often feel faint or have spells of severe dizziness?	Yes	No
4.	Has a doctor ever said your blood pressure was too high	Yes	No
5.	Has a doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by, or might be made worse with exercise	Yes	No
6.	Is there any other good physical reason why you should not follow an activity program even if you want to?	Yes	No
7.	Are you 65 and not accustomed to vigorous exercise	Yes	No

If you answer "yes" to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary.

I have read this questionnaire, I understand it does not provide a medical assessment in lieu of a physical examination by a physician.

Participant's signature____________________ Date __________

Investigator'signature____________________ Date___________

Adapted from PAR-Q Validation Report, British Columbia Department of Health, June, 1975.

Reference:

Hafen, B. Q. & Hoeger, W. W. K. (1994). Wellness: Guidelines for a Healthy Lifestyle. Morton Publishing Co: Englewood, CO.

APPENDIX 4 DEMOGRAPHICS DATA FORM

Please answer the following questions as honestly as possible.

Age: __________

Gender: __________

Race/Ethnicity: _____________________

Are you a native English speaker (Is English your first language)? Yes _____ No _____

Please describe any regular exercise patterns in which you participate, including physical labor as part of employment: ____

____

____

____

____

Have many hours a week do you work out (if applicable)? __________

For what period of time have you been working out (if applicable)? __________

Please check Yes or No for the following questions as they apply to you:

Do you have any cardiovascular or musculoskeletal condition (conditions of the heart, lungs, muscles, or bones/joints) that affects your heart rate or ability to perform manual labor? If you are pregnant or think you might be pregnant, also check "yes"

Yes _____ No _____

Are you currently taking any medications that may affect your heart rate? Yes _____ No _____

Are you currently experiencing any pain that would affect your ability to perform lifting activities?

Yes _____ No _____

APPENDIX 5 NASA-TLX

NASA-TLX DESCRIPTIONS

Refer to these descriptions as you complete the Workload Rating sheet.

Mental Demand: *Low/High* How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand: *Low/High* How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal Demand: *Low/High* How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance: *Excellent/Poor* How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Effort: *Low/High* How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration Level: *Low/High* How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

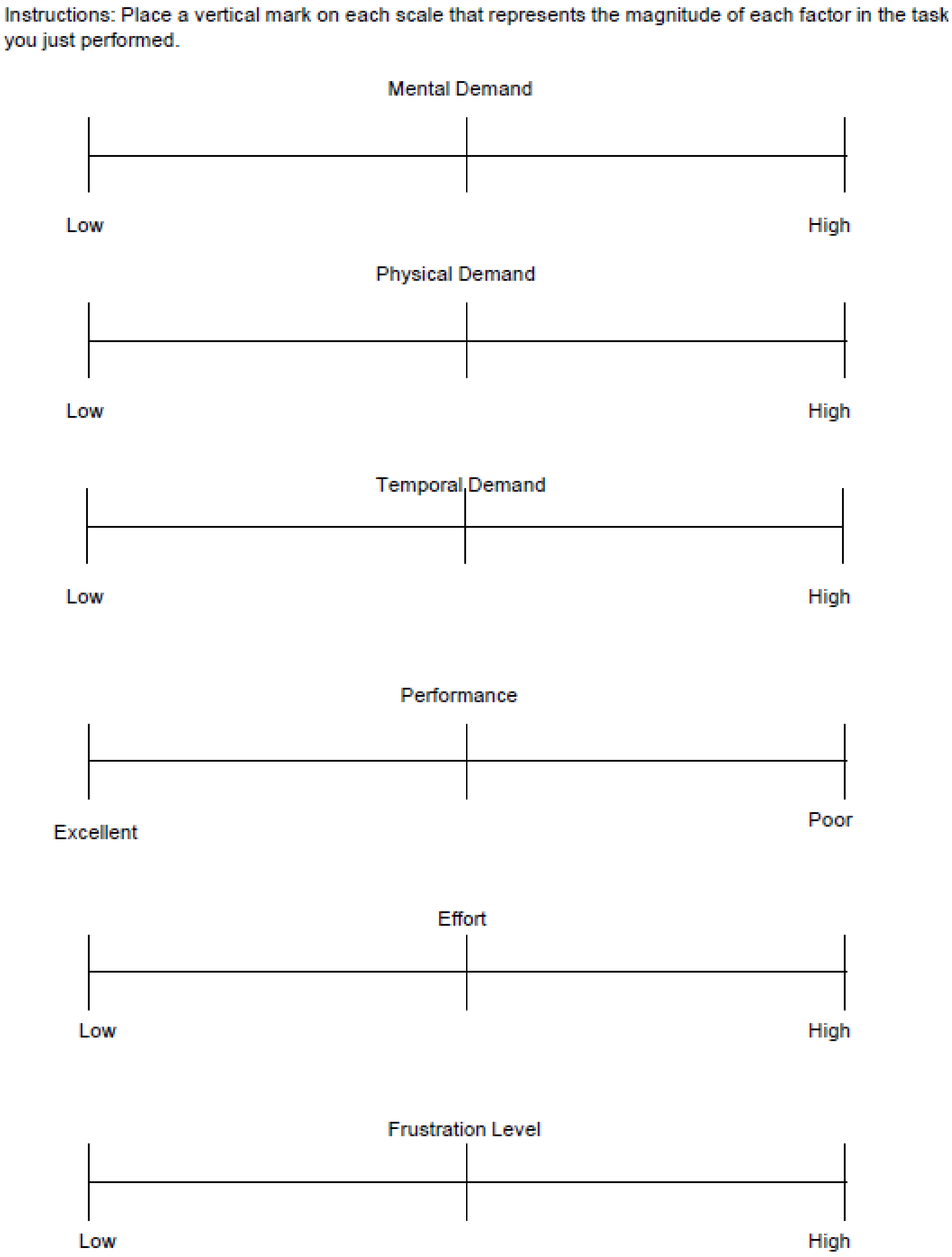
NASA-TLX PAIR WISE COMPARISONS

For each pair of demands, circle the demand that you feel will be a greater source of workload in the task you are about to complete. Please refer to the description sheet for each demand if needed.

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

Effort Frustration

WORKLOAD RATING



Instructions: Place a vertical mark on each scale that represents the magnitude of each factor in the task you just performed.

Mental Demand

Low High

Physical Demand

Low High

Temporal Demand

Low High

Performance

Excellent Poor

Effort

Low High

Frustration Level

Low High

APPENDIX 6 COMFORT QUESTIONNAIRE

Comfort level of wearing the watch:

1 **What was your level of ease in doing the task while wearing the watch ?**

(1) Very difficult
(2) Somewhat difficult
(3) Neutral
(4) Somewhat easy
(5) Very easy

2 **What was your awareness level of the watch during the experiment?**

(1) Very aware
(2) Somewhat aware
(3) Neutral
(4) Somewhat unaware
(5) Not aware at all

3 **What was your level of distraction from the watch during the task?**

(1) Very distracted
(2) Somewhat distracted
(3) Neutral
(4) Not Distracted
(5) Not Distracted at all

4 **The watch was adjustable to accommodate your wrist size?**

(1) Strongly disagree
(2) Disagree
(3) Neutral
(4) Agree
(5) Strongly agree

5 **What was your overall level of comfort while wearing the watch?**

(1) Very Uncomfortable
(2) Uncomfortable
(3) Neutral
(4) Comfortable
(5) Very comfortable

Comfort level of wearing the chest strap:

6 **What was your level of ease in doing the task while wearing the chest strap ?**
(1) Very difficult
(2) Somewhat difficult
(3) Neutral
(4) Somewhat easy
(5) Very easy

7 **What was your awareness level of the chest strap during the experiment?**
(1) Very aware
(2) Somewhat aware
(3) Neutral
(4) Somewhat unaware
(5) Not aware at all

8 **What was your level of distraction from the chest strap during the task?**
(1) Very distracted
(2) Somewhat distracted
(3) Neutral
(4) Disagree
(5) Strongly disagree

9 **The chest strap was adjustable to accommodate your chest size?**
(1) Strongly disagree
(2) Disagree
(3) Neutral
(4) Agree
(5) Strongly agree

10 **What was your overall level of comfort while wearing the chest strap?**
(1) Very Uncomfortable
(2) Uncomfortable
(3) Neutral
(4) Comfortable
(5) Very comfortable

Comfort level of the watch and the chest strap:

1 **Describe your level of comfort while wearing the heart monitor (watch and chest**

1 strap)
(1) Very Uncomfortable
(2) Uncomfortable
(3) Neutral
(4) Comfortable
(5) Very comfortable

1 Describe your level of discomfort while wearing the heart monitor (watch and chest
2 strap)
(1) Very Uncomfortable
(2) Uncomfortable
(3) Neutral
(4) Comfortable
(5) Very comfortable

1
3 Describe your level of anxiety while wearing the heart monitor
(1) Very anxious
(2) Somewhat anxious
(3) Neutral
(4) Somewhat calm
(5) Very calm

1
4 In a work day, I would be willing to wear this monitor doing the same task?
(1) Strongly disagree
(2) Disagree
(3) Neutral
(4) Agree
(5) Strongly agree

APPENDIX 7 MENTAL ACTIVITY

Subpart E—Exit Routes, Emergency Action Plans, and Fire Prevention Plans

Authority: Secs. 4, 6, 8, Occupational Safety and Health Act of 1970 (29 U.S.C. 653, 655, 657); Secretary of Labor's Order Nos. 12-71 (36 FR 8754), (8-76 41 FR 25059), 9-83 (48 FR 35736) or 1-90 (55 FR 9033), 6-96 (62 FR 111), or 3-2000 (65 FR 50017), as applicable.

§1910.33 Table of contents.

This section lists the sections and paragraph headings contained in §§ 1910.34 through 1910.39.

Sec. 1910.34 Coverage and definitions.
  (a) Every employer is covered.
  (b) Exit routes are covered.
  (c) Definitions.

Sec. 1910.35 Compliance with NFPA 101-2000, Life Safety Code.

Sec. 1910.36 Design and construction requirements for exit routes.
  (a) Basic requirements.
  (b) The number of exit routes must be adequate.
  (c) Exit discharge.
  (d) An exit door must be unlocked.
  (e) A side-hinged exit door must be used.
  (f) The capacity of an exit route must be adequate.
  (g) An exit route must meet minimum height and width requirements.
  (h) An outdoor exit route is permitted.

Sec. 1910.37 Maintenance, safeguards, and operational features for exit routes.
  (a) The danger to employees must be minimized.
  (b) Lighting and marking must be adequate and appropriate.
  (c) The fire retardant properties of paints or solutions must be maintained.
  (d) Exit routes must be maintained during construction, repairs, or alterations.
  (e) An employee alarm system must be operable.

Sec. 1910.38 Emergency action plans.
  (a) Application.
  (b) Written and oral emergency action plans.
  (c) Minimum elements of an emergency action plan.
  (d) Employee alarm system.
  (e) Training.
  (f) Review of emergency action plan.

Sec. 1910.39 Fire prevention plans.
  (a) Application.
  (b) Written and oral fire prevention plans.
  (c) Minimum elements of a fire prevention plan.
  (d) Employee information.

§1910.34 Coverage and definitions.

1910.34(a) *Every employer is covered.* Sections 1910.34 through 1910.39 apply to workplaces in general industry except mobile workplaces such as vehicles or vessels.

1910.34(b) *Exits routes are covered.* The rules in Sec. Sec. 1910.34 through 1910.39 cover the minimum requirements for exit routes that employers must provide in their workplace so that employees may evacuate the workplace safely during an emergency. Sections 1910.34 through 1910.39 also cover the minimum requirements for emergency action plans and fire prevention plans.

1910.34(c) *Definitions.* Electroluminescent means a light-emitting capacitor. Alternating current excites phosphor atoms when placed between the electrically conductive surfaces to produce light. This light source is typically contained inside the device.

Exit means that portion of an exit route that is generally separated from other areas to provide a protected way of travel to the exit discharge. An example of an exit is a two-hour fire resistance-rated enclosed stairway that leads from the fifth floor of an office building to the outside of the building.

Exit access means that portion of an exit route that leads to an exit. An xample of an exit access is a corridor on the fifth floor of an office building hat leads to a two-hour fire resistance-rated enclosed stairway (the Exit).

Exit discharge means the part of the exit route that leads directly outside or to a street, walkway, refuge area, public way, or open space with access to the outside. An example of an exit discharge is a door at the bottom of a two-hour fire resistance-rated enclosed stairway that discharges to a place of safety outside the building.

Exit route means a continuous and unobstructed path of exit travel from any point within a workplace to a place of safety (including refuge areas). An exit route consists of three parts: The exit access; the exit; and, the exit discharge. (An exit route includes all vertical and horizontal areas along the route.)

High hazard area means an area inside a workplace in which operations include high hazard materials, processes, or contents.

Occupant load means the total number of persons that may occupy a workplace or portion of a workplace at any one time. The occupant load of a workplace is calculated by dividing the gross floor area of the workplace or portion of a workplace by the occupant load factor for that particular type of workplace occupancy. Information regarding "Occupant load" is located in NFPA 101-2000, Life Safety Code.

Refuge area means either:

(1) space along an exit route that is protected from the effects of fire by separation from other spaces within the building by a barrier with at least a one-hour fire resistance-rating; or

(2) A floor with at least two spaces, separated from each other by smoke-resistant partitions, in a building protected throughout by an automatic sprinkler system that complies with Sec. 1910.159 of this part.

Self-luminous means a light source that is illuminated by a self-contained power source (*e.g.*, tritium) and that operates independently from external power sources. Batteries are not acceptable self-contained power sources. The light source is typically contained inside the device.

§1910.35 Compliance with NFPA 101-2000, Life Safety Code.

An employer who demonstrates compliance with the exit route provisions of NFPA 101-2000, the Life Safety Code, will be deemed to be in compliance with the corresponding requirements in Sec. Sec. 1910.34, 1910.36, and 1910.37.

§1910.36 Design and construction requirements for exit routes.

1910.36(a) Basic requirements. Exit routes must meet the following design and construction requirements: **(1)** An exit route must be permanent. Each exit route must be a permanent part of the workplace.

1910.36(a)(2) An exit must be separated by fire resistant materials. Construction materials used to separate an exit from other parts of the workplace must have a one-hour fire resistance-rating if the exit connects three or fewer stories and a two-hour fire resistance-rating if the exit connects four or more stories.

1910.36(a)(3) Openings into an exit must be limited. An exit is permitted to have only those openings necessary to allow access to the exit from occupied areas of the workplace, or to the exit discharge. An opening into an exit must be protected by a self-closing fire door that remains closed or automatically closes in an emergency upon the sounding of a fire alarm or employee alarm system. Each fire door, including its frame and hardware, must be listed or approved by a nationally recognized testing laboratory. Section 1910.155(c)(3)(iv)(A) of this part defines "listed" and Sec. 1910.7 of this part defines a "nationally recognized testing laboratory."

1910.36(b) The number of exit routes must be adequate. **(1)** Two exit routes. At least two exit routes must be available in a workplace to permit prompt evacuation of employees and other building occupants during an emergency, except as allowed in paragraph (b)(3) of this section. The exit routes must be located as far away as practical from each other so that if one exit route is blocked by fire or smoke, employees can evacuate using the second exit route.

1910.36(b)(2) More than two exit routes. More than two exit routes must be available in a workplace if the number of employees, the size of the building, its occupancy, or the arrangement of the workplace is such that all employees would not be able to evacuate safely during an emergency.

1910.36(b)(3) A single exit route. A single exit route is permitted where the number of employees, the size of the building, its occupancy, or the arrangement of the workplace is such that all employees would be able to evacuate safely during an emergency.

Note to paragraph 1910.36(b): For assistance in determining the number of exit routes necessary for your workplace, consult NFPA 101-2000, Life Safety Code.

1910.36(c) Exit discharge. **(1)** Each exit discharge must lead directly outside or to a street, walkway, refuge area, public way, or open space with access to the outside.

1910.36(c)(2) The street, walkway, refuge area, public way, or open space to which an exit discharge leads must be large enough to accommodate the building occupants likely to use the exit route.

1910.36(c)(3) Exit stairs that continue beyond the level on which the exit discharge is located must be interrupted at that level by doors, partitions, or other effective means that clearly indicate the direction of travel leading to the exit discharge.

1910.36(d) An exit door must be unlocked. **(1)** Employees must be able to open an exit route door from the inside at all times without keys, tools, or special knowledge. A device such as a panic bar that locks only from the outside is permitted on exit discharge doors.

1910.36(d)(2) Exit route doors must be free of any device or alarm that could restrict emergency use of the exit route if the device or alarm fails.

1910.36(d)(3) An exit route door may be locked from the inside only in mental, penal, or correctional facilities and then only if supervisory personnel are continuously on duty and the employer has a plan to remove occupants from the facility during an emergency.

1910.36(e) A side-hinged exit door must be used. **(1)** A side-hinged door must be used to connect any room to an exit route.

1910.36(e)(2) The door that connects any room to an exit route must swing out in the direction of exit travel if the room is designed to be occupied by more than 50 people or if the room is a high hazard area (i.e., contains contents that are likely to burn with extreme rapidity or explode).

1910.36(f) The capacity of an exit route must be adequate. **(1)** Exit routes must support the maximum permitted occupant load for each floor served.

1910.36(f)(2) The capacity of an exit route may not decrease in the direction of exit route travel to the exit discharge.

Note to paragraph 1910.36(f): Information regarding "Occupant load" is located in NFPA 101-2000, Life Safety Code.

1910.36(g) An exit route must meet minimum height and width requirements.

1910.36(g)(1) The ceiling of an exit route must be at least seven feet six inches (2.3 m) high. Any projection from the ceiling must not reach a point less than six feet eight inches (2.0 m) from the floor.

1910.36(g)(2) An exit access must be at least 28 inches (71.1 cm) wide at all points. Where there is only one exit access leading to an exit or exit discharge, the width of the exit and exit discharge must be at least equal to the width of the exit access.

1910.36(g)(3) The width of an exit route must be sufficient to accommodate the maximum permitted occupant load of each floor served by the exit route.

1910.36(g)(4) Objects that project into the exit route must not reduce the width of the exit route to less than the minimum width requirements for exit routes.

1910.36(h) An outdoor exit route is permitted. Each outdoor exit route must meet the minimum height and width requirements for indoor exit routes and must also meet the following requirements:

1910.36(h)(1) The outdoor exit route must have guardrails to protect unenclosed sides if a fall hazard exists;

1910.36(h)(2) The outdoor exit route must be covered if snow or ice is likely to accumulate along the route, unless the employer can demonstrate that any snow or ice accumulation will be removed before it presents a slipping hazard;

1910.36(h)(3) The outdoor exit route must be reasonably straight and have smooth, solid, substantially level walkways; and

1910.36(h)(4) The outdoor exit route must not have a dead-end that is longer than 20 feet (6.2 m).

§1910.37 Maintenance, safeguards, and operational features for exit routes.

1910.37(a) The danger to employees must be minimized. **(1)** Exit routes must be kept free of explosive or highly flammable furnishings or other decorations.

1910.37(a)(2) Exit routes must be arranged so that employees will not have to travel toward a high hazard area, unless the path of travel is effectively shielded from the high hazard area by suitable partitions or other physical barriers.

1910.37(a)(3) Exit routes must be free and unobstructed. No materials or equipment may be placed, either permanently or temporarily, within the exit route. The exit access must not go through a room that can be locked, such as a bathroom, to reach an exit or exit discharge, nor may it lead into a dead-end corridor. Stairs or a ramp must be provided where the exit route is not substantially level.

1910.37(a)(4) Safeguards designed to protect employees during an emergency (*e.g.*, sprinkler systems, alarm systems, fire doors, exit lighting) must be in proper working order at all times.

1910.37(b) Lighting and marking must be adequate and appropriate. **(1)** Each exit route must be adequately lighted so that an employee with normal vision can see along the exit route.

1910.37(b)(2) Each exit must be clearly visible and marked by a sign reading "Exit."

1910.37(b)(3) Each exit route door must be free of decorations or signs that obscure the visibility of the exit route door.

1910.37(b)(4) If the direction of travel to the exit or exit discharge is not immediately apparent, signs must be posted along the exit access indicating the direction of travel to the nearest exit and exit discharge. Additionally, the line-of-sight to an exit sign must clearly be visible at all times.

1910.37(b)(5) Each doorway or passage along an exit access that could be mistaken for an exit must be marked "Not an Exit" or similar designation, or be identified by a sign indicating its actual use (*e.g.*, closet).

1910.37(b)(6) Each exit sign must be illuminated to a surface value of at least five foot-candles (54 lux) by a reliable light source and be distinctive in color. Self-luminous or electroluminescent signs that have a minimum luminance surface value of at least .06 footlamberts (0.21 cd/m^2) are permitted.

1910.37(b)(7) Each exit sign must have the word "Exit" in plainly legible letters not less than six inches (15.2 cm) high, with the principal strokes of the letters in the word "Exit" not less than three-fourths of an inch (1.9 cm) wide.

1910.37(c) The fire retardant properties of paints or solutions must be maintained. Fire retardant paints or solutions must be renewed as often as necessary to maintain their fire retardant properties.

1910.37(d) Exit routes must be maintained during construction, repairs, or alterations. **(1)** During new construction, employees must not occupy a workplace until the exit routes required by this subpart are completed and ready for employee use for the portion of the workplace they occupy.

1910.37(d)(2) During repairs or alterations, employees must not occupy a workplace unless the exit routes required by this subpart are available and existing fire protections are maintained, or until alternate fire protection is furnished that provides an equivalent level of safety.

1910.37(d)(3) Employees must not be exposed to hazards of flammable or explosive substances or equipment used during construction, repairs, or alterations, that are beyond the normal permissible conditions in the workplace, or that would impede exiting the workplace.

1910.37(e) An employee alarm system must be operable. Employers must install and maintain an operable employee alarm system that has a distinctive signal to warn employees of fire or other emergencies, unless employees can promptly see or smell a fire or other hazard in time to provide adequate warning to them. The employee alarm system must comply with Sec. 1910.165.

§1910.38 Emergency action plans.

1910.38(a) Application. An employer must have an emergency action plan whenever an OSHA standard in this part requires one. The requirements in this section apply to each such emergency action plan.

1910.38(b) Written and oral emergency action plans. An emergency action plan must be in writing, kept in the workplace, and available to employees for review. However, an employer with 10 or fewer employees may communicate the plan orally to employees.

1910.38(c) Minimum elements of an emergency action plan. An emergency action plan must include at a minimum:

1910.38(c)(1) Procedures for reporting a fire or other emergency;

1910.38(c)(2) Procedures for emergency evacuation, including type of evacuation and exit route assignments;

1910.38(c)(3) Procedures to be followed by employees who remain to operate critical plant operations before they evacuate;

1910.38(c)(4) Procedures to account for all employees after evacuation;

1910.38(c)(5) Procedures to be followed by employees performing rescue or medical duties; and

1910.38(c)(6) The name or job title of every employee who may be contacted by employees who need more information about the plan or an explanation of their duties under the plan.

1910.38(d) Employee alarm system. An employer must have and maintain an employee alarm system. The employee alarm system must use a distinctive signal for each purpose and comply with the requirements in Sec. 1910.165.

1910.38(e) Training. An employer must designate and train employees to assist in a safe and orderly evacuation of other employees.

1910.38(f) Review of emergency action plan. An employer must review the emergency action plan with each employee covered by the plan:

1910.38(f)(1) When the plan is developed or the employee is assigned initially to a job;

1910.38(f)(2) When the employee's responsibilities under the plan change; and

1910.38(f)(3) When the plan is changed.

§1910.39 Fire prevention plans.

1910.39(a) Application. An employer must have a fire prevention plan when an OSHA standard in this part requires one. The requirements in this section apply to each such fire prevention plan.

1910.39(b) Written and oral fire prevention plans. A fire prevention plan must be in writing, be kept in the workplace, and be made available to employees for review. However, an employer with 10 or fewer employees may communicate the plan orally to employees.

1910.39(c) Minimum elements of a fire prevention plan. A fire prevention plan must include:

1910.39(c)(1) A list of all major fire hazards, proper handling and storage procedures for hazardous materials, potential ignition sources and their control, and the type of fire protection equipment necessary to control each major hazard;

1910.39(c)(2) Procedures to control accumulations of flammable and combustible waste materials;

1910.39(c)(3) Procedures for regular maintenance of safeguards installed on heat-producing equipment to prevent the accidental ignition of combustible materials;

1910.39(c)(4) The name or job title of employees responsible for maintaining equipment to prevent or control sources of ignition or fires; and

1910.39(c)(5) The name or job title of employees responsible for the control of fuel source hazards.

1910.39(d) Employee information. An employer must inform employees upon initial assignment to a job of the fire hazards to which they are exposed. An employer must also review with each employee those parts of the fire prevention plan necessary for self-protection.

APPENDIX TO SUBPART E TO PART 1910—Exit Routes, Emergency Action Plans, and Fire Prevention Plans.

This appendix serves as a nonmandatory guideline to assist employers in complying with the appropriate requirements of subpart E.

§1910.38 Employee emergency plans.

1. *Emergency action plan elements.* The emergency action plan should address emergencies that the employer may reasonably expect in the workplace. Examples are: fire; toxic chemical releases; hurricanes; tornadoes; blizzards; floods; and others. The elements of the emergency action plan presented in paragraph 1910.38 can be supplemented by the following to more effectively achieve employee safety and health in an emergency. The employer should list in detail the procedures to be taken by those employees who have been selected to remain behind to care for essential plant operations until their evacuation becomes absolutely necessary. Essential plant operations may include the monitoring of plant power supplies, water supplies, and other essential services which cannot be shut down for every emergency alarm. Essential plant operations may also include chemical or manufacturing processes which must be shut down in stages or steps where certain employees must be present to assure that safe shut down procedures are completed.

The use of floor plans or workplace maps which clearly show the emergency escape routes should be included in the emergency action plan. Color coding will aid employees in determining their route assignments. The employer should also develop and explain in detail what rescue and medical first aid duties are to be performed and by whom. All employees are to be told what actions they are to take in these emergency situations that the employer anticipates may occur in the workplace.

2. *Emergency evacuation.* At the time of an emergency, employees should know what type of evacuation is necessary and what their role is in carrying out the plan. In some cases where the emergency is very grave, total and immediate evacuation of all employees is necessary. In other emergencies, a partial evacuation of nonessential employees with a delayed evacuation of others may be necessary for continued plant operation. In some cases, only those employees in the immediate area of the fire may be expected to evacuate or move to a safe area such as when a local application fire suppression system discharge employee alarm is sounded. Employees must be sure that they know what is expected of them in all such emergency possibilities which have been planned in order to provide assurance of their safety from fire or other emergency.

The designation of refuge or safe areas for evacuation should be determined and identified in the plan. In a building divided into fire zones by fire walls, the refuge area may still be within the same building but in a different zone from where the emergency occurs.

Exterior refuge or safe areas may include parking lots, open fields or streets which are located away from the site of the emergency and which provide sufficient space to accommodate the employees. Employees should be instructed to move away from the exit discharge doors of the building, and to avoid congregating close to the building where they may hamper emergency operations.

3. *Emergency action plan training.* The employer should assure that an adequate number of employees are available at all times during working hours to act as evacuation wardens so that employees can be swiftly moved from the danger location to the safe areas. Generally, one warden for each twenty employees in the workplace should be able to provide adequate guidance and instruction at the time of a fire emergency. The employees selected or who volunteer to serve as wardens should be trained in the complete workplace layout and the various alternative escape routes from the workplace. All wardens and fellow employees should be made aware of handicapped employees who may need extra assistance, such as using the buddy system, and of hazardous areas to be avoided during emergencies. Before leaving, wardens should check rooms and other enclosed spaces in the workplace for employees who may be trapped or otherwise unable to evacuate the area.

After the desired degree of evacuation is completed, the wardens should be able to account for or otherwise verify that all employees are in the safe areas.

In buildings with several places of employment, employers are encouraged to coordinate their plans with the other employers in the building. A building-wide or standardized plan for the whole building is acceptable provided that the employers inform their respective employees of their duties and responsibilities under the plan. The standardized plan need not be kept by each employer in the multi-employer building, provided there is an accessible location within the building where the plan can be reviewed by affected employees. When multi-employer building-wide plans are not feasible, employers should coordinate their plans with the other employers within the building to assure that conflicts and confusion are avoided during times of emergencies. In multi-story buildings where more

Instructions: Use the provided regulations to find the answers to each question. You have 10 minutes to complete this section. Please work as quickly and accurately as possible.

1. How many exit routes must be provided in a workplace?

    a. 1
    b. 2
    c. 3
    d. 4

2. What is the definition of *occupant load*?
    a. Total number of persons that may occupy a workplace
    b. Total weight of persons on a floor of a workplace
    c. Amount of weight allowed on an elevator
    d. Total number of persons allowed on a bus

3. How long must materials used for exits resist fire in a building of three or fewer stories?
    a. 1 hour
    b. 2 hours
    c. 3 hours
    d. 4 hours

4. How wide must an exit access be?
    a. 20 inches
    b. 28 inches
    c. 36 inches
    d. 40 inches

5. What is the minimum height of letters on an exit sign?
    a. 3 inches
    b. 4 inches
    c. 5 inches
    d. 6 inches

6. Which of the following is ***not*** a requirement of an emergency action plan?
    a. Must be in writing (for more than 10 employees)
    b. Must include procedures for emergency evacuation
    c. Must include the phone number of the closest fire station
    d. Must be available for employee review

7. Which of the following is a required characteristic of a fire exit door?
   a. Must swing out in the direction of travel
   b. Must be side-hinged
   c. Must remain unlocked (with a few exceptions)
   d. All of the above

8. A written fire prevention plan must include a list of all of the following ***except***
   a. Major fire hazards
   b. Handling and storage procedures for hazardous materials
   c. Potential ignition sources and their control
   d. Location of all fire extinguishers

9. What is an *exit discharge*?
   a. Continuous and unobstructed path of exit travel to a place of safety
   b. Portion of an exit route that is separated from other areas
   c. Part of the exit route that leads directly outside
   d. Portion of an exit route that leads to an exit

10. An employer who demonstrates compliance with exit route provisions of which Code will also be deemed in compliance with codes of this document?
    a. Fire Safety
    b. Life Safety
    c. Health Safety
    d. Emergency Safety

11. What is the minimum height of the ceiling of an exit route?
    a. 8 ft 2 inches
    b. 7 ft 6 inches
    c. 6 ft 6 inches
    d. 7 ft 2 inches

12. Each ext sign must be illuminated to a surface value of what?
    a. 54 lux
    b. 20 lux
    c. 65 lux
    d. 32 lux

13. The outdoor exit route must not have dead-end that is longer than how many feet?
    a. 15 feet
    b. 30 feet
    c. 10 feet
    d. 20 feet

14. What must doorways that can be mistaken as an exit be marked with?

a. “No”
b. “Next”
c. “Not an Exit”
d. “Go”

15. How often must fire retardant paints or solutions be renewed?
    a. Every 3 years
    b. Every year
    c. Every 4 years
    d. As often necessary to maintain their fire retardant properties

16. What is not acceptable as a self-contained power source?
    a. Batteries
    b. Tritium
    c. Self-lit exit sign
    d. Paint that glows in the dark

17. An area which includes high hazard materials, processes, or contents is known as what?
    a. Safe Area
    b. Emergency Area
    c. High Hazard Area
    d. Exit Area

18. How is the occupant load calculated?
    a. Dividing the gross floor area by the occupant load factor
    b. Adding the gross floor area to the occupant load factor
    c. Multiplying the gross floor area to the occupant load factor
    d. Subtracting the gross floor area from the occupant load factor

19. A light source that is illuminated by a self-contained power source is said to be what?
    a. Powerful
    b. Battery Operated
    c. Self-luminous
    d. All of the above

20. What is an exit access?
    a. Portion of an exit route that is generally separated from other areas
    b. Portion of an exit route that leads to an exit
    c. Portion of an exit route that leads directly outside or to a street
    d. An unobstructed path of exit travel form any point within an workplace to a place of safety

VITA

Satya Paritala was born in Warangal in September, 1985. Warangal is in Southern India and is known for its historical significance. She attended middle and high school there. She earned her undergraduate degree from Kakatiya Institute of Science and Technology, in the field of electronics and communications engineering in June, 2007. She joined the Department of Construction Management and Industrial Engineering, at Louisiana State University in August, 2007. At LSU she worked as a graduate assistant in the Department of Industrial Engineering. She expects to receive her Master of Science in Industrial Engineering degree in Fall 2009. Satya is an active member of the Alpha Pi Mu engineering honor society and the Institute of Industrial Engineers. She intends to pursue her MBA after working for a few years.