THE EFFECT HEART RATE VARIABILITY BIOFEEDBACK TRAINING FOR IMPROVING COGNITIVE PERFORMANCE AMONG FEMALE MANUFACTURING OPERATORS

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We certify that the thesis entitled "The Effect of Heart Rate Variability Biofeedback for Improving Cognitive Performance among Female Manufacturing Operators" is written by Auditya Purwandini Sutarto . We have examined the final copy of this thesis and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Technology Management. We herewith recommend that it be accepted in fulfillment of the requirements for the degree of Doctor of Philosophy specializing in Technology Management

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurently submitted for award of other degree.

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Dedicated to my husband and my little angels

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ABSTRACT

Cognitive is an essential characteristic of capacity factors that promotes a good work performance. To address with more sophisticated global manufacturing environment, performance at the operative level becomes more critical because of predominantly cognitive tasks assigned and less importance of human manual control. Moreover, most operators perform their cognitive functions below their peak performance due to many reasons such as fatigue, boredom, and stress. To date there has not been much research conducted on the use of biofeedback training for cognitive performance enhancement. Heart rate variability (HRV) biofeedback shows potential application in performance enhancement. The objective of this study is to examine the effect of HRV biofeedback training for the improvement of cognitive performance in electronic manufacturing operators industry. Subjects consisted of 36 female operators from an electronic manufacturing factory in Kuantan, Malaysia who were randomly assigned as the experimental group ($n = 19$), and control group ($n = 17$). The intervention participants received five session of weekly HRV biofeedback training of 30-50 minutes each. Physiological stress profiles, cognitive performance, and self-reports questionnaire (Depression, Anxiety, and Stress Scale) were assessed before and after the intervention. Results of two-way repeated measures ANOVA indicated that there were significant group x time interaction effects for attention, memory, and cognitive flexibility. Within group analysis using paired *t*-tests revealed that, as opposed to the control group, the intervention group improved significantly on all cognitive measures. The training participants also showed decrease on depression, anxiety, and stress (all $p < 0.01$). Significant within-group improvements were also found for the biofeedback participants during physiological stress profile in percentage of LF activity and breaths per minute. Further, the biofeedback group showed significant increase in LF activity, SDNN, and slower breathing rate throughout five sessions. The HRV data confirms that the participants learned how to effectively manipulate and control activity in the autonomic nervous system. Similar significant results did not exist in the control group. In summary, this study provides potential application of HRV biofeedback for operator's cognitive performance enhancement, in parallel with increase HRV.

ABSTRAK

Kognitif merupakan ciri yang penting dari segi fakta kapasiti yang mempromosikan presetasi kerja yang baik bagi menghadapi persekitaran perkilangan yang lebih global dan canggih. Prestasi pada pekerja level operator pengeluar menjadi kritikal kerana sebahagian besar tugas yang diberikan adalah kognitif dan kurang pemantauan. Lain daripada itu, kebanyakannya pekerja kilang menjalankan fungsi kognitif mereka dibawah prestasi puncak mereka kerana pelbagai alasan seperti keletihan, kebosanan, dan stress. Sehingga kini belum ada banyak ujian yang dilakukan mengenai penggunaan latihan biofeedback dalam peningkatan prestasi kognitif. Variabiliti kadar jantung (HRV) biofeedback menunjukkan potensi dalam peningkatan prestasi. Tujuan kajian ini adalah untuk menguji pengaruh latihan biofeedback HRV untuk peningkatan prestasi kognitif dalam industri pembuatan. Subjek terdiri dari 36 pekerja wanita daripada kilang pembuatan elektronik di Kuantan, Malaysia, yang secara rawak ditugaskan sebagai kumpulan biofeedabck (n = 19) dan kumpulan kawalan (n = 17). Para peserta ujian menerima lima sesi latihan biofeedback HRV, satu kali tiap minggu, masing-masing 30-50 minit. Profil fisiologis stress, prestasi kognitif, dan soal selidik (Skala Kemurungan, Kegelisahan, dan Stress) diukur sebelum dan selepas ujian. Hasil penemuan ANOVA dua hala ukuran berulang menunjukkan bahawa terdapat pengaruh interaksi kumpulan x masa yang signifikan untuk perhatian, memori, dan fleksibilitas kognitif. Dalam analisis kumpulan dengan menggunakan ujian t untuk dua kumpulan sampel bersandaran menunjukkan, bertentangan dengan kumpulan kawalan, kumpulan biofeedback meningkat secara signifikan pada semua ukuran kognitif. Para peserta latihan juga menunjukkan penurunan tahap kemurungan, kegelisahan, dan stress (semua $p < 0.01$). Perbaikan dalam kumpulan juga dijumpai signifikan di kumpulan biofeedback dalam peratusan aktiviti LF dan nafas per minit. Seterusnya kumpulan biofeedback menunjukkan peningkatan ketara dalam aktiviti LF < SDNN, dan tingkat pernafasan lebih lambat sepanjang lima sesi latihan. Data HRV menegaskan bahawa para peserta belajar bagaimana memanipulasi secara kesan dan mengendalikan aktiviti sistem saraf autonomi. Keputusan yang signifikan tidak ketara pada kumpulan kawalan. Kesimpulannya, kajian ini menunjukkan potensi biofeedback HRV untuk peningkatan prestasi kognitif pekerja kilang seiring dengan peningkatan HRV.

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LIST OF ABBREVIATION

HR	Heart Rate
HRV	Heart Rate Variability
ANS	Autonomic Nervous System
CNS	Central Nervous System
LF	Low Frequency
VLF	Very Low Frequency
HF	High Frequency
SDDN	Standard Deviation N-N Interval
IBI	Inter Beat Interval
RFT	Resonant Frequency Training
EEG	Electroenchepalography
EMG	Electromyography
ECG	Electrocardiography
r^2	Square of Pearson Correlation
d	Cohen effect size

GLOSSARY OF TERMS

A	Autonomic Nervous System (ANS)	The part of the peripheral nervous system that acts as a control system functioning largely below the level of consciousness, and controls visceral functions. The ANS affects heart rate, digestion, respiration rate, salivation, perspiration,diameter of the pupils, micturition (urination), and sexual arousal. Whereas most of its actions are involuntary, some, such as breathing, work in tandem with the conscious mind. It is divided into two subsystems: the parasympathetic nervous system and sympathetic nervous system
B	Baroreceptor	are sensors located in the blood vessels of several mammals. They are a type of mechanoreceptor that detects the pressure of blood flowing through them, and can send messages to the central nervous system to increase or decrease total peripheral resistance and cardiac output. Baroreceptors act immediately as part of a negative feedback system called the baroreflex, as soon as there is a change from the usual mean arterial blood pressure, returning the pressure to a normal level. They are an example of a short-term blood pressure regulation mechanism. Baroreceptors detect the amount of stretch of the blood vessel walls, and send the signal to the nervous system in response to this stretch. The nucleus tractus solitarius in the medulla oblongata recognizes changes in the firing rate of action potentials from the baroreceptors, and influences cardiac output and systemic vascular resistance through changes in the ANS.
	Baroreflex	One of the body's homeostatic mechanisms for maintaining blood pressure. It provides a negative feedback loop in which an elevated blood pressure reflexively causes heart rate and, thus, blood pressure to decrease; in similar fashion, decreased blood pressure depresses the baroreflex, causing heart rate and, thus, blood pressure to rise
C	Central Nervous System (CNS)	The central nervous system (CNS) is that part of the nervous system that consists of the brain and spinal cord. The CNS is one of the two major divisions of the nervous system. The other is the peripheral nervous system (PNS) which is outside the brain and spinal cord. The peripheral nervous system (PNS) connects

the central nervous system (CNS) to sensory organs (such as the eye and ear), other organs of the body, muscles, blood vessels and glands. The peripheral nerves include the 12 cranial nerves, the spinal nerves and roots, and what are called the autonomic nerves that are concerned specifically with the regulation of the heart muscle, the muscles in blood vessel walls, and glands.

E	Electrocardiography (ECG)	Transthoracic interpretation of the electrical activity of the heart over time captured and externally recorded by skin electrodes. It is a noninvasive recording produced by an electrocardiographic device.
	Electroenchepalography (EEG)	The recording of electrical activity along the scalp produced by the firing of neurons within the brain. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a short period of time, usually 20–40 minutes, as recorded from multiple electrodes placed on the scalp.
	Electromyography (EMG)	A technique for evaluating and recording the electrical activity produced by skeletal muscles. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, recruitment order or to analyze the biomechanics of human or animal movement.
H	High frequency band (HF)	Heart rate variability in the frequency band of 0.15–0.4 Hz. This is under control of the parasympathetic nervous system, and is associated with respiratory activity. Although respiratory sinus arrhythmia usually occurs within this band, it may occur at other frequencies if individuals breathe at a rate that is outside this frequency band
	Homeostatic	In human, it refers to the body's ability to physiologically regulate its inner environment to ensure its stability in response to fluctuations in the outside environment and the weather. The liver, the kidneys, and the brain (hypothalamus, the autonomic nervous system and the endocrine system help maintain homeostasis. The liver is responsible for metabolizing

		toxic substances and maintaining carbohydrate metabolism. The kidneys are responsible for regulating blood water levels, re-absorption of substances into the blood, maintenance of salt and ion levels in the blood, regulation of blood pH, and excretion of urea and other wastes. An inability to maintain homeostasis may lead to death or a disease, a condition known as homeostatic imbalance
I	Inter Beat Interval (IBI)	A scientific term used in reference to the time interval between individual beats of the mammalian heart. IBI is generally measured in units of milliseconds. Individual human heart IBI values can vary from as short as 5 milliseconds to as long as 70 milliseconds. In normal heart function, each IBI value varies from beat to beat. This natural variation is known as heart rate variability (HRV). However, certain cardiac conditions may cause the individual IBI values to become nearly constant, resulting in the HRV being nearly zero. This can happen, for example, during periods of exercise as the heart rate increases and the beats become regular. Certain illnesses can cause the heart rate to increase and become uniform as well, such as when a subject is afflicted by an infection.
L	Low frequency band (LF)	Heart rate variability in the frequency band of 0.05–0.15 Hz. This is usually under control of both the sympathetic and parasympathetic nervous systems, and may reflect thermal control and baroreflex control of blood pressure through changes in heart rate. It includes the 0.10 Hz component. It is sometimes called the Traube-Hering-Mayer wave.
P	Power Spectrum	In statistical signal processing and physics, the spectral density, power spectral density (PSD), or energy spectral density (ESD), is a positive real function of a frequency variable associated with a stationary stochastic process, or a deterministic function of time, which has dimensions of power per Hz, or energy per Hz. It is often called simply the spectrum of the signal. Intuitively, the spectral density captures the frequency content of a stochastic process and helps identify periodicities
R	Respiratory Sinus Arrhythmia (RSA)	A naturally occurring variation in heart rate that occurs during a breathing cycle. Heart rate increases during inhalation and decreases during exhalation. Heart rate is normally controlled by centers in the medulla

		oblongata. One of these centers, the nucleus ambiguus, increases parasympathetic nervous system input to the heart via the vagus nerve. The vagus nerve decreases heart rate by decreasing the rate of SA node firing. Upon expiration the cells in the nucleus ambiguus are activated and heart rate is slowed down. In contrast, inspiration triggers inhibitory signals to the nucleus ambiguus and consequently the vagus nerve remains unstimulated.
S	Standard Deviation N-N Interval (SDNN)	This is a time domain measure. It is a general marker of overall adaptability of the system. It is the standard deviation of normal beat-to-beat intervals (SDNN
V	Very low frequency (VLF)	Heart rate variability in the frequency band of 0.005–0.05 Hz. This is under control of the sympathetic nervous system, and may reflect thermal control and baroreflex control of blood pressure through changes in vascular tone.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In recent decades, Malaysia has transformed itself from a country that long relied on agricultural commodities and mining to an industrialized economy. The manufacturing industry is an important engine of economic growth to the Malaysian economy. In the year 1990, it contributed to 24.6 per cent of gross domestic product (GDP). The contribution of the manufacturing industry to GDP increased to 29.2 percent in the year 2008 (Department of Statistics Malaysia, 2009). Although in the year 2009 the manufacturing sector recorded a lower GDP growth of 9.3%, it still contributed to the largest Malaysia's export as much as 41.2 percent of total export, led by exports of electronic products (Department of Statistics Malaysia, 2010). Furthermore, the manufacturing industry in Malaysia has generated a significant amount of employment to the economy. Total employees work in manufacturing sector account for 16.6 percent of employed person in the year 2008 in which most of them serve as operators (Department of Statistic Malaysia, 2010).

The Malaysia Productivity Corporation (MPC) reported that in the year 2008 individual improvement performance accounts for 29.4 percent of total performance elements in the manufacturing sector (MPC, 2009). Regarding its significance contribution of into manufacturing productivity, many firms have been applying variety strategies to improve operators' work performance as a warranty for continuous growth. Common strategies have been executed either as organizational-based approach, such as design of workstation, tools and equipment (Yusuff et al, 1994, and Yeow and Sen, 2003), and optimization of physical environment (Ismail et al., 2009), or individual-based approach, for instance providing training (Yeow and Sen, 2003, and Mustafa et al., 2009). Nevertheless, no study has been reported on enhancing cognitive performance among operators worldwide.

Nowadays, rapid development of modern technologies imposes higher requirements concerning the efficiency of cognitive processes on workers. In today's complex and sophisticated manufacturing system, performance at the operative level becomes more critical because of predominantly cognitive tasks assigned and less importance of human manual control (Hou et al., 1993). It is a common fact that most people perform their cognitive skills below their peak cognitive capacity level. In workplace, there are a number of factors that can affect cognitive performance negatively, such as fatigue, sleep deprivation, boredom, and stress (Bourne and Yaroush, 2003). A boredom, distracted, or tired operator will perform low productivity, or worse, pose a threat of accidents with irreparable consequences (Suvorov, 2006).

Furthermore, based on a work performance model (Blumberg and Pringle, 1982), cognitive is an essential factor of capacity dimension that facilitates an individual to perform task effectively. In combination with emotional balance which is a crucial part of willingness dimension, high cognitive performance level will promote a good work performance despite unfavourable opportunity dimension provided. Therefore, this model will be used as an underpinning theory of this study.

Several studies have suggested various strategies to deal with the assessment and maintenance of cognitive qualities. Hallam et al. (2002) and Cockerton et al. (1997) found that providing background music led to better performance on some cognitive functions. Training has also been proposed as a useful tool for the improvement of cognitive functions including cognitive training (Willis et al., 2006), motor-imagery training (Papadelis et al., 2007), meditation (Moore and Malinowski, 2009), and aerobic training (Kramer et al., 1999, and Hansen et al., 2004). Despite the above works, to date there has not been much training approach has been carried out to apply psychophysiological self-regulation training which uses operators' physiology feedback as a tool to enhance their cognitive functions during their work.

Meanwhile, individual cognitive performance state is not static but fluctuates significantly throughout the day (Newell et al., 2003). Among other risk factors such as nutrition and exercise, stress is the most influencing factor on individual cognitive state (Staal, 2004). In psychophysiology literature, stress is viewed as something that breaks the homeostatic relationship between cognition and the environmental demand. To cope with this problem, various strategies of stress management programs have been undertaken as reviewed by Murphy (1996), Matuszek, (1999) and DeFrank and Cooper (1987). Of the techniques that focus on individual-based, currently biofeedback or psychophysiological self-regulation is a popular approach that attempts to counteract the biological stress response. Nevertheless, no studies have been found that evaluate the efficacy of biofeedback on improving cognitive performance as possible "side effects" of reduced stress-related symptoms.

The concept of psychophysiological is pertinent to the classic inverted-u shape principle of human function curve (Yerkes and Dodson, 1908). This theory reveals that moderate levels of arousal are seen as optimal in regards to producing maximum performance. In a more recent theory, the general terms arousal and performance can be replaced by the use of concept autonomic nervous system (ANS) and cognitive performance (Duschek et al., 2009). People who have ANS balance will perform their cognitive function optimally. Information obtained from an individual's ANS level, thus might be utilized to optimize performance, to prevent reduced well being or health or to prevent accidents (Caldwell, 1994, and Andersen and William, 2007). Technique to use such information is often named a psychophysiological self-regulation.

More specifically, psychophysiological self-regulation refers to the ability of a person to control affective and cognitive states based on ANS and central nervous system (CNS) functioning (Prinzel et al. 2001). The techniques use physiological indicators of these states and provide biofeedback so that the person learns these associations and how to modulate their occurrence. The correction of these human biological conditions is supported by the growing of computer systems with biofeedback in various modalities (bioengineering systems). Visual, auditory, or tactile stimulation are used and, with the subjects' active involvement, self-regulation and self control skills can be acquired and used to correct of their state (Suvorov, 2006).

Currently, there has not been much research conducted on the use of psychophysiological training for performance enhancement in work place. One of the studies was reported by Prinzel et al. (2001) on the use of electroencephalogram (EEG) biofeedback (neurofeedback) for controlling operator's hazardous state of awareness. In addition to neurofeedback, recently heart rate variability (HRV) feedback which is derived from cardiovascular activity shows potential application in performance enhancement.

HRV-biofeedback training works by teaching people to recognize their involuntary heart rate variability and to control patterns of this physiological response. There are several HRV training strategies which can effectively be used to increase cardiac variability in a health enhancing way including resonant frequency training (Lehrer et al., 2000), psychophysiological or heart rhythm coherence feedback, (McCraty 2003), and inherent harmonics or oscillatory biofeedback (Suvorov, 2006). All of these strategies have been successfully applied not only in clinical setting but also in variety domains. McCraty and Tomasino (2004) presented psychophysiological coherence to facilitate people in developing a greater awareness of the connection between their emotions, physiology, and behaviour. This strategy has been effective to reduce musical performance anxiety (Thurber, 2006), increase test scores in high school students (McCraty et al., 2000) and improve sport performance (McCraty and Tomasino, 2004, and Tanis, 2008). In work place setting, Barrios-Choplin et al. (1997) found that HRV biofeedback combined with emotional regulation techniques led to an increase in the workers' productivity and a decrease in the symptoms of stress among company workers comprised of managers, engineers, and factory workers. Moreover, emergency assistance doctors gained benefits of adaptive biological regulation with oscillatory biofeedback from psychophysiological training prior to and during 24-hour duty shifts (Suvorov, 2006). Furthermore, the resonant frequency training strategy has been successfully applied to improve hitters' performance in baseball (Strack, 2003) as well as cognitive performance among female university students in a pilot study (Sutarto and Wahab, 2008). The results from these previous studies are encouraging and indicate the possible effectiveness of use HRV biofeedback in work place settings. HRV biofeedback equips operators with skills to counteract the adverse effects of daily stressor or other block factors on their cognition during work.

1.2 PROBLEM STATEMENT

The manufacturing sector is one of the important sectors to the growth of the Malaysian economy. In the year 2008, it contributed to 29.2 percent of total GDP and employs the largest number workers, accounting for 16.6 percent of total employment which mostly served as operators in the year 2009 (Department Statistic of Malaysia, 2009, 2010). In addition, the contribution of individual performance accounted for 29.4 percent of total productivity elements in the year 2008. Therefore it is extremely important in improving performance of workers at operative level. According to the theory of work performance by Blumberg and Pringle (1982), improving work performance might be directed toward increase opportunity, willingness, and capacity dimensions. Numerous strategies, commonly organizational-approach intervention, have been carried out to provide better opportunity to perform tasks such as redesign of workstation, tools and equipment (Yusuff et al., 1994, and Yeow and Sen, 2003), and optimization physical environment (Ismail et al., 2009). Until now, there is lack of studies examining intervention that can be used for the improvement of both the capacity and the willingness dimensions at operative level. Of the few studies, mostly were carried out by training knowledge, rule, or skill-based training (Yeow and Sen, 2003, and Mustafa et al., 2009), and stress management program (Edimansyah et al., 2008). No work has documented any intervention for the improvement or maintenance cognitive functions among operators.

Finding strategies to improve cognitive performance is considerably important because cognitive is a crucial component of capacity factors to perform work effectively (Blumberg and Pringle, 1982). Furthermore the increase in complexity of the manufacturing industry each year shifts the nature of the human operator’s task from an emphasis on psychomotor activities to an emphasis on cognitive activities. As most of manufacturing employees work at operative level, there is a need to search the appropriate technique for the improvement of their cognitive performance. The present study is concerned about the basis of the individual-focused intervention rather than organization-focused intervention. Even though organizational-based interventions are definitely a valuable goal however, the individual-based strategies are still favourable for a number of logistical and conceptual reasons, including: 1) they are generally inexpensive, and can be established and evaluated in a short period of time, 2) their focus of change is on the worker, rather than the workplace, 3) they address the issue of individual difference (Newell et al. 2003, and Blatter and Cajochen, 2007)

There is a great deal of research indicating the positive effect of music on the cognitive performance improvement (Hallam et al, 2002, and Cockerton, 1997). A variety of training has also been proposed as powerful tools for enhancing cognitive abilities through modifying individuals' skills or attitudes mechanism (Willis et al., 2006; Papadelis et al., 2007, and Moore and Malinowski, 2009) or aerobic training (Kramer et al., 1999, and Hansen, et al., 2004). However, no study to date has been conducted in using psychophysiological self-regulation training for the improvement cognitive performance. Since the success of operator's performance in work systems also depends on their specific ability to work in their environment for a long period of time with minimal error (Suvorov, 2006), the development of a safe, easy-to-implement method to maintain the required cognitive functional level without adverse effects is strongly needed. Psychophysiological training approach can be employed to quickly assist operators to maintain their cognitive focus when performing their work.

One of promising psychophysiology training strategies is by using workers' heart rate variability (HRV) feedback. HRV represents the beat to-beat changes in the interbeat interval (Task Force, 1996). The beat-to-beat variability is affected by ANS activity. It is accepted by scientists that the interaction at the heart is a reflection of ANS balance or imbalance in the body in general (Berntson et al., 1997). Optimum variability in heart rate is crucial because diminished HRV indicates susceptibility to physical and psychological stressors, and disease (Lehrer, 2007). On the opposite, higher HRV has been linked with creativity, psychological resilience, and a more developed capacity to control affective, cognitive, and physiological of stress (Hansen et al., 2003, and Appelhans and Luecken, 2006).

Furthermore, Duschek et al. (2009) proposed a relationship between ANS and cognitive performance that follows a classic concept of inverted u-shaped principle (Yerkes and Dodson, 1908). According to this, both over arousal and under arousal conditions are accompanied by decline in performance while best functional conditions are expected at mid range arousal. A number of researchers has reported that altering a person's arousal state may lead to improved cognitive performance which is often accompanied by subjectively perceived of reduced emotional symptoms (Tart 1969; Ray et al., 2001; Lehrer et al., 2003; Casden, 2005; Thurber, 2006, and Karavidas et al., 2007). One of widely-used strategies is by using HRV activity as a knowledge feedback (i.e. HR biofeedback) to correct the state toward the optimum (McCraty, 2002, and Sutarto and Wahab, 2008). Researchers have published findings that indicate positive effects of using HRV feedback for improving human performance in non-clinical purposes, such as increasing test score among high school students (McCraty, 2000), enhancing sport performance (Strack, 2003; Lagos et al., 2008, and Tanis, 2008), and improving psychomotor quality (Suvorov, 2006). However, currently there is no published research evaluating the efficacy of HRV biofeedback for the improvement of operators' cognitive performance. It was also confirmed by Paul Lehrer in his e-mail on July 12, 2008 who commented that the proposed study will be the first attempt working in this area. Therefore, the effectiveness of HRV biofeedback on a variety of cognitive qualities will be assessed in this study. As the most prominent outcome of HRV biofeedback training is an improved physiological functioning (Lehrer et al., 2003), an evaluation of change in HRV measures will be done as well.

Moreover, back to inverted-u shape principle, stress effects on cognition are mediated by arousal (Bourne and Yaroush, 2003). Over other risk factors such as nutrition and exercise, stress is the most influencing factor on individual cognitive state (Staal, 2004). Furthermore, according to the Cognitive Continuum theory (Hammond, 2000), stress is viewed as something that breaks the homeostatic relationship between cognition and the environmental demand (the task). All of these premises are also supported by work performance model that emphasize on the interrelationship between ability to control negative emotional symptoms such as stress and cognitive capability (Blumberg and Pringle, 1982).

On the other hand, HRV biofeedback also shows potential as effective tool for improving resilience to stress and emotional well-being in healthy subjects (Barios-Choplin et al., 1997, 1999, and McCraty et al., 2003). Accordingly, in addition to cognitive performance, this study also aims to assess whether HRV biofeedback could reduce operator's negative emotional symptoms, particularly in terms of depression, anxiety, and stress.

1.3 OBJECTIVES OF THE RESEARCH

The main purpose of this study is to assess the effect of HRV biofeedback training for the improvement of operators' cognitive performance. Specifically, the study is conducted to fulfil the following objectives:

1. To develop HRV biofeedback training module for the improvement of operator's cognitive performance
2. To examine the effect of HRV-biofeedback training on operators' cognitive performance.
3. To determine the impact of HRV-biofeedback training on operators' emotional symptoms
4. To assess the effect of HRV-biofeedback training on operators' physiological states

1.4. RESEARCH HYPHOTHESES

The research hypotheses of the study are as follows:

1. The training group will show an increase in HRV as compared to a non-training control group from pre to post across three conditions (baseline, stressor, and recovery).
2. The training group will show a decrease in breaths per minute as compared to a non-training control group from pre to post across three conditions (baseline, stressor, and recovery).
3. The training group will show an increase in concentration performance as measured by D2 Attention Test, compared to a non-training control group from pre to post.
4. The training group will show an increase in short term memory as measured by Sternberg Memory Test to a non-training control group from pre to post.
5. The training group will show an increase in cognitive flexibility as measured by Stroop Colour and Word Test to a non-training control group from pre to post

6. The training group will report a reduction in depression symptoms as measured by DASS, compared to a non-training control group from pre to post
7. The training group will report a reduction in anxiety symptoms as measured by DASS, compared to a non-training control group from pre to post
8. The training group will report a reduction in stress symptoms as measured by DASS, compared to a non-training control group from pre to post
9. There will be a correlation between changes in cognitive performance and emotional symptoms in the training group

1.5 SIGNIFICANCE OF THE STUDY

Operators' performance contributes significantly into manufacturing sector productivity. Any opportunities that can direct to operator's performance enhancement hence should not be overlooked. On the other hand the increased automation and increasing sophistication of industrial equipment have changed the nature of the operator's task into more cognitive demand. To ensure that operators can deal with cognitive inhibit factors while performing their task, many strategies for the performance improvement should be searched. This study is among the first to use psychophysiological training, namely heart rate variability (HRV) biofeedback at operative level in manufacturing settings. The result of this study will be of great value to the operators with respect of well-being and psychological comfort in performing their task. It is expected that HRV biofeedback training will be incorporated into the training curriculum so that operators will obtain not only technical and management skills but also self-regulation skill to control their work physiology.

Furthermore, with regard to its practical, versatile and cost-effectiveness attributes, HRV biofeedback provides innumerable potential applications in cognitive performance enhancement in a wide range of work environment. The study will be beneficial, if repeated in operators in other industry or service sectors such as emergency response centre, air traffic controller, intensive care unit, and telecommunication operator.

Within area of biofeedback, this study will add to the body of research that investigates the feasibility of HRV biofeedback in work setting. This study also extends the existing knowledge of biofeedback used by investigating the cognitive performance as an objective improvement indicator which previously had not been researched.

1.6 SCOPE OF RESEARCH

This research aimed to assess the efficacy of HRV biofeedback strategy on operators' cognitive performance. Numerous studies found that cognitive performance is affected with stress rather than other risk factors (Hancock and Warm, 1989; Lehner, 1997; Bourne and Yaroush, 2003; Staal, 2004, and Lane, 2004). Moreover, research has shown that improvement on cognition is in line with reduced emotional symptoms (Ray et al, 2001, and Casden, 2005). Therefore in this current study the assessment of operator's emotional symptom before and after HRV biofeedback training was also carried out. It is expected that reduced emotional symptoms (i.e. depression, anxiety, and stress) mediate cognitive performance changes.

The operator term used refers to workers at operative level in electronic manufacturing industry in Malaysia. The electronics industry is not only the largest exporter of manufactured products but also the largest employer in the manufacturing sector. Besides, more than 60 percent of its workforce consisted of women (Department of Statistics Malaysia, 2010). The choice of female operators in an electronic manufacturing industry in Malaysia as the research setting was based not only on practicality but also on facts empirical findings that they are much more susceptible to reduced cognitive performance because of higher level of stress (Taylor et al., 2000). At workplace stress influences both men and women. Women, yet, often face extra burden of combining family and work responsibilities. Due to occupational segregation, women often find themselves in jobs where there is a heavy workload combined with participation and little decision-making autonomy. These two factors bring about often having to cope with more stressful situations than men (Di Martino and Musri, 2001). This is particularly true in Malaysia (Di Martino and Musri, 2001).

The hypotheses would be evaluated among real operators to deal with generalization issue that the training can be applied in real work setting. Because of constraints of resources and convenience sampling used in this study, nonetheless, the number of real operators involved in this replication was relatively small. The operators were recruited around Kuantan, Pahang, Malaysia, in other words the sample was limited in terms of the location and type of work.

Furthermore, since each task performed by operators may have different outcome criteria, it would not be easy to assess the effect of the training on work performance directly. Therefore this present study would evaluate operators' cognitive performance as their performance index. It is well-known that people must employ some cognitive functions while performing their tasks. The domain of cognitive functioning would be investigated including attention, short term memory (sometimes termed working memory), and cognitive flexibility, as proposed by numerous researchers (Wesnes et al., 1987, Parrot, 1986; Hockey and Hamilton, 1983, and Budde and Barkowsky, 2008).

1.7 DEFINITION OF TERMS

Manufacturing Operator

A manufacturing operator is responsible for performing variety of mechanical tasks in a manufacturing plant with the support of technicians and engineers. Specific duties of manufacturing operators include working on lathe or similar machines, assembling part of product, doing quality control, using heavy mobile equipments, performing maintenance on various equipments used in the plant, etc. The subjects used in this study were electronic manufacturing operator whose jobs range from assembly, inspection, moulding, and winding.

Cognition

Cognition is defined as the mental processes that are involved in perception, attention, memory, problem solving, reasoning, and making decisions (Andrade and May, 2004).

Cognitive Performance

Cognitive performance can be defined as abilities and skills from the psychological functional ranges of perception, attention (concentration), learning and retention, thinking and intelligence, and psychomotor activity, all of which can be assessed by the test (Budde and Barkowsky, 2008)

Biofeedback

According to consensus by Applied Psychophysiology and Biofeedback (AAPB), Biofeedback Certification Institute of America (BCIA) and International Society for Neurofeedback and Research (ISNR) (May 18, 2008), biofeedback is a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance. Precise instruments measure physiological activity such as brainwaves, heart function, breathing, muscle activity, and skin temperature. These instruments rapidly and accurately "feed back" information to the user. The presentation of this information — often in conjunction with changes in thinking, emotions, and behavior — supports desired physiological changes. Over time, these changes can endure without continued use of an instrument.

Heart Rate variability

Heart rate variability (HRV) is total variability in heart rate, often measured by the standard deviation of nonartifactual interbeat intervals, not contaminated by missed heartbeats. Other measures of dispersion also are used (Task Force, 1996).

Heart Rate Variability (HRV) Biofeedback

HRV biofeedback is a non-invasive form of biofeedback which is aimed to teach people change tonic level of physiological arousal by increasing HRV amplitude (Lehrer2007). The monitoring of HRV activity is detected through electrocardiogram (ECG) or photoplethysmography (PPG). Respiration measure is usually incorporated into HRV biofeedback. This dual method is particularly useful in learning how to breath abdominally (diaphragmatically), and therefore in any conditions to do with the respiratory system.

Respiratory Sinus Arrhythmia (RSA)

RSA is defined as a change of heart rate associated with respiration such that heart rate increases during inhalation and decreases during exhalation (Berntson et al., 1997).

Depression

In general, depression is defined as a lowering of mood from its normal state In this study, depression is defined as self-perception of an abnormal emotional state characterized by dysphoria, hopelessness, devaluation of life, self-deprecation, and lack of interest/involvement, anhedonia and inertia according to the depression component of the Depression Anxiety Stress Scales (DASS) (Lovibond and Lovibond, 1995).

Anxiety

According to Lovibond and Lovibond (1995), anxiety is a state of emotional arousal characterised by both somatic and autonomic response and anticipation of negative events which typically, but not exclusively, are psychological in character. In this study, anxiety is operationally defined as self-perceived autonomic arousal, skeletal musculature effects, situational anxiety, and subjective experience of anxious affect according to the anxiety component of the Depression Anxiety Stress Scales (DASS).

Stress

Selye (1956) defined stress as the non-specific response of the body to any demand made upon it. With respect to human performance, stress-related phenomena are often classified as emotional, cognitive, and physical (Van Gemmert and Van Galen, 1997). In this study, stress is defined as the self-perceived difficulty in relaxing, nervous arousal, easily upset/agitated, irritable/over-reactive and impatience according to the stress component of the Depression Anxiety Stress Scales (DASS) (Lovibond and Lovibond, 1995).

1.8 OVERVIEW OF THE THESIS

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In order to provide background underlying the thesis, the first section of Chapter 1 explained the introduction of this study. A problem statement then was formulated and was followed by description of objectives of the research. The last section pertained to the significance of the study and scope of research. Chapter 2 provides a review of the literature which is divided into seven sections. The first section describes the concept of work performance and a review of literatures on work performance enhancement. The second section discusses the cognitive performance and psychophysiology. This section also covers the relationship between arousal, cognitive performance, and stress and strategies used to deal with arousal states. The third section presents the description of autonomic nervous system and heart rate variability. The fourth section discusses the concept of biofeedback and research documenting the use of biofeedback for performance enhancement. The theory of a specific biofeedback protocol, named resonant frequency training biofeedback is elaborated in the sixth section along with a review of studies regarding its application. Finally, the seventh section presents the strategies incorporated in the study. Chapter 3 is presented in four major sections. The first section restates the research questions and research hypotheses. The second section covers the methods involved in the study. The selection of subjects is described along with the apparatus and experimental tasks employed in the study. This section also includes the experimental procedure and the training protocol applied in subjects. In the third section, the development of training strategy module is presented. Last section pertains to design and analysis of the study. Chapter 4 presents the statistical analyses for each hypothesis. The results of the data and interpretation of the findings are discussed and displayed either in table or figure. Chapter 5 consists of four major parts. First, a summary of finding, second, a discussion of the results and how the findings are consistent or inconsistent with the literature review. Then, work implication and limitation of the study as well as recommendation for future research are offered. Finally, a conclusion is provided.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In general this chapter will discuss the importance of cognition in operator's work performance and the applied psychophysiology strategy, named biofeedback training for the cognitive performance improvement. First discussion will be emphasized on the description of work performance dimensions and review previous studies for work performance enhancement focusing on individual intervention. As completing the task critically depends on operator's cognition, a description of cognitive performance will be elaborated in section two as well as its relationship with psychophysiology area such as arousal and stress. The third section will reveal autonomic nervous system and heart rate variability as these concepts underlie the intervention used in this study. Furthermore, a technique developed from psychophysiological that is known as biofeedback will be presented thoroughly in section four. Previous literatures investigating the effect biofeedback for performance enhancement will be also reviewed. The fifth and last section will discuss resonant frequency, a specific biofeedback protocol used in the study, and strategies incorporated in the biofeedback module.

2.2 WORK PERFORMANCE

The use of HRV biofeedback training for this study is driven by the theoretical basis of Blumberg and Pringle's work performance model (1982). This model has dominated research on human performance in the last 20 years (Matthew et al., 2000).

This model consists of three dimensions that work interactively as shown in Figure 2.1. At the individual level, performance is determined by opportunity, willingness, and capacity, and in turn, is a partial determinant of each. Capacity refers to the physiological and cognitive capabilities that facilitate an individual to perform task effectively. The willingness dimension comprises the psychological and emotional characteristics that influence the degree to which an individual is inclined to perform a task. Finally, opportunity consists of the particular configuration of the field of forces surrounding a person and his or her task that allows or limits that person's task performance and that are beyond the person's direct control. Each of these dimensions interacts with the others to ensure performance. Variables of each dimension are illustrated in Table 2.1. A rigid interpretation of the model would imply that the effects of willingness, capacity, and opportunity must be evaluated in any study of work performance. It may not be needed, however, to consider all of these variables (Blumberg and Pringle, 1982). Currently, there is lack of studies investigating intervention that can be used for the improvement of both the capacity and the willingness dimension.

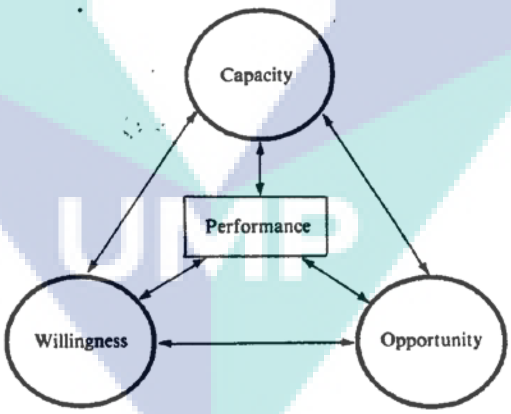

Figure 2.1: Interaction of the Dimension of Work Performance

Source: Blumberg and Pringle (1982)

Based on this model, Blumberg and Pringle (1982) predicted that higher capacity and willingness will produce high performance though the opportunity is less favourable. Even if the level of either capacity or willingness is lower, workers might still show moderate performance. Therefore, this present study is concerned about finding a strategy that has positive effect in enhancing some variables in both dimensions, particularly with individual-focused approach rather than organization-focused intervention. A proposed contribution of such strategy in the Blumberg and Pringle's model is displayed in Figure 2.3. and is described further in later subsection.

On the other hand, improving performance of workers at operative level is highly considered important as operators are the largest occupational group in the manufacturing sector (Department Statistic of Malaysia, 2010). According to the Malaysia Productivity Corporation (MPC), the individual performance contributes for 29.4 percent of total performance elements in the manufacturing sector in the year 2008 (MPC, 2010).

Table 2.1: Dimensions of Work Performance

Dimensions	Variables
Capacity	Ability, health, knowledge, skills, intelligence, level of education, endurance, stamina, energy level, motor skills
Willingness	Motivation, job satisfaction, job status, anxiety, legitimacy of participation, attitude, perceived task characteristics, job involvement, ego involvement, self-image, personality, norms, values, perceived role expectations, feelings of equity
Opportunity	Tools, equipment, materials, and supplies; working conditions; actions of coworkers; leader behaviour; mentorism; organizational policies, rules, and procedures; information; time' pay

Source: (Blumberg and Pringle, 1982)

2.2.1 Previous Studies on Work Performance Enhancement

In ergonomics or human factor literatures, there have been various studies carried out to improve operator's work performance in Malaysian manufacturing sector such as design of workstation, tools and equipment (Yusuff et al., 1994; Yeow and Sen, 2003, and Iqbal et al., 2004), and optimization of physical environment (Ismail, et al., 2009). However, only few studies were reported on the use of individual-focused approach for improving the capacity and willingness dimensions. In non-scholarly area (i.e. practical application), there are numerous modules that aim to improve work performance. For example, Bacal (2004) recommends 24 strategies for supervisor and managers for improving performance at workplace. Concisely, these strategies consist of managing performance, setting performance incentives, conducting effective reviews, identifying causes, managing conflict with graces, and developing employees. Sankaran (2010) also proposes program for workers to become peak performers at work. This program contains seven modules which cover various topics such as how to manage workload, handling multitasks, and leadership. Nevertheless these strategies focused on middle to up level employees instead of workers at operative level. At operative level, most of the work performance enhancement strategies were carried out by providing training on knowledge, rule, or skill-based (Yeow and Sen, 2003, and Mustafa et al., 2009). However, such training does not equip operators with a self-regulation skill to handle block factors inhibiting their work performance. Common self-regulation strategies used are related to job stress management.

This is not surprising as researchers showed that block factors are more influenced by stress rather on variables such as exercise and nutrition (Staal, 2004). In addition stress might have a more negative impact on productivity and satisfaction than that produced by other risk factors. Therefore, many organizations have instituted individualized stress management program to combat the effect of stress in the workplace. It is expected that such program can boost operator's productivity. There has been a growing body of research concerning the positive effect of various stress management techniques. DeFrank and Cooper (1987) differentiated the techniques focus into individual (e.g. relaxation, biofeedback, exercise, cognitive coping strategies, time management), individual/organisational interface (e.g. relationships at work, role issues), and organization (e.g. organizational structure, job rotation, selection and placement). In another study, Hart (1990) proposed four main approaches to stress management program: physiological, behavioural, psychological, and environmental. The physiological approach is the most popular of all the approaches which is an internally focused method. It works towards reducing excessive physiological arousal. This approach consists of progressive muscle relaxation, biofeedback, relaxation response, autogenic training, relaxation imagery, and aerobic training. A psychological approach is directed to teach people how to make their thinking work for them rather than against them. As a result, people will have healthier, more balanced, perspective. It includes cognitive restructuring, self-statement modification, and psychological coping statements. Meanwhile, learning skills such as time management, assertiveness training, conflict resolution, and problem solving are examples of behavioural stress management techniques. The last three techniques, however, are particularly effective ways of reducing stress that has resulted from involvement with other people. Finally, the environmental approach aims to change the environment and to prevent unnecessary stress. This includes change in management practices, clearer job description, and job enrichment. Furthermore, a meta analysis review on stress management strategies in the workplace revealed that a variety of interventions is not shown to be differentially effective (Kelley, 1995). Murphy (1996) also investigated the efficacy of stress management programs. According to his 20-year review, covering various program, he concluded that stress management approaches that combined techniques were most effective. In spite of the benefits of the stress management, however, studies conducted among workers at operative level are very rare (David, 1987; Barios-Choplin et al., 1997, 1999, and Edimansyah et al., 2008).

In Malaysian manufacturing sector, only one study was ever reported on the use of stress management in operators (Edimansyah et al., 2008). The authors evaluated the efficacy on short duration stress management training on self-perceived depression, anxiety and stress. Subjects consisted of 118 male automotive workers who were assigned to experimental ($n = 60$) and control group ($n = 58$). The program consisted of aerobic exercise, stress management manual, video session, lecture, question and answer session, and pamphlet and poster session were given in the experimental group. Results indicated that the mean scores for the depression and anxiety were significantly decreased, ($p = 0.036$, and $p = 0.011$, respectively) after the intervention program in the experimental group as compared to the control group. No similar effect was observed for the mean scores for stress ($p = 0.104$). These findings suggested that short duration stress management training is effective in reducing some aspects of self-perceived depression, anxiety and stress in male automotive workers. Nonetheless, as any other stress management intervention, the outcome was obtained from psychological self-report assessment that relied on operators' judgment which might or might not be accurate. Additionally, it is still unclear whether the training might also have positive effect on task performance. Since measuring effect of a particular intervention on work performance directly (e.g. output quantity, product reject, work pace, etc), is difficult, hence researchers suggests the cognitive ability test for predicting performance (Reeves et al., 2007). Furthermore, this study tested male automotive industry workers so the results may not generalize to other populations such as electronic manufacturing female operators concerning its largest contribution to the Malaysian economy as well as the largest employer (MPC, 2009).

On the other hand, to perform work effectively, it is necessary not only to reduce operator's stress-related symptoms, but also to improve operator's capacity, particularly with respect to her/his cognitive performance. Nevertheless, no studies to date is aimed to attain both goals. Thus, there is a need to develop an intervention tool to improve cognitive performance as well as reduce stress-related risks to performance. This current study proposed a psychophysiological training or biofeedback approach which may show a powerful adjunctive tool to achieve both goals. Biofeedback derives from the basic concept that human have natural regulatory mechanism. Integrating biofeedback with training or learning model is suggested as being particularly useful as a performance enhancement modality. Its methodology allows the user to build or develop skills that restore brain and body processes to optimal homeostatic conditions (Matuszek, 1999, and Schwartz, N.M and Schwartz, M.S., 2003). From this perspective, it is important to emphasize that the goal in biofeedback is to maintain and promote desirable levels of functional harmony, rather than simply to reduce anxiety by relaxing deeply (Norris and Fahrion, 1993). Before discussing further on the biofeedback intervention itself, the importance of cognitive performance and the definition psychophysiology will be described in the following subsection.

2.3 COGNITIVE PERFORMANCE AND PSYCHOPHYSIOLOGY

The cognitive performance of a person is an important indicator for the specific capabilities and needs one has in a certain situation. According to Newell, et al. (2003), cognitive performance is viewed as an update of a complex of cognitive abilities which is influenced by both the intellectual abilities and non-intellectual factors. Thus, the individual cognitive performance level varies significantly whose level is affected by changes of the environment, the individual affective state, health status, fatigue, circadian rhythm, or nutrition. On the other hand, due to an increase in the use of technology, industrial operators face increasing demands upon their cognitive function and monotonous control. Such demands can lead to problems of decreased attention, fatigue, and drowsiness. Thus, the ability to maintain sustained attention on a given stimulation source or task is a crucial determinant of cognitive performance (Pattyn et al., 2008).

A great number of researches have shown that operators are prone to reduced cognitive performance during work (Gluckman, 1990; Fox, 1993; Marsh et al., 1997, and Temple et al., 2000). Many stressful conditions affect cognitive performance such as time pressure, work load and overload, boredom or monotony, fatigue and sleep deprivation, noise, ambient temperature, and extreme environments (Bourne and Yaroush, 2003, and Culverhouse, 2007). For example, radar operators can have a 70% drop in efficiency (i.e. slowing in reaction times) within 30 min of commencing a trial, through boredom (Gluckman, 1990). The result of simulated radar display known as the Clock Test from Mackworth's study also showed a 12% decline in the frequency of signal detections after only 30 minutes of performing the task and an 18% drop by the end of the 2-hour session (Gluckman, 1990) which were indicated by an increase in error rates. Moreover, Temple et al. (2000) observed that 30 minutes or more of sustained vigilance produces not only a performance decrement, but also increases in felt workload and stress. In addition to attention, memories can be also very unstable. Most people have difficulty remembering even three items after 18 seconds and their short-term memory can decay within 2 seconds (Marsh et al., 1997).

2.3.1 Definition of Cognitive Performance

To understand what is cognitive performance a clear definition should be given. The cognitive component refers to the operation and interaction of and between mental processes used during task performance. This can include thinking, perceiving, recognizing, remembering, judging, learning, knowing, attending and problem solving (Andrade and May, 2004). While the term 'performance', in cognitive psychology, refers to the measurement of several processes that can be represented both in cognitive and somatic functions of the brain (Budde and Barkowsky, 2008). It denotes abilities and skills from the psychological functional ranges of perception, attention (concentration), learning and retention, thinking and intelligence, and psychomotor activity, all of which can be assessed by test. Thus, cognitive performance is not defined by a single value like the intelligence quotient but rather as a combination of performance of several cognitive functions and processes (Budde and Barkowsky, 2008).

One of the main advantages of cognitive performance tests is that they can measure the basic factors that compose real-life performance (Whetherell, 1997). Accordingly, measuring cognitive performance has a wide range of application, that is, they can be applied in various combinations to build a representation of any real-life task. In cognitive psychology, cognitive performance is not classified by a single value as the intelligence quotient but rather as a combination of performance of several cognitive functions and processes (Burde and Barkowsky, 2008). Cognitive psychologist have identified and studied perception, attention, memory, decision making, problem solving and response execution that are candidates for performance decrement (Bourne and Yaroush, 1993). On the other hand, in the psychopharmacology studies, it is frequently demonstrated that a drug or therapy affects a certain aspect of task performance and not the others, whatever that aspect might be called and whatever the task's theoretical basis (Wetherell, 1997). In this study, therefore, the evaluation of biofeedback was carried out on three domains of cognitive functioning: attention, memory, and cognitive flexibility. These cognitive tasks were selected on the basis of general psychological functions on operators’ work performance as suggested by Wesnes et al. (1987), Parrott (1986), and Hockey and Hamilton (1983).

One critical aspect of higher cognitive function is the ability to maintain attention and to perform repetitive cognitive processes over some period of time. The attention system governs all cognitive processes, from perception to decision and execution (Fafrowicz and Marek, 2008). Attention determines how our brain processes information at sensory, motor, and other areas. In test terms, it is commonly thought of as the ability to detect fairly frequent targets in a matrix of rapidly presented, repetitive stimuli (Wetherell, 1997). In the present study, attentional capacity was assessed using a classic letter cancellation test (“Attentional Performance Test’’, Test d2, Brickenkamp, 1998). Tasks of this type address the cognitive components of selective and sustained attention that are undoubtedly of vast importance in everyday life (Johnson and Proctor, 2004). In the test subjects have to select and mark as many target stimuli as possible in a given amount of time, hence it also has certain load on speed of information processing.

In addition to attention, memory is a logical part of every aspect of human performance. People routinely remember information for short periods, for example, memorizing a string of numbers while placing a call. This rapid, short-term memorization of a small number of items is called short-term or working memory. Researchers have defined the upper limit or the capacity of working memory to be around 7 ± 2chunks of information. A chunk is the unit of working memory space, defined jointly by the physical and cognitive properties that bind items within the chunk together. Thus, the sequence of four related letters, X, H, K, E, consists of four chunks as does the sequence of four digits, 5, 8, 7, 3. In relation with attention, memory, whether verbal or spatial, is resource-limited. It depends very much upon the limited supply of attentional resources. In this study, a classic test, Sternberg's memory scanning task was conducted to examine individual's memory before and after intervention (Sternberg, 1966).

Finally, cognitive flexibility or executive functioning is the human ability to adapt the cognitive processing strategies to face new and unexpected conditions in the environment (Cañas et al., 2003). In detecting that a situation has changed and the necessities of a non–routine response, a higher level of attentional control is needed. In being cognitively flexible a person needs both to address and interpret the new situation restructuring her/his knowledge in order to adapt her/his behavioural strategies accordingly. When a person in not cognitively flexibility, they act in a nonfunctional way in coping with situational demands, therefore they would often perform erroneously. In this study, the Stroop Color-Word Test was used to evaluate subject's cognitive flexibility. The Stroop test provides insight into cognitive effects that are experienced as a result of attentional fatigue (Golden and Freshwater, 2002).

2.3.2 Intervention for Cognitive Performance Enhancement

Researchers have studied many strategies to deal with the assessment and maintenance of vigilance and attention in conditions of monotonous or versatile activity. Blood and Ferriss (1993) found that modality and tempo of music interacted in influencing ratings of anxiety, satisfaction and productivity. Smith (1969) hypothesized that music decreases tension and boredom and may be correlated with routine work. Fox and Embrey (1972) also reported that playing music while performing a repetitive task, particularly just after arousal level has been on the peak and it can elevate performance levels. These suggestion have been supported by more recent numerous experiments. A study of Hallam et al. (2002) demonstrated that calm music led to better participant's performance on an arithmetic task and a memory task than no music. It was also found that background music on cognitive test performance led to improved performance when compared with a control condition (Cockerton et. al, 1997). The positive effect of music on some cognitive abilities can be attributed to changes in listeners' arousal or mood (Thompson et al., 2001). On the other hand researchers also found that some kinds of music may also negatively affect human performance in tasks such as immediate and delayed recall memory tasks (Furnham and Bradley, 1997) and attention and vigilance (Dalton and Behm, 2007). However providing music in a shop floor may not be applicable because different types of personality would report differential preferences for music listening. Extraverts reported preferring to work in more social and arousing environments while introvert preferred to the presence of relaxing music (Cassidy and MacDonald, 2007).

In addition to music, various kinds of training such as cognitive training (Ansiau et al., 2005; Willis et al., 2006, and Llewellyn et al. 2008), meditation (Moore and Malinowski, 2009), motor-imagery training (Papadelis et al., 2007), and aerobic training (Kramer et al., 1999, and Hansen et. al., 2004) have been proposed as powerful tools for enhancing cognitive abilities through modifying individuals' skills or attitudes mechanism. Although cognitive training was highly successful in improving some cognitive abilities, yet such training was commonly aimed to deal with cognitive aging. Of the few strategies for enhancing cognitive functions among productive age workers, the target users are predominantly middle to up level employees. For example, the use of mind mapping (Buzan, 2005) and memory exercising (Lapp, 1995). Meanwhile, Moore and Malinowski (2009) reported that practicing mediation yields mindfulness that is intimately linked to improvements of attentional functions and cognitive flexibility. Although it is an effective technique and rapidly gaining in popularity in western countries but the religious issue will be a great obstacle to be applied among Malaysian workers who are mostly Moslem.

The effectiveness of mental imagery training on cognitive performance was examined by Papadelis et al., (2007). Twenty healthy volunteers participated in the study who were divided in two groups: the control group (3 males and 7 females) and the imagery-training group (5 males and 5 females). Both groups were trained at the flight simulation program for ten sessions. The subjects of imagery group were asked to perform for ten additional imagery-training sessions of 20 min each. They performed each one of the imagery training session just before each actual training session. The subjects of the actual performing group (control group) were asked additionally to passively observe the task in order to have equal time of exposure to the task. An electronic flight simulation program (MATB—a PC based Multiple Attribute Task Battery) was used to assess motor and cognitive performance before and after mental practice. The results revealed significantly the higher performance level of the imagery-training group compared to the control group. The ANOVA results revealed higher statistically significant increases on performance as measured by root mean square of error (RMSE) (p = 0.026) and false alarm for lights (p = 0.00994) in the imagery training group, compared to the control group between before and after training sessions. However no significant differences between the two groups for the response time for correct responses were found. Therefore, the results show that this mental practice improves the components which are strongly correlated to spatiotemporal motor control rather than cognitive functions. Moreover, such training may be less appropriate to be used by operators in manufacturing industry regarding its different characteristic of tasks from flight simulation task.

Several studies have investigated the influence of aerobic fitness on cognitive function although the overall effect size is somewhat small (Etnier et al., 1997). Kramer et al. (1999) found that aerobically trained subjects showed improvements in performance on tasks that required executive control compared to anaerobically trained subjects. The subjects were studied over a period of 6 months. Furthermore, Hansen (2004) reported that male sailors participated in an 8-week training program showed faster reaction times and higher accuracy in executive tasks, whereas a paired sailors group who had been de-trained for 8 weeks had no significant change in these tasks. The trained male sailors also showed physical fitness that is indicated by higher oxygen consumption (VO_2 max). Although the benefits of exercise are undoubted, lack of time is the most commonly barrier to do exercise among workers. A study of Mohd Nordin et al. (2003) described that high levels of knowledge and attitudes towards exercise among women workers in a Malaysian electronics factory were not followed by practice. The main reasons for not exercising were lack of time, laziness, not interested in exercising and lack of friends to exercise with.

To address the shortcomings of previous researches, this current study presents a psychophysiology approach derived from heart rate variability as a new tool to improve operators' cognitive performance. Through the psychophysiology strategy along with biofeedback mechanism and with the operators' active involvement, operators are trained how to self-regulate their physiological states and achieve optimum function as a result. Some of the advantages of this strategy over other strategies are simple to learn and use including during work. Detailed of its features will be discussed further. To highlight the importance of psychophysiological training, more discussion on psychophysiology and relationship among arousal, and cognitive performance will be elaborated in the following subsection.

2.3.3 Psychophysiology

In his book, Andreassi (2007) proposed the definition of psychophysiology as: "the study of relations between psychological manipulations and resulting physiological responses, measured on the living organism, to promote understanding of the relation between mental and bodily process" (p. 2). In the realm of human performance, thus, a psychophysiological strategy allows the study of the impact of stressors on a different level than is possible with a cognitive performance strategy (Caldwell et al., 1994). The psychophysiologist is able to contribute some understanding about the underlying physiological changes accompanying the behavioural changes which are studied in a performance-based approach. Psychophysiology uses non-invasive procedures to understand psychological events by examining the concurrent activity of the brain, heart, muscles, etc., and seeks to understand the relevance of physiological events by exploring them in the psychological realm (Caldwell et al., 1994, and Andreassi, 2007).

Psychophysiological processes are measured with various biofeedback modalities. Muscle contraction and relaxation is measured by electromyography (EMG). Temperature change is assessed via fingertip thermometers. Skin resistance influenced by sweat is evaluated by electrodermal assessments (EDR). Cardiovascular activity is measured via heart rate, heart rhythm, and blood pressure. Respiration is analyzed by the depth and rate of breathing, and brain wave activity is measured by electroencephalography (EEG) (Arena and Schwartz, 2003).

Psychophysiology may be used to evaluate the psychological fitness of operators, investigating whether the body is in an optimal state to perform a particular task (Caldwell et al., 1994). When someone is not fit for performing a task, it doesn't necessarily mean that he or she is ill. Their energetic state may not be optimal because activation is too low due to sleep loss or fatigue, stress, negative emotions, or some pharmacological substance. Physiological information about a person's readiness to perform can be combined with other information about that person's general well being and their actual job performance to better predict future operational capacity.

2.3.4 Relationship between Arousal, Cognitive Performance, and Stress

In particular with regard to psychophysiology, work performance model described in previous subsection (2.2) may be further extended using Yerkes-Dodson model (1908) in an attempt to explain the relationship among arousal which is commonly indexed physiologically, cognitive performance, and stress. Arousal, alertness, and activation are terms used in the psychological literature to describe a basic energetic state of an organism (Bourne and Yaroush, 2003). Arousal is capable of variation in time. As an organism becomes more aroused, it also becomes more alert and more highly active, at least up to a point. Arousal regulation is known to be a crucial aspect for a quality performance. Arousal includes a general physiological response but behavioural responses and cognitive processes are also indicators of arousal (Staal, 2004). Arousal can be measured in a variety of ways (i.e., pulse rate, heart rate, blood pressure, galvanic skin response, etc.). As displayed in Figure 2.2, classic concepts from motivational psychology suggested an inverted u-shaped association between arousal and performance efficiency (Yerkes and Dodson, 1908, and Hebb, 1955). The middle of the curve is called the optimal level. At this point is where the subject performs at his/her highest level. However, performance suffers if the subject becomes too stressed or over aroused, distressed, or he/she becomes under aroused. The concept is important for this study because it highlights the need for tools and techniques that can be used by individuals to gain the optimal level of performance without causing unnecessary stress.

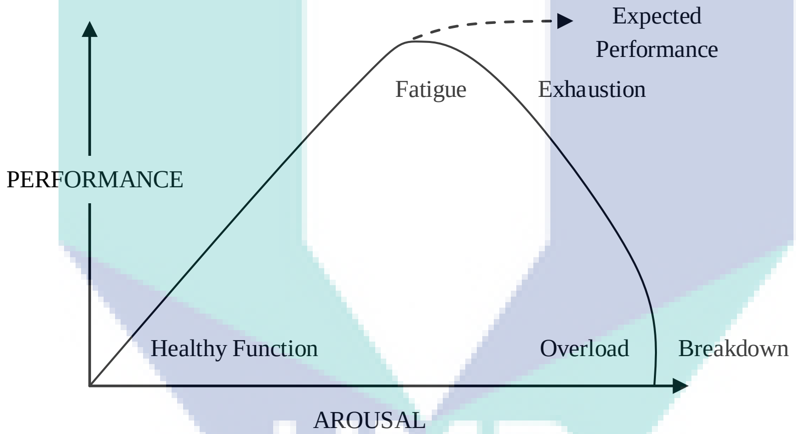

Figure 2.2: Human function curve –relationship between performance and Arousal following the Yerkes-Dodson principle

Adapted from: Staal (2004)

Duschek et al. (2009) suggested the use of concept autonomic nervous system and cognitive performance to replace the general terms arousal and performance. Cardiovascular psychophysiology has also contributed to the inverted u-shaped principle. Changes in cardiovascular activity relate to facilitation or inhibition of information processing (Aasman et al., 1987). Both the sympathetic and parasympathetic systems contribute to cardiovascular regulation (Levy and Pappano, 2007). Harmonious equilibrium between sympathetic and parasympathetic functions leads to the optimal autonomic balance. Caldwell (1994) and Andersen and William

(2007) suggested that information obtained from physiological variables such as cardiovascular activity might be used to optimize performance, to prevent reduced well being or health or to prevent accidents.

Furthermore, arousal and cognitive performance also have very close relationships with stress (Bourne and Yaroush, 2003, and Lane, 2004). Stress effects on cognition are mediated by arousal. Like arousal itself, stress can have either positive or negative effect on performance. It depends on the intensity of the stressor, the momentary state of arousal when the stressor arises, the nature of the task to be performed under stress, the skill of the performer, and other variables (Bourne and Yaroush, 2003).

Some literatures used the term stress while discussing arousal which also follows the inverted-u principle (Welford, 1973, and Hancock and Warm, 1989). Welford (1973) hypothesized that stress arises when an organism departs from an optimal condition. In turn, it causes imbalance in the organism's state. In a more recent study, Hammond (2000) explored this hypothesis by presenting a new framework, called the Cognitive Continuum theory. This framework is based on two existing views, one of coherence (behaviour results from an interaction between cognitive processes and environmental demands), and one of correspondence (behaviour results directly from the demand and the outcome of the response to that demand). According to this theory, stress is viewed as something that breaks the homeostatic relationship between cognition and the environmental demand (the task). As depicted in Figure 2.2, a small amount of stress in the environment is needed to perform the task effectively. At some point, stress for a given task and individual attains an optimal level. At some high level, however, stress will degrade performance. The pressure of an emergency, time urgency, close assessment by others, risk of bodily harm, or other strong stressors cause performance degrades, or worse fails. When stress is extreme, a performer might "choke" or "panic" (Lehner, 1997). Furthermore, Wofford and Daly (1997) described the human stress response comprising three areas: physiological arousal (i.e., heart rate, blood pressure, temperature, etc.), psychological responses (i.e., dissatisfaction, anxiety, sleep problems, depression, irritation, etc.), and behavioural responses (i.e., work performance, eating disorders, aggression, drug abuse, poor relations, etc.).

Considering all the explanation above, a modification of Yerkes-Dodson's model proposed by Duschek et al. (2009) appears to be useful in understanding the process being explored in this study. In conjunction with a work performance model (Blumberg and Pringle, 1982) described previously, it provides an adequate framework for a psychophysiological intervention where gaining greater awareness of emotional levels such as stress through physiological monitoring may lead to increased autonomic control. Such physiological control may influence an operator's ability to maintain the desired point of optimal cognitive functioning. The operator not only learns how to reduce high levels of negative emotional symptoms but also how to recognize when the body is dysregulated and then adjust her intensity levels to match the demands of the situation. Figure 2.3 illustrates proposed contribution of this study (i.e. intervention) on the Blumberg and Pringle's model after taking into account Yerkes-Dodson's model.

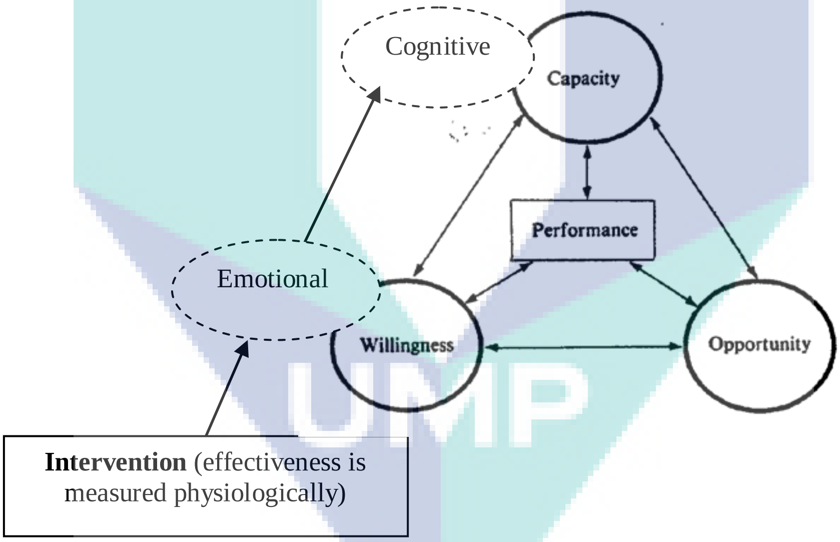

Figure 2.3: Proposed Contribution of this Study. Further description of intervention (i.e. HRV biofeedback) found in later subsection

2.3.5 Strategies for Dealing with Arousal States

Several methods have been designed to alter a person's arousal or internal state either through learned forms of self-control or through control of others (Druckman and Swets, 1998). In general, these methods are directed to produce altered states of consciousness. They include mediation, hypnosis, relaxation, and biofeedback. The internal state of the organism changes with time of day, health, mental activity, and alertness. Since many of these factors are under control, it is not difficult to train people to produce different internal states. These altered internal states do influence physiological processes, including the electrical activity recorded from the scalp and autonomic nervous system (Tart, 1969). Changes in internal state are also frequently accompanied by subjective reports of feelings of well-being, relaxation, increased concentration, and so on (Tart, 1969; Ray et al., 2001; Lehrer et al., 2003; Casden, 2005; Thurber, 2006, and Karavidas et al., 2007).

There is some evidence that differences in internal state may lead to changes in performance (Druckman and Swets, 1998). This is particularly true of physical activity. For example, if a person is warned about the incidence of a signal for which a response is required, there is a marked change in internal state during the time between the warning and the signal to perform. This change in alertness will lead to more efficient processing than if the person had not been prepared for the signal (Kahneman, 1973). There is also some evidence that training people to activate a particular mental state can sometimes produce changes in internal state that may lead to improved cognitive performance. Such training is commonly termed as biofeedback which may take form as neurofeedback (Vernon et al., 2003; Vernon, 2005, and Egner and Gruzelier, 2004) and heart rate variability biofeedback (McCraty, 2002, and Sutarto and Wahab, 2008).

2.4 AUTONOMIC NERVOUS SYSTEM AND HEART RATE VARIABILITY

The main purpose of the autonomic nervous system (ANS) is to control all human organs and systems to maintain optimum performance or homeostatic function of the organism influenced by various internal and external factors (Andreassi, 2007). This control is performed by the two branches of the ANS called the sympathetic nervous system and the parasympathetic nervous systems. These systems work together in a complex synergistic ways that can be additive, subtractive, or reciprocal to provide the appropriate internal environment to meet shifts in both internal and external demands (Porges, 1995). The parasympathetic nerves are modulated primarily by internal changes in the viscera. The sympathetic nerves are primarily activated by changes in external environment via somatic efferent nerve fibres. The parasympathetic maximizes the function of the internal organs associated with growth and restoration. In contrast, the sympathetic promotes increased metabolic output to deal with challenges from the external environment. So, for example, external challenges such as temperature change, noise or pain will produce attenuated parasympathetic nerves tone and increased sympathetic nerves activity. Because the ANS is an integrated system comprising both peripheral and central neurons, measuring the peripheral visceral activity e.g. the heart, provides a window to the brain structures that regulate visceral function and state (Tiller et al., 1996.).

Heart rate variability (HRV) is a very important measure in assessing ANS function. HRV represents the beat to-beat changes in the interbeat interval (time between two successive R-waves) (Task Force, 1996). Each R-wave represents a contraction of the heart and corresponds to the pulse as illustrated in Figure 2.4. The beat-to-beat variability is affected by ANS activity. It is accepted by scientists that the interaction at the heart is a reflection of ANS balance or imbalance in the body in general (Berntson et al., 1997). Lehrer suggests that reduced HRV is evidence of vulnerability to physical and psychological stressors, and disease (Lehrer, 2007). In contrast, higher HRV has been associated with creativity, psychological resilience, and a more developed capacity to control affective, cognitive, and physiological of stress (Hansen et al., 2003, and Appelhans and Luecken, 2006), thus optimum variability is essential.

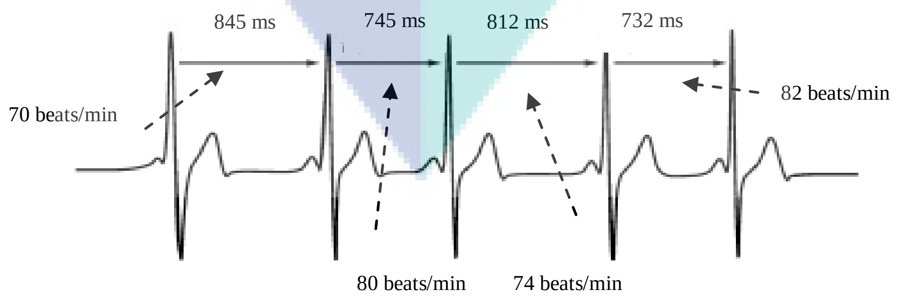

Figure 2.4: Heart Rate Variability

The normal variability in heart rate is due to the synergistic action of the two branches of the ANS, which operates in balance through neural, mechanical, humoral and other physiological mechanisms to maintain cardiovascular parameters in their optimal ranges and to allow proper responses to changing external or internal conditions (McCraty et al., 2001). In a healthy individual, thus, the heart rate estimated at any given time reflects the net effect of the parasympathetic (vagus) nerves, which slow heart rate, and the sympathetic nerves accelerate it. These changes are influenced by emotions, thoughts and physical exercise. Changes in heart rhythms affect not only the heart but also the brain's ability to process information, including decision-making, problem-solving and creativity. They also directly affect the emotions. High vagal tone (parasympathetic) is associated with the ability to self-regulate and therefore to have greater behavioural flexibility and adaptability in a changing environment. On the other hand, low vagal tone is associated with poor self-regulation and a lack of behavioural flexibility (Porges, 1992). Thus, the study of HRV is a powerful, objective, and noninvasive tool to measure neurocardiac function that reflects heart–brain interactions and ANS dynamics (Task Force 1996, and Tiller et al., 1996). The analysis of HRV can be used to explore the dynamic interactions between physiological, mental, emotional and behavioural processes (McCraty and Tomasino, 2004).

In general, HRV measures are quantified using time domain or frequency domain measure. SDNN is often used as an estimate of overall HRV which reflects the oscillating influences of the sympathetic and parasympathetic systems on the cardiac or cardiovascular adaptability, while frequency domain analyses HRV have been used to assess autonomic balance. The SDNN is the standard deviation of the N-to-N interval and is expressed in milliseconds (ms). People with SDNN values below 50 ms are classified as unhealthy, 50-100 ms have compromised health, and above 100 ms are healthy (Berntson et al., 1997).

The mathematical transformation (Fast Fourier Transform) of HRV data into power spectral density (PSD) is used to break down and quantify sympathetic and parasympathetic activity and total ANS activity. Power spectral analysis reduces the HRV signal into its constituent frequency components and quantifies the relative power of these components. This allows clinicians or researchers to measure the percentage of this signal within each of three main frequency bands. High frequency (HF) HRV ranges from 0.15–.4 Hz reflects the inhibition and activation of the vagus nerves by breathing at normal rates. Low–frequency (LF) HRV (0.05–0.15 Hz) associates highly with baroreflex gain, and is influenced by both the sympathetic and parasympathetic systems. Very low frequency (VLF) band (0.005-0.05 Hz) represents sympathetic activation or reduced parasympathetic inhibition (Task Force, 1996). Figure 2.5 shows a power spectrum of the HRV waveform. The power (height of the peak) in each band reflects the activity in the different branches of the nervous system. HRV parameters are summarized in Table 2.2

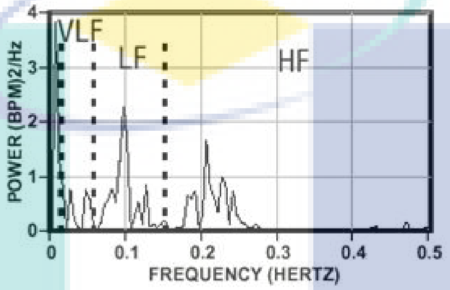

Figure 2.5: Power spectrum of the HRV waveform

Source: McCraty, et al. (2001)

Table 2.2: Heart Rate Variability Measures

Source: Task Force (1996)

Measures	**Interpretation and Measurement**
Heart Rate (HR)	Average inter-beat-interval (IBI) or R-spike to R-spike interval (RRI), Heart Period (HP) (in milliseconds); or heart rate (beats per minute) (Task Force, 1996).
Very low frequency (VLF)	Heart rate variability in the frequency band of 0.005–0.05 Hz. This is under control of the sympathetic nervous system, and may reflect thermal control and baroreflex control of blood pressure through changes in vascular tone.
Low frequency band (LF)	Heart rate variability in the frequency band of 0.05–0.15 Hz. This is usually under control of both the sympathetic and parasympathetic nervous systems, and may reflect thermal control and baroreflex control of blood pressure through changes in heart rate. It includes the 0.10 Hz component. It is sometimes called the Traube-Hering-Mayer wave.

Table 2.2: Continued

Measures	Interpretation and Measurement
High frequency band (HF)	Heart rate variability in the frequency band of 0.15–0.4 Hz. This is under control of the parasympathetic nervous system, and is associated with respiratory activity. Although respiratory sinus arrhythmia usually occurs within this band, it may occur at other frequencies if individuals breathe at a rate that is outside this frequency band
Standard deviation of all N-N intervals (SDNN)	This is a time domain measure. It is a general marker of overall adaptability of the system. It is the standard deviation of normal beat-to-beat intervals (SDNN).

It has been shown in a number of studies that during mental or emotional stress, there is an increase in sympathetic activity and a decrease in parasympathetic activity (Aasman et al., 1987; Backs and Seljos, 1994, and Duschek et al., 2009). This results in increased strain on the heart as well as on the immune and hormonal systems. Increased sympathetic activity is associated with a lower ventricular fibrillation threshold and an increased risk of fibrillation, in contrast to increased parasympathetic activity, which protects the heart. Figure 2.6 illustrates the nervous system links between the heart and brain. The sympathetic branch speeds heart rate while the parasympathetic slows it. Heart rate variability is due to the interaction between the two branches of the nervous system and the afferent signals sent from the heart to the brain (baroreceptor network).

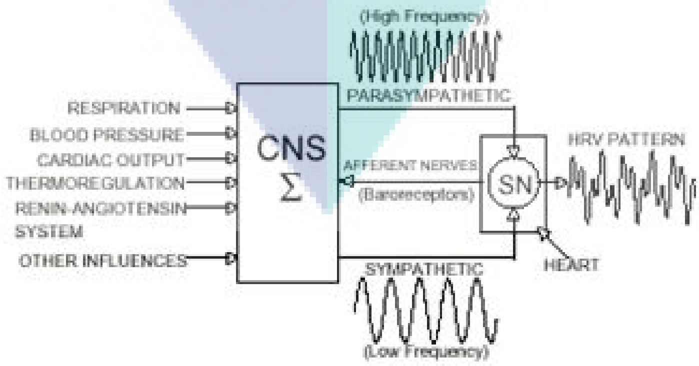

Figure 2.6. Relationship between Nervous System and the Heart and Brain

Source: McCraty, et al. (2001)

Furthermore, in mental workload and cognitive psychophysiology literature, HRV has been widely used to assess operators' mental workload (Ryu and Myung, 2005). Numerous studies have related HRV to various sources of mental effort, such as working memory (Mulder and Mulder, 1981, and Aasman et al., 1987) and attention (Vincent et al., 1996, and Hansen et al., 2003). Porges (1992) proposed a theoretical framework on the link between parasympathetic cardiovascular control and attentional performance. Parasympathetic influences on heart rate can be reliably quantified by respiratory sinus arrhythmia (RSA), the variation in heart rate that accompanies breathing. The RSA is mediated through inhibitory vagal fibres to the sinus node (Task Force, 1996, and Berntson et al., 1997) and may be derived from the HF band of the HRV spectrum that is usually associated with respiration. Porges (1992) postulated that higher resting levels of cardiac vagal tone are associated with improved attentional capacity. This is consistent, for instance, with Hansen et al.'s (2003) study in a group of sailors. Subjects who had higher HRV displayed better performance on working memory and continuous performance tests than those with lower HRV. Moreover, the spectral analysis of HRV reveals an inhibitation of the 0.1 Hz low-frequency (LF) component under conditions of increased cognitive demand, e.g., complex decision-making, increased working memory load (Tattersall and Hockey, 1995, and Tripathi et al., 2003). Regarding the importance relationship between HRV and cognitive processing, however, no research has been carried out on the use of HRV as a "knowledge" feedback to correct operators' physiological states toward the optimum. Through biofeedback technique, operators learn to control their physiological responses by providing them with an information signal, as sensory feedback, about biological conditions of which they may not be ordinarily aware.

2.5 BIOFEEDBACK

According to the Association for Applied Psychophysiology and Biofeedback (AAPB), Biofeedback Certification Institute of America (BCIA), International Society for Neurofeedback and Research (ISNR), (May 18, 2008), biofeedback is defined as "a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance. Precise instruments measure physiological activity such as brainwaves, heart function, breathing, muscle activity, and skin temperature. These instruments rapidly and accurately "feed back" information to the user. The presentation of this information — often in conjunction with changes in thinking, emotions, and behaviour — supports desired physiological changes. Over time, these changes can endure without continued use of an instrument”. People do not function physiologically optimally for numerous reasons. One of the most common is not realizing when some physiological system is not functioning at the best level for any particular situation. For example, many runners do not use optimal breathing patterns for sustained running. Technologies such as biofeedback help people recognize how a physiological system is functioning and learn to form a habit of controlling the system so it works optimally.

The simple versions of biofeedback are commonly found in household devices such as mirror, scale, and thermometer. In general, the principle of biofeedback is illustrated in Figure 2.7. Suitable sensors mounted on the skin detect desired physiology signals (e.g. brainwave, temperature, heart rate). Using an aid of amplifier, the signals are changed into a display in some ways (visual, audio, tactile, or combination). The user then uses the display to recognize relationships between sensations and actual levels of physiological response and to control patterns of this response following the reference signals.

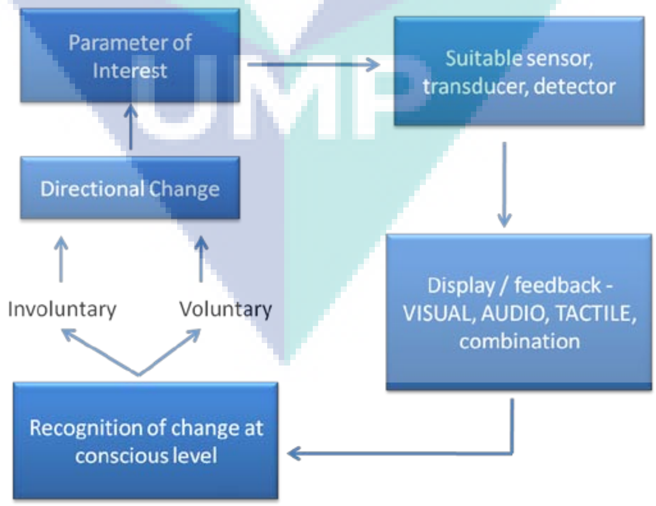

Figure 2.7: Principles of Biofeedback

Adapted from: (Schwartz, N.M., and Schwartz, M.S, 2003, and Sherman, 2004)

There are at least four different explanations as to why biofeedback works. The operant conditioning model emphasizes that reinforcement and punishment are contingent on “selected ongoing physiological responses.” This model emphasizes that learning follows the application of reinforcement. The information processing model proposes that biofeedback works because the individual is given feedback about physiological responses that were previously undetectable by them. The theory of voluntary control emphasizes that an individual cannot control process directly. Rather he or she relies on motor changes to affect these internal changes. Finally, the psychobiological model attempts to integrate these three models. The psychobiological model explains that biofeedback helps the individual to self-regulate through both psychological processes and biological processes (Schwartz and Andrasik, 2003).

Over the past 50 years, researchers have used biofeedback to do everything from helping people relax to treating severe headaches, chronic pain, and high blood pressure. Currently, biofeedback has been applied in wider areas, not only for clinical purposes but also for the enhancement of sport and work performance. The following types of biofeedback are in common usage today (Schwartz, N.M., and Schwartz, M.S, 2003, and Sherman, 2004).

(i) Surface Electromyogram (sEMG) biofeedback. A typical placement of sEMG sensor is the frontalis (forehead) or the trapezius (shoulder) muscles. As muscles become more tense, they make more electricity. SEMG biofeedback is mainly used to promote the relaxation of those muscles involved in backaches, headaches, neck pain and grinding one’s teeth. The feedback from sEMG display helps clients learn to relax overly tense muscles, better activate weak muscles, or change the coordination pattern among agonist, antagonist, and synergist muscles

(ii) Temperature biofeedback. Thermistors are used to record skin temperature (usually from the fingertip) in order to track near-surface blood flow. Near-surface blood flow changes with sympathetic activity, pain, and many pathological conditions. The goal of the training is directed to control client’s temperature.

(iii) Electroencephalogram (EEG) biofeedback or neurofeedback. Neurofeedback is a sophisticated form of biofeedback based on specific aspects of cortical activity. The brain's electrical activity is recorded from sensors mounted on the surface over various parts of the brain. The goal of neurofeedback training is to teach the individual what specific states of cortical arousal feel like and how to activate such states voluntarily

(iv) Heart Rate Variability (HRV) biofeedback. HRV represents the beat to beat changes in the interbeat interval (time between two successive R-waves). HRV biofeedback training is aimed to teach people change tonic level of physiological arousal by increasing HRV amplitude (Lehrer, 2007). The monitoring of HRV activity is detected through electrocardiogram (ECG) or photoplethysmography (PPG). Respiration measure is usually incorporated into HRV biofeedback. This dual method is particularly useful in learning how to breath abdominally (diaphragmatically), and therefore in any conditions to do with the respiratory system.

2.5.1 Biofeedback as Performance Enhancement Training

Performance has been characterized as functioning along a range, with dysfunctional performance positioned at one extreme side and optimal performance positioned at the other (Vernon, 2005). Change in performance may either convey those within a distressed population, which work at or close to the dysfunctional end of the range, up to a normative baseline, or enhance the performance of those at the normative baseline shifting them closer to the optimal area. The focus of interest for this study is the biofeedback training of non-distressed population of healthy persons whose initial performance falls within a normative baseline.

In reviewing the literature on the prospect of the use of a variety of biofeedback modalities for performance enhancement, there are two types of biofeedback modalities typically used: neurofeedback, and HRV biofeedback. Several studies have supported the use of these types of biofeedback for performance enhancement in variety settings such as music (Egner and Gruzelier, 2003, and Thurber, 2006), dance (Raymond et al., 2005), sport (Strack, 2003, and Tanis, 2008), and education (Rasey et al., 1996, and McCraty et al., 2000).

2.5.2 Electroencephalography (EEG) Biofeedback/Neurofeedback

There is a great deal of research investigating the relationship between particular EEG frequency components and performance on specific cognitive tasks (Vernon, 2005). This becomes an underlying rational for the use of neurofeedback training to enhance cognitive performance. Egner and Gruzelier, (2001, 2004) and Vernon et al., (2003) showed that neurofeedback has been successfully used to enhance attentional and memory performance in healthy subjects, who were instructed to increase their EEG band power in a frequency range of 12–15 Hz, termed "sensorimotor rhythm" (SMR). In recent study (Hanslmayr et al., 2005), an increase in upper alpha power resulted from neurofeedback training was positively correlated with the improvement in cognitive performance as measured by mental rotation task.

On the other hand, in particular with respect to workplace purpose, not much effort on the use of biofeedback in human operators has been done. One of the few studies was reported by Prinzel et al. (2001) on the use of electroencephalogram (EEG) biofeedback in conjuction with adaptive automation to minimize the onset of hazardous state of awareness. Eighteen university students acted as simulated operators were participated and assigned to three groups (self-regulation, false feedback, and control). Subjects carried out a compensatory tracking task from the Multi-Attribute Task Battery (MATB) that was cycled between three levels of task difficulty on the basis of the electroencephalogram (EEG) record. In addition, subjective workload was assessed using the NASA TLX. The researchers found that psychophysiological self-regulation could enhance cognitive resource management skills of operators. The participants who had received EEG biofeedback (neurofeedback) training performed significantly better in controlling hazardous states of awareness and reported lower subjective mental workload than participants in the false feedback and control groups. However, the main purpose of such neurofeedback was to be incorporated into adaptive automation in automated pilot cockpit. It still needs some years away to be implemented in wider areas because of highly sophisticated technology required.

2.5.3 Heart Rate Variability (HRV) Biofeedback

Due to the advancement in biofeedback technology, recently heart rate variability (HRV) feedback also shows potential application in performance enhancement. Over other types of biofeedback, HRV feedback is more reflective of both the sympathetic and parasympathetic branches of the ANS's activity and the harmonization between them, and thus it provides a window into the dynamics of the system as a whole (McCraty and Tomasino, 2004). Most other biofeedback methods are designed to control tonic levels of various physiological functions (e.g., muscle tension, finger temperature, heart rate, blood pressure, etc.). HRV biofeedback training aimed to control oscillatory variability in heart rate, thus directly strengthening and exercising the body's important self-modulatory reflexes: the baroreflex (Lehrer and Vaschillo, 2003). In contrast, other biofeedback methods affect these mechanisms more indirectly by teaching people to control tonic level of blood pressure, heart rate, skin temperature, etc. The latter tasks are considerably more difficult than learning to increase HRV (Lehrer, 2007). By improving the body's ability to modulate itself, the balance between the sympathetic and parasympathetic becomes more strongly regulated, thus HRV biofeedback may be proven useful for dealing with autonomic dysregulation (Lehrer and Vaschillo, 2003). Specific compared to EEG feedback, HRV feedback is also much simpler and more straightforward to learn and use, which facilitates rapid improvement. Further, its cost-effectiveness also makes it accessible to a greater number of people and in a wide range of applications (McCraty and Tomasino, 2004). Considering these reasons, HRV biofeedback shows more promising application in work setting for operators' performance enhancement.

Extensive researches have been conducted by the Heart Math Institute on the use of HRV biofeedback termed psychophysiological coherence in diversity. A combination of rhythmic breathing and the intentional self-induction of a sincere positive emotional state facilitate coherence in the autonomic nervous system. When heart-brain dynamics are modified in this way, the brain's information processing capabilities may change. These changes lead to potential improvement in faculties such as motor skills, focused attention, and discrimination (McCraty, 2003).

Barios-Choplin et al. (1997) conducted an exploratory study examining the impact of Inner Quality Management (IQM) on a group of Motorola employees (30 factory workers). HRV biofeedback was incorporated in this 3-month study. Results indicated that there were significantly increased productivity through the improvement of job satisfaction and communication, and through the reduction of tension and anxiety (all reported at $p < 0.05$). The improvement on psychological measures were supported by the reduction in subjects' resting autonomic activity, suggesting a shift in their baseline emotional state to one of decreased tension and anxiety. Nonetheless, an absence of control or comparison group was a major drawback of this study. There were many events in addition to the IQM training that could have influenced participants in the 3 months from the first training to the end of the study.

Similar technique was also used on 54 employees in the Information Technology Services Division of a state agency that was experiencing change-related turmoil (Barios-Choplin et al., 1999). Measures of personal and organizational quality (POQA) in the trained employees were compared to those of a 64-member comparison group who had not received the training. After completion of the training, seven weeks from the initial assessment, the study group demonstrated significant reductions in measures of stress and negative emotion, specifically in anger, 20%; distress, 21%; depression, 26%; sadness, 22%; and fatigue, 24%. Subjects also reported significant increases in measures of positive emotion and organizational effectiveness compared to the untrained group, specifically in goal clarity, 9%, and productivity, 4%.

Both aforementioned studies (Barios-Choplin et al., 1997, and 1999) used biofeedback as part of larger intervention program hence it is difficult to ascertain biofeedback's true effect on performance. Furthermore, increased productivity or work performance was measured using a variety of self-report psychological measures, thus the extent to which the training affected on objective performance were not examined. In human performance literature, Hancock and Vasmatzidis (1998) contend that, rather than either self-report or physiological measures, task performance level should be the primary criterion for determining the effects of exposure to stress. They argue that change in behavioural performance efficiency is the most sensitive reflection of human response to stress, and that error-free performance is the principal criterion of work efficiency, especially in high-technology systems. Therefore, behavioural performance assessment should surpass physiological assessment or self-report as the primary exposure criterion, although these other measures still provide important additional information. Consequently, in this study, the effect of proposed intervention was assessed using all of these measures to obtain more accurate and comprehensive conclusion.

In the laboratory setting, McCraty (2002) also evaluated the efficacy of quite a similar technique on cognitive performance in an auditory discrimination task. In this investigation, 30 subjects were randomly divided into matched control and experimental groups based on age and gender. The experimental group used the Cut-Thru intervention as HRV biofeedback strategy in the interval between the two auditory discrimination tasks, while the control group engaged in a relaxation period during this time. Cognitive performance was assessed by determining subjects' reaction times in an oddball auditory discrimination task before and after practicing the HRV-biofeedback technique or relaxation to increase cardiac coherence. As compared to the control group, the experimental group subjects using HRV-biofeedback technique demonstrated a significant increase in heart rhythm coherence ($p < 0.05$) and a significant decrease in reaction times in the discrimination task ($p < 0.05$) following the application of the technique. The results of this study support the hypothesis that the changes in brain activity that occurs during states of increased psychophysiological coherence direct to changes in the brain's information processing capabilities. Although this finding is certainly promising, however, the author used restricted auditory cognitive task and thus cannot be generalized to other domains of cognitive functioning. Besides, in daily work operators encounter predominantly visual-cognitive task or a combination of both modalities. According to Hancock and Meshkati, (1988), the performance differences among operators were also found between input modality (e.g. auditory versus visual) used in an experimental task pertaining to human performance studies. To address with this drawback, in this current study, a variety of cognitive performance tests were employed to obtain more representative cognitive functions including attention, memory, concentration performance, and cognitive flexibility. Moreover, the results from this study were immediate effects which did not involve learning as one of fundamental aspect of biofeedback training (Shellenberger and Green, 1986, and Schwartz, N.M. and Schwartz, M.S., 2003).

In addition to psychophysiological coherence, there is also another HRV biofeedback strategy, named oscillatory biofeedback. Suvorov (2006) used this strategy to induce inherent harmonics on 15 male students. Subjects received 5 daily sessions and each session lasted approximately 30 minutes. This biofeedback control directed to strength, restore or create harmonics associated with respiratory movements and inherent harmonics by doing specific breathing rhythm. To assess operator's quality at pre and post intervention, a computer test of spatial thinking, attention, and visual information-processing speed was utilized. The quantity of correct responses and the speed of information processing were used as performance criteria. The result revealed that 14 participants showed strengthening or formation of inherent harmonics while only one subject whose inherent harmonics remained unformed. The oscillatory biofeedback led not only to the presence of inherent harmonics but also facilitated to the improvement of the quality of operator activity. The result of the *t*-test showed that subjects had a 44.5% reduction of error ($p < 0.01$) and had a 42.3% increase of the information processing rate ($p < 0.01$). A single follow up study was conducted after 1 ½ years with the same subjects. The majority of participants showed retained inherent harmonics. In spite of its potential feature, the protocol of oscillatory biofeedback including description of specific breathing rhythm and how to carry out the technique were not provided by the author. The theoretical underlying of this technique thus remains unclear. Besides, this study employed one group pretest-postest design and no control group was assigned, thus lack of control for various explanation was noticeably high (Stangor, 2007, and Gravetter and Forzano, 2009). It greatly limits their internal validity. Both McCraty (2002) and Suvorov (2006) conducted laboratory training employing non real operators whom might have different characteristics than real workers. It raises, then, generalization issue to be applied in work setting. The findings of McCraty (2002) and Suvorov (2006) though certainly promising, are restricted to discrimination and psychomotor task and thus cannot be generalized to other domains of cognitive functioning.

2.6 RESONANT FREQUENCY TRAINING BIOFEEDBACK

In this present study, a HRV-biofeedback or resonant frequency training (RFT) biofeedback (note: HRV/RFT can be used synonymously) was utilized to enhance operator's cognitive functions. The protocol is developed based on work of Lehrer, Vaschillo, and Vaschillo (2000). In review of the training criteria just described, resonant breathing appears to become the most promising strategy being used in this study. It is a well-established technique for more than 20 years of research endeavours (Vaschillo et al., 2002). All of HRV biofeedback strategies are essentially directed to augment the amplitude of HRV. Over other strategies, however, RFT biofeedback demonstrates how to obtain greater of this amplitude instead of simply producing a smooth or sine wave-like pattern of heart rhythm. Compared to psychophysiological coherence, RFT technique works by allowing subjects to gain control of their physiology than relax under pressure. Lehrer and Vaschillo (2003) conducted research on the use of RFT in 54 healthy subjects who were assigned randomly 23 to the biofeedback group and 31 to the waiting list group. They noted that none of the physiological changes in biofeedback group were closely associated with self-reported experiences of relaxation. This result suggested that the cardiorespiratory effects cannot be explained by relaxation whereas other HRV biofeedback techniques use the relaxation as the mediating role in enhancing performance. In real work settings, cognitive performance decrement is influenced either by stress or fatigue (Pattyn et al., 2008) rather than anxiety. Thus RFT presents opportunities to be applied outside that of emotional regulation. Finally, RFT needs only four sessions (Lehrer, 2007), irrespective of age, to teach the subjects acquire the targeted resonant breathing while oscillatory biofeedback may require up to 15-20 sessions to get inherent harmonics (Suvorov, 2006).

Resonant frequency training is a specific biofeedback training strategy that is aimed to generate maximal increases in amplitude of respiratory sinus arrhythmia (RSA) (Lehrer et al., 2000), thus it is also often called RSA biofeedback. RSA refers to cyclical oscillation in heart rate coincident with the respiratory cycle, such that increases in heart rate occur during inhalation and decreases in heart rate during exhalation. RSA is a component of HRV which reflects homeostatic activity and adaptability (Berntson et al., 1997). A threat to homeostasis elicits an arousal response and may lead to physical or mental malfunction (Wyller et al., 2009). Back to inverted-u principle (Welford, 1973, and Duschek et al., 2009), there is a relationship between arousal and optimal performance. Each individual has a specific arousal level at which he/she performs optimally. Therefore, it is expected that skills achieved from RFT can be used by individuals to gain the optimal level of performance without causing unnecessary stress.

With reference to HRV, it is now recognized that the variability (rhythm) of a heart is an indicator of both physiological resiliency and behavioural flexibility, reflecting the person's capacity to adapt to stress and environmental demands (Andreassi, 2007). Normal heart rate is characterized by constant rhythmical variability, associated with various reflexes related to physiological regulation including hemodynamic responses to respiration, baroreflex, and thermal regulation (Task Force, 1996, and Berntson et al., 1997). A high degree of instability or too little variation can be detrimental to efficient physiological functioning. Increase on HRV measures is a marker of better interaction between the sympathetic and parasympathetic branches of the autonomic nervous system, and if sustained may potentially lead to improved functioning in all bodily systems (Tiller et al., 1996, and McCraty, 2006). Lehrer et al. (2000) suggested that RFT biofeedback can mediate a homeostatic state in the body because resulted cardiovascular system displays continuous rhythmic variation. The biofeedback displays the process of breathing, the rate of breathing, and the amplitude of breathing. Trainee pursues smooth, even breathing, with large amplitude and low rate. RFT is used most commonly in treating a variety of diseases in which autonomic factors play a role.

In clinical settings, HRV biofeedback produces large increases in heart rate variability in almost everyone, usually within a few minutes of the beginning of training (Vaschillo et al., 2006). A large amount of researches has shown that maximal increases in amplitude of heart rate oscillation are produced when the cardiovascular system is rhythmically stimulated by paced breathing at a frequency of about 0.1 Hz (6 breaths per minute). This effect is linked to resonance properties of the cardiovascular system resulting from activity of the heart rate (HR). Resonance in any system generally is characterized by very high amplitudes of oscillation all at a single frequency (Lehrer and Vaschillo, 2003).

Most individuals can learn RFT biofeedback training easily which involves slowing the breathing rate (around six breaths/min) to each individual's resonant frequency. Breathing at an individual's resonant frequency maximizes HRV as measured by SDNN and HR Max – HR Min (Lehrer, 2007). Breathing at an individual's resonant frequency also doubles the energy in the low frequency (LF) band (0.05-0.15 Hz) and centres the peak frequency about 0.1 Hz. The LF oscillator represents the influence of both the parasympathetic and sympathetic branches and blood pressure regulation. Inside the major arteries of the cardiovascular system tiny pressure sensors called baroreceptors relay information to the sinus node of the heart to optimize homeostasis in the blood pressure system.

Maximal control over HRV at the resonant frequency can be obtained in most people after approximately four sessions of training (Lehrer, 2007). According to Moss and Shaffer (2004, 2009), subjects can maximize HRV at this resonant frequency by creating a "relaxed mental state, with a positive emotional tone, breathing diaphragmatically at a rate of about 5-7 breaths per minute. Each of these components is critical. Respiration rate is important because breathing is an oscillator that drives the heart rhythm. Moreover, slow diaphragmatic breathing coupled with a positive emotional tone maximizes HRV in the LF range because it superimposes the effects of three oscillations: breathing, autonomic activity, and blood pressure regulation. Figure 2.8 shows that when breathing occurs at resonant frequency, heart rate should have the most profound oscillations synchronous with breathing. By the end of inhalation heart rate attains its maximum level and respectively by the end of exhalation heart rate reaches its minimum level (i.e. respiratory sinus arrhythmia)

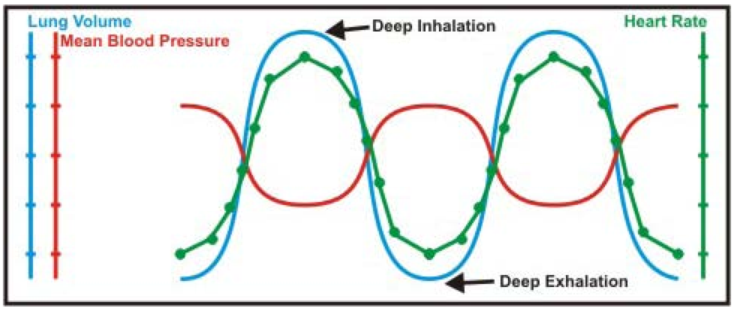

Figure 2.8: Relationship between breathing, blood pressure, and heart rate produced at resonant frequency

Source: Pougatchev, V. and Pougatchev, I. (2007)

2.6.1 Application of Resonant Frequency Biofeedback

Although nothing has particularly been done with workers, using resonant frequency heart rate biofeedback shows promise in clinical and non-clinical populations and may be generalized to work settings. In laboratory setting, Lehrer et al. (2000) used breathing techniques guided by heart rate biofeedback among healthy subjects. They found that when breathing is combined with HRV biofeedback, subject in training group were able to create resonance in the cardio respiratory system between the effects of respiration and those of the baroreflex. Practicing this method daily and consistently also increases total heart rate variability with almost all of the oscillations peaking at a single frequency, 0.1 Hz (Figure 2.8). In another study, Lehrer et al. (2003) also demonstrated the neuroplasticity effect of the baroreflex among healthy adults. This effect suggests that the increase of baroreflex may affect and improve autonomic regulation throughout the day among individuals trained in this method.

In clinical setting, Karavidas et al. (2007) examined the feasibility of feasibility of using HRV biofeedback to treat major depression. Eleven participants included four males and seven females, aged 25–58 (Mean = 45, *SD* = 10.8) participated in a weekly 10-session HRV biofeedback protocol. Severity of depression was assessed at the orientation session (baseline) and at sessions four, seven and ten. Using Beck Depression Inventory II, participants reported reduction on cognitive symptoms of depression, $t\ (29) = -3.525$, $p = 0.001$ as well as neurovegetative component, $t\ (29) = -.812$, $p < .001$. Both were observable by session four. There was a 26.7%

improvement in cognitive symptoms from baseline to session four, and a 41.7% improvement from baseline to session ten. There was a 43.7% decrease in neurovegetative symptoms from baseline to session four, and a 62% decrease from baseline to session ten. Although the improvements were subjectively perceived, they might indicate a possibility to get similar effects while being evaluated objectively by outside observers.

In a more recent study, Siepmann et al. (2008) assessed the feasibility of using HRV biofeedback to treat moderate to severe depression. Thirty eight participants, aged 18–47 years (mean = 28, SD = 7.3) participated in a six-session HRV biofeedback protocol conducted over two weeks. This sample consisted of 14 patients with depression (13 female, 1 male) and 12 healthy volunteers (6 female, 6 male) who all received active treatment. Another 12 healthy subjects acted as an active control who sat in front of the computer screen switched on, but were not instructed to breathe in a paced way or to maximize their HRV. Severity of depression was measured by the Beck Depression Inventory (BDI) and anxiety was measured with the Spielberger State-Trait Anxiety Inventory (STAI). Scores of BDI and STAI were found reduced during biofeedback and at follow up as compared to baseline (χ^2 (2) = 11.2, $p < 0.05$; χ^2 (2) = 8.7, $p < 0.05$, respectively). In addition, depressed patients had reduced anxiety, decreased heart rate and increased HRV after conduction of biofeedback ($p < 0.05$). On the opposite, no changes of mood nor HRV were present in healthy subjects receiving biofeedback nor in those who were under an active control group.

In non clinical area, one of successful application of this technique has been shown by work of Strack (2003) in improving batting performance. Forty three baseball players were randomly assigned into training (n = 22, Mean = 16.7, *SD* = 0.89) and control group (n = 21, Mean = 16.9, *SD* = 0.83). Participants performed a competitive batting contest and a six week RFT biofeedback. Participants were measured on batting performance and self-reports of state anxiety (CSAI-2), flow (FSS-2), and a visual analogue scale (VAS) of how well the baseball was tracked visually. Results showed that biofeedback group showed a 60% improvement compared to a 21% improvement for the control group. Not as predicted, scores on cognitive anxiety subscale remained constant over time in both groups. Moreover, both group showed better visual tracking of the baseball. Finally, partial support was noted on the occurrence of the subjective state of flow. Although not all of hypotheses were confirmed, results of this study highlight the potential benefits of resonant biofeedback training for performance enhancement with athletes. It is expected that the technique will have positive effects for performance enhancement in manufacturing operators.

In another sport application study, Lagos et al. (2008) evaluated HRV biofeedback on the mood, physiology, and sport performance of a 14-year-old golfer. The golfer attended ten consecutive sessions of HRV biofeedback once per week. Each session lasted 45–60 minutes. Sessions one, four, seven, and ten served as recording sessions. Similar with prior studies on resonant biofeedback (Strack, 2003; Karavidas et al. 2007, and Siepmann et al., 2008), the format and duration of sessions followed the protocol outlined previously by Lehrer et al. (2000). Results show that total HRV, low-frequency HRV, and amplitude of oscillation at 0.1 Hz were considerably increased during biofeedback practice. This effect became stronger across sessions, suggesting increases in baroreflex gain. Following HRV biofeedback, the golfer achieved his personal record score for 18 holes of golf, and his mean golf score (total number of shots per 18 holes of golf) was 15 shots lower than in his previous golf season. The golfer received no golf instructions during HRV biofeedback training. Additionally, he reported reduction in four out of five negative mood states between session one and session ten on the on Profile of Mood States (POMS). After ten weeks of training, he reported a complete absence of tension, depression, anger, and fatigue. The golfer's cognitive and somatic anxiety was also reduced, as measured by the Competitive Anxiety in Sport (CSAI-2). The results of this case study suggest that HRV biofeedback training may help the athlete cope with the stress of competition and/or improve neuromuscular function.

In a pilot study, Sutarto and Wahab (2008) used resonant breathing biofeedback to improve cognitive performance among female university students ((Mean = 20.56, *SD* = 0.57). Nine subjects underwent the 6 sessions of HRV biofeedback training. The analysis of Wilcoxon test revealed significant increase ($p < 0.05$) on Stroop Colour-Word test, and arithmetic performance test after biofeedback training across eight of nine subjects. This has been supported by significant change ($p < 0.05$) toward lower frequency (LF) oscillation over all sessions. However, in addition to small sample size, the absence of a control group in this study allows the possibility that the results were produced by nonspecific factors, including passage of time and placebo factors (Gravetter and Forzano, 2009, and Stangor, 2007). More detailed this preliminary study was described in section three.

2.7 STRATEGIES USED IN RESONANT BIOFEEDBACK MODULE

2.7.1 Diaphragmatic Breathing

People breathe about 20,000 times a day. Males breathe 12-14 breaths per minute compared to 14-16 breaths per minute for females. Hyperventilation often exceeds 20 breaths per minute (Moss and Shaffer, 2009a). The respiratory cycle consists of an inspiratory phase, inspiratory pause, expiratory phase, and expiratory pause which are controlled by separate mechanisms, as illustrated in Figure 2.9. The excursion of an abdominal strain gauge, which indexes respiratory amplitude, is often greatest during the inspiratory pause.

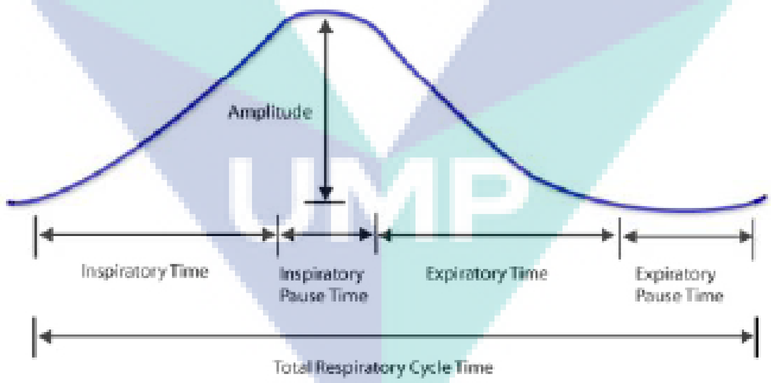

Figure 2.9: Respiration Cycle

Source: Moss and Shaffer (2009a)

There are five unhealthy breathing patterns that reduce oxygen delivery to the lungs and suppress heart rate variability. These include thoracic breathing, clavicular breathing, reverse breathing, hyperventilation, and apnea. Such dysfunctional respiration contributes to asthma, anxiety (panic), functional cardiac symptoms, and other syndromes (Moss, 2009a). It is no coincidence that the majority of relaxation techniques (e.g. yoga, meditation, etc.) include breathing retraining as a central component (Reiner, 2008). Various forms of breathing retraining have been found to be effective treatments and/or treatment adjuncts for anxiety disorders and other disorders of autonomic dysregulation (Lehrer and Woolfolk 2007, and Zucker et al., 2009). Regardless what are the techniques, the main component of breathing retraining is diaphragmatic breathing which is also an effective strategy known to reliably increase HRV (Tripathi 2004; Lehrer, 2007, and Reiner, 2008).

Diaphragmatic breathing increases the carbon dioxide concentration of arterial blood compared to thoracic breathing. This lowers blood pH, weakens the bond between haemoglobin and oxygen, and increases oxygen delivery to body tissues. To achieve maximum HRV, trainers may teach their clients to modify their diaphragmatic breathing cycle. This may involve slowing their respiration rate to their resonant frequency and adjusting time spent during inspiration, expiration, and the pauses after these phases (Moss and Shaffer, 2009a). In clinical settings, most patients begin diaphragmatic exercise, they frequently use excessive effort. Excessive breathing effort can produce dysponesis, resulting in forceful abdominal movement and breath-holding until “starved for oxygen” (Moss and Shaffer, 2009b). Consequently, Peper and Holt (1991) cautioned against trying too hard and recommended that patients use about 70% of maximum effort during breathing practice. They proposed what is currently known as effortless diaphragmatic breathing. It comprises a slower respiration rate (< 8) with large tidal volume (> 2000ml), and smooth flow rates, predominant abdominal expansion during the inhalation and abdominal contraction during exhalation. The exhalation time which includes and exhalation pause is significantly longer than the inhalation time and the end-tidal CO2 is 5% (Fried and Grimaldi, 1993). In addition, respiratory sinus arrhythmia is increased and in phase with the breathing pattern. In practicing effortless diaphragmatic breathing, passive attention is encouraged, allowing the breath to move in and out without effort. This approach induces internal quieting (mindfulness) and relaxation.

It has been shown that slow full diaphragmatic breathing approximately 6-7 breaths per minute (Gevirtz and Lehrer, 2003) produces “Resonant Frequency” sinusoidal wave form with heart rate, CO_2 levels, and respiration in parallel. With inhalation, heart rate rises, CO_2 increases, and pneumograph curve rises while during exhalation all of three decrease (see Figure 2.8).

2.7.2 Pursed-Lips Breathing

Pursed-lips breathing (PLB) is a technique whereby exhalation is done through a resistance created by constriction of the lips (Spahija et al., 2005). Pursed-lips breathing is frequently taught to patients with chronic obstructive pulmonary disease (COPD) in respiratory physiotherapy programs to improve breathing efficiency and better manage dyspnea during activities of daily living. This breathing pattern seems to be more effective than spontaneous breathing in COPD patients. Lehrer (2007) suggests that this technique can be extended applying to healthy subjects in learning resonant breathing because it produced a more physiological and efficient ventilation. It promotes prolonged exhalation than inhalation, leading to lower breathing frequency and higher tidal volume (De F Fregonezi et al., 2004). As a result, tidal volume increases, gas exchange improves, and oxygen consumption decreases

2.7.3 Dzikir

Most religious and spiritual traditions, regardless of cultural context, have emphasized the value of experiencing and expressing positive emotions such as love, care, appreciation, compassion, tolerance, forgiveness (Childre and McCraty, 2001). A unique study by Bernardi et al. (2001) assessed the effects of the rosary prayer and yoga mantras on autonomic cardiovascular rhythms. People who recited the Ave Maria or Yoga Mantra showed improved of regularity of breathing as well as slowing of respiration to six breaths per minute. These findings were in accord with outcome of resonant breathing exercise which all of them produced large increases in HRV at the frequency of 0.1 Hz. Although no previous research has dealt with the cardiovascular rhythm (HRV) effect of dzikir, it is expected that recitation of dzikir would help subjects achieve the training target. Since the main focus of this study is on resonant breathing, the effect of dzikir was not investigated further.

2.7.4 Providing Cognitive Support

In human performance training such as sports or music, learners are not expected to learn a skill solely by trial-and-error, or imagine letting a person learn to drive a car by trial-and-error. This is also true for biofeedback training. Regardless what kind of the training, trainee needs adequate cognitive support, such as rationale of the training, instruction, and coaching. Studies on the use of cognitive behavior modification have revealed the importance of positive instructions, positive self-talk, and positive imagery for effective coaching, teaching and therapy with humans (Allen, 1998, and Butler et al, 2006). Research in psychology, education, and sports has also documented the importance of a positive interaction between teacher and student, coach and athlete, therapist and client (Sutherland and Oswald, 2005, and Sánchez et al., 2009). Moreover, the importance of the positive or negative expectations of the coach or teacher on motivation and performance has been well demonstrated (Appelbaum, 1996; Sarazzin et al., 2006, and Biswas-Diener, 2009). All of these are relevant in biofeedback training research. Taking into consideration all of these, this current study highlighted on providing adequate cognitive support. First, participants in the training group were given clear instruction and rationale of the training. Second, the researcher also continuously motivated and encouraged the participants as well as maintained positive interaction with them.

Furthermore, as learning a new skill such as playing tennis, a learner cannot play well without regular practice, nor can biofeedback trainees. In most cases, training in the laboratory or the clinic is not sufficient for learning self regulation skills and for transfer of training to other situations. Thus, successful biofeedback training requires home practice as an integral component of the mastery and generalization process (Shellenberger and Green, 1986). In this study, a home practice was also incorporated in the training. A detailed of the home practice contents is provided in research method section.

2.7.5 Mastery Task

Mastery is the ability to demonstrate the learned skill under unfavorable conditions, both in and out of the laboratory or clinic (Shellenberger and Green, 1986). By achieving mastery, subject will have the ability to transfer both physiological and cognitive skills to any situation, to achieve healthy psychophysiological homeostasis and maintain homeostasis when encountering stressors, or to recover from stress rapidly (Budzynski et al. 1973; Sharpley, 1994, and Sharpley et. al, 2000). Incorporating the demonstration of psychophysiological mastery into research and clinical practice can be done by demonstration of self-control without feedback in relaxed settings and or demonstration of self-control without feedback in stressful situations (i.e cold room, cold pressor test, stress profile, performance tasks, and interpersonal confrontations). Concerning with the importance of providing mastery task, in this study, participants in the training group were given arithmetic mental stressor at particular sessions. In addition, to evaluate whether the training group were successful at mastering the skill, a physiological stress profile, also used arithmetic task which was also administered at pre and post intervention. Mental arithmetic is the most commonly examined stressor in stress and human performance literatures and it has been demonstrated repeatedly to induce elevations in plasma catecholamine levels such as epinephrine and norepinephrine (Biondi and Picardi, 1999). Detailed arithmetic tasks used in this study is described in Chapter 3.

2.8 SUMMARY

Contribution of operator's performance in company's productivity can not be overlooked. Individual-based strategies for improving their performance might be directed to enhance their willingness or capacity dimensions (Blumberg and Pringle, 1982). Considering the adverse effect of stress on productivity over other risk factors, a large body of researches has well documented the use of numerous stress management training for reducing stress among workers as an effort to improve their performance. Nonetheless, lack of studies has been devoted in reducing work stress-related symptoms for workers at operative level.

On the other hand, cognitive performance is a fundamental capacity variable of worker whose state fluctuates throughout the day. With respect to stress, stress has significant effects on cognitive performance, either positively or negatively. The effects are mediated by arousal. According to an inverted u-shaped curve from Yerkes-Dodson law (Yerkes and Dodson, 1908, and Hebb, 1955), performance degrades if a person becomes over aroused, distressed, or he/she becomes under aroused. Research has shown that changing a person's arousal state may lead to improved cognitive performance and also often accompanied by subjectively perceived of reduced emotional symptoms (Tart, 1969; Ray et al., 2001; Lehrer et al., 2003; Casden, 2005; Thurber, 2006, and Karavidas et al., 2007). One of widely-used strategies is by using psychophysiology activity or arousal state as a knowledge feedback to correct the state toward the optimal (McCraty, 2002; Vernon et al., 2003; Egner and Gruzelier, 2004; Vernon, 2005, and Sutarto and Wahab, 2008). This strategy is often called as biofeedback.

Currently biofeedback has also gain widespread implementation not only in clinical settings but also in healthy subjects a performance-enhancement tool ranging from sport, music, education to workplace settings (Rase et al., 1996; Barios-Choplin et al., 1997, 1999; McCraty et al., 2000; Egner and Gruzelier, 2003; Strack, 2003; Raymond et al., 2005; Thurber, 2006, and Tanis, 2008). Compared with other biofeedback strategies, heart rate variability (HRV) biofeedback offers many advantageous (McCraty and Tomasino, 2004, and Lehrer, 2007) which shows more potential to be applied in workers at operative level. It is a new window to autonomic nervous system assessment and control of dysregulation.

Research previously noted in this review has highlighted HRV biofeedback as a tool for improving autonomic nervous system function which results in an improved resilience to stress and overall improved psychological as well as physical health in healthy subjects (Barios-Choplin et al., 1997, 1999, Lehrer et al., 2003, Strack, 2003; Lagos et al. 2008). Nonetheless, to date, there are few studies that were reported on the use of HRV biofeedback for the improvement of cognitive performance. Most of the research literature deals with reduction of stress-related symptoms either in clinical setting or in healthy subjects (Karavidas et al. 2007; Siepmann et al., 2008; Lagos et al., 2008, and Zucker et al., 2009). Karavidas et al. (2007) found improvement in some aspect of cognition based on the subjectively perceived of the subjects. Only two studies on HRV biofeedback utilized objectively cognitive performance assessment (McCraty, 2002, and Sutarto and Wahab, 2008). However, these studies are based on collegiate samples, with very few studies examining HRV biofeedback training with real workers (Barios-Choplin, 1997, and 1999). In addition, these studies were limited to lack of research control (i.e. inadequate sample size, lack of control group), and unstandardized cognitive test battery. This present literature review found no investigations have been found on the use HRV biofeedback for the improvement of cognitive performance in industrial operators.

This present study will be among the first attempt to test the effectiveness of HRV biofeedback for improving cognitive performance among industrial operators. Participants in the training group will be trained to maintain autonomic activity within certain bandwidths. This study will also attempt to correct problems from previous studies by employing some cognitive functioning tests including attention, memory, and cognitive flexibility. In addition, to explore whether a reduction in stress-related symptoms facilitates cognitive performance improvement, operator's emotional states will also be evaluated. Resonant frequency breathing is a specific HRV biofeedback strategy used in this study which includes breathing at the resonant frequency in combination with diaphragmatic and pursed lips breathing, and dzikir. Providing adequate cognitive support and mastery task were also incorporated in the training.

CHAPTER 3

RESEARCH METHODS

3.1 INTRODUCTION

The purpose of this study is to examine the effectiveness of HRV biofeedback training in improving cognitive performance among manufacturing operators. The effects of this training were investigated on several cognitive functions, physiological parameters, and self-report physiological measure. This chapter will be organized in the following order: (1) a brief description of the preliminary study; (2) a restatement of research question and hypotheses; (3) method including subjects, apparatus, experimental task, procedure, training sessions, dependent/variables measures; (4) the development of HRV biofeedback module; and (5) research design and data analysis.

3.2. SUMMARY OF PRELIMINARY STUDY

3.2.1. Method

A preliminary study was undertaken to assess whether the HRV biofeedback training was likely to be practical in homogenous sample before applying it in real operators (Sutarto and Wahab, 2008). In this preliminary study, the effect of HRV biofeedback was evaluated among nine female undergraduate students who were recruited from the Universiti Malaysia Pahang. They received six sessions of HRV biofeedback training during three weeks, two sessions per week. Each session lasted approximately 30 minutes which consisted of 5 minutes baseline and 20-25 minutes HRV biofeedback. The procedure of HRV biofeedback training referred to the protocol by Lehrer et al (2000). On the first meeting the participants performed several cognitive tests. Results of the pre-training were compared with of the post-training at the end of six training sessions afterward. The effect of biofeedback training were examined by administering three cognitive task: Stroop Color-Word Test (cognitive flexibility), memory (verbal memory), and arithmetic test (decision making). As a measure of training progress, the percent of total HRV shifted to the LF range was assessed between sessions using Biofeedback Stress Management Kit developed by Institute of Molecular biology and Biophysics, Russian Academy of Medical Sciences.

3.2.2. Results

Results of the Wilcoxon-signed rank test revealed that there were increases in several cognitive functions after training among students as simulated operators. Specifically, of nine participants, eight were able to improve their cognitive performance (see Table 3.1). On the whole, all participants except subject 4 showed progress in all parameters of operator's cognitive performance. These were in line with the increase of LF activity in most of all sessions. By the end of training, the decrease of the LF activity in participant 4 was accompanied by the absence of positive results in her Stroop and arithmetic test.

Table 3.1: Pre- and Post-test of the Cognitive Performance of Preliminary Result

Subject	**Stroop Interference Score**		**Memory test (accuracy)**		**Arithmetic (accuracy)**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
1	36.3	65.2	4	7	0	7
2	58.8	60.4	8	10	1	3
3	63.0	63.6	9	11	2	7
4	48.1	40.8	3	6	4	3
5	56.8	66.7	7	8	3	6
6	46.8	47.2	13	15	1	2
7	54.6	53.8	6	12	2	7
8	53.5	58.4	10	10	4	4
9	46.2	57.7	4	8	2	2
Median	53.50	58.40	7	10	2	4
z	-1.955		-2.536		-2.120	
Exact *Sig* (1-tailed)	0.027		0.004		0.023	
Size effect (*r*)	-0.46		-0.598		-0.50	

Training effectiveness between sessions was assessed using Friedman's ANOVA test with repeated measures on percent of total HRV power moved to the LF range. Result indicated a significant change toward LF range over all training sessions (χ^2 = 34.044, $p < 0.001$). Wilcoxon signed-rank tests were used to follow up this finding with all of the effects were reported at 0.003 level of significance (0.05 divided by 15 comparisons). As summarized in Table 3.2, the LF oscillation significantly increased from the first session of the training to the third session, Z_{13}= -2.429, r_{12} = -0.572, and the following subsequent sessions.

Table 3.2: Pairwise Comparison of LF Oscillation Change between Subsequent Sessions in University Students as Simulated Operators.

Comparison	Z	*p*
S_2 - S_1	-2.4286	0.006
S_3 - S_1	-2.6656	0.002*
S_4 - S_1	-2.6656	0.002*
S_5 - S_1	-2.6656	0.002*
S_6 - S_1	-2.6656	0.002*
S_3 - S_2	-2.6656	0.002*
S_4 - S_2	-2.6656	0.002*
S_5 - S_2	-2.6656	0.002*
S_6 - S_2	-2.6656	0.002*
S_4 - S_3	-2.3102	0.099
S_5 - S_3	-2.6656	0.002*
S_6 - S_3	-2.6656	0.002*
S_5 - S_4	-2.6656	0.002*
S_6 - S_4	-2.6656	0.002*
S_6 - S_5	-2.5471	0.004

Note. S_i = Session$_i$, i = 1, …,6. $^*p < 0.003$, after applying the Bonferroni correction.

3.2.3. Limitation

The results of this study should be interpreted with caution due to small sample size and no control group. Further study, therefore, utilized larger sample size which then was assigned in the training and control group. As the mechanism by which the improved cognitive functions were still unclear, the future assessed the effect of similar training on the reduction of negative emotional symptoms or stress. Researchers have shown that cognitive performance has strong relationships with stress (Bourne and Yaroush, 2003, and Lane, 2004). Furthermore, in the present study, the biofeedback participants performed physiological stress profile to assess their ability to transfer what they learned when no special instruction was provided.

From physiological measures, the Biofeedback Game Kit device used in the pilot study only recorded heart rate measures recorded from the photoplethysmograph sensor. As the respiration rate is a crucial parameter in resonant breathing biofeedback, thus the future study used a more sophisticated biofeedback system device which provided wider features and more quantitative measurement of cardiovascular and respiratory system. There had been also a lot of data artifacts because the signals had been contaminated by electrical noise from the recording environment and subject's movement. Since any artifacts might interfere the analysis of these signals, further study employed heart rate variability (HRV) analysis software to correct such artifacts as well as also calculate desired measures (e.g. percentage of LF power).

3.3. RESTATEMENT OF RESEARCH QUESTIONS AND HYPOTHESES

3.3.1 Research Questions

What effect does heart rate variability biofeedback training have on cognitive performance experienced by operators?

3.3.2 Research Hypotheses

1. The training group will show a significant increase in percentage of LF activity as compared to a control group from pre to post across three conditions (baseline, stressor, and recovery).
2. The training group will show a significant decrease in breathing rate as compared to a control group from pre to post across three conditions (baseline, stressor, recovery).
3. The training group will show a significant improvement in attention as compared to a control group from pre to post.

4. The training group will show a significant improvement in memory as compared to a control group from pre to post.
5. The training group will show a significant improvement in cognitive flexibility as compared to a control group from pre to post.
6. The training group will report a significant reduction in depression as compared to a control group from pre to post.
7. The training group will report a significant reduction in anxiety as compared to a control group from pre to post
8. The training group will report a significant reduction in stress as compared to a control group from pre to post
9. There will be a correlation between changes in cognitive performance and emotional symptoms in the training group

3.4. METHOD

3.4.1. Subjects

The research participants were female operators at an electronic manufacturing industry located in Kuantan, Pahang, Malaysia. In Malaysia, the electronics industry is the leading industry in the manufacturing sector and one of the largest employers (Department of Statistic Malaysia, 2010). Women are concentrated in labor-intensive operations in manufacturing sector such as clerical workers, equipment operators, production workers, and service workers. Finally, restriction to one gender decreased the variance of the physiological data.

The goal of this study was to examine the pre and post mean difference between the experiment and control group. This study employed a combination of convenience selection and random assignment. The Operation Manager of the factory received a letter and a proposal with respect to the study. Upon obtaining approval from the management (see Appendix A on page 146), the Manager asked the factory supervisors to select operators from production departments. The selection of potential participants was done based on availability (i.e. convenience sampling).

Forty potential subjects attended the meeting to get some information regarding the study including the length of study, voluntarily to decline, benefits of the research, and risk to participant, and a brief description of the study (see Appendix B on page 147). Then, subjects were asked their willingness to participate in the study. Two subjects refused to participate because they intended to resign during the study, one subject was excluded as she could not read in Malaysian or Standard Malay and one subject declined because she had low vision which hindered her ability to perform cognitive tests. Upon giving report to their supervisors, four new candidates were selected. As other previous candidates, the new candidates were also given information regarding the study. Total subjects consisting of forty operators agreed to participate in the study. They were randomly assigned to the intervention and control group.

Then, subjects were screened for the presence of hyperventilation or abnormal breathing using a Nijmegen questionnaire (see Appendix C on page 149). The Nijmegen Questionnaire consists of 16 complaints whose frequency of incidence can be indicated on a five-point ordinal scale (1 = never, 5 = very frequently). The complaints relate to different systems: (a) cardiovascular, e.g. ‘palpitations’; (b) neurological, e.g. ‘dizzy spells’, ‘tingling fingers’; (c) respiratory, e.g. ‘shortness of breath’; (d) gastro-intestinal, e.g. ‘bloated abdominal sensation’; (e) psyche, e.g. ‘tense’ (Van Dixhoorn and Duivenvoorden, 1985). The points accompanying each endorsed answer were totalled. Those who got scores of 23 out of 64 or greater would be excluded from the study (Van Dixhoorn and Duivenvoorden, 1985, and Moss, 2009). High scores on the Nijmegen Questionnaire indicate the presence of abnormal breathing and a variety of somatic and mental symptoms based on breath patterns. Moreover, participants who were suffered from diabetes, and were taking medication that can decrease physiological or autonomic arousal were also excluded. All participants met the inclusion criteria and signed and returned consent forms. However, one participant in the intervention group was unable to register a finger pulse and was excluded, two subjects in the control group dropped out before completion because of job resignation, and one subject in the control group did not attend the first session later because of family issue. The final sample used in analyses was 36 participants, 19 in training group and 17 in control group, who completed both pre to post- training assessment. All participants were debriefed upon study completion but before data analysis individually by the investigator. Participants in the training group were given a reimbursement of RM 60 while the control participants were given souvenirs. Figure 3.1 shows sampling process used in this study.

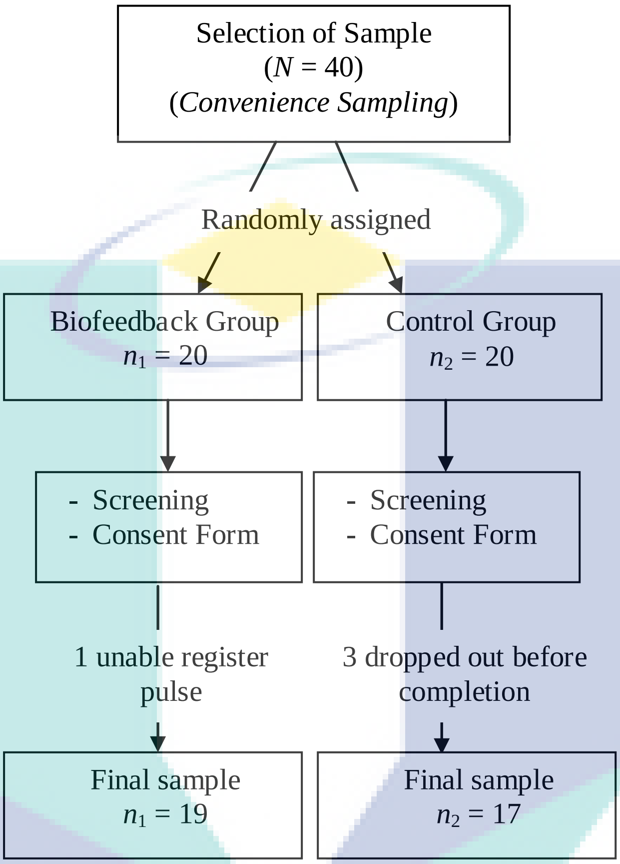

Figure 3.1: Sampling Process

Approval to conduct this study was granted by the Institutional Review Board of Faculty of Medicine at the International Islamic University Malaysia (see Appendix D on page 150). Means, standard deviation and percentages for demographic characteristics are listed in Table 3.3.

3.4.2. Informed Consent

Participants read and signed and informed consent (Appendix B) prior to participation in the study. The informed consent stated the nature of the study, the benefits and risks of participating in the study and the option of the participants to withdrawal from the study at any time. It stated that all data obtained from the client would remain confidential. It was also stated that the results of the study would be available to the subjects upon request.

Table 3.3: Demographic Characteristics of the Study Sample

Characteristic	**Total (*N* = 36)**	**Biofeedback (*n* = 19)**	**Control (*n* = 17)**
Age			
Mean	36.3	35.6	37.1
S.D.	10.14	10.58	9.88
Education			
No high school (< 7 yrs)	13.8%	10.5%	17.6%
High school (9 – 11yrs)	86.1 %	89.5%	82.4%
Years of Working			
Less than 5 yrs	44.4%	42.1%	47.1%
5 – 10 yrs	5.5%	10.5%	0%
More than 10 yrs	50%	47.4%	52.9%
Ethnicity			
Malay	94.4%	94.7%	94.1%
Indian	5.6%	5.3%	5.9%

3.4.3. Apparatus

For the purpose of this study, physiological measurements were derived from J&J I-330-C2 developed by J&J Engineering Inc (see Figure 3.2). This instrument was also used in all sessions to assist subjects in the experimental group in achieving HRV biofeedback training target. A 14-inch laptop screen presented a respiration curve, instantaneous heart rate, and an on-line Fourier spectrum of heart rate, as biofeedback information to subjects. The cardiovascular data were derived from electrocardiography (ECG) and respiration sensor. ECG signals were processed through 20-400 Hz bandpass filter. Data was collected by attaching two gel-free electrodes (J&J product MC 5D) to the wrist. Heart rate measures were recorded from R-R intervals. Respiration was recorded with a MC-3MY pneumograph sensor, a magnetic strain gage. The strain gage was placed across the abdomen and secured. As the elastic stretches, the voltage across the gage changes and relative changes are measured with a range of 0-100 units of relative strength. Using a Windows Use3 Software embedded in the device, computer screen presented a respiration curve, instantaneous heart rate, and an on-line Fourier spectrum of heart rate, as biofeedback information to subjects.

Figure 3.2: J&J Engineering and Sensors used in the Study

3.4.4 Experimental Tasks

The structure of the study followed the pattern of a randomized control group pre-test/post-test design. This study uses two independent variables, the groups in which subjects are assigned (RFT biofeedback, control) and the time assessment (pre, post). The effects of RFT training were assessed on three main dependent variables: cognitive performance tests, physiological variables (resonant frequency bandwidths, SDNN, and respiration rate), and emotional symptoms (Depression Anxiety and Stress Scale).

In real work settings, operators commonly have to attend to more than one task at a time which needs some cognitive functions being activated. In the current study, the cognitive functions were evaluated by administering three cognitive task: d2 Attention Test, Sternberg Test, and Stroop Color-Word Test

3.4.4.1 D2 Attention Test

The d2 Test of Attention was administered to measure selective attention and mental concentration (Brickenkamp and Zillmer, 1998). The test measures processing speed, rule compliance, and quality of performance in response to the discrimination of similar visual stimuli thereby allowing for an estimation of individual attention and concentration performance. The test was originally designed to measure driving efficiency and has been broadly used for many types of attention-based studies and clinical applications. The d2 Test has reliably been used to test the attention of healthy participants (Brickenkamp and Zillmer, 1998). The d2 Test of Attention can be administered to a large group of participants by a single proctor. The standardized test form is presented in a landscape layout of 14 test lines with 47 characters for a total of 658 items (see Appendix E on page 151). The test items are consisted of the characters "d" and "p" marked with one to four dashes, arranged either individually or in pairs above and below the letter. The subject is required to scan across each line to identify and cross out all "d"s with two dashes. The d2 test has been used for assessing the efficacy of a variety of intervention on attention performance (Moore and Malinowski, 2009, and Buddea et al., 2008)

3.4.4.2 Sternberg Memory Test

Of various memory tests commonly utilized in human performance's researches, Sternberg's memory search test was chosen because it has been widely used and it is considered as the most sensitive of the memory tests that are suitable for repeated testing (Human Factors Section, 1996). Sternberg (1966) described a series of studies of memory search processes using the additive factor method. The basic experimental task presents a set of digits (the memory set) followed by a probe digit. Subjects are required to decide whether or not the probe is a member of the memory set, and their reaction times are measured. For example, if the set were 5873 and the probe were 7, the correct response would be "yes"; if the probe were 2, the correct response would be "no". In this paradigm it is the identity of the digits in the series, but not their order, that is relevant to the binary ("yes"/"no") response.

In this study, a computerized modification of Sternberg memory test developed using Visual Basic was used (Indra and Bohdaneck, 1994). The reaction time (RT) was defined as the time from the beginning of the test stimulus to the occurrence of the response. The next trial began less than 2 sec after the key press. The mean interval between the response for one trial and the start of the subsequent trial was ~ 2.5 sec (Raghavachari et. al, 2001).

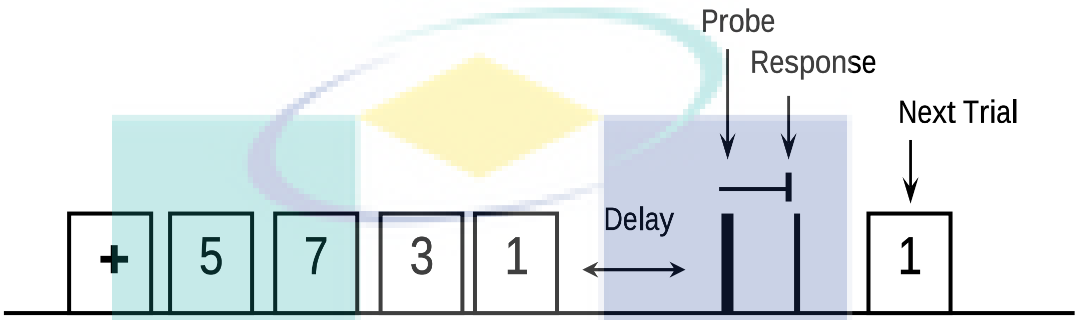

Figure 3.3: Schematic of the Sternberg test (adapted from Raghavachari et. al, 2001

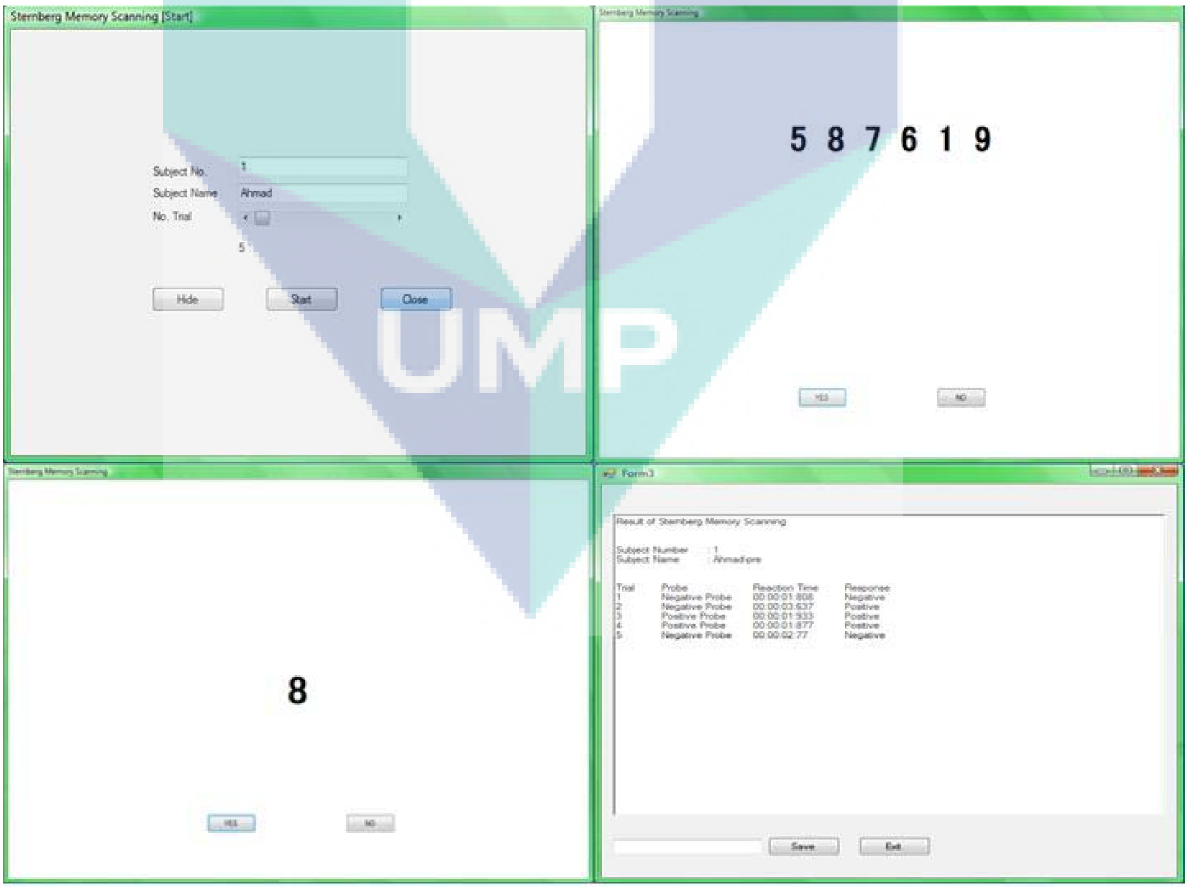

Figure 3.4: Print Screen of Sternberg Test

3.4.4.3 Stroop Color and Word Test

The Stroop Intereference Colour-Word Test is a psychological test of individual’s mental (attentional) vitality and flexibility that was originally developed by Stroop (Stroop, 1935). The Stroop Test provides insight into cognitive effects that are experienced as a result of attentional fatigue. The Stroop Test asks subjects to relay to the investigator the colour of the word that they are reading. Distracting variables were added by having all of the words read actual colour names that existed in the test (Golden and Freshwater, 2002). The cognitive mechanism involved in this task is called directed attention which is associated with cognitive flexibility, resistance to interference from outside stimuli, creativity, and psychopathology. These influence the individual's ability to cope with cognitive stress and process complex input. The standardized version test consists of three pages. Each page has 100 items, presented in 5 columns of 20 items. The Word Page consists of the words “RED”, “GREEN”, and “BLUE” arranged randomly and printed in black ink on a white 8.5” x 11” sheet of paper. No word is allowed to follow itself within a column. The Colour page consists of 100 items, all written as XXXX, printed in either red, green, or blue ink. No colour was allowed to follow itself in a column, nor to match the corresponding item on the Word page. The Colour-Word page consists of the words from the Word page printed in the colours from the Colour page. The Stroop task or one of its variations is perhaps the most widely used test for the assessment of attentional interference or cognitive flexibility (Staal, 2004; Lane, 2004, and Sherlin et al., 2009) as well as for examining the effect of some treatment or interventions (Moore and Malinowski, 2009, and Moya-Albiol et al., 2001).

3.4.4.4 Mental Arithmetic Test

Mental arithmetic is considered to be typical of day-to-day environmental stressor because it is cognitively-demanding, time-pressured, and high scores are rewarded (Sharpley et al., 2000). These are the three major characteristics of workplace stressors noted by Cinciripinni (1986), and it may be of value to examine the effects of mental arithmetic upon the HRV data of subjects who are not required to speak during problem-solving. Moreover, arithmetic test is commonly used as a mental stressor during cardiovascular recording (Yasumasu et al., 2006, and Reyes et al., 2009)

A modification of the “serial 7’s” cognitive test was administered to participants to induce physiological stress during stress profile. To ensure transfer of skills from laboratory to "real life," stressful situations must be created for the trainee that will simulate real life situations. The “serial 7’s” test is test is the most universally used stress test in research and clinical practice (Arena and Schwartz, 2003). The usual time-span of this stress test is between 1 to 4 minutes (Arena and Schwartz, 2003). The experimenter asks subjects to subtract by seven from the number 207. Another format of arithmetic test was also used to assist subjects dealing with stressor while practicing the technique. The arithmetic test problems were adapted from ANAM® module (Reeves et al., 2007) and Sharpley (2000). All problems required an addition and subtraction sequence in the form of “$x + y - z =$”. The task consisted of a series of 20 questions which each problem took 5 seconds to be read out and subjects were given 4 seconds to respond verbally.

3.4.4.5 DASS

The DASS is a set of three self-report scales designed to measure the negative emotional states of depression, anxiety and stress (Lovibond and Lovibond, 1995). Each of the three DASS scales contains 14 items, divided into subscales of 2-5 items with similar content (see Appendix F on page 153). The Depression scale assesses dysphoria, hopelessness, devaluation of life, self-deprecation, lack of interest/involvement, anhedonia, and inertia. The Anxiety scale assesses autonomic arousal, skeletal muscle effects, situational anxiety, and subjective experience of anxious affect. The Stress scale is sensitive to levels of chronic non-specific arousal. It assesses difficulty relaxing, nervous arousal, and being easily upset/agitated, irritable/over-reactive and impatient. Subjects are asked to use a 4-point severity/frequency scale (0 = Did not apply to me at all, 1 = Applied to me to some degree, or some of the time, 2 = Applied to me to a considerable degree, or a good part of the time, and 3 = Applied to me very much, or most of the time) to rate the extent to which they have experienced each state over the past week. Scores for Depression, Anxiety and Stress are calculated by summing the scores for the relevant items. Scores for Depression, Anxiety and Stress are calculated by summing the scores for the relevant items. In general the higher the total score for each subscale, the more sever is the respective emotional syndromes problem. According to suggestion by Lovibond and Lovibond (1995), for most research purposes, it is much better to use DASS scores rather than attempt to divide a sample into "normal" vs "clinical" or "high" vs "low". However, for clinical purposes, a set of cut-off scores for each scale has been developed to help characterise degree of severity relative to the population. Table 3.4 displays the general guidelines of DASS categorical score.

As the scales of the DASS have been shown to have high internal consistency and to yield meaningful discriminations in a variety of settings, the scales should meet the needs of both researchers and clinicians who intend to measure current state or change in state over time (e.g., in the course of treatment) on the three dimensions of depression, anxiety and stress. Since the essential development of the DASS was conducted with non-clinical samples, it is suitable for screening normal adolescents and adults. In this study, DASS was delivered in Standard Malay which has been validated for Malaysian population. The BM DASS has very good Cronbach's alpha values of .84, .74 and .79, respectively, for depression, anxiety and stress (Musa et al., 2007).

Table 3.4: Cut-off Scores for Depression, Anxiety, and Stress Scale of DASS

Category	Scale		
	Depression	**Anxiety**	**Stress**
Normal	0 - 9	0 - 7	0 - 14
Mild	10 - 13	8 - 9	15 - 18
Moderate	14 - 20	10 -14	19 - 25
Severe	21 - 27	15 - 19	26 - 33
Extremely Severe	28	20 +	34 +

3.4.5 Procedure

Participants were randomly assigned into either a control or training group. The intervention group received five sessions of HRV biofeedback training, one session per week. Five sessions were chosen based upon consensus of previously done HRV biofeedback studies that dealt with performance enhancement (Strack, 2003; Thurber, 2006; Lehrer, 2007; Tanis, 2008, and Sutarto and Wahab, 2008). Each session lasted minimum 20 minutes. Lack of amount of sessions or insufficient length of each training session might be categorized as methodological and conceptual errors in biofeedback studies (Shellenberger and Green, 1986). In this research, each session lasts approximately 30 – 50 minutes which consisted of 10 minutes of session review, 5 minutes baseline, and 20 minutes RFT biofeedback. In the session four and five, participants in the training group received additional 10 minutes to learn the technique with mental stressor. Participants in the control group received five 20 minutes sessions where participants were monitored physiologically. They were provided with same feedback display as the training group but with no instruction or biofeedback.

In the first meeting following discussion of the objectives and aims of the study, each participant read and signed an informed consent (Appendix B). They also filled demographic questionnaire to collect participants' characteristics (see appendix G on page 157). A stress profile (baseline/stressor/recovery) was also conducted and the following physiological parameters were assessed: Heart Rate Variability and respiration rate. HRV spectral activity (HF, LF, and VLF) and time-domain measure (SDNN) were assessed prior to the cognitive performance task pre and post. After that, participants in both groups performed several cognitive tests as the pre test. The post test was conducted one week after the final training period, thus allowing for some measure of maintenance (Sharpley, 1994, and Sharpley et al., 2000).

In the Stroop Colour-Word Test, participants were given a booklet containing all three pages, but views only one page at a time. The booklet was placed directly in front of the subject on a flat surface. After listening the instruction, the subjects began the experiments. Participants were given 45 seconds to complete as many items as possible for each page. Because most of participants' common language is Standard Malay, the Colour and Colour-Word pages were read out in Standard Malay while the Word-page remained read in English. A stopwatch was used to administer the test. The stroop interference scores were recorded at pre and post biofeedback intervention.

In the d2 attention test, each subject received a recording blank with the front page on top and a pencil without eraser. The front page provides sections for recording data about the test subject and a practice sample. The reverse page is the standardized test form. After listening the instruction, the subjects fill their personal data and try the practice line. During the test, the subject has to scan the lines to identify and cross out all occurrences of the letter “d” with two dashes while ignoring the other characters. The subject is allowed 20 seconds per line.

For the memory test, lists of 2-6 digits were presented randomly on a computer screen. After a delay period, a probe item was shown. Then subject decided whether or not it was one of the digits in the list. The digits where chosen at random by the computer, and no single list contained repeated letters The subjects responded by pressing the left control (i.e. laptop mouse) key if the probe item was on the list and the right control key otherwise. The lists consisted of 50 trials.

3.4.6 Training sessions

Training sessions were conducted in a quiet training room of an electronic manufacturing company located in Kuantan, Pahang, Malaysia. Each participant attended the training approximately at the same time and same day every week. Training was given individually. The following is a brief description of the intervention training. The protocol followed the suggestion of Lehrer et al. (2000).

<u>Session 1</u>

In the first session, the experimental group was introduced to the biofeedback equipment, the training method and protocol as suggested by Lehrer et al. (2000). Each participant was instructed to breathe at their resonant frequency with a “quiet mind” while their heart rate oscillation were being measured. They were instructed to breathe at rates of 6.5, 6, 5 and 4.5 at about 2 minutes each to find their “resonant frequency” at which their RSA is the highest (Lehrer et al., 2000, and Lehrer, 2007). Vaschillo et al. (2006) have suggested that finding a person’s resonant frequency and teaching the person to breathe at that frequency needs considerable concern. Normally people breathe at a rate of 12–20 breaths per minute. Deliberate slow paced breathing can cause an increase in tidal volume that more than compensates for the decrease in respiration rate. It thus often produces hyperventilation and temporarily disordered cardiovascular regulation (Lehrer et al., 1997). To be beneficial, the RF HRV BFB procedure must train people not to breathe too deeply, while they breathe slowly, at the resonant frequency. The resonant frequency usually is characterized by 1) the highest low-frequency power; 2) the highest low-frequency peak; and 3) respiration and heart rate variability in phase with each other. If these measures are discrepant, this will usually be between two specific frequencies. Thus, the researcher should repeat the process at those frequencies. If the measures remain discrepant, then resonant frequency is chosen based on the highest low-frequency spectral peak obtained. If a respiratory frequency seems to meet all of these criteria, for instance having a higher frequency power peak than adjacent higher and lower frequencies, it may not need to examine all of the other frequencies. However, the researcher should repeat the frequency yielding the highest peak along with adjacent frequencies, in order to confirm the finding. After determining resonant frequency process was completed, the researcher informed the subject of his (her) resonant frequency (i.e., the frequency of maximum amplitude).

A pacing stimulus provided by J&J engineering device guided the participants to breathe at the targeted frequencies and when to inhale and exhale. They were instructed to inhale abdominally and exhale through pursed-lips with exhalation longer than inhalation. At the end of first session, participants were taught to do relaxed diaphragmatic/abdominal breathing as well as pursed-lips breathing.. They were instructed to practice breathing diaphragmatically on a daily basis, minimum of 5-minutes (20 minutes/day total) practice segments. They were allowed to choose any time of day in which to practice breathing (e.g. before/after sleep, on the way to come or go home, during work rest). Participants also received a simple module (see Appendix G on page 153) explaining how to practice the breathing skills at home between sessions.

<u>Session 2-3</u>

In the second and third session, at the first 10 minutes, homework compliance was assessed including a review relaxed abdominal/diaphragmatic breathing. Most of participants in the biofeedback group reported practicing the technique before sleep.

Five participants reported having no time to practice at home. Thus, they were encouraged to practice during working hours. They were asked to use the technique for instance when they felt fatigue or sleepy because research has shown that such conditions might lead to imbalance homeostasis (Blatter and Cajochen 2007, and Wijesuriya et al., 2007). In general, the researcher questioned the participant's about practicing outside of sessions, the difficulties while learning the technique, and any benefits from the biofeedback training. After reviewing previous session, next step by step participants were taught to maximize the peak amplitude of RSA according to their resonant frequency using the pacing stimulus. This aspect of training was repeated until subjects were able to meet the criteria of maximizing spectral activity near 0.1 Hz while maintaining diaphragmatic breaths. As a manipulation check for the biofeedback, the percentage of LF activity was monitored for the intervention group during training sessions. Figure 3.5 illustrates recording measurement of one subject in the biofeedback group while practicing the technique in a particular session. At the end of session two, subjects were instructed to practice at home a combination of relaxed abdominal pursed-lips breathing and resonant breathing on a daily basis.

<u>Session 4-5</u>

Overall, in the session 4 and 5, the training content was not much difference than previous sessions. At the beginning of each session, a review of the technique and homework compliance was assessed. Along with the RFT biofeedback, subjects in the intervention group attended to a mentally demanding (stressor) task—mental arithmetic. A six minutes arithmetic task was given during the training sessions. Participants simultaneously answered the arithmetic problem while attempting to maintain resonance breathing. This task offered the challenge of workplace stressor while attempting to maintain the desired resonance frequency (Cinciripinni, 1986). The arithmetic task was given with the goal of helping subjects gained proficiency in controlling performance pressure and autonomic activity. Providing the arithmetic task is an effort to achieve mastery that ensures transfer of skills from laboratory to "real life". Subjects received two sets of mental arithmetic questions, preceded by instructions and two practice questions to ensure that understood the task.

Figure 3.5: Screenshot Subject learned the technique by following breathing pacer presented on the computer screen

3.4.7 Dependent/Variable Measures

3.4.7.1 Cognitive Performance Measures

Stroop Color-Word Test. The interference score T-Score is calculated by subtracting the Predicted Colour-Word score from the actual uncorrected Raw Colour-Word Score. This score reflects the individual's cognitive flexibility, creativity, and reaction to cognitive pressures. In this study, the interference T-score is calculated using scoring software provided by the publisher (Golden and Freshwater, 2002).

Sternberg Memory Test. Reaction time for correct response. Only correct trials with reaction times 2.5 sec were used for analysis. However, overall data showed no significant error found both omission and commission, thus all data were included in the analysis.

D2 Attention Test. The concentration performance (CP) score provides an excellent index of the coordination of speed and accuracy of performance. CP is derived from the number of the correctly crossed out relevant items ("d" with two dashes) minus the errors of commission. Duschek et al (2008) suggested that CP index represents ''attentional capacity'' which are particular reliable and tamper-resistant.

In addition to the cognitive performance tests, pre-post measures of the following physiological parameters are assessed: HRV spectral activity (LF, HF, VLF) and respiration rate

3.4.7.2 Physiological Measures

Heart Rate (HR). Heart rate measures were obtained from 512 samples/second measurement of IBI with changes between each consecutive R-wave of the heart. A Fast Fourier Analysis was next applied to record measures of activity within specific spectral bands. The measures might fall into: 0.15 to 0.4 (HF activity), well established to be indicative of parasympathetic activity; 0.01 to 0.07 (VLF activity), usually thought of as sympathetically mediated; 0.08 to 0.14 (LF activity), mediated by both sympathetic and parasympathetic activity primarily by the baroreceptor.

Respiration. Respiration was measured by a strain gage placed around the abdomen which changes voltage signals during stretching. Breathing patterns was determined by measuring breathes per minute (BPM) over 30-second period.

Each of the physiological measures were taken approximately 10-15 minutes prior to pre and post cognitive testing for both intervention and control group. A 4-minute baseline, 2-minute stressor ("serial 7's"), and a 4-minute recovery period were recorded. During training, HRV activities were recorded in each of the five sessions for intervention group. Two ECG wrist electrodes and a respiration strain gage were attached and 30-second averages for each frequency range (HF, LF, and VLF) were obtained for the initial 20-minutes of each 30-minute sessions. These averages were used to determine what percentage of the total power stems from LF activity. A screenshot of real time HRV feedback is depicted in Figure 3.6.

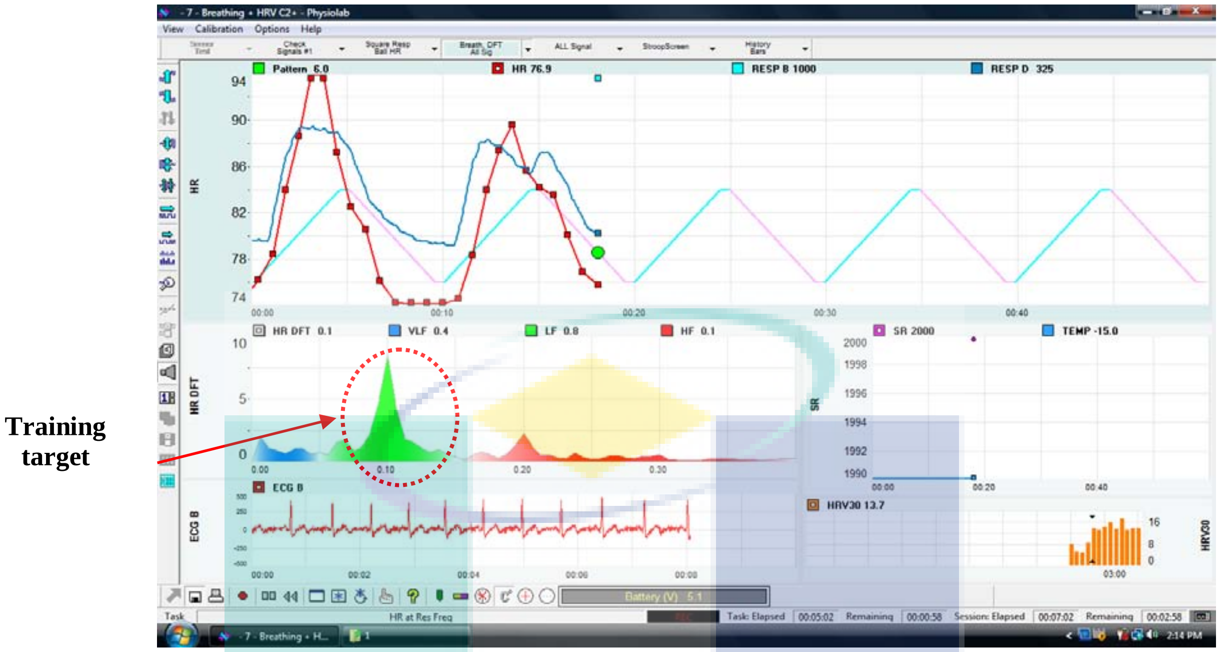

Figure 3.6: Screenshot of HRV feedback during training. Green Peak around 0.1 Hz indicating subject be able to breathe at her resonant frequency

3.4.7.3 Data Reduction

Heart rate data were averaged across 0.5-s intervals at a sampling rate of 512 hertz. As USE 3 Software from J&J Engineering device provided only heart rate data, the data were converted into inter beat interval (IBI) data measured in milliseconds. Then IBI data were edited using the Kubios HRV Program (the Biosignal Analysis Group, Department of Physics, University of Kuopio, Finland). The program also calculated a power spectrum density (PSD) estimate for the RR intervals series. The estimate then was extracted to obtain each power of VLF, LF, and HF. Figure 3.7 displayed an example of Kubios calculation summary report for desired parameters.

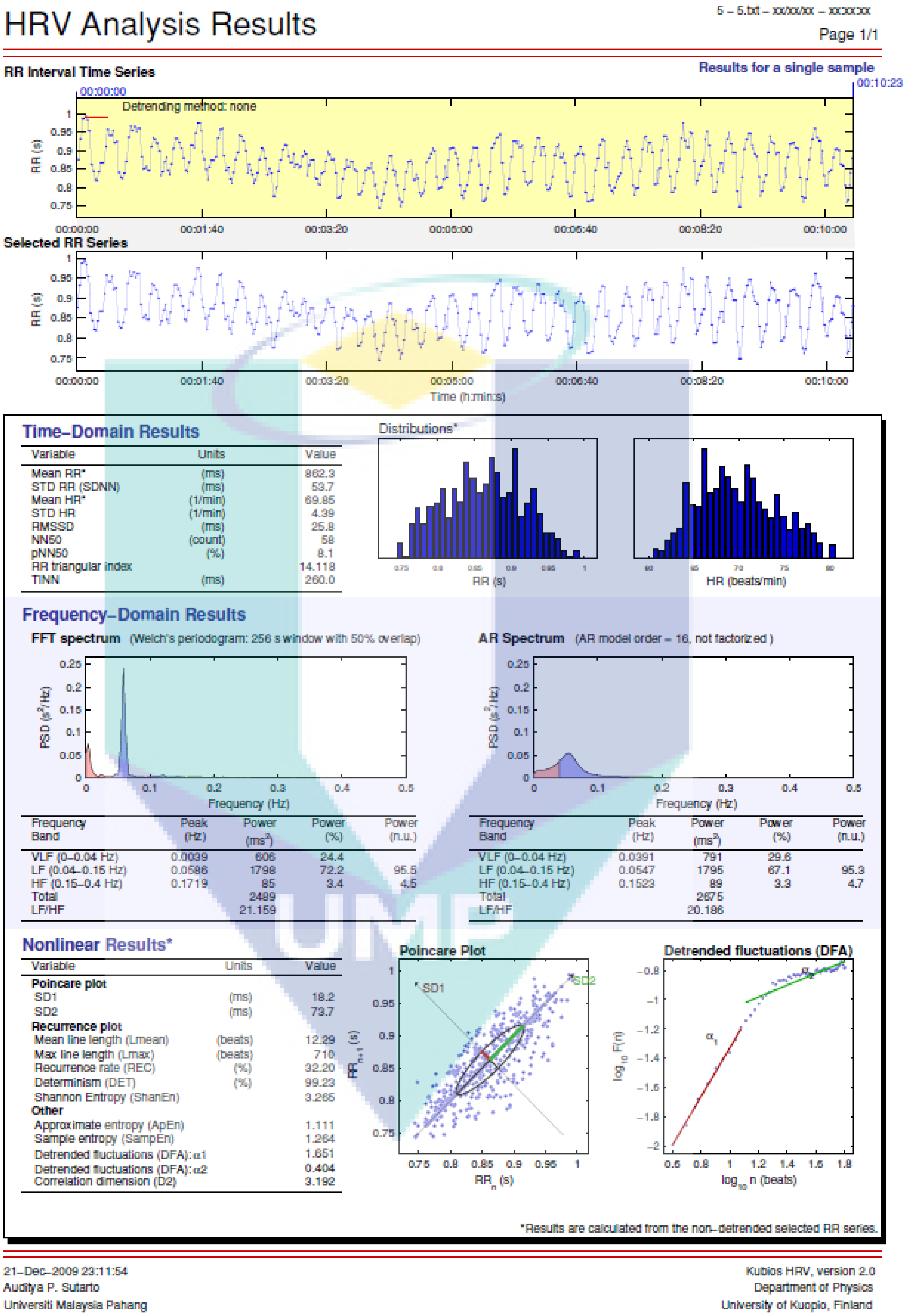

Figure 3.7: Kubios Summary Report

3.5 HRV BIOFEEDBACK MODULE

3.5.1 The Development of Module

The content of HRV biofeedback module used in this present study was modified from previous module used among university student (Sutarto and Wahab, 2008) which was developed mainly based on protocol by Lehrer et al. (2000). According to preliminary observation and interview with targeted subjects (i.e. operators), the potential subjects reported that they should have worked overtime every workday, approximately from 7 am to 9 pm. Consequently, they did not have much time to read and learn the module as well as to practice the skill at home. Therefore, in addition to their education background consideration, a simpler module was developed. In general the module consists of the following topics while detailed of module can be seen in appendix D:

a. Diaphragmatic and Pursed-Lips Breathing

Breathing exercise follows a technique developed by Peper (1990). In his module "Breathing for Health with Biofeedback", Peper described the physiology of breathing, dysfunctional breathing, how to do diaphragmatic or abdominal breathing, and visual relaxation. In the preliminary study (Sutarto and Wahab, 2008), in addition to the description of biofeedback, all of these contents were also included. Yet, concerning operator's educational background, providing technical terms for operators seemed less effective. Therefore, in this present study, the theoretical background was omitted from the module's content. The investigator provided description on training method verbally. As previously mentioned, due to lack of time to practice at home, visual relaxation was not introduced to the training operators. They were encouraged to focus on practicing breathing technique and citing dzikir as an alternative "relaxation tool". Moreover, pursed-lips breathing, which was not covered in Peper's module, was also introduced because it was essential for promoting prolonged exhalation than inhalation as well as breathing efficiency (De F Fregonezi et al., 2004)

To assist one in mastering the diaphragmatic breathing skill, Peper recommended the use of four biofeedback modalities: Galvanic Skin Response (GSR), which measures individual's sweat response on the fingertips; temperature sensors;

EMG; and respiration sensor. Since HRV is a vital measure of resonant breathing biofeedback, this present study utilized two biofeedback devices: ECG sensor heart rate and respiration sensor. Here are the general steps that subjects should follow on how to do the breathing skills:

1. If learning diaphragmatic breathing while sitting is difficult, subjects should do it while lying supine with a five pound weight (e.g. book) on the abdomen. Then they try doing it while sitting. Eventually they should be able to do abdominal breathing in all positions.
2. Using pursed-lips breathing during exhalation. Subjects should inhale through the nose and exhale through pursed lips.

b. Resonant Breathing

Script for teaching resonant breathing followed guidelines by Lehrer et al. (2000) and Lehrer (2007).

c. Incorporating the techniques into daily lives. This topic will be presented in home practice section.

3.5.2. Home Practice

As regular home practice is one of essential ingredients for successful biofeedback training research, participants in the training group was given a home practice. Participants in the training group were expected to practice breathing skills at home in the same way they practiced in the biofeedback training sessions. In general home practice consisted of the following items:

1. Practicing 3 to 5 times a day of diaphragmatic and pursed-lips breathing with each segment last approximately 5 – 10 minutes. (This may also be done in front of the mirror as a visual home feedback device).
2. Breathing diaphragmatically in anticipation to stressors or situations which previously evoked dysfunctional breathing.
3. After mastering at diaphragmatic breathing, combining the technique with resonant breathing.
4. Use the second-hand of a watch to time the breathing cycle. Or counting out loud to increasingly higher numbers with one cycle breath lasts approximately ten seconds.

Breathe in to count of 4 and breathe out to count of 6. Counting numbers can be substituted by citing dzikir.

5. Prolonged a combination of diaphragmatic, pursed-lips, and resonant breathing practice (>15 minutes) every day
6. As a part of home practice, subjects were also encouraged to practice in any conditions such as during work hour, going to and back from work, waiting in line, bothered by something someone has said, in pain, fatigue, stress, boredom, and drowsy, etc.

3.6. DESIGN AND ANALYSIS

A series of mixed ANOVA design with two independent variables was used to assess changes over time and differences between groups. The subjects were randomly assigned to either an RFT biofeedback group or a control group (1st independent variable, between-group variable). The time assessment (pre, post) was the second independent and one repeated-measure variable. The effects of the RFT training were assessed on several cognitive test variables: interference score of the Stroop test, concentration performance of the d2 attention test, and response times of the memory test. Within-group analyses using paired *t*-tests then was used to assess whether any significant improvement in each group was found from pre-intervention to post-intervention on each cognitive measure.

In addition to the significance level, the effect size of each of variables measured was also reported. Effect size emphasises the size of the difference in program evaluation rather than confounding this with sample size (Field, 2005). In other words, it measures the magnitude of a treatment effect (Kirk, 2007). The use of effect size is strongly encouraged by American Psychology Association regardless of the significance of the test statistic. This study used square of Pearson's correlation coefficient (r^2) as reported effect size. Table 3.5 shows guidelines to interpret the effect size (Field, 2005).

Physiological variables were measured during stress profile conducted before and after the training period. Resonant frequency bandwidths (HF, LF, VLF), BPM (breaths per minute), heart rate (HR), and standard deviation normal to normal (SDNN) data were collected at baseline, stress, and recovery periods. Three-way mixed ANOVA was used to analyze physiological data with group as the first independent variable and between-group variable, while time assessment and condition (baseline, stress, recovery) acted as the second and third independent as well as two repeated-measure variables. In addition to pretest-posttest design, a mixed ANOVA design was conducted to measure some physiology parameters of both the training and control group throughout five training sessions. The aim of this design is to evaluate whether any physiological change across all sessions. Type I error was controlled for by reducing the alpha level, as determined by the Bonferroni Test (Field, 2005)

Table 3.5: Category of Pearson's Correlation Coefficient (*r*) Effect Size

r	**Category**	**Interpretation**
0.10	Small effect	The effect explain 1% of the total variance
0.30	Medium effect	The effect explain 9% of the total variance
0.50	Large effect	The effect explain 25% of the total variance

A correlation analysis between measures of change in self-report psychological and cognitive measure was conducted using Spearman's rho. This analysis is non parametric analogue of the Pearson correlation coefficient that is used when the data have deviated parametric assumption such as non-normally distributed data (Field, 2005). All statistical analysis was carried out with the aid of SPSS version 15.0 software package. The level of significance was $p < 0.05$ for all of the tests.

CHAPTER 4

RESULT

4.1 PROCEDURES FOR PROCESSING DATA

Data was inspected for errors in scoring and data entry. Categorical data such as years of working, education, and DASS categorical scores were inspected by analyzing the maximum and minimum values, checking the number of valid cases and missing cases. Continuous data, such as age, and scores on outcome measures, was similarly analyzed by inspecting the minimum, maximum, and mean values of the scores. No errors were noted upon inspection. To test whether distribution of each outcome measure meet normality assumption, the Kolmogorov-Smirnov tests (*D* statistics) were conducted in addition to observing the respective skewness and kurtosis value. A significant value (less than 0.05) indicates a deviation of normality. Furthermore, prior to interpretation of each analysis, data were examined for violations of assumptions. Assumption testing for analysis of variance (ANOVA) consisted of: checking normality, homogeneity of variance, and sphericity for repeated measure (Field, 2005). When a violation of an assumption data was found, instead of removing the case, all of the respective data was log transformed. Log transformation was done by taking the logarithm of each observation (Field, 2005). A flow chart of steps for determining whether parametric or non parametric analysis used is illustrated in Figure 4.1

After thorough investigation, distribution of SDNN for the biofeedback group during stressor and recovery at pre-training was not normal (D (19) = 0.241, p = 0.005; D (19) = 0.233, p = 0.008, respectively). SDNN of the control group during stressor condition at pre-training and post-training also deviated from normality (D (17) = 0.245, p = 0.008; D (17) = 0.357, p < 0.001, respectively). In addition, though all of SDNN outcome across five sessions met normality assumption, yet SDNN at session 2-5 did not meet the assumption of equal cell variances (all $p > 0.05$). All of SDNN data were then normalized with log transformations

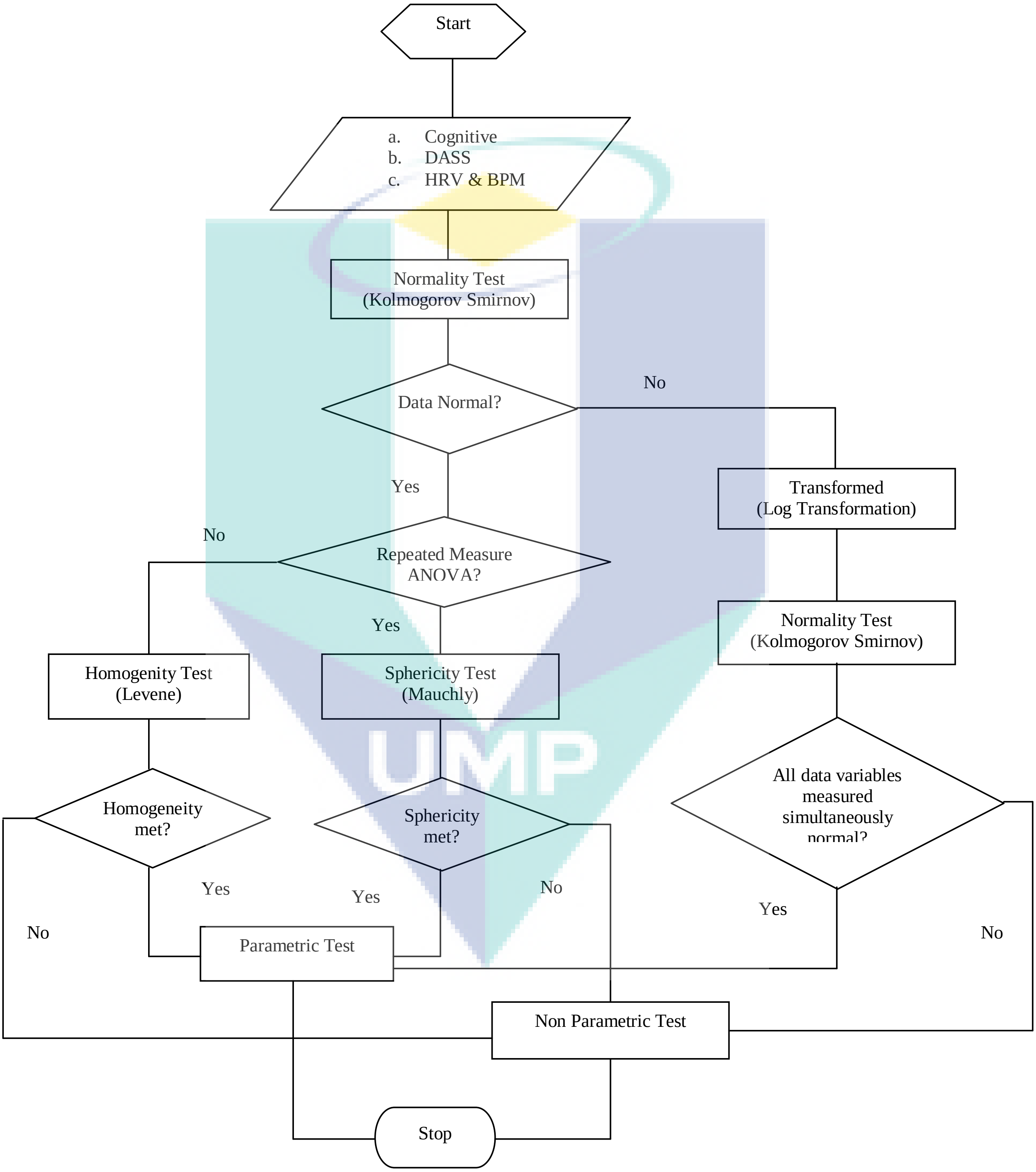

Figure 4.1: Flow Chart of Data Processing (Parametric or Non Parametric)

Violation of normality assumptions were also noted for the anxiety scale of DASS for the biofeedback group at pre-training (D (19) = 0.217, p = 0.019), and the depression and the stress scores for the biofeedback group at post-training (D (19) = 0.259, $p < 0.01$, D (19) = 0.234, $p < 0.01$, respectively). Similar results were present on breaths per minute (BPM) data at session 1 – 3 for the biofeedback group and at session 2 for the control group (D (19) = 0.224, p = 0.013; D (19) = 0.244, p = 0.004; D (19) = 0.206, p = 0.032; D (17) = 0.228, p = 0.019, respectively). Transforming DASS and BPM data, however, did not improve the normality, thus subsequent analyses were carried out using non parametric statistics.

4.2. GROUP EQUIVALENCE

The effectiveness of random assignment in achieving pretest group equivalence was determined by conducting independent-sample *t*-tests and Chi-square analyses on demographic and outcome variables at baseline. The intervention and control groups did not significantly differ by age, years of working, and education completed as shown in Table 4.1. Mann Whitney-test (*U* statistic) was used to analyze each scale of DASS score. In addition, each scale was also analyzed using Chi-square analyses to examine between-group differences with respect to the categorical scores of DASS. There were no significant differences found between the training and the control group on all subscales of DASS as measured either by continuously or categorically (see Table 4.2). Similarly, no pre-training differences existed between groups with respect to all baseline scores of cognitive measures (see Table 4.2).

A stress profile was conducted on each participant prior to the cognitive performance assessment. The group equivalence on physiological data was analyzed by carrying out a series of two-way mixed ANOVA at baseline (4 minutes), stressor (2 minutes), and recovery (2 minutes) periods. Analysis revealed no significant differences found between the biofeedback and the control group on each frequency bandwidth (VLF, LF, and HF) and breaths per minute (see Table 4.3) across three conditions. However, this analysis produced significant pre-training differences for heart rate (HR). The control participants showed higher significant heart rate across three conditions with significant interaction. In subsequent analysis no correlation was noted between

HR and cognitive improvement. Therefore, it was concluded that these differences had no effect on cognitive performance.

Table 4.1: Group Equivalence on Demographic Variables

Measures	Group	Mean	S.D.	df	*t* or χ^2	*p*
Age	Biofeedback	35.6	10.58	34	*t* = -0.449	0.656
	Control	37.1	9.88			
Years of Working	Biofeedback	< 5 yrs	42.1%	2	χ^2 = 1.895	0.388
		5 – 10 yrs	10.5%			
		> 10 yrs	47.4%			
	Control	< 5 yrs	47.1%			
		> 10 yrs	52.9%			
Education	Biofeedback	No high school	10.5%	1	χ^2 = 0.380	0.537
		High school	89.5%			
	Control	No high school	17.6%			
		High school	82.4%			

Table 4. 2: Group Equivalence on Baseline Outcome Measures (DASS and Cognitive Performance)

Measures	Group	Mean	S.D.	df	*U* or χ^2	*p*
DASS	**(Continuous)**					
Depression	Biofeedback	11.58	5.910	-	*U* = 107.50	0.088
	Control	8.41	4.963			
Anxiety	Biofeedback	10.84	5.699	-	*U* = 147.00	0.654
	Control	9.88	5.266			
Stress	Biofeedback	13.89	6.806	-	*U* = 134.50	0.400
	Control	12.12	6.353			
	(Categorical)					
Depression	Biofeedback	Normal	42.1%	3	χ^2 = 3.284	0.350
		Mild	10.5%			
		Moderate	21.1%			
		Severe	26.3%			
	Control	Normal	35.3%			
		Mild	11.8%			
		Moderate	35.3%			
		Severe	17.6%	3	χ^2 = 1.078	0.782
Anxiety	Biofeedback	Normal	36.8%			
		Mild	15.8%			
		Moderate	36.8%			

Table 4.2: Continued

Measures	Group (Categorical)	Mean	S.D.	df	*U* or χ^2	*p*
	Control	Normal	47.1%			
		Mild	29.4%			
		Moderate	23.5%			
Stress	Biofeedback	Normal	63.2%	3	χ^2 = 0.935	0.817
		Mild	10.5%			
		Moderate	21.1%			
		Severe	5.3%			
	Control	Normal	64.7%			
		Mild	11.8%			
		Moderate	23.5%			
Cognitive						
Stroop test	Biofeedback	61.80	8.24	34	*t* = -0.344	0.733
	Control	62.82	9.62			
D2 attention test	Biofeedback	90.53	39.15	34	*t* = -1.887	0.068
	Control	114.59	37.08			
Memory test	Biofeedback	1553.91	188.28	34	*t* = 1.152	0.257
	Control	1489.43	140.87			

Table 4.3: Physiological Variables by Experimental Groups

Measures	df	*F*	*p*
HR:			
Main Effect	1	6.845	0.005*
Condition x Group	2	11.366	0.002*
VLF			
Main Effect	1	0.001	0.980
Condition x Group	2	1.132	0.328
LF			
Main Effect	1	0.034	0.855
Condition x Group	2	0.106	0.900
HF			
Main Effect	1	0.026	0.874
Condition x Group	2	2.724	0.073
SDNN			
Main Effect	1	1.748	0.182
Condition x Group	2	1.359	0.264
Breath per minute			
Main Effect	1	0.323	0.711
Condition x Group	2	0.848	0.364

*$p > 0.05$

4.3. MANIPULATION CHECK/VERIFICATION OF TRAINING EFFECTS

4.3.1. Physiological Measures

To determine whether participants in the biofeedback training group actually learned the technique effectively (research objective number four), the HRV data for each session was analyzed. Those who successfully did the technique would produce a shift in the HR toward the LF range, increased SDNN and slower breath rates. Pacing stimulus for each participant in the training group was set according to the resonant frequency calculated from the session one. On average, participants in the biofeedback group breathed at 5.9 ≈ 6 breaths per minute with standard deviation 0.61. Table 4.4 shows the breathing rate at which the biofeedback participants achieved their resonant frequency.

Table 4.4: Breathing Rate at Resonant Frequency

Breathing rate (BPM)	Percentage (*n* = 19)
5	21.1%
6	47.4%
6.5	31.6%

Training effectiveness between groups and within sessions was assessed via two-way mixed design ANOVA with repeated measures on percent of total HRV power shifted to the LF range. Result showed a significant main effect, F (4, 136) = 10.466, $p < 0.001$, $r^2 = 0.192$ and a significant interaction for session by group, F (4, 136) = 10.615, $p < 0.001$, $r^2 = 0.190$. The difference between group was also found significantly, F (1, 34) = 44.831, p = < 0.001, with a large effect size $r^2 = 0.569$. A separate analysis using one way repeated measure ANOVA revealed that participants in the biofeedback group made significant progress in their learning over session F (4, 72) = 16.208, $p < 0.001$, with a medium effect size $r^2 = 0.474$ as opposed to the control group F(4, 64) = 0.756, $p = 0.558$, r^2 =0.045. Table 4.5 displays the means and standard deviations for session one through session five of both the biofeedback and control group. Figure 4.1 illustrates improvement in LF activity across five sessions. As shown in Table 4.6, subjects were able to shift their HRV toward LF range significantly at the session four and five compared to the session one, two, and three.

Table 4.5: Means and S.D of Percentage of LF Power by Groups across Five Sessions

Group	Session Means (S.D)				
	1	**2**	**3**	**4**	**5**
Biofeedback	35.31 (16.09)	41.94 (17.11)	47.06 (19.08)	63.52 (17.94)	63.85 (16.38)
Control	26.39 (9.56)	26.27 (12.77)	30.61 (12.49)	24.85 (11.19)	28.67 (11.43)

Note. S.D = Standard Deviation, LF = Low Frequency

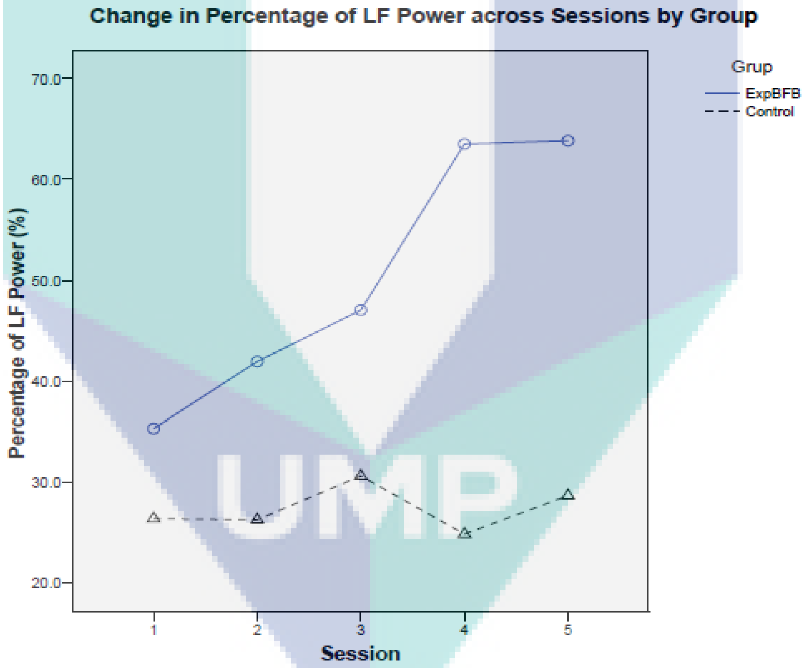

Figure 4.2: Manipulation Check - Participant Progress in LF Activity across Five Sessions for Both Groups.

The SDNN results, via two-way mixed design ANOVA, did not demonstrate a significant session effect, F (4, 34) = 1.705, p = 0.152, r^2 = 0.048. Yet, it produced a significant interaction for session by group, F (1, 34) = 3.291, p < 0.05, with a small effect size r^2 = 0.088. The difference between group was also found significantly, F (1, 34) = 7.346, p < 0.01, r^2 = 0.178. Further one way repeated measure ANOVA showed that SDNN increased significantly from session 1 to 5 (F (4, 72) = 3.060, $p < 0.05$) with a small effect $r^2 = 0.145$, while the control group showed the opposite (F (4, 64) = 0.619, $p = 0.651$) (see Figure 4.3). Means and standard deviation of SDNN data for both groups from session 1 to 5 is depicted in Table 4.7. Furthermore, as shown in Table 4.8 the increase of SDNN in the training group was observable at session 5 while of LF activity at session 4 (see Table 4.6).

Table 4.6: Pairwise comparison in percentage of LF activity for the Biofeedback Group

Session (*i*)	**Session (*j*)**	**Mean Difference (*i* - *j*)**	p^a
1	2	-6.637	1
	3	-11.753	0.113
	4	-28.216	0.000**
	5	-28.542	0.000**
2	3	-5.116	1
	4	-21.579	0.002**
	5	-21.905	0.002**
3	4	-16.463	0.015*
	5	-16.789	0.019*
4	5	-0.326	1

Note. [a] Bonferroni correction was applied. $^{*}p < 0.05$. $^{**}p < 0.005$

Table 4.7: Means and S.D of SDNN by Groups across Five Sessions

Group	**Session Means (S.D)**				
	1	**2**	**3**	**4**	**5**
Biofeedback	56.86 (18.76)	62.99 (25.53)	62.24 (29.45)	68.28 (33.42)	76.88 (33.04)
Control	50.68 (20.50)	45.59 (12.32)	45.24 (15.13)	47.57 (18.83)	45.35 (19.17)

Note. S.D = Standard Deviation, SDNN = SD of N-N interval

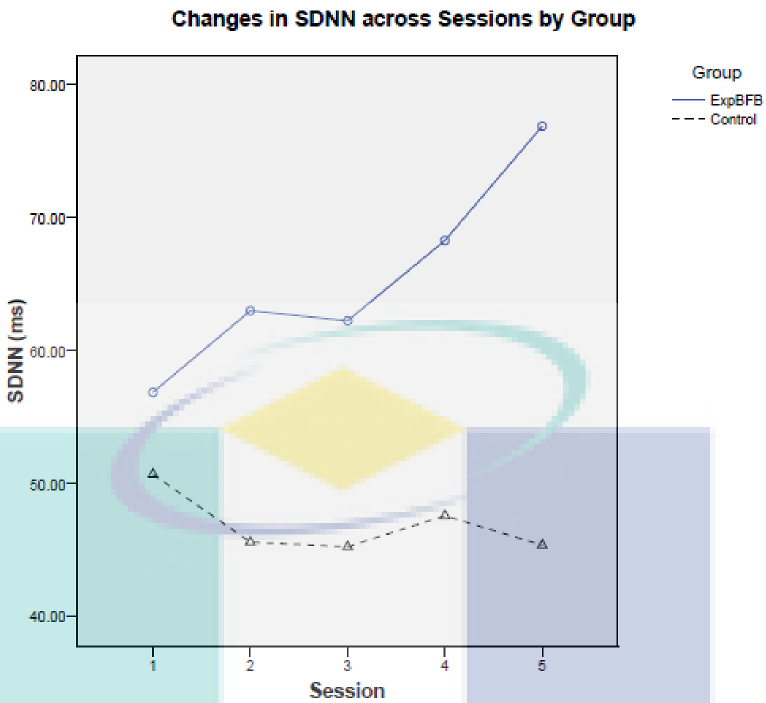

Figure 4.3: Manipulation Check - Participant Progress in SDNN across Five sessions for Both Groups

Table 4.8: Pairwise comparison in percentage of SDNN for the Biofeedback Group

Session (*i*)	Session (*j*)	Mean Difference (*i* - *j*)	p^a
1	2	-6.137	0.199
	3	-5.384	0.335
	4	-11.421	0.062
	5	-20.02	0.002**
2	3	0.753	0.848
	4	-5.284	0.239
	5	-13.889	0.037*
3	4	-6.037	0.270
	5	-14.642	0.034*
4	5	-8.605	0.185

Note. [a]Bonferroni correction was applied. $^{*}p < 0.05$. $^{**}p < 0.005$

As breathing rate data deviated from normality assumption, two separate Friedman ANOVA's tests were conducted to compare the breathing rate across five sessions. As shown in Figure 4.4, the breathing rate of the biofeedback participants significantly changed over the five sessions (χ^2 (4) = 20.660, $p < 0.001$, as opposed to of the control participants (χ^2 (4) = 6.286, p = 0.179). To follow up these findings, Wilcoxon tests were carried out for each comparison. A Bonferroni correction was applied and so all effects were reported at a 0.05/10 comparison = 0.005 level of significance. Table 4.9 shows the significance for all comparison for the biofeedback group. Although the changes in BPM were significant only between sessions two and three, four, and five, the overall breathing rate tended to decrease throughout all sessions (see Figure 4.4).

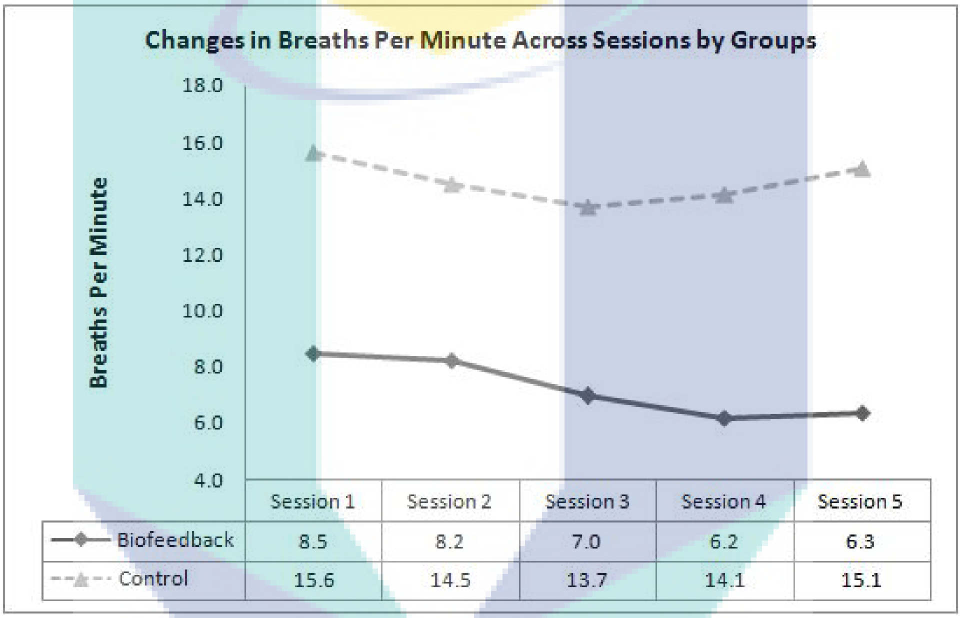

Figure 4.4: Manipulation Check - Participant progress in BPM across five sessions for Both groups.

Table 4.9: Pairwise comparison in BPM for of the Biofeedback Group

Comparison	**Ranks**	**N**	**Mean Rank**	**Sum of Ranks**	***Z***	***p***
$S_2 - S_1$	Negative	9	9.61	86.5	-0.342	0.732
	Positive	10	10.35	103.5		
	Ties	0				
$S_3 - S_1$	Negative	10	12.5	125	-1.208	0.227
	Positive	9	7.22	65		
	Ties	0				
$S_4 - S_1$	Negative	13	11.81	153.5	-2.356	0.018*
	Positive	6	6.08	36.5		
	Ties	0				

Table 4.9: Continued

Comparison	Ranks	N	Mean Rank	Sum of Ranks	*Z*	*p*
$S_5 - S_1$	Negative	11	12	132	-2.027	0.043^*
	Positive	7	5.57	39		
	Ties	1				
$S_3 - S_2$	Negative	16	10.69	171	-3.060	0.002^{**}
	Positive	3	6.33	19		
	Ties	0				
$S_4 - S_2$	Negative	16	11.31	181	-3.463	0.001^{**}
	Positive	3	3	9		
	Ties	0				
$S_5 - S_2$	Negative	17	9.56	162.5	-3.354	0.001^{**}
	Positive	1	8.5	8.5		
	Ties	1				
$S_4 - S_3$	Negative	15	10.57	158.5	-2.557	0.011^*
	Positive	4	7.88	31.5		
	Ties	0				
$S_5 - S_3$	Negative	14	9.68	135.5	-2.179	0.029^*
	Positive	4	8.88	35.5		
	Ties	1				
$S_5 - S_4$	Negative	10	7.65	76.5	-0.393	0.694
	Positive	8	11.81	94.5		
	Ties	1				

Note. S_i = Session$_i$, $i = 1, \ldots, 5$. $^*p < 0.05$. $^{**}p < 0.005$, after applying the Bonferroni correction.

4.3.2 Qualitative Data

During the training, a number of biofeedback participants provided qualitative feedback about practicing outside of sessions and training effectiveness. Feedback was gathered during review session at the beginning of each session via verbal reports. Generally, subjects' responses on training benefits can be categorized into three answers: quality of sleep, breathing more comfortable and reduced fatigue. According to Table 4.10, among 79% of total training participants who practiced outside of sessions, about 60% (or 47% of total biofeedback participants) reported that the resonant biofeedback training had positive effect on their quality of sleep. Approximately 32% presented that their breathing are more comfortable. Moreover, about 63% of total training participants claimed that using the technique helped them combat with sleepiness and fatigue while they were working. It is not surprising because they had to work overtime continuously more than 10 hours/day which led to sleep deprivation whereas they were not provided with sufficient rest time. Further observation in Table 4.10 revealed that subjects whose age below 30 seemed lack of interest practicing outside of sessions compared than older age. Consequently, they did not gain benefits as those who kept practicing. Furthermore, one subject, 34 years old age, experienced her tight feeling in chest had this problem disappear after attending four sessions. In addition, one month after post assessment, a 44-year old subject who established the resonant breathing skill as a habitual practice in her daily lives reported that her overall health had improved without further specifying.

4.4. PHYSIOLOGICAL STRESS PROFILE

This subsection provides findings corresponding to hypothesis one and two of this study. Prior to cognitive performance assessment, a physiological stress profile was conducted for each participant in both groups. At pre-training both groups showed reactivity to stress compared to baseline and recovery periods as measured by LF activity No significance between or within-group differences existed on LF activity and breaths per minute at baseline, stress, and recovery. Figure 4.5 displays percentage of LF values from pre-training to post-training by group and assessment period.

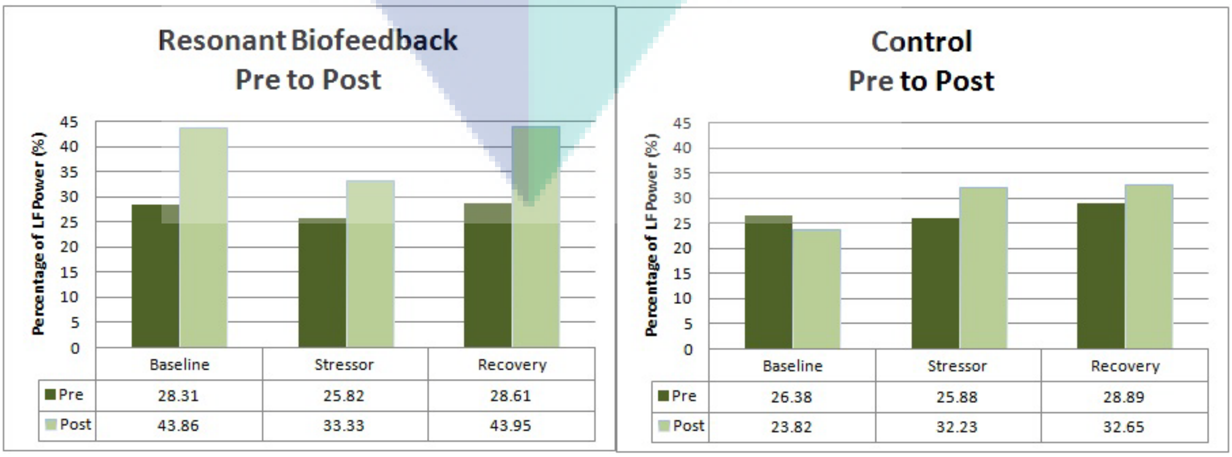

Figure 4.5: Percentage of Low Frequency (LF) Power at Pre and Post Training by Groups and Assessment Period.

Table 4.10: Summary of Verbal Feedback Data

Subject	Age	Years of Working	Years of Education	Practice	Quality of sleep	Breathing more comfortable	Fatigue	Notes
2	44	20	9	1	1	1	1	Improved overall health
3	55	20	9	1	1	1	1	
4	41	20	9	1	0	0	1	
5	41	20	8	1	1	0	0	
6	44	20	9	0	0	0	0	
7	34	10	9	1	1	1	1	Tight feelings in chest disappear
8	39	20	7	1	0	0	0	
9	20	2	10	0	0	0	0	
10	22	0.17	10	1	0	0	1	
11	45	22	9	1	1	1	1	
12	35	12	11	1	1	0	1	
13	18	0.75	11	0	0	0	0	
14	35	0.25	9	1	0	0	1	
15	21	0.42	8	1	0	0	1	
16	40	3	6	0	1	0	0	
17	44	20	9	1	1	1	1	
18	45	5	9	1	0	0	0	
19	22	6	11	1	0	0	1	
20	31	2	9	1	1	1	1	
			Frequency	15	9	6	12	
			Percentage	78.9	47.4	31.6	63.2	

A three-way ANOVA with two repeated measures was conducted to determine whether any significant difference from pre to post training across three periods. There were a significant main effect for time, F (1, 34) = 20.757, $p < 0.001$, with a medium effect size $r^2 = 0.324$ and a significant time x group interaction on percentage of LF activity, F (1, 34) = 9.350, $p < 0.01$, $r^2 = 0.146$. However, no significant effect was found for condition (F (2, 68) = 1.682, $p = 0.194$, $r^2 = 0.047$) and condition x group (F (2, 68) = 2.477, $p = 0.092$, $r^2 = 0.068$) as well as an interaction between time and condition (F (2, 68) = 0.337, $p = 0.715$, $r^2 = 0.010$). Between-groups effect was found significantly different, F (1, 34) = 4.218, $p < 0.05$, $r^2 = 0.110$ was also present. Within-group analysis using paired t-test for dependent samples revealed that, as opposed to the control group, the biofeedback participants increased their HRV power toward LF activity at baseline, stressor, and recovery after training (Table 4.11).

Table 4.11: Results of Within-Group Analysis on LF Activity for the Stress Profile

Period	Group	t	df	p	r^2
Baseline Pre – Post	Biofeedback	- 4.119	18	0.000*	0.485
	Control	0.718	16	0.241	0.031
Stressor Pre – Post	Biofeedback	- 3.352	18	0.002**	0.384
	Control	- 1.354	16	0.098	0.103
Recovery Pre - Post	Biofeedback	- 2.789	18	0.006**	0.302
	Control	- 1.013	16	0.163	0.060

$^{*}p < 0.001$. $^{**}p < 0.05$.

An increase of LF activity in the biofeedback group was also followed by a decrease of very low frequency (VLF) power (Figure 4.6) which is of indicator sympathetic nerves during a mental stressor task (Yagi et al., 1999, and Duschek et al., 2009). As illustrated in Figure 4.6, reduction of VLF activity was more profound in the biofeedback group than in the control group. Further statistical analysis of VLF measures, however, was not carried out because short term recording of VLF is somewhat problematic that should be avoided when interpreting the power spectral density of short-term electrocardiographs (Task Force, 1996).

In addition to frequency-domain measures of HRV, time-domain measures were also calculated during physiological stress profile. Participants in the biofeedback group increased their SDNN above 50 ms during baseline and recovery (see Figure 4.7). But not as predicted, they were not able to increase HRV when attending mental stressor task. On the opposite, SDNN of the control group dropped below 50 ms across three conditions. As VLF measure, short term recording of SDNN (< 5 minutes) is less reliable for further analysis (Task Force, 1996).

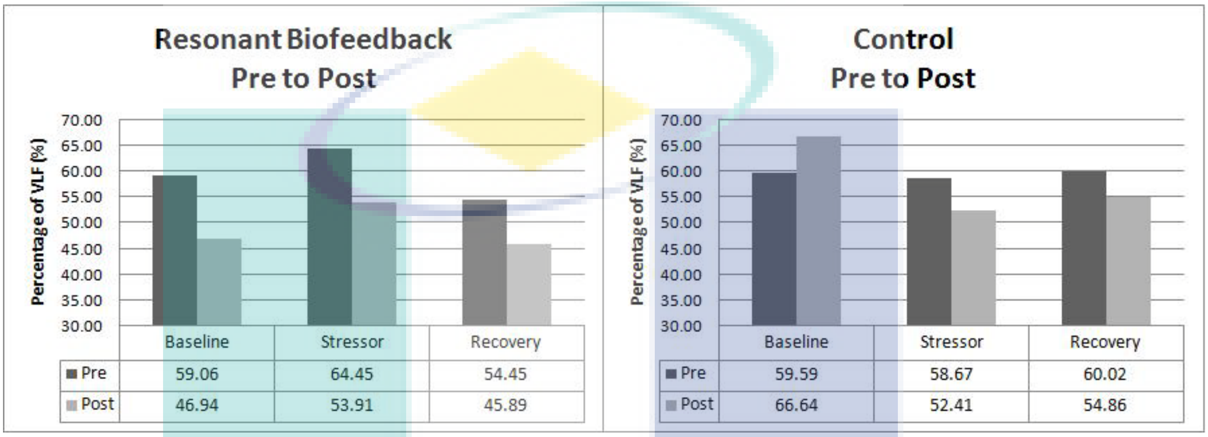

Figure 4.6: Percentage of Very Low Frequency (VLF) Power at Pre and Post Training by Groups and Assessment Period

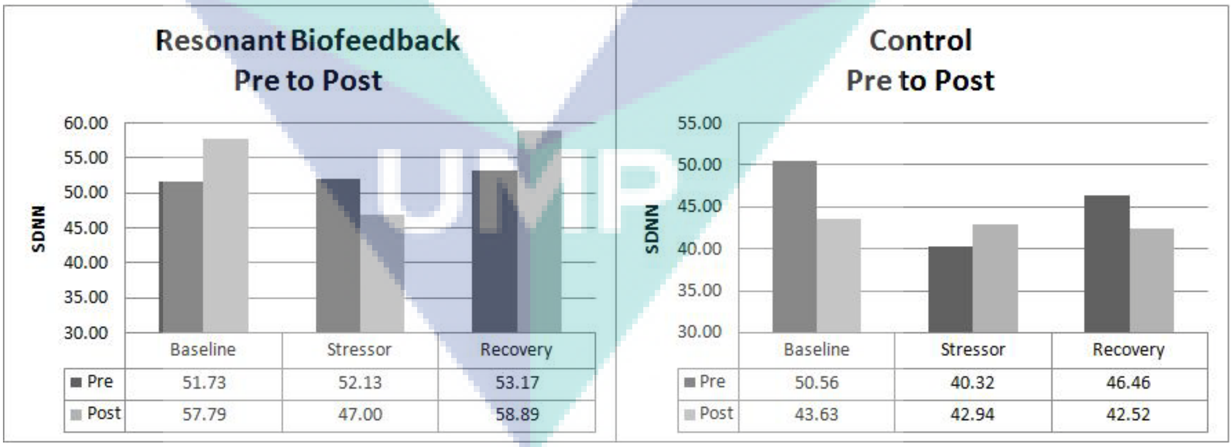

Figure 4.7: SDNN (Standard Deviation Normal to Normal) at Pre and Post Training by Groups and Assessment Period

For breathing rate, in general, both groups showed no difference breathing pattern at pre and post-training (Figure 4.8) with the highest breathing rate occurred during stressor period. A group x time x condition repeated measures ANOVA revealed a significant main effect for time, F (1, 34) = 25.236, $p < 0.001$, with a medium effect,

r^2 = 0.388 and for conditions, F (1, 34) = 8.337, $p < 0.01$, small effect r^2 = 0.196. There was also a significant group by time interaction, F (1, 34) = 5.731, $p < 0.05$, with a small effect size, r^2 = 0.088. Nonetheless, result did not show a significant interaction effect on condition x group, F (1, 34) = 0.138, p = 0.872, r^2 = 0.003, and on time x condition x group, F (1, 34) = 0.526, p = 0.593, r^2 = 0.015. Between-group effect was not found significant either, F (1, 34) = 0.569, p = 0.456, r^2 = 0.016. Paired-sample t-test was then carried out to examine the changes in BPM from time 1 to time 2 on the biofeedback and the control group (see Table 4.12). Although participants in both group showed a decrease in BPM over time at all periods, significant results only existed in the biofeedback group.

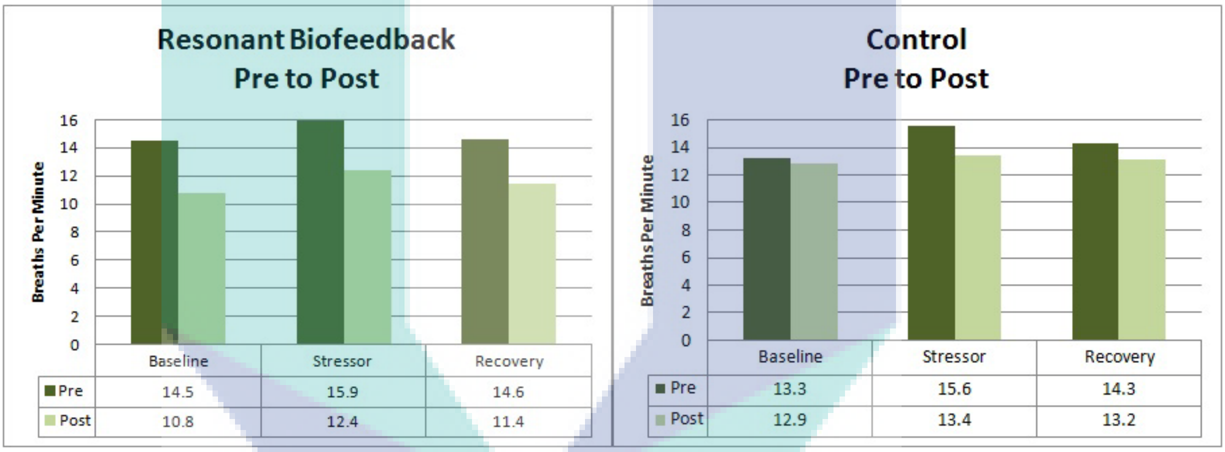

Figure 4.8: Breaths per minute at Pre and Post Training by Groups and Assessment Period

Table 4.12: Results of Within-Group Analysis on BPM for the Stress Profile

Period	Group	t	df	p	r^2
Baseline Pre – Post	Biofeedback	3.435	18	0.003 *	0.396
	Control	0.435	16	0.669	0.012
Stressor Pre – Post	Biofeedback	3.368	18	0.003 *	0.387
	Control	2.023	16	0.060	0.204
Recovery Pre - Post	Biofeedback	3.444	18	0.003*	0.397
	Control	1.187	16	0.252	0.081

*$p < 0.01$.

4.5. COGNITIVE PERFORMANCE AND SELF-REPORT EMOTIONAL MEASURES (DASS)

Following results were presented to answer research objective number two and three whether HRV biofeedback training is effective to improve cognitive performance as well as reduce negative emotional symptoms among female manufacturing operators. Moreover, presentation of findings related to evaluation of hypothesis three through nine were also provided.

4.5.1 Attention

Hypothesis three predicted that the resonant biofeedback training participants would show higher attention or concentration performance as measured by d2 attention test than participants in the control group. Table 4.13 provides means and standard deviation of pre and post d2 attention test for both groups. Result from two-way mixed ANOVA revealed a significant time effect for the two groups, F (1, 34) = 33.363, $p <$ 0.001, with a medium effect size r^2= 0.448. There was also a significant time x group interaction, F (1, 34) = 7.393, $p <$ 0.01, but with a small effect size r^2 = 0.098. No significant differences between group existed (F (1, 34) = 0.671, p = 0.4184) but paired-sample t test analysis revealed improved attention in the biofeedback group, t (18) = -6.61, $p <$ 0.001 with a large effect size, r^2 = 0.708. On the opposite, non significant effect was found in the control group, t (16) = -1.99, p = 0.064, r^2 = 0.0107. The biofeedback group showed a 46% improvement compared to a 13% improvement for the control group. Figure 4.9 displays pre-post concentration performance by group.

Table 4.13: Means and S.D. of Concentration Performance by Groups Pre-post Training

Group	Pre-training M (SD)	Post-training M (SD)
Biofeedback	90.53 (39.151)	131.84 (43.016)
Control	114.59 (37.079)	129.53 (49.356)

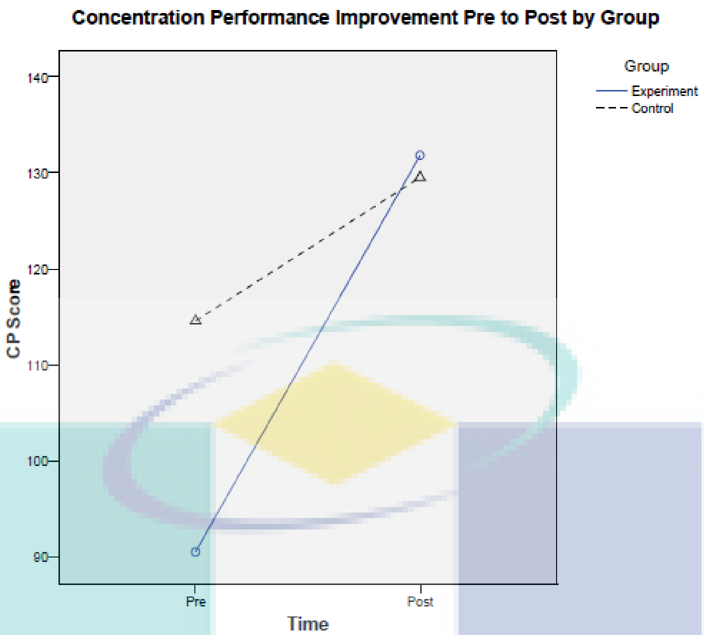

Figure 4.9: Concentration Performance Improvement from Pre to Post by Group

4.5.2. Memory

Hypothesis four predicted that the resonant biofeedback training participants would response faster in Sternberg memory test compared to participants in the control group. Means and standard deviation of pre and post response times for both groups are given in Table 4.14. The biofeedback group showed a 10.5% improvement compared to a 2.6% improvement for the control group. ANOVA investigation showed a significant main effect for time, F (1, 34) = 20.426, $p < 0.001$, with a large effect size $r^2 = 0.311$ and a significant time x group interaction, F (1, 34) = 11.345, $p < 0.01$, $r^2 = 0.173$. There was no difference between groups on memory test, F (1, 34) = 0.007, $p = 0.935$. Further analysis of paired-sample t revealed a significant improvement for the biofeedback group over time, t (18) = 5.135, $p < 0.001$ with a large effect size r^2 = 0.594, while the improvement of memory performance of the control group was not significant, t (16) = 0.879, $p = 0.683$, $r^2 = 0.0461$. A graph of memory performance improvement can be seen in Figure 4.10.

Table 4.14: Means and S.D. of Response Times by Groups Pre-post Training

Group	Pre-training M (SD)	Post-training M (SD)
Biofeedback	1553.93 (188.88)	1390.16 (127.08)
Control	1465.23 (202.90)	1427.28 (169.29)

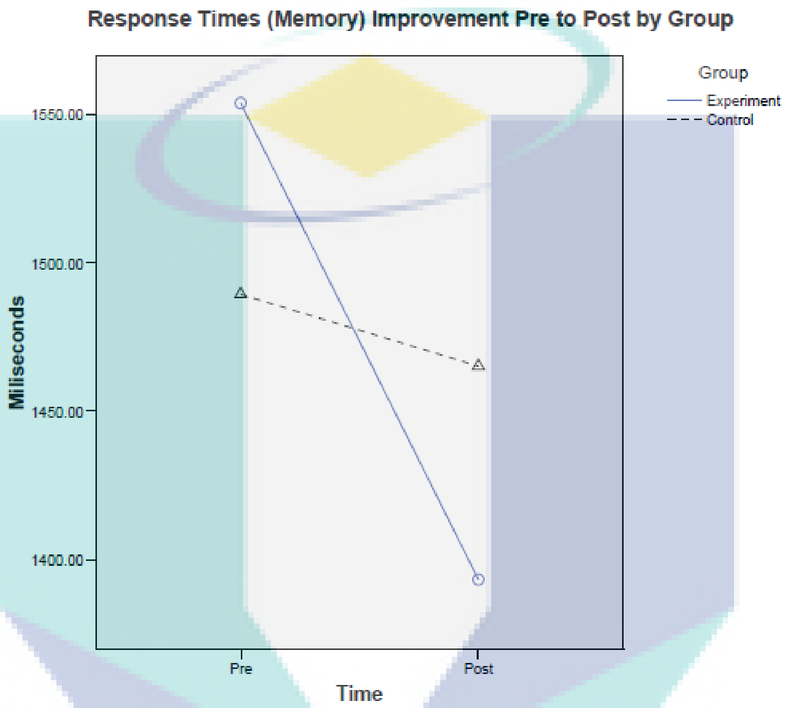

Figure 4.10: Response Times Improvement from Pre to Post by Group

4.5.3 Cognitive Flexibility

Hypothesis five predicted that participants who received HRV biofeedback would demonstrate greater cognitive flexibility performance indicated by interference score of the Stroop test than the control participants from pre to post. Table 4.15 illustrates means and standard deviation of pre and post d2 attention test for both groups. The biofeedback group showed a 5.8% improvement compared to a 0.9% improvement for the control group. A 2 x 2 (group x time) repeated measures ANOVA revealed a significant within group changes from pre to post F (1, 34) = 5.045, $p < 0.05$, with a medium effect size r^2 = 0.121. There were no significant time by group interaction, F (1, 34) = 2.771, p = 0.05, r^2 = 0.066 as well as between-group difference

F (1, 34) = 0.0316, p = 0.860. A dependent t-test analysis revealed that the biofeedback participants improved their cognitive flexibility over time t (18) = -2.759, $p < 0.001$, with a large effect size, $r^2 = 0.545$. No significant difference on the interference score of the control group was present from pre to post, t (16) = 0.415, p = 0.3415, $r^2 = 0.01$. Figure 4.11 shows pre-post cognitive flexibility performance by group.

Table 4.15: Means and S.D. of Interference Score by Groups Pre-post Training

Group	Pre-training M (SD)	Post-training M (SD)
Biofeedback	61.80 (8.24)	65.38 (6.40)
Control	62.82 (9.62)	63.35 (11.28)

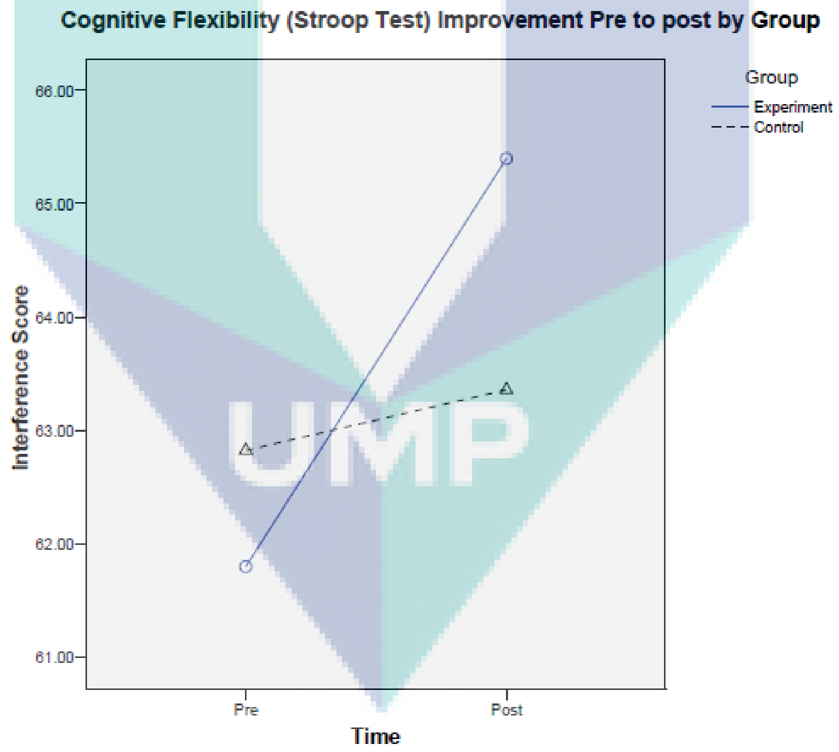

Figure 4.11: Interference Score Improvement from Pre to Post by Group

4.5.4 Self-Report Measures (DASS)

Hypothesis six through eight predicted that the biofeedback group would report significantly decreases on depression, anxiety, and stress score, respectively, than the control group from pre to post. Median and 25 and 75 quartile of the each of DASS scores at pre and post-training can be seen in Table 4.16. Result of Wilcoxon signed-rank test showed that participants in the biofeedback group reported significant lower score on depression (Z = -2.826, $p < 0.01$, large effect size, $r^2 = 0.420$), anxiety (Z = -2.854, $p < 0.01$, large effect size $r^2 = 0.429$), and stress (Z = -2.733, $p < 0.01$ with a large effect size, $r^2 = 0.393$). On the opposite, the control group did not report any significant reduction on DASS-Depression (Z = -1.732, $p = 0.083$, $r^2 = -0.217$), DASS-Anxiety (Z = -1.518, $p = 0.129$, r^2 =- 0.100) and DASS-Stress (Z = -1.414, $p = 0.157$, r^2 = - 0.013).

Table 4.16: Median and 25 – 75 Quartile for the DASS Scores from Pre to Post

DASS Scale	Group	Pre-Training	Post-Training
		Median (25 – 75 Quartile)	
Depression	Biofeedback	12 (5 – 16)	5 (2 – 8)
	Control	10 (4 – 13)	4 (2.5 – 11)
Anxiety	Biofeedback	8 (6 – 18)	5 (3 – 14)
	Control	11 (7.5 – 14)	11 (7.5 – 14)
Stress	Biofeedback	13 (9 – 21)	9 (6 – 12)
	Control	11 (6.5 – 18.5)	10 (8 – 16)

Further analysis using the DASS cut-off scores presented the percentage of falling into one category for each scale in both groups over time, as displayed in Table 4.17. The value could be interpreted as, for example, upon completion of training, 63.2% of participants in the biofeedback group were categorized normal in terms of depression symptoms as compared to 23.5% of the control group. Furthermore, Table 4.18 showed the percentage of subjects in both groups who shifted toward lower, higher or equal than pre-training category. These results revealed that more than 20% of the training participants did move toward lower category (e.g. mild to normal) in each scale of DASS.

Table 4.17: Percentage of DASS Cut-off Scores (Category) from Pre to Post

Measures	Group		Pre-Training	Post-Training
Depression	Biofeedback	Normal	42.1%	63.2%
		Mild	10.5%	5.3%
		Moderate	21.1%	10.5%
		Severe	26.3%	21.1%
	Control	Normal	35.3%	23.5%
		Mild	11.8%	5.9%
		Moderate	35.3%	52.9%
		Severe	17.6%	17.6%
Anxiety	Biofeedback	Normal	36.8%	78.9%
		Mild	15.8%	0.0%
		Moderate	36.8%	21.1%
		Severe	10.5%	0.0%
	Control	Normal	47.1%	58.8%
		Mild	29.4%	23.5%
		Moderate	23.5%	17.6%
Stress	Biofeedback	Normal	63.2%	78.9%
		Mild	10.5%	5.3%
		Moderate	21.1%	10.5%
		Severe	5.3%	5.3%
	Control	Normal	64.7%	64.7%
		Mild	11.8%	23.5%
		Moderate	23.5%	11.8%

Table 4.18: Percentage of Pre-Post Differences on DASS Category

		Decrease (%)	Equal (%)	Increase (%)
Depression	Biofeedback	52.6	47.4	0
	Control	17.6	82.4	0
Anxiety	Biofeedback	31.6	57.9	10.5
	Control	5.9	70.6	0
Stress	Biofeedback	21.1	68.4	10.5
	Control	11.8	88.2	23.5

4.5.5 Correlation between Cognitive Performance and DASS

The relationship between participants' reduction on depression, anxiety, and stress (delta scores) and cognitive performance improvement (delta scores) was investigated by bivariate Spearman's rho correlations. Delta score for each measure was calculated by subtracting respective value Time 1 from Time 2. For CP and Stroop interference scores, higher delta scores reflected greater improvement, while response times values reflected the opposite. For each scale of DASS scores, the less the delta scores, the higher the respective scale reduction. Table 4.19 displays the Spearman, r_s, correlation matrix of outcome measures improvement (delta changes scores) on the total sample.

Improvements in attention (ΔCP) showed correlations with memory (ΔRT) (r_s = -0.282, p = 0.048) and cognitive flexibility (ΔIS) (r_s = 0.438, p = 0.004), indicating that higher attention performance was associated with faster response times and greater cognitive flexibility. Concerning emotional symptoms, improvement in attention was correlated with reduced anxiety and stress (r_s = - 0.495, p = 0.001; r_s = - 0.308 p = 0.034, respectively). A decrease in response times of the Sternberg test was also associated with improvement in cognitive flexibility (r_s = - 0.298, p = 0.039) as well as reduction in and stress (r_s = - 0.309, p = 0.034). A change in response times, however, was found not significantly associated either with depression (r_s = - 0.144, p = 0.201) or anxiety (r_s = - 0.171, p = 0.160). As opposed to the above results, greater cognitive flexibility performance did not show a correlation with reduction in depression, anxiety, and stress scale of DASS (r_s = 0.1584, p = 0.178; r_s = - 0.061, p = 0.363; r_s = - 0.0851, p = 0.311, respectively). In summary, there was not enough evidence to state that hypothesis nine was proven.

Table 4.19: Bivariate Spearman's Correlations of Cognitive and Self-Report Psychological Measures (Delta Change Scores)

	Δ CP	**Δ RT**	**Δ IS**	**Δ Depression**	**Δ Anxiety**	**Δ Stress**
Δ CP	1					
Δ RT	-0.282^{*}	1				
Δ IS	0.438^{**}	-0.298^{*}	1			
Δ Depression	0.043	0.144	0.1584	1		
Δ Anxiety	-0.495^{**}	0.171	-0.061	0.237	1	
Δ Stress	-0.308^{*}	0.309^{*}	-0.0851	0.252	0.606^{**}	1

Note. N = 36. $^{*}p < 0.05$. $^{**}p < 0.01$. CP =Concentration Performance. RT = Response Time. IS = Interference Score

UMP

CHAPTER 5

DISCUSSION

5.1 OVERVIEW

The purpose of this study was to determine the effectiveness of using HRV biofeedback as a modality in the performance enhancement. The main goal was to assess whether the resonant biofeedback training would direct to improvements in cognitive performance among industrial operators. The remainder of this chapter will be organized in the following order: (1) summary of study findings; (2) discussion follow result section; (3) work or practical implication; (4) limitation of the present study; and (5) recommendations for future research directions

5.2 SUMMARY OF FINDINGS

Overall, the results of this study show that the development of HRV biofeedback module which consisted of a 5-week course of biofeedback training had significant positive effect on a group of operators. In particular, participants in the biofeedback group showed significant improvements from baseline to follow-up assessment in cognitive performance and self-report emotional symptoms (i.e. depression, anxiety, and stress). These improvements were followed by increase physiological index among training participants. During physiological stress profile, significant within-group improvements were also noted for the biofeedback participants in percentage of LF activity and breaths per minute. Further, the biofeedback group showed significant increase in LF activity, SDNN, and slower breathing rate throughout five sessions. The HRV data confirms that the participants learned how to effectively manipulate and control activity in the autonomic nervous system which continued to homeostasis balance. Similar significant results did not exist in the control group. In short, all of the objectives of this study, as stated in Chapter 1, have been achieved. Nonetheless, the correlation between each cognitive performance and self-report DASS was not found statistically significant. Thus, of nine hypothesis evaluated, there was not enough evidence to support hypothesis nine, suggesting that reduced negative emotional symptoms could not be a mediate factor for the cognitive performance enhancement.

5.3. MANIPULATION CHECK

5.3.1. Physiological Measures

In addition to pre-post test measurement, the researcher used manipulation check to assess the direct effect of the manipulation (i.e. HRV biofeedback training) (Gravetter and Forzano, 2009). As intended by the study, participants attended the resonant biofeedback practiced and progressively learned the technique over the duration on the training program. Researchers have shown that HF values reduce and LF values increases when people breathe slowly about six breaths/minute (Gevirtz and Lehrer, 2003). HRV data showed that participants in the biofeedback group learned to increase their HRV using the procedures they had been taught. Figure 3.4 shows an example that subject no 7 in the biofeedback group was able to breathe at, or close to her resonant frequency at certain session. Overall, the breathing rate of the biofeedback participants decreased across five sessions of which the decrease was significantly apparent by session 3 (see Table 4.4 and Figure 4.4). Furthermore, Tables 4.5 show that, as expected in resonant biofeedback training, significant increases in LF activity reflects resonance effects involving both respiratory sinus arrhythmia and baroreflex gain (Lehrer et al., 2003, and Vaschillo et al., 2002). The changes from this system as well as those that occur from shifting toward LF activity reinforce homeostatic control within the body. These findings were supported by an increase in SDNN value, an indicator of overall adaptability. As opposite to the training group, similar results were not found in the control group.

Furthermore, post-hoc tests showed that significant improvement of LF activity was observable by session four (see Table 4.6). This result is consistent with Karavidas et al (2007) who found an increase in LF spectral power was significantly apparent in session four of ten sessions of biofeedback training. A somewhat different than LF parameters outcome, participants required one more session so their SDNN values significantly increased, as displayed in Table 4.8. Yet, most of them were able to increase SDNN values to just above 50 ms after attending the session one. This value is an indicator of normal HRV to healthy adults (Task Force, 1996). Conversely, the control participants maintained their SDNN below 50 ms.

5.3.2. Qualitative Data

Another notable finding was noted in qualitative data where 47% of the training group biofeedback experienced improved quality of sleep. Although the validity of the data were questionable, these responses were found similar with previous studies in patients (Zucker et al., 2009; Karavidas et al., 2007) which had employed standardized questionnaires. Besides, more than 50% of the biofeedback participants provided verbal feedback that practicing resonant breathing is effective to combat with fatigue and sleepiness during work hour. Although fatigue at work is a normal everyday experience, however, in the case of severe fatigue it may affect the person’s performance in the occupational (Beursken et al., 2000). The training participants reported that they have been working overtime more than 25 hours/week within the last three months. This condition potentially evokes severe long term fatigue or burnout that may lead sick leave and work disability. Although no particular investigation on HRV biofeedback and fatigue has been conducted, the Institute of HeartMath (IHM) acclaims that the HRV biofeedback training may be effective to address with fatigue problem as it has been supported in numerous researches among employees (Barios-Choplin et al., 1997, 1999, and McCraty et al, 2003). The theoretical underpinning this viewpoint is the close relationship between stress and fatigue (Institute of HeartMath, 2009)

5.4. PHYSIOLOGICAL STRESS PROFILE

Consistent with the predictions, the biofeedback participants increased their HRV power toward LF activity at baseline, stressor, and recovery after training (Figure 4.5). A similar result was also found on breaths per minute (BPM) measure. At pre-training, participants in the both groups showed reactivity to stress. Post-training assessment revealed that both groups habituated to the stressor. However the significant decrease only existed in the biofeedback group, as opposed to the control group (see Figure 4.8). Apparently, the training participants used the slow diaphragmatic breathing technique during stressor condition although no special instruction was provided. This finding is consistent with Sharpley (1989) who examined the effectiveness of biofeedback training in controlling heart rate reactivity to a psychological stressor (i.e. mental arithmetic). At post comparison, the participants who received training significantly lowered their heart rate reactivity even though they were not specifically instructed to do so. In another study with similar technique, Goodie and Larkin (2001) found that the group received heart rate feedback performed significantly lower heart rate, systolic blood pressure, and total peripheral resistance responses to the videogame challenge compared to that at pre training. They suggested that biofeedback training helped reduce cardiovascular and hemodynamic responses to a mental stressor (Goodie and Larkin, 2001).

An increase in LF spectral power during stressor period was accompanied by reduced VLF. As suggested by Berntson et al (1997), LF variability may provide an important index of mental effort or other cognitive processes in psychophysiological studies. Thus, a change of HRV spectral power toward LF activity may combat the negative physiological effects of stressors because it inhibits sympathetic activity during stress. Subjects were able to shift the sympathetic activity to a more balance autonomic nervous system. Previous literatures have well documented the correlation between LF activity, baroreflex, and cognitive functioning. On one hand, Vaschillo et al. (2002) used HRV biofeedback as a method for assessing baroreflex function. Their result revealed why voluntary increases in HRV always occur in the LF range (Lehrer et al., 1997) where HR resonance can occur. Their findings showed that people can produce large-amplitude oscillations in HR, and that these seem to stimulate baroreflex activity. In other words, repeated high-amplitude stimulation increases the efficiency of baroreflexes. On the other hand, Yasumasu et al. (2006) have presented the relationship between cognitive functioning and baroreflex. They found that baroreceptor reflex sensitivity was inhibited during mental stress. The level of this baroreceptor inhibition is negatively and significantly associated with the level of cognitive performance during mental load stress tasks. They proposed that the interactions between baroreceptor cardiac function and cognitive functions is possibly a dynamic mechanism of fundamental importance for cardiovascular regulation and a vital mechanism supporting adaptive responses to stressful conditions. This aids interaction between organism and environment, therefore allowing more efficiently coordination of organism attentional resources for goal-directed behaviour and adaptability. All of these may explain that HRV biofeedback training indeed produced an increase in baroreflex gain during mental stressor at post-intervention.

Contrary with the LF activity, the time domain measure (i.e. SDNN) at baseline, stressor, and recovery from pre to post did not confirm with the frequency domain results but still shows an interesting finding. Most studies that have analysed the relationship between HRV and cognition utilized only one HRV index as a dependent variable (Hansen et al., 2003, 2004, and Lane et al., 2009) or manipulated one HRV index as an independent variable (Hansen et al., 2003). Results from this study may be suggestive that although time and frequency domain measures are highly correlated, they may not represent exactly the same physiological substance.

5.5. COGNITIVE PERFORMANCE

Overall, participants in both groups tended to improve their cognitive functioning upon completion of the training as revealed by significant time effect in attention, memory and cognitive flexibility. ANOVA analysis showed that the resonant biofeedback group produced significant improvement in all of the cognitive measures when compared to controls. In addition to significance value, the effect size of the concentration performance, memory, and cognitive flexibility in the training participants, each was reported large ($r > 0.5$ or $r^2 > 0.25$), suggesting the effect of biofeedback training was indeed a substantive finding.

These findings are consistent with previous research documenting the effect of HRV biofeedback in auditory cognitive task (McCraty, 2000). They found that the experimental group increased their response times significantly from pre to post brief-training of heart rhythm coherence biofeedback. The control group participants, who simply relaxed during the interval between tests, showed no change in mean reaction time from the first to the second discrimination task. However this current study has some advantages over the previous study. The previous study assessed the immediate effects while the current study showed the more-long term effects of a 5-week biofeedback training. Although the short HRV biofeedback training was transferred well to the majority of participants and produced significant effect (McCraty, 2000), most study on the use of RSA or HRV biofeedback suggested more than a brief training period (Lehrer et al., 2003; Karavidas et al., 2007; Siepmann et al., 2008; Sherlin et al. 2009, and Zucker et al., 2009). When the technique learnt from a brief training period of HRV biofeedback is applied outside laboratory setting, for instance in factory, a large number of participants may face difficulty in learning it effectively. Shellenberger and Green (1986) emphasized that short term of biofeedback training period (e.g. less than three sessions) will hamper the mastery which equips the subjects with the ability to demonstrate the learned skill under adverse conditions, both in and out of the training. Nonetheless, Karavidas et al. (2007) found that ten sessions of HRV biofeedback may not be necessary to improve efficacy of HRV biofeedback. Vaschillo et al. (2002) also demonstrated that approximately four hours of training are necessary to teach people the skill of HRV biofeedback.

Regardless the training duration, McCraty and Tomasino (2004) and McCraty (2002) presented possible explanation how HRV biofeedback how greater HRV amplitude resulted from biofeedback training correlates with improved cognitive functioning. They proposed the existence of psychophysiological coherence that is harmonious interactions of the body’s subsystem. They found that increased psychophysiological coherence, as result of HRV biofeedback, corresponds with better homeostatic regulation and the changes in the brain's information processing capabilities. The changes lead to cognitive processing improvement such as focused attention, discrimination, and motor skills. Such skills are crucial to the work settings and are often under-trained for operators (McCraty, 2003). With respect to resonance effect as underlying protocol used in this study, HRV biofeedback elicited resonant oscillations in the cardiovascular system and apparently normalized autonomic regulation due to an increase baroreflex gain (Lehrer and Vaschillo, 2003; Lehrer et al., 2003, Vaschillo et al., 2006). The baroreceptors have effects on the brain, mediating cardiovascular influences on the central nervous system (CNS). Baroreceptor activation–inhibition could produce a modulation on CNS structures with implications for cognitive processing of environmental inputs. As such, these techniques may have been responsible for the substantial enhanced in the operator's cognitive performance and reduced the emotional symptoms they experienced during work.

Another interesting finding was present on the correlation between delta change scores on each cognitive measure. As displayed in Table 4.19, each cognitive measure correlated significantly with the two others while the most profound correlation was noted between attention and cognitive flexibility. As described earlier, of all the tasks the human brain performs, perhaps none is more important for the performance of other tasks than attention. Attention is a driver for other functions from perception to decision and execution (Fafrowicz and Marek, 2008). It is not surprising that improvement in attention might direct to improvement in memory and cognitive flexibility.

5.6. DEPRESSION, ANXIETY, AND STRESS

This study also showed that resonant biofeedback produced a significant decrease in depression (58.3%), anxiety (37.5%), and stress (30.8%) symptoms in the biofeedback training group from pre to post intervention. The mechanism for reduced negative emotional symptoms may be biofeedback effects on autonomic regulation. Resonant frequency breathing biofeedback elicits high-amplitude oscillations in the cardiovascular functions, which in turn train autonomic reflexes (Lehrer et al., 2003). This training restores autonomic balance or homeostasis and improves autonomic control that supports emotional regulation.

The effect size on each measure also supports the efficacy of the training. Although the use of biofeedback for improving cognitive performance is a very new approach but it is commonly applied as workplace stress intervention. Results from this study show that the magnitude of the training affect reduction in each emotional symptoms is large (r^2), approximately 0.40. It indicates that 40% of the total variation in each emotional symptom is accounted for by the biofeedback training. Although this value might be amplified because of small sample size, these findings are still impressive when taking into consideration the unique effect of HRV biofeedback without supplementary skill such as cognitive coping strategies, time management

(DeFrank and Cooper, 1987). Karavidas et al. (2007) also evaluated the unique effect of HRV biofeedback in clinical setting and reported a large effect size (*d* = 3.6), even though the absence of a control group might contribute to their large effect size. This effect size along with of this present study surpasses the effect size reported by Kelley (1995) in his meta analysis study. He revealed a small effect of biofeedback intervention either in industry (*d* = 0.28) or non-industry settings (*d* = 0.35). Prior reviewed biofeedback interventions were predominantly directed in controlling tonic level of muscle tension, blood pressure, heart rate, skin temperature, etc. — tasks that are noticeably more difficult than learning to increase HRV (Lehrer, 2007). The use of HRV biofeedback as a part of stress management intervention has just been commenced in late of 90 (Barios-Choplin et al, 1997, 1999, and McCarty and Tomasino, 2004). As noted earlier, HRV biofeedback is more reflective of both branches of the autonomic nervous system and the harmonization between them, and thus it provides a window into the dynamics of the entire system (McCraty and Tomasino, 2004). Moreover, rather than trying to teach people change tonic levels of physiological arousal functions, this method is aimed at exercising and strengthening one of the body's important self-modulatory reflexes: the baroreflex. Because of the pervasive effects of the baroreflex in maintaining autonomic and emotional stability, this method may be useful for treating emotional regulation (anxiety and depression) (Lehrer and Vaschillo, 2003). Thus, it is not surprising that HRV biofeedback training has more encouraging effects than those other types of biofeedback.

Results of this study are in accord with some of the prior literature examining the effect of HRV biofeedback in depressed patients (Karavidas et al, 2007, and Siepmann et al. 2008). Karavidas et al. (2007) found that even by session four, subjects participating in HRV biofeedback demonstrated attenuation in several indices of depression, particularly neurovegetative components (i.e. sleep hygiene, fatigue, concentration. Their data showed that HRV biofeedback systematically stimulated the vagus nerve both during practice sessions and between sessions. Although the correlation between amplitude of changes in physiological variables and magnitude of changes in depression was not established, attenuation in depressive levels were paralleled with increases in LF HRV and SDNN at session four, where significant symptom alleviation occurred. These findings suggested that symptom alleviation occurred at the point where the patient had maximally learned the skill of resonant frequency breathing.

Another study in reduction of depression also supported these current results Siepmann et al. (2008). Time and frequency domain parameters of HRV were found increased and subjective mood was noted improved in depressed patients when being followed up after treatment with HRV biofeedback. HRV biofeedback training may enhance vagal heart rate regulation by inducing focused concentration in conjunction with emotional self-control. This cognitive-emotional response is associated with a neural circuit where the prefrontal and the anterior cingulate cortex play an important role, as the adaptive control of emotion and goal-directed behavior is initiated and maintained (Thayer and Lane 2000).

In addition to depression, HRV biofeedback also shows potential for dealing with anxiety and stress. In a case study of a young golfer, ten sessions of HRV biofeedback training enhanced the golfer's ability to cope with anxiety and various other negative mood states which in turn improved his athletic performance (Lagos et al., 2008). It was also supported by increase both total HRV and LF activity within and between sessions. Likewise, Zucker et al. (2007) showed that HRV biofeedback significantly reduced post traumatic stress disorders symptoms among 19 patients after attending 4-week training. Increases in HRV as measured by SDNN were significantly associated with PTSD symptom reduction. Although prior studies were mostly applied in patients, a consistent result was attained through this study in healthy subjects. All of these results provide support for the efficacy of HRV biofeedback in improving physiological and psychological functions among industrial workers.

According to DASS cut-off scores (Table 3.3), at baseline condition, a number of subjects either in the biofeedback or control group had severe category, as shown in Table 4.17. Upon completion of biofeedback training, a shift toward lower category (e.g. severe to moderate) was present in a number of subjects in the biofeedback group. Although both Karavidas et al., (2007), Siepmann et al. (2008), and Zucker et al. (2009) proposed that HRV biofeedback demonstrates promise for the adjunctive treatment of emotional disorders, it must be highlighted that HRV biofeedback in this present study was not meant to treat serious stress-related disorders. With regard to ethical consideration, thus some actions were taken to follow up this finding. First, upon completion the training, respective subject was told about her actual emotional condition, related risks, and the consequences. The researcher then asked their approval to report their DASS data to the management so necessary actions for helping them would be taken. If they refused, they were encouraged to seek professional assistance by themselves. At least they should meet the health practitioner provided by the factory.

5.7. COGNITIVE PERFORMANCE AND DASS

Even though a particular correlation analysis between changes in HRV-related outcomes and cognitive performance has not been conducted, parallel results between those measures could not be neglected. From an exploratory perspective, this study also attempted to find the mechanisms behind the findings. Based on model displayed in Figure 2.3, emotional-balanced state was hypothesized to become a mediator of cognitive performance enhancement. This hypothesis (i.e. hypothesis nine) was built on the basis of theoretical rationale and prior HRV biofeedback studies explained in previously subsection. All of these hence provide a rationale for measuring underlying changes mechanism.

As described in Chapter 4, results of bivariate Spearman's correlation analysis showed that changes in stress level correlated significantly with changes in attention and memory but not with cognitive flexibility. Moreover, reduction in anxiety had a notably association with improved attention but not with the two other improved cognitive measures. Somewhat contrary to prediction, not all of the amplitude of changes in each DASS measure significantly correlated with the magnitude of changes in each cognitive measure. It is still not clear whether attenuation in emotional symptoms mediated the relationship between biofeedback training and cognitive performance.

The last finding is somewhat inconsistent with prediction made by the proposed model (see Figure 2.3.) which suggests that emotional symptoms are negatively correlated with cognitive performance. When particularly considering the predictor

(HRV measure) and mediator (i.e. emotional state) variables, it is not surprising. Although on a conceptual level, the proposed relation between the predictor and the mediator has a clear theoretical rationale, of the studies that found parallel results between HRV-related and emotional-related outcomes, only two which had conducted correlation or multiple regression analyses (Karavidas et al., 2007 and Zucker et al., 2009). Karavidas et al. (2007) conducted a correlational analysis between measures of change in physiological and depression measures using Kendall's tau. They found no significant correlations between physiological and depression data although both measures showed improvement. Lehrer et al. (2003) also reported that none of the physiological changes resulted from HRV biofeedback in healthy subjects were closely associated with self-reported experiences of relaxation. This suggests that the cardiorespiratory effects cannot be explained by relaxation. On the contrary, using hierarchial multiple regression, Zucker et al. (2009) found that increases in HRV were significantly associated with PTSD symptom reduction. The inconsistent results migt be attributed to methodological limitation. All of these may be possible rationales why as yet no model describing relationship between HRV biofeedback and emotional states has been established. Back to the proposed model (Figure 2.3), consequently, it becomes plausible that significant association between the mediator and the outcome (i.e. cognitive performance) variables did not exist. In brief, lack of significant correlation between changes on cognitive performance and emotional states implies that their relationship is still a hypothesis. Future research may further clarify the relationship among autonomic functioning, cognitive performance, and emotional levels.

Notwithstanding lack of significant relationship found, a parallel increase in cognitive performance and reduced self-report physiological itself could not be disregarded. A significant correlation between anxiety and attention is of particular interest as their relationship has been revealed in a number of studies either within area of human performance or psychophysiology (Thayer et al., 1996; Thayer and Lane, 2000; Hammond, 2000; Bourne and Yaroush, 2003, and Staal, 2004). According to a model proposed by Thayer and Lane (2000), emotional self regulation involves selective attention. The ability to sustain and shift attention is an important component of organism self-regulation and adaptability. Individuals that worry a significant portion of the day show less physiological flexibility and adaptability to changing task demands. In short, low HRV is associated with poor affective information processing, thus autonomic regulation as resulted from HRV biofeedback training allows an individual to meet the challenges of changing environment.

There are no comparable studies that assess the effects of HRV biofeedback on cognitive performance and emotional-symptoms in a non-clinical population of healthy adults. However, several studies on a variety of cognitive performance enhancement may show a relationship between cognitive performance and the reduction of emotional symptoms or improvement of well-being. The following studies will be used to illustrate this relationship. The first study (Moore and Malinowski, 2009) compared a group of meditators experienced in mindfulness meditation (*n* = 25) with a meditation-naïve control group (*n* = 25) on measures of Stroop interference and the d2 attention test. Meditators performed significantly better than non-meditators on all measures of attention. Self-reported mindfulness was also higher in meditators than non-meditators and correlations with all attention measures were of moderate to high strength. Overall the results suggest that attentional performance and cognitive flexibility are positively related to meditation practice and levels of mindfulness. Wallace and Shapiro (2006) proposed a mental balance model that facilitates the integration of western psychological and Buddhist meditation. According to this model the components conation (motivation, intention), attention, cognition and affect/emotion need to be developed and balanced to achieve profound well-being. Thus, cognitive flexibility can be fostered by building on improved attentional abilities, which are initially trained and developed as previously done by Moore and Malinowski (2009). This perspective is also supported by a recent representative study of a population above 50 years of age (Llewellyn et al. 2008). The authors reported that higher levels of psychological well-being are related to better global cognitive function and performance in multiple cognitive domains. Their standpoint is supported by experimental evidence that inducing positive mood states influences cognitive performance over short periods (Ashby et al., 2002). Thus it may be possible that high levels of psychological well-being are beneficial for cognitive function over longer time periods.

In a more complete evaluation study, Casden (2005) investigated the effect of asthanga yoga on autonomic, cognitive functioning, psychological symptoms, and somatic complaints in 48 healthy participants. Participants in the yoga group (*n* = 22) showed significant differential improvement in abdominal style breathing, positive mood, fatigue, quality of life, sleep quality, energy, concentration and short-term memory, compared to the control group. Contrary to expectation, autonomic functioning did not show significant differences between groups. This might be predicated to lack of sample size and different yogic technique employed because another study on yoga found an increase in LF power (Raghuraj et al., 1998) after practicing kapalabhati technique.

5.8. WORK IMPLICATION

Given the significant contribution of operator's performance in the manufacturing productivity, it is strongly needed to implement a new training approach to enhance their work performance with respect to improved cognitive performance and reduced stress-related symptoms. Practitioner training programs and the scholar literature place emphasize performance focus mainly on ways in which managers can increase the capacity and willingness. Even though organizational based interventions is certainly a valuable goal (DeFrank and Cooper, 1987), however, the individually based is still favourable because they are often less expensive and take into account the individual nature of the block factor (e.g. stress) response which impact on workplace performance (Mastuzek, 1999). The purpose of training and development, for instance, is to improve the operator's capacity to perform. A wealth of literature on motivation, leadership, anxiety, and attitudes relates to how willingness might be enhanced.

Results from this study showed that HRV biofeedback training has significant effects on cognitive and emotional symptoms. The mechanism for cognitive performance and emotional effects may be biofeedback effects on autonomic regulation. HRV biofeedback elicits high-amplitude oscillations in the cardiovascular functions, which in turn train autonomic reflexes (Lehrer et al., 2003). The increase in LF and total HRV within sessions reflects resonance effects. This training restores autonomic balance and improves autonomic control that supports emotional regulation and brain processing.

As stress affect negatively on productivity and satisfaction than that produced by other risk factors, it is needed to add other stress intervention technique as an adjunctive too. HRV biofeedback training may be combined with other strategies or intervention to be more beneficial. Biofeedback has been shown to be an effective approach to stress management and provides an excellent adjunct therapy to modern relaxation techniques. It makes a synergistic effect with other techniques so that higher outcomes are evidenced when biofeedback used to enhance the effects of other techniques (Barios-Choplin, 1997, 1999; Matuszek, 1999, and Sharpley, 1989). It is expected that multi-modal performance enhancement techniques may lead to greater outcomes and long-term benefits. Any strategy for performance enhancement should be an adjunct to organizational change interventions (Murphy, 1996).

In biofeedback training, it is assumed that the client has the ability to learn the skill set necessary for the training to be successful. Much of the success of training is attributed on a good working relationship between the trainer and the trainee, a sharing of knowledge and skills, and mutual respect for the medium (Shellenberger and Green, 1986, and Schwartz, 2003). As any other training, a successful training should consist of consciousness, cognitive understanding, language, positive expectations, motivation, and positive interaction with the coach, teacher, or therapist (Appelbaum, 1996; Sutherland and Oswald, 2005; Sarazzin et al., 2006; Biswas-Diener, 2009, and Sánchez et al., 2009). Due to the importance of these issues, there are several things should be considered before applying HRV biofeedback training. First it is important to consider the trainer's skill. In addition to biofeedback knowledge, a good trainer should have coaching and managerial skills. Lack of personal attention from the trainer may result in incomplete understanding of the techniques and decreased motivation to practice (Kelley, 1995).

Second, regarding lack of time to practice, homework training should be emphasized. Providing the participants with more tips to practice at workplace is recommended since they only have little time to do so at home. Moreover, stressor used as mastery tasks should be extended. It may include demonstration of self-control without feedback in relaxed settings (e.g. adjusting physical environment such as room temperature and noise), demonstration of self-control without feedback in stressful situations, e.g. cold room, providing noise, stress profile, performance tasks, and interpersonal confrontation. Goodie and Larkin (2006) found that transfer of biofeedback training was not so easily attained by subjects who had been effectively learned the skill. In their study, participants generally maintained the skill learned from heart rate biofeedback during the immediate post-training assessment. However they were unable to transfer those skills during short delay and long delay post-training session when feedback was no longer present and failed to transfer heart rate reduction skills to novel tasks. These results suggest that the successful transfer of heart rate feedback training to daily tasks may require continuous training during encounters with daily stressors. Another important aspect of workplace interventions is that of continued training. Workers may be motivated to practice the technique throughout the training (about five weeks) and after completing the training, but adherence tends to decrease with time. Offering "refreshment" session three to six months after the completion of the training can provide workers not only with increased motivation to adhere to the practice of the technique but also with reminders on the correct method of practicing the technique.

5.9. LIMITATION OF THIS STUDY

This study was limited in several ways which would decrease the ability to generalization issue in other settings. First of all, the results of the current study may be limited to the sample size and characteristics. The sample population used in this study mainly consisted of female Malays workers in electronic manufacturing industry. The results may not be generalized to non operators or to non manufacturing industrial setting. Although several studies using HRV/RSA biofeedback (Lehrer and Woolfolk, 2007; Reiner, 2008; Karavidas et al., 2007, and Zucker et al., 2009) have revealed that there are long-term changes associated with this technique, the results of this study cannot be generalized to long-term changes in HRV. It is still unclear whether the training effects of HRV BFB enlarge, decrease, or remained consistent over time. Longitudinal research is thus warranted.

Another limitation of the study was the difficulty to demonstrate a direct relationship between biofeedback training and work performance particularly if assessed in terms of quantity or quality of work output. One of the reasons is the multitude of extraneous variables that can potentially influence work performance (Blumberg and Pringle, 1982). Further research may consider using various performance indicators which focus more on individual/organisational interface such as job satisfaction, absenteeism, turnover, health care utilization and claims (DeFrank and Cooper, 1987). Nonetheless, HRV biofeedback training may not be applied as a "stand alone" strategy, it will yield much better outcomes particularly in terms of organizational outcome, if it works as an adjunctive intervention.

Despite its shortcoming, this research has a major strength over other researches. Most researches on HRV biofeedback in healthy subjects evaluated only the effect on subjective report (Barios-Choplin et al. 1997, 1999; Karavidas et al., 2007, and Zucker et al., 2009), only two employed objective assessment (McCraty, 2002, and Sutarto and Wahab, 2008). Moreover, Murphy (1996) has suggested that stress intervention researchers should place more emphasis on performance indicators rather than self-report and psychological indicators. To the best our knowledge, this is the first randomized control trial examining the effect HRV biofeedback on both objective and subjective performance measurement. This research evaluated various cognitive functions: attention, memory, and cognitive flexibility. In addition, the emotional symptoms among workers were evaluated including their depression, anxiety, and stress level. Therefore, this study will provide a more comprehensive description on autonomic regulation, cognitive performance and emotional symptoms since all of these have a strong interrelationship in human performance researches (Bourne and Yaroush 2003; Staal, 2004, and Lane, 2004).

This study also has limitations that were beyond the control of the researcher. First, upon agreement with the management, the subjects were volunteers from the total work group and therefore did not represent a random sample of all female operators. They were recruited as sample by their supervisors on availability basis during the selection day (convenience sampling). To reduce bias selection, the researcher told the supervisor that there were no special criteria for selecting subjects. The supervisor was free to choose potential participants. Second, because of high production rate, the management only agreed to provide maximum 40 participants. Third, in the interest of maximizing effectiveness, simplicity, and trust, it was the researcher's intention to conduct the training and assessment sessions herself as well as there was only single assessor who had knowledge in this area. This might lead the attitude of the participants toward the researcher could bias the results of the training. This is known as the 'Hawthorne effect' (Rothlisberger and Dickson, 1939) or 'Searchlight effect' (Shackel, 1999) where participants think that they are being personally evaluated. Consequently, they will find any way, however unexpected or unintended, to give their best performance. To minimize this effect, this study hence utilized a control group who also attended five sessions without learning biofeedback technique. The control group showed cognitive performance improvement as well although it is not statistically significant. However, this weakness should be more corrected in future studies by assigned a biofeedback instructor who is not involved in the design or assessment of participants in the study.

In summary, despite the limitations of this study, resonant biofeedback training demonstrates promise for the new training approach for enhancing cognitive functions in industrial operators. Our data suggest that subjects learned successfully to shift their HRV toward LF range as well as regulate their respiration rate in a relatively short time period. Similar to these findings, previous researches indicated that maximal control over HRV at the resonant frequency can be obtained in most people after approximately four sessions of training (Lehrer et al., 2003; Karavidas et al., 2007, and Lehrer, 2007).

5.10. RECOMMENDATION FOR FUTURE RESEARCH

Further research of this promising intervention is warranted in larger and heterogeneous sample and workplace settings either in manufacturing or other industries (e.g. automotive manufacturing operators, control room operators, air traffic controller). Moreover, in biofeedback researches, it is not appropriate to apply double, even single blind method (Shellenberger and Green, 1986). Double blind implies that biofeedback training does not involve learning, that biofeedback has a special power independent of the user and provider, as do drugs. This implication and the research that followed from it have hindered the development of biofeedback training and incorrectly underestimated its potential. However there are still many ways to deal with lack of methodology from this research. Further study may assign different experimenters who act as a trainer or as a test assessor. To separate placebo effect from “real” training effects, in addition to no-treatment control group, a placebo control group can be included (Gravetter and Forzano, 2009). Teaching skill such as visual relaxation or imagery, or providing false feedback might be incorporated as a placebo intervention.

With respect to experimental procedure, to obtain more reliable and complete HRV data, physiological stress profile should be administered over ten minutes with each period of measurement taking a minimum five minutes recording. Longer time recording also allows analyzing the relationship between changes in physiological, psychological and cognitive performance. It is also recommended to record autonomic parameters under resting conditions and during execution of the cognitive task. One may assume that features of autonomic control assessed during cognitive processing show the closest link to performance (Duschek et al., 2009). As a result, relationship between changes in physiological and cognitive performance can be explored further. Furthermore, it is also important to examine the effects of HRV biofeedback between sessions not only in physiological measures but also in cognitive and psychological parameters. Following a study by Lehrer et al. (2003), it may be necessary to evaluate all these parameters at minimum three sessions. As this study was relatively short follow-up period, more attention should be given to conducting long term follow-up (e.g. three months from the end of training). Finally, underlying mechanism on the role of autonomic nervous system regulation in improving performance still needs further investigation.

5.11. CONCLUSION

The present study is among the first to examine the effects of HRV biofeedback training on cognitive performance and self-perceived depression, anxiety and stress in female electronic manufacturing industry operators. HRV biofeedback is designed specifically to reduce autonomic reactivity and attempts to regulate homeostatic mechanisms (Lehrer et al., 1997, and Lehrer et al., 2003). This study used resonant breathing strategy which is aimed to teach the subjects breathe correctly following their resonant frequency. During resonance breathing, real time heart rate and respiration form a perfect phase relationship such that subjects inhale until their heart rate peaks and exhale as it falls, until it begins to rise again (Vaschillo et al., 2004). When this occurs, the baroreceptors are stimulated, strengthening the overall capacity of the body's homeostatic function (Lehrer and Vaschillo, 2003; Gevirtz and Lehrer, 2003, and Lehrer, 2007). In turn, this should restore autonomic balance and improve autonomic control that supports emotional regulation and brain processing (Lehrer et al., 2003, and Lagos et al., 2008)

Result showed that improved autonomic nervous system or homeostatic regulation was noted in the training group after attending five sessions of HRV (i.e. resonant frequency) biofeedback training. It was reflected by a shift into percentage of LF spectral power and increase time-domain measure SDNN, along with slower breathing rate. The control group who were instructed to sit and relax did not display any significant improvement on physiological measures across five sessions.

Moreover, the quantitative results did support most of the hypotheses. The biofeedback training group showed significant improvement in percentage of LF activity and breathing rate, as compared to a control group from pre to post across three conditions (baseline, stressor, recovery). From pre to post intervention, as opposed to the control group, the biofeedback participants also displayed significant improvement in attention, memory, and cognitive flexibility. The effect size confirmed that the magnitude of the training was large. The biofeedback participants also reported significant reduction in self perceived depression, anxiety, and stress (DASS). Although not all of correlations between changes in cognitive performance and emotional symptoms (DASS) were significantly found, the parallel findings of both could not be overlooked. It indicated that HRV biofeedback training indeed show potential to be applied as operator's performance enhancement strategy in workplace.

For work implication issue, HRV biofeedback intervention yielded significant finding which is comparable to those evidenced in studies of numerous individual-focus stress management programs. To produce better observable outcomes, HRV biofeedback might be combined with any other intervention either individual or organizational-based. Future studies are warranted in larger and heterogeneous sample and other industries as well as to further clarify the interrelationship among autonomic functioning, cognitive performance, and emotional symptom. To conclude, HRV biofeedback as a performance enhancement tool offers immense opportunities for training operators to correct their arousal levels and not only to improve their cognitive performance but also to achieve profound well-being.

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APPENDIX A

APPROVAL LETTER TO COLLECT DATA FROM BI TECHNOLOGY

TT electronics

BI Technologies Corporation Sdn. Bhd. (21949-T)
A-1445, Jalan Tanjung Api, 25050 Kuantan
Pahang Darul Makmur, Malaysia
Telephone: +60 9 514 5522
Facsimile: +60 9 514 3555
Website: www.bitechnologies.com

No Rujukan Kami:: BI/HRD/PHD STUDENT/001/09
No. Rujukan Tuan: UMP/17.01/13.16.01(01)

Tarikh: 13hb Mei 2009.

Kepada:
Prof. Dr.Ahmad bin Othman
Dekan
Fakulti Kejuruteraan Pembuatan dan Pengurusan Teknologi,
Universiti Malaysia Pahang,
Karung Berkunci 12,
25000 Kuantan,
Pahang Darul Makmur.

Tuan,

Per **PENGESAHAN PELAJAR Ph D**

Merujuk Surat tuan UMP/17.01/13.16.01(01) bertarikh 14 hb April 2009 mengenai perkara diatas dan seterusnya ingin memaklumkan kapada tuan bahawa pihak pengurusan telah bersetuju untuk mengambil pelajar tuan Encik Auditya Purwandini Sutarto Nombor Pelajar 07002 untuk menjalankan kajian sebagaimana yang dinyatakan didalam surat tuan.

Harap pelajar tersebut dapat menghubungi kami dengan memberi jadual penyelidikan tersebut.

Sekian,terima kasih.

UMP

Yang benar,
Untuk dan Bagi Pihak
BI TECHNOLOGIES CORPORATION SDN.BHD

KOO PENG HON
Pengarah Kewangan

BI technologies
A subsidiary of TT electronics plc

APPENDIX B
INFORMED CONSENT

LATIHAN BIOFEEDBACK DAN PRESTASI KERJA

Auditya Purwandini Sutarto
Universiti Malaysia Pahang

MAKLUMAT PERSETUJUAN

Pengenalan
Anda diundang untuk turut serta dalam kajian penyelidikan untuk menilai hubungan pembelajaran pengawalan-diri, pernafasan, dan prestasi kerja anda. Pengawalan-diri ini akan dibuat menggunakan Heart Rate Variability (HRV) ataupun variasi kadar degupan jantung dan latihan tindakbalas biologi (biofeedback)

Adalah sangat penting bagi anda untuk membaca dan memahami beberapa prinsip asa yang digunakan kepada semua yang mengambil bahagian dalam kajian ini: (a) kajian ini terbuka secara sukarela; (b) Sebarang manfaat secara peribadi tidak dijami walaupun kebanyakan orang telah mendapat manfaat daripada kajian sebelum ini; (c) sebarang penemuan penting yang berkati dengan pembelajaran anda akan dibincangkan bersama; (d) Anda dibenarkan menarik diri daripada kajian ini pada bila-bila masa dengan apa jua alasan tanpa sebarang akibat.
Kajian semulajadi, risiko, kesulitan, ketidakselesaan, dan mana-mana maklumat yang bersangkut-paut tentang kajian ini dibincangkan dibawah. Kami meminta anda untuk membaca dokumen ini dan bertanya sebarang persoalan yang ada sebelum mempersetujui untuk turut serta dalam kajian ini. Sila bertanya kepada Pn. Auditya selaku ketua kepada projek penyelidikan ini untuk menjelaskan sebarang makumat yang tidak difahami. Kajian ini sedang dijalankan oleh Universiti Malaysia Pahang.

Latarbelakang Maklumat
Tujuan kajian ini adalah untuk mengesan keberkesanan latihan HRV biofeedback dalam memperbaiki prestasi kerja. Kajian ini diharapkan dapat ditambah kedalam penyelidikan yang sedia ada tentang penerapan biofeedback bagi subjek yang sihat

Tatacara Prosedur
Anda akan menjadi salah seorang daripada 10 hingga 20 orang jumlah peserta dalam kajina ini yang akan menjalani empat hingga enam sesi latihan dalam tempoh enam minggu. Setiap sesi berlangsung selama 30 – 45 minit. Anda akan diminta untuk bernafas menggunakan alat biofeedback. Sebelum sesi latihan pertama bermula, anda akan menjalani satu set pra-ujian. Selepas semua sesi latihan selesai, anda akan

mempersembahkan satu set pasca-ujian untuk menilaia samaada sebarang kesan yang ketara terhadap prestasi anda.

Risiko dan Manfaat dalam Kajian ini

Kajian ini mempunyai beberapa risiko. Pertama, dalam jangka masa pendek, kajian akan ditambah lebih banyak tekanan dalam jadual anda pada waktu sesi latihan dijalankan, anda akan diminta untuk berjumpa dengan penyelidik sekali dalam seminggu untuk sesi biofeedback selama 30 -45 minit. Kedua, anda akan merasai sedikit kekecewaan dan kebimbangan kerana tubuh badan anda diubah kepada pengawalan-sendiri. Latihan tubuh badan anda untuk tabiat pernafasan adalah sama dengan mempelajari sukan atau teknik baru. Ia akan dipraktikkan diluar sesi pembelajaran seperti yang dicadangkan di dalam modul.

Manfaat kajian ialah tabiat tindakbalas autonomik maksima menerusi pernafasan pada frekuensi tertentu. Anda boleh mengawal tindakbalas tubuh banda anda kepada factor harian dan keputusannya, ia akan meningkatkan prestasi kerja anda.

Sulit

Segala maklumat yang didapati dari kajian ini akan kekal sulit, sehingga dibenarkan oleh pihak mahkamah. Segala yang diperkatakan dan data yang dikumpul daripada setiap peserta akan kekal sulit dan akan digunakan hanya sebagai kod subjek pada diertasi atau mana-mana penerbitan penyelidikan.

Sukarela kepada Kajian ini

Penyertaaan anda adalah secara sukarela. Anda berhak untuk tidak terus menyertai kajian ini pada bila-bila masa. Tiada keputusan yang negatif kepada anda untuk menyertai atau tidak. Sila bertanya sekiranya anda mempunyai soalan ini. Anda akan diberikan salinan borang ini untuk rujukan.

Kenyataan Setuju

Tandatangan saya dibawah ini menunjukkan bahawa saya telah membaca semua maklumat diatas dan berpeluang untuk menanyakan soalah bagi membantu saya memahami segala yang membabitkan penyertaan saya. Saya bersetuju untuk menyertai kajian ini

Tanda tangan ____ Date ____________

Tanda tangan penyelidik _____________________________________ Date ____________

APPENDIX C

NIJMEGEN QUESTIONNAIRE

Mindful Physiology Institute

Breathing Checklist and Capnography Report

Nijmegen and Breathing Symptom List

Name________________________ Date________________

Sex________ Age________ Approx Ht and Wt__________ Medication________________

Main Patient/client expectations ________________________

A number of complaints are listed below that may possibly apply to you. For each symptom, please place a checkmark in the column that best describes how often it occurs.

	Never	Rarely *Less than 1 a wk*	Sometimes *2 or 3 times a wk*	Often *Daily*	Very often *Several times / day*	Situations
1. Sharp pain in chest						
2. Tension						
3. Blurred, hazy vision						
4. Dizziness						
5. Confusion or a sense of losing normal contact with surroundings						
6. More rapid or deep breathing						
7. Shortness of breath, difficulty breathing						
8. Tightness in Chest						
9. Bloated abdomen						
10. Tingling of fingers						
11. Unable to breathe deeply						
12. Stiffness of fingers and arms						
13. Tightness around the mouth						
14. Cold hands or feet						
15. Heart palpitations, (fast irregular heartbeat)						
16. Feelings of anxiety						
Score						[Total ____]
17. Breath holding						
18. Poor concentration and focus						
19. Fatigue easily						
20. Sighing or gasping						
21. Mouth breathing						
22. Worried about my breathing						
23. Poor sleep						
23. Frequently reported snoring						
24. Daytime sleepiness						

Situations in which you experience the above symptoms, often or very often.

Please place the corresponding numbers in the ***Situations*** column of the above table

1	At work	8	Physical exercise/exertion	15	Driving
2	Resting (between tasks)	9	Being confronted by others	16	Meeting authority figures
3	Out with partner	10	Travelling, unfamiliar places	17	Feeling anxious/worried
4	Interacting with children	11	Socialising	18	Being put in charge
5	Feeling stressed	12	Speaking in public	19	Learning new tasks
6	Feeling tired	13	Playing a musical instrument	20	Feeling unsure of self
7	Interacting with groups	14	Expressing feelings	21	Performing difficult tasks

For Trainer only: Attach profile graphical and numerical data. Observations and readings at end of baseline measurement were as follows:

Resting ETCO2 ______ Avg. Breaths/min ______ Time measured ______ Breath hold time________

Observations:____

APPENDIX D

APPROVAL LETTER TO CONDUCT RESEARCH

الجامعة الاسلامية العالمية ماليزيا

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

يونيۏرسيتي اسلام انتارابغسا مليسيا

(Company No. 101067-P)

KULLIYYAH OF MEDICINE

Our Ref. : IIUM/305/20/4/10( )
Date : 30th July 2009

Asst. Prof. Dr. Nora Mat Zin
Department of Psychiatry
Kulliyyah of Medicine
International Islamic University Malaysia

Dear Dr. Nora, السلام عليكم ورحمة الله وبركاته

BIOFEEDBACK TRAINING AND COGNITIVE PERFORMANCE

I would like to refer you to the matter stated above.

Your research proposal entitled "*Biofeedback Training and Cognitive Performance*" was discussed in the Kulliyyah Ethics Committee Meeting No 2/2009 on 8th July 2009. The Committee has approved your research and kindly proceed accordingly.

Thank you and والسلام

UMP

Yours sincerely,

PROF. DR. NASSER MUHAMMAD AMJAD
Deputy Dean
Research and Postgraduate Affairs

cc Dean, Kulliyyah of Medicine

IIUM Kuantan Campus, Jalan Istana, Bandar Indera Mahkota 25200 Kuantan, Pahang Darul Makmur, MALAYSIA
Tel : 09-5716400 Fax : 09-5716770

APPENDIX E

D2 ATTENTION TEST

Front Page

Name: ____________________

Age: ________ Sex: ☐ male ☐ female

Handedness: ☐ L ☐ R

Years of education: ____________________

Occupation: ____________________

d2 Test of Attention

Rolf Brickenkamp & Eric A. Zillmer

Examiner: ____________________ Date: ____________

Example: d d d

Practice line:

d	p	d	d	d	d	p	d	d	p	d	d	d	d	p	p	d	d	d	p	d	d
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

	Raw Score	Percentage	Percentile Rank	Standard Score
TN (total number)				
Omissions: E1				
Commissions: E2				
E (errors)				
TN-E (total-errors)				
CP(concentration performance)				
FR (fluctuation rate)				

S-Syndrome: ☐

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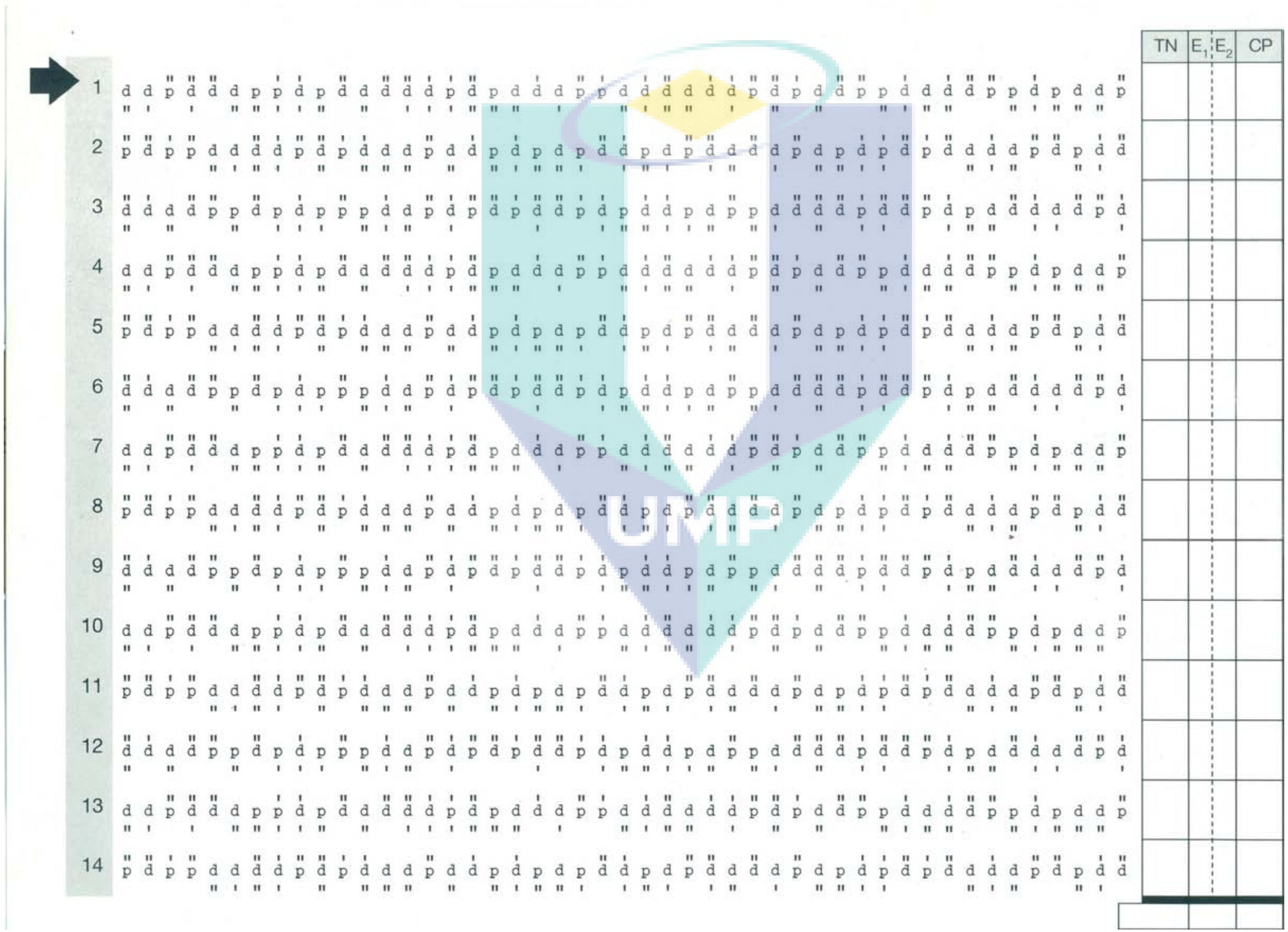
Order number #01 013 22

UMP

Back Page



APPENDIX F

DEPRESSION, ANXIETY, STRESS SCALE (DASS)

DASS

Nama: *Tarikh:*

Sila baca setiap kenyataan di bawah dan bulatkan pada nombor 0,1,2 atau 3 bagi menggambarkan keadaan anda sepanjang minggu yang lalu. Tiada jawapan yang betul atau salah. Jangan mengambil masa yang terlalu lama untuk menjawab mana-mana kenyataan.

Skala pemarkahan adalah seperti berikut:

0 **Tidak langsung** menggambarkan keadaan saya
1 **Sedikit atau jarang-jarang** menggambarkan keadaan saya.
2 **Banyak atau kerapkali** menggambarkan keadaan saya.
3 **Sangat banyak atau sangat kerap** menggambarkan keadaan saya

1	Saya dapati diri saya menjadi kesal/marah disebabkan perkara-perkara yang kecil.	0	1	2	3
2	Saya sedar mulut saya terasa kering	0	1	2	3
3	Saya tidak dapat mengalami perasaan positif sama sekali	0	1	2	3
4	Saya mengalami kesukaran bernafas (contohnya pernafasan yang laju, tercungap-cungap walaupun tidak melakukan senaman fizikal)	0	1	2	3
5	Saya rasa diri saya tidak bergerak ke mana-mana	0	1	2	3
6	Saya cenderung untuk bertindak keterlaluan dalam sesuatu keadaan	0	1	2	3
7	Saya mempunyai perasaan gementar (seperti kaki menjadi lemah)	0	1	2	3
8	Saya rasa sukar untuk relaks	0	1	2	3
9	Saya dapati diri saya di dalam keadaan yang menjadikan saya amat risau dan menjadi tenang semula selepas ianya berakhir	0	1	2	3
10	Saya rasa saya tidak mempunyai apa-apa untuk diharapkan	0	1	2	3
11	Saya dapati diri saya mudah merasa kesal	0	1	2	3
12	Saya rasa saya menggunakan banyak tenaga dalam keadaan cemas	0	1	2	3
13	Saya rasa sedih dan murung	0	1	2	3
14	Saya dapati diri saya hilang kesabaran sekiranya saya dilambatkan oleh sesuatu (seperti lif, lampu trafik, terpaksa lama menunggu)	0	1	2	3
15	Saya rasa macam nak pengsan	0	1	2	3
16	Saya rasa saya hilang minat dalam segala hal	0	1	2	3
17	Saya tidak begitu berharga sebagai seorang individu	0	1	2	3
18	Saya rasa yang saya mudah tersentuh	0	1	2	3
19	Saya banyak berpeluh (contohnya pada tangan) walaupun bukan pada suhu tinggi atau tiada pergerakan fizikal.	0	1	2	3
20	Saya berasa takut tanpa sebab yang munasabah	0	1	2	3
21	Saya rasa hidup ini sudah tidak bermakna lagi	0	1	2	3

Translation by Dr Ramli Musa

Sila lihat muka surat sebelah ☞

Ingatan skala permarkahan:

0 **Tidak langsung** menggambarkan keadaan saya
1 **Sedikit atau jarang-jarang** menggambarkan keadaan saya.
2 **Banyak atau kerapkali** menggambarkan keadaan saya.
3 **Sangat banyak atau sangat kerap** menggambarkan keadaan saya

22	Saya dapati diri saya sukar ditenteramkan	0	1	2	3
23	Saya rasa sukar menelan	0	1	2	3
24	Saya tidak dapat merasakan keseronokan dalam apa yang saya lakukan	0	1	2	3
25	Saya sedar tindakbalas jantung saya walaupun tidak melakukan aktiviti fizikal (contohnya kadar denyutan jantung bertambah, atau denyutan jantung berkurangan)	0	1	2	3
26	Saya rasa duka dan tidak keruan	0	1	2	3
27	Saya dapati diri saya mudah marah	0	1	2	3
28	Saya rasa hampir-hampir menjadi panik/cemas	0	1	2	3
29	Saya dapati sukar untuk bertenang setelah sesuatu membuatkan saya kesal	0	1	2	3
30	Saya risau saya akan 'dihambat' oleh tugas yang remeh dan tidak biasa dilakukan	0	1	2	3
31	Saya tidak bersemangat dengan apa jua yang saya lakukan	0	1	2	3
32	Saya sukar bersabar pada gangguan terhadap perkara yang sedang saya lakukan	0	1	2	3
33	Saya di dalam keadaan yang terlalu gementar	0	1	2	3
34	Saya rasa diri saya langsung tidak berharga	0	1	2	3
35	Saya hilang pertimbangan pada perkara yang menghalang saya meneruskan apa yang saya lakukan	0	1	2	3
36	Saya rasa amat takut	0	1	2	3
37	Saya melihat tiada masa depan untuk saya menaruh harapan	0	1	2	3
38	Saya rasa hidup ini tidak bermakna	0	1	2	3
39	Saya dapati diri saya semakin gelisah	0	1	2	3
40	Saya bimbang keadaan di mana saya mungkin menjadi panik dan melakukan perkara yang membodohkan diri sendiri	0	1	2	3
41	Saya rasa menggeletar (contohnya pada tangan)	0	1	2	3
42	Saya sukar untuk mendapatkan semangat bagi melakukan sesuatu perkara	0	1	2	3

UMP

DEPRESSION, ANXIETY, STRESS SCALE (DASS)
(ENGLISH VERSION)

DASS

Name: *Date:*

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

1	I found myself getting upset by quite trivial things	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I just couldn't seem to get going	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I had a feeling of shakiness (eg, legs going to give way)	0	1	2	3
8	I found it difficult to relax	0	1	2	3
9	I found myself in situations that made me so anxious I was most relieved when they ended	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting upset rather easily	0	1	2	3
12	I felt that I was using a lot of nervous energy	0	1	2	3
13	I felt sad and depressed	0	1	2	3
14	I found myself getting impatient when I was delayed in any way (eg, lifts, traffic lights, being kept waiting)	0	1	2	3
15	I had a feeling of faintness	0	1	2	3
16	I felt that I had lost interest in just about everything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I perspired noticeably (eg, hands sweaty) in the absence of high temperatures or physical exertion	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life wasn't worthwhile	0	1	2	3

Please turn the page

Reminder of rating scale:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

22	I found it hard to wind down	0	1	2	3
23	I had difficulty in swallowing	0	1	2	3
24	I couldn't seem to get any enjoyment out of the things I did	0	1	2	3
25	I was aware of the action of my heart in the absence of physical exertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3
26	I felt down-hearted and blue	0	1	2	3
27	I found that I was very irritable	0	1	2	3
28	I felt I was close to panic	0	1	2	3
29	I found it hard to calm down after something upset me	0	1	2	3
30	I feared that I would be "thrown" by some trivial but unfamiliar task	0	1	2	3
31	I was unable to become enthusiastic about anything	0	1	2	3
32	I found it difficult to tolerate interruptions to what I was doing	0	1	2	3
33	I was in a state of nervous tension	0	1	2	3
34	I felt I was pretty worthless	0	1	2	3
35	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
36	I felt terrified	0	1	2	3
37	I could see nothing in the future to be hopeful about	0	1	2	3
38	I felt that life was meaningless	0	1	2	3
39	I found myself getting agitated	0	1	2	3
40	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
41	I experienced trembling (eg, in the hands)	0	1	2	3
42	I found it difficult to work up the initiative to do things	0	1	2	3

APPENDIX G
DEMOGRAPHIC FORM

Nama: ____ Tarikh: ______________

1. Umur _______tahun
2. Lama Belajar (Sekolah) ______________ tahun
3. Pekerjaan ______________________________

   Department _________________________
4. Lama Bekerja _____________ tahun
5. Pernahkah Anda mengikuti sebarang kursus pengawalan stress?

   ____
6. Jika pernah, berapa lama kursus tersebut mengambil masa?

   ____
7. Apakah saat ini Anda atau dalam masa 6 bulan ini sedang dalam rawatan dokter atas suatu penyakit atau masalah psikologi (misalnya kejiwaan)?

   ____
8. Jika ada, sila jelaskan

   ____

UMP

APPENDIX H
HRV Biofeedback Module

1. INTRODUCTION

1.1 What is HRV-Biofeedback?

Biofeedback is a form of self-regulation in which individuals learn to control certain internal bodily processes that normally occur involuntarily, such as heart rate blood pressure, muscle tension, and skin temperature. These activities can be measured with electrodes and displayed on a monitor that both the participant and his or her instructor can see. The monitor provides feedback to the participant about the internal workings of his or her body. This person can then be taught to use this information to gain control over these "involuntary" activities. Over the past 50 years, researchers have used biofeedback to do everything from helping people relax to treating severe headaches, chronic pain, and high blood pressure. Currently, biofeedback has been applied in wider area, not only for medication but also the enhancement of sport and work performance.

One of the promising of biofeedback is Heart Rate Variability (HRV)-biofeedback. Heart rate variability (HRV) itself is defined as a measure of the oscillation of the interval between consecutive heartbeats.

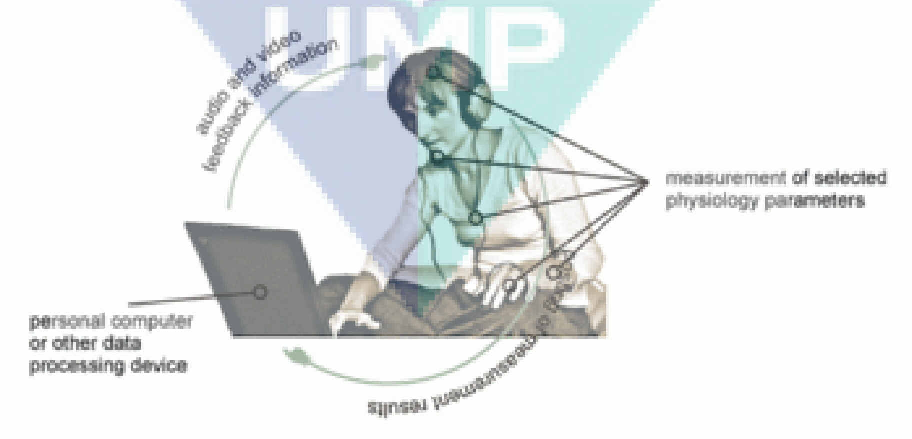


Figure 1. The Biofeedback Method

HRV is influenced by both of the excitatory sympathetic and the inhibitory parasympathetic branches of the ANS. These two branches which often opposed interact are responsible for modulating individuals' physiological arousal and their capacity to meet the demands of both mental and physical stress. HRV has relevance for physical, emotional, and mental function. Research has shown that higher HRV is associated with creativity, psychological flexibility, and a more developed capacity to adjust cognitive, affective, and physiological responses to stress. On the contrary, low HRV is linked to anxiety disorders, depression, and cardiovascular disease.

By means of HRV-biofeedback, people are trained to change the variability and dominant rhythm in their heart activity. HRV-biofeedback has been successfully applied in a wide range of applications, not only in clinical setting but also educational, sport, and work community.

1.2 What are the benefits of applying the technique for University Students?

Many findings have been reported on successful of application HRV-biofeedback in a variety of areas include in education setting such as on reducing test-anxiety, enhancing math test-score, and improving overall well-being. You can gain the same benefits by employing the technique as your new habit in your daily lives to improve their academic performance.

Whatever your daily activities, the successful performance on the academic and in personal life requires many cognitive skills. These include memory, attention and concentration, planning, problem solving, cognitive flexibility, language, perception, and others. For instance, reading a text book activates all cognitive areas with emphasizes much on attention and memory. However, most people operate below their peak cognitive capacity level. These skills can be improved through HRV-biofeedback training encompasses specific breathing technique, visualization, and biofeedback training.

If you do the technique following the guide means you are in the right path, then you'll master the skills and not only your cognitive functions be improved but also your emotional well-being overall. The skill will be preserved as long as you keep practicing it everyday as it becomes your new health habit.

2. Resonant Breathing Technique

Breathing is a fundamental behavioural manifestation of our psychological and physiological state, from the breath that marks the beginning of life to the breath that marks the end. When we experience different emotions such as frustration versus appreciation, we will produce different breathing pattern as shown in this figure.

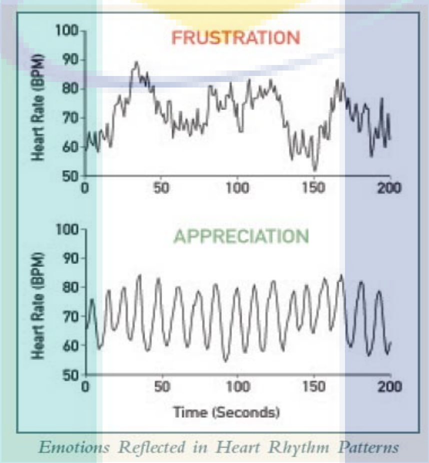


Figure 2. Emotions Reflected in Heart Rhythm Patterns

Breathing at slow and specific frequency will generate resonance between respiratory sinus arrhythmia (RSA) and oscillations. From the following figures, you may see the difference amplitude of HRV and coherence yielded by breathing at low and high frequency per minute.

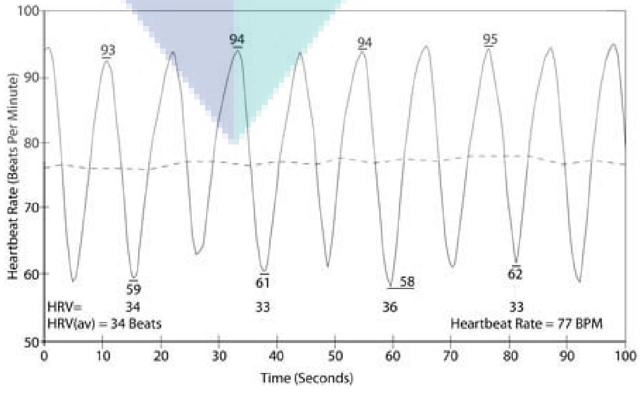


Figure 3. High HRV, High Coherence (actual measurement) produced when breathing at low frequency

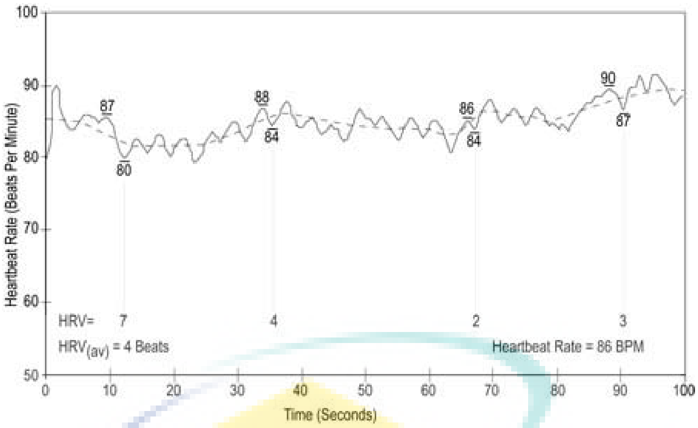


Figure 3. Low HRV, Modest Coherence (actual measurement) produced when breathing at high frequency

2.1 What is Resonant Breathing technique?

In this training, a HRV coherence-building method, called a resonant frequency technique is developed to enhance your cognitive functions i.e. attention/vigilance, memory, and decision-making. Normally, people breathe at a rate of 12-20 breaths per minute whereas the greatest HRV is produced by relaxed breathing at around six breaths per minute. Breathing at rates within the low frequency range, centering at approximately 0.1 Hz will increase your RSA (respiratory sinus arrhythmia).

What is RSA?

Your heart rate tends to go up when you breathe in and to go down when you breathe out. These changes in heart rate are called "respiratory sinus arrhythmia," or RSA. RSA triggers very powerful reflexes in the body that help it to control the whole autonomic nervous system (including your heart rate, blood pressure, and breathing). We will train you to increase the size of these heart rate changes to exercise these important reflexes. Moreover, reliably high amplitudes of RSA can be generated by breathing at six oscillation/min; a task that most people can perform with little training.

As part of this training we will provide you information about the swings in heart rate that accompany breathing. If you practice the technique regularly at home, you will strengthen the reflexes that regulate the autonomic nervous system. This should help improve your cognitive skills and ability to manage everyday stress. There is evidence that training these reflexes will help you to cope with inhibiting factors of cognitive functions, anxiety attack, and other emotional problems. To perform the method, you might use diaphragmatic breathing technique combined with visual relaxation.

2.1.1 Diaphragmatic Breathing

Your diaphragm is a sheet-like muscle that separates your stomach (abdomen) and your chest. Your diaphragm works to help you breathe in and out. When you inhale, the diaphragm lowers, your stomach pushes out, and your chest cavity swells. This gives the lungs more space to expand into and increases the amount of air that you can inhale. Diaphragmatic breathing is intended to help you use the diaphragm correctly while breathing to:

- Strengthen the diaphragm
- Decrease the work of breathing by slowing your breathing rate
- Decrease oxygen demand
- Use less effort and energy to breathe

Each breath takes in more oxygen and releases more carbon dioxide. This slower breathing, combined with the rhythmical pumping, helps activate your parasympathetic nervous system (i.e. your relaxation response). Such breathing helps to harmonize your nervous system and reduce the amount of stress in your lives. And this, of course, has a positive impact on your overall health.

One of the things you will learn to do in this method is relaxed breathing. When you are relaxed, your chest and your abdomen relax and you begin to breathe more naturally, so that your abdomen expands when you inhale and contracts (goes back in) when you exhale. The chest should not move

a. Sit or lay in a comfortable position or stand in front of a mirror. Take a relaxed position with loose garments. For first time, it may be easier do this exercise when you are lying down. With practice, you should be able to do abdominal breathing in all positions. Imagine almost that you are breathing through your feet, so that the work of breathing never even gets close to your chest. If you have never done diaphragmatic breathing before, pretend you are yawning. Just go ahead and yawn, your diaphragm naturally expands and contracts. Put your hand on your belly a few times to get used to it. Once you have gotten used to this, you won't have to pretend you are yawning, but you will actually do it quite naturally.

b. Put one hand on the chest and one on the stomach. It is often helpful of you put a small book on your stomach, and try to breathe so that the book rises as you inhale and falls as you exhale.
c. Slowly inhale through the nose.
d. As inhalation occurs, feel the stomach moving inwards with the hand. If the chest expands, focus on breathing with the diaphragm. As you inhale smoothly, your lower hand should move up and down while your upper hand doesn't move much at all.
e. Slowly exhale through pursed lips to regulate the release of air so the abdomen will fall inwards again.
f. Remember to exhale longer than inhale. Breathe smoothly, allowing no jerkiness or irregularities to disturb the steady flow. Do not try too hard. It will improve with time.
g. Practice diaphragmatic breathing at home for about 20-40 minutes each day. Do it at the same time as you are practicing other techniques and resonant frequency breathing (described later).

2.1.2 Visual Relaxation

This relaxation technique involves refocusing your attention to something calming and increasing awareness of your body. Research on the visual relaxation has provided the evidence that this simple technique can increase energy, decrease fatigue as well as increase arousal from a sleepy (drowsy) state. It can increase motivation, productivity, and improve decision-making ability. Here are the steps you may follow

- Start the exercise by sitting or lying in a comfortable position and deep diaphragmatic breathing.
- You will decide where you want to go in your image before starting. Some people like to have several destinations in mind since, at first, it may be difficult to stay interested in any one image for very long.
- You can leave your eyes open or you can shut them. Most people prefer to close their eyes when creating a mental image.

- Imagine a scene in which you feel at peace and restful. For example it could be a beach, a mountain retreat, a hiking trail, your own back yard, a fishing pond, or wherever else appeals to your personal sense of beauty.
- In creating your image, **picture all the details with all of your senses-** everything you can see, hear, smell, and feel**.** For example: If your chosen spot is relaxing at the ocean, try to imagine:
  - ✓ Vision: the warmth of the sun
  - ✓ Smell: the smell of salt water
  - ✓ Sounds: the sound crashing waves,
  - ✓ Feel: the feel of the grains of sand
- Attempt to feel this emotion in your body as you continue to breathe deeply through your diaphragm.

2.1.3 Resonant Breathing

After practicing the combination of and visual relaxation regularly for a week, now you will learn to merge it with the resonant breathing technique. You are trained to breathe at 6 cycles per minute so you will produce a spike of heart rate variability at around 0.1 Hz in which the greatest amplitude of heart rate oscillation occurs. Each breath should be around 10 seconds and remember to do longer exhalation than inhalation. You should use the second-hand of a watch to time the breathing cycle.

As any other skills, you can expect to get significant result by practicing all the techniques described above simultaneously on a daily basis. You may take 3-4 times per day each 10 minutes and are encouraged to do natural breathing as your normal breathing. Make all the skills as your new health habit. These will promote entrainment of physiological systems and help to balance heart rhythms, emotional states, hormonal and autonomic function.

2.2 HRV-Biofeedback Training

A large number of researches has shown that people are capable of voluntarily producing a specific rhythm or other purposed breathing criteria of heart rate and heart rate variability using biofeedback techniques. Thus HRV-biofeedback training may be considered a more effective technique rather than verbal instruction in the control of heart rate variability.

2.2.1 What is HRV-Biofeedback Training?

HRV-biofeedback training works by teaching people to recognize their involuntary heart rate variability and to control patterns of this physiological response. In healthy subjects, HRV-biofeedback training have been conducted to enhance cognitive performance in education, music, and sport settings, as well as to cope with work and daily stress. Thus, through this module you will learn to perform HRV–biofeedback training that can be used in improving your cognitive performance, particularly your cognitive ability on attention, discrimination, quick and accurate reaction, and memory. The general scheme of HRV-biofeedback training works is provided in figure 4.

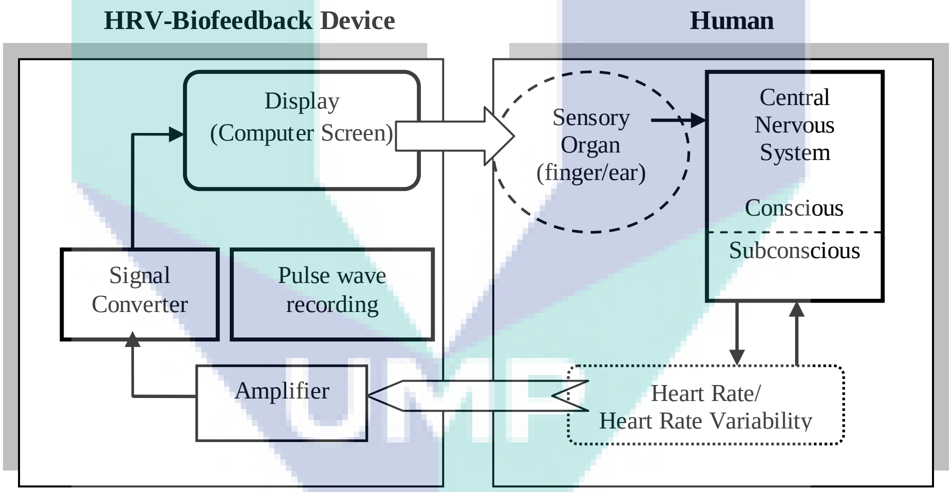


Figure 4. The Scheme of HRV-Biofeedback Training

You will get the feedback visually by playing biofeedback games. A pulse detector device equipped with a sensor will be attached to your index or middle finger to measure your heart rhythm. The signals received will be transformed to information displayed on the computer screen. From the information you become aware of the results of your effort to control your physiological state. Your success at winning the games will depend on your ability to use this biofeedback to control your heart rate variability. As described above, the training criterion is to breathe at 6 cycles per minute. Breathing at this frequency will reinforce the reflexes that control the autonomic nervous system and help you to tackle inhibiting factors of cognitive functions, anxiety attack, and other emotional problems. After completing each session of HRV-biofeedback training, you will feel more energized and are ready to perform your activities much better.

2.2.2 What device/tool is used in this training?

The device used in this training is Biofeedback Computer Games-based training which is developed and designed by the Institute for Molecular Biology and Biophysics (Russian Academy of Medical Sciences, Siberian Branch), to train people to be in control of their own physiological indices. With the help of this device, people get reliable information about the progress of mastering the technique.

Training with the help of Biofeedback Games is directed to the evaluating of your progress to breathe at specific frequency. Thus, you are advised to come to laboratory to follow laboratory training. The instructor will assist you to correct your breathing learning and play the Biofeedback games. You also can ask her/him if you find any problems regarding the technique. To evaluate whether any improvement after mastering breathing skill on particular cognitive areas, you will perform several types of cognitive test before and after (pre and post) biofeedback training. **This is not an intelligent test**, so you are no need to prepare for the test.

While learning this technique, **keep in mind one general rule**: use the strategies described in this module attentively and consciously and you will find great fun and benefits from these games. More importantly, you will achieve a resonance between RSA and oscillation that can and will help you to relax and simultaneously empower yourself with ability to enhance your cognitive performance so as to reach your potential academically. Before conducting either home or laboratory training, please assure both of your emotion and physical fitness are well satisfied.

2.3 How long is required to carry out the training?

The training consists of both laboratory-based and home training which all sessions will take 4 weeks. On laboratory-based training, you will use biofeedback instrument to evaluate your training progress). The laboratory HRV-biofeedback training will take less than 8 hours during three weeks, while each session of laboratory training only takes 30 minutes. Your attendance at each laboratory training session will be recorded by the instructor. Here are the schedules you should follow so you are able to improve your cognitive performance.

Technique	**Home Training**	**Laboratory-based Training**
• Diaphragmatic breathing • Visual Relaxation	4 times/day each 5-10 minutes for 1 week	2 times/week for 1 week, total twice
Resonant breathing (breathing at specific frequency with combination of two techniques above)	4 times/day each 5-10 minutes for 3 weeks	2 times/week for 3 week, total 6 times

Laboratory Training

No	**Session**		**Activity**
1	Week 1	1	Introduction
2		2	a) Pre-Cognitive Performance Test b) First session of HRV-biofeedback training
3		3	Laboratory HRV-Biofeedback training
4	Week 2	1	Laboratory HRV-Biofeedback training
5		2	Laboratory HRV-Biofeedback training
7	Week 3	1	Laboratory HRV-Biofeedback training
8		2	Laboratory HRV-Biofeedback training
9	Week 4	1	Laboratory HRV-Biofeedback training
10		2	Post-Cognitive Performance Test

You will be provided with individual diaries in which to record the time and the duration of resonant breathing activities undertaken in daily session outside the laboratory-based training.

In addition to the schedule above, you are encouraged to practice these exercises almost anywhere, in any situation, such as when you are

• waiting in line or stuck in traffic

• bothered by something someone has said

• overwhelmed by what you need to accomplish

• in pain

Remember that all the techniques are skills. And as with any skill, **your ability to master improves with practice**. Be patient with yourself! Do not get angry or stressed out with yourself; just give it time. Then enjoy the outcome!

2.4 What the benefits of the training?

As you master on this breathing skill, you will modulate your maximal autonomic responses which lead to the improvement of your physically respond by:

- Slowing your heart rate
- Lowering blood pressure
- Slowing your breathing rate
- Reducing the need for oxygen

Furthermore, you may also gain the following benefits:

1. Improved concentration
2. Reduced test anxiety
3. Fewer emotional responses
4. Greater ability to handle problems
5. More efficiency in daily activities
6. Improved your overall health

Simple Version Module used for Operators

BERLATIH DI RUMAH

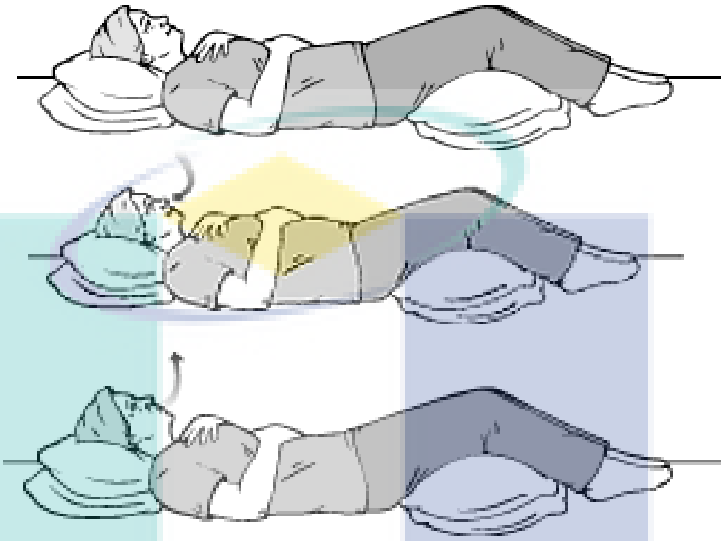
Pernafasan merupakan perkara paling asas kepada keadaan psikologi dan fisiologi diri. Pernafasan menandakan bermulanya kehidupan dan juga menandakan pengakhiran sebuah kehidupan bilamana ia terhenti. Tambahan pula, kaedah pernafasan juga mempengaruhi fisiologi dan psikologi diri kita. Dalam latihan ini, anda akan diperkenalkan dengan beberapa teknik pernafasan. Walaubagaimana pun, perkara paling utama yang perlu dititik beratkan adalah pernafasan dalam keadaan tenang. **Bernafaslah dengan tenang dan selesa dan elakkan memaksa diri dalam proses mencuba.**

PERNAFASAN DIAFRAGMA

Salah satu perkara yang anda akan pelajari adalah kaedah pernafasan tenang dan bersahaja. Apabila kita berada dalam keadaan tenang dan bersahaja, dada dan perut turut berada dalam keadaan relaks dan kita akan mula bernafas secara semulajadi membuatkan perut mengembang apabila kita menarik nafas dan mengecut apabila kita menghembus nafas. Keadaan dada adalah tidak berubah.

1. Duduk atau baring pada posisi yang selesa atau berdiri di hadapan cermin dengan berpakaian yang agak longgar. Cuba posisi berbaring atau berdiri dihadapan cermin terlebih dahulu kerana ianya lebih mudah. Kemudian barulah mencuba posisi duduk. Seterusnya anda boleh melakukan pernafasan diafragma atau perut ini dalam mana-mana posisi sekalipun.
2. Letakkan salah satu tangan anda di atas dada, dan salah satu tangan lagi di atas perut. Adalah dinasihatkan supaya anda meletakkan sebuah buku kecil di atas perut anda, dan apabila anda menarik nafas, buku tersebut akan bergerak keatas. Sebaliknya apabila anda menghembuskan nafas, buku tersebut akan bergerak ke bawah.
3. Secara perlahan-lahan, **tarik nafas melalui hidung**. Dalam proses ini, anda akan dapat merasakan perut bergerak ke dalam dan ke atas. Semasa dada anda mengembang, cuba fokus untuk bernafas melalui perut. Apabila anda menarik nafas,

tangan yang berada di bahagian bawah seharusnya bergerak ke atas dan kebawah, manakala tangan yang berada di bahagian atas seharusnya mengalami pergerakan yang sangat sedikit ataupun tiada pergerakan lansung



Gambarajah 1. Bernafas diafragma sembari berbaring. Diafragma/perut anda sepatutnya bergerak semasa bernafas dan keadaan dada tidak berubah

Gambarajah 2. Bernafas diafragma/perut dalam posisi duduk

4. Secara perlahan-lahan, **hembuskan nafas melalui bibir** untuk mengawal udara yang keluar supaya perut berada di posisi asal semula.

Gambarajah 3. Bernafas dengan benar: Tarik nafas melalui hidung, hembus nafas melalui bibir

5. Perlu diingatkan supaya **memperuntukkan masa yang lebih lama semasa menghembus nafas berbanding menyedut nafas.** Bernafaslah secara perlahan dan konsisten. Penguasaan teknik ini akan meningkat sedikit demi sedikit tanpa kita sedari.
6. Praktikkan latihan ini di rumah selama 5 – 10 minit 3 – 4 setiap hari

PERNAFASAN ‘RESONANT’

Setelah anda mahir melakukan pernafasan diafragma, seterusnya anda akan mempelajari cara pernafasan pada frekuensi resonant dimana biasanya rata-rata individu boleh melakukannya sebanyak 6 kali seminit. Frekuensi resonant ini akan menghasilkan **Heart Rate Variability (HRV)** ataupun variasi kadar degupan jantung pada amplitut yang maksima. Setiap pernafasan seharusnya berlaku dalam tempoh 10 saat dan diingatkan supaya masa yang diperuntukkan untuk menghembus nafas adalah lebih lama berbanding menyedut nafas. Anda boleh menggunakan bantuan jam untuk memastikan masa yang digunakan untuk kitaran pernafasan atau mengira 1, …, 4 semasa Anda menyedut napas, dan 5, ..., 10 semasa menghembus napas. Berzikir dengan lafaz Subhanallah ataupun Allahu Akbar juga boleh Anda buat.

MEMPERAKTIKKAN KEMAHIRAN PERNAFASAN DALAM AKTIVITI HARIAN

Perlu diingat bahawa segala teknik yang dipelajari adalah kemahiran. Dan setiap kemahiran itu hanya boleh ditingkatkan mutunya melalui latihan!

Sama seperti kemahiran yang lain, teknik yang dipelajari perlulah dipraktikkan setiap hari untuk mencapai tahap yang memberangsangkan. Anda disarankan supaya melakukan latihan 4 kali sehari setiap 10 minit dan cuba bernafas senormal yang mungkin. Jadikan kemahiran pernafasan ini sebagai tabiat baru untuk kesihatan. Keadaan ini dapat meningkatkan sistem fisiologi dan membantu untuk mengimbangkan ritma degupan jantung, tahap emosi, hormon dan fungsi autonomi.

1. Jadikan pernafasan diafragma sebagai cara anda bernafas setiap hari
2. Praktikkan 5-10 minit sebelum dan selepas tidur
3. Praktikkan 3 minit setiap jam di tempat kerja terutama apabila dilanda keletihan, kelesuan, kebosanan, dan stress.

Cuba lakukan latihan ini seboleh-bolehnya di mana-mana dan pada bila-bila masa sahaja sebagai contoh ketika anda sedang

- ✓ menunggu barisan atau terkandas dalam kesesakan lalulintas
- ✓ menunggu seketika sementara panggilan telefon dijawab
- ✓ terganggu oleh sesuatu yang diperkatakan oleh seseorang
- ✓ tertekan dengan tugasan yang perlu anda selesaikan
- ✓ dalam kesakitan, mengantuk, penat, stress

Sentiasa mengingati satu perkara!

Perkembangan dan kemajuan latihan ini adalah sepenuhnya terletak di atas bahu anda. **Perlu juga difahami disini bahawa tiada sebarang perubahan drastik boleh berlaku dengan sekelip mata.** Segalanya tertakluk kepada keazaman anda untuk melakukannya – walaupun ianya sesuatu yang mudah- untuk memastikan bahawa kemajuan boleh dicapai. Gunakan dan lakukan teknik yang telah diterangkan dalam modul ini dan anda akan mendapatinya sebagai sesuatu yang memberi faedah dan menyeronokkan. Kami menyarankan anda untuk meluangkan beberapa minit setiap hari untuk mempraktikkan kemahiran pernafasan ini. Ia akan menjadi tabiat yang baik jika kerap dilakukan dan seterusnya mampu membantu anda untuk meningkatkan tahap kesihatan dan prestasi kerja. .

"... Ketenangan minda membolehkan pernafasan menjadi lebih teratur dan sekaligus minda akan berfungsi dengan lebih baik .."

PANDUAN BERNAPAS RESONAN

Salah satu perkara yang anda akan pelajari adalah kaedah pernafasan tenang dan bersahaja. Apabila kita berada dalam keadaan tenang dan bersahaja, dada dan perut turut berada dalam keadaan relaks dan kita akan mula bernafas secara semulajadi membuatkan perut mengembang apabila kita menarik nafas dan mengecut apabila kita menghembus nafas. Keadaan dada adalah tidak berubah

1. Diaphragmatic Breathing

* Duduk atau baring pada posisi yang selesa atau berdiri di hadapan cermin dengan berpakaian yang agak longgar
* Letakkan salah satu tangan anda di atas dada, dan salah satu tangan lagi di atas perut
* Secara perlahan-lahan, **tarik nafas melalui hidung** dan **hembuskan nafas melalui bibir.** Apabila anda menarik nafas, tangan yang berada di bahagian bawah seharusnya bergerak ke atas dan kebawah, manakala tangan yang berada di bahagian atas seharusnya mengalami pergerakan yang sangat sedikit ataupun tiada pergerakan lansung
* Perlu diingatkan supaya memperuntukkan masa yang lebih lama semasa menghembus nafas berbanding menyedut nafas.
* Bernafaslah secara perlahan dan konsisten. Penguasaan teknik ini akan meningkat sedikit demi sedikit tanpa kita sedari.

2. Hadirkan Emosi Positif

Aktifkan dan cuba hadirkan perasaan sebenar Anda untuk menghargai seseorang atau sesuatu dalam hidup Anda. Tumpukan dan fokus pada nilai-nilai positif dihati Anda dan teruskan pernafasan

3. Bernapas Resonant

Setelah anda mahir melakukan pernafasan diafragma, seterusnya anda cubalah untuk bernafasan pada frekuensi resonant dimana biasanya rata-rata individu boleh melakukan sebanyak 5 –7 kali seminit. Anda boleh menggunakan bantuan jam untuk memastikan masa yang digunakan untuk kitaran pernafasan.

Perlu diingat bahawa segala teknik yang dipelajari adalah kemahiran. Dan setiap kemahiran itu hanya boleh ditingkatkan mutunya melalui latihan!

- Jadikan pernafasan diafragma sebagai cara anda bernafas setiap hari
- Praktikkan 5-10 minit sebelum dan selepas tidur
- Praktikkan 3 minit setiap jam di tempat kerja

Cuba lakukan latihan ini seboleh-bolehnya di mana-mana dan pada bila-bila masa sahaja sebagai contoh ketika anda sedang

- ☺ dalam keletihan, kebosanan, tekanan, kesakitan
- ☺ terganggu oleh sesuatu yang diperkatakan oleh seseorang
- ☺ membuat keputusan, tertekan dengan tugasan yang perlu anda selesaikan
- ☺ berada dalam barisan

Kita adalah apa yang kita praktikkan setiap masa. Kecemerlangan bukanlah perlakuan tetapi adalah tabiat

APPENDIX J
LIST OF PUBLICATION

Sutarto, A.P., and Abdul Wahab, M.N. 2008. *The Use of Biofeedback for Enhancing Cognitive Performance in Industrial Training Setting.* National Conference on Skills and Competencies in Education (NCSCE) 2008, Universiti Sains Malaysia (USM), Penang, Malaysia, Februari 2008 (in press)

Sutarto, A.P. and Abdul Wahab, M.N. 2008. *The Development of Heart Rate Variability (HRV) -Biofeedback Training Protocol to Improve Visual Inspection Performance.* Proceeding Malaysian Technical Universities Conference on Engineering and Technology (MUCET) 2008, Perlis, Malaysia

Sutarto, A.P. and Abdul Wahab, M.N. 2008. *Biofeedback Technique for Improving Human Operator's Cognitive Performance.* International Cyber Ergonomics Conference 2008 (CD Rom, University of Malaysia Sarawak, 15 September-15 October 2008

Sutarto, A.P., Abdul Wahab, M.N., and Mat Zin, N. 2009. *Psychophysiology Training for Improving Human Performance in Manufacturing Industry*. Paper presented at the International Conference on Human Capital Development 2009, Universiti of Malaysia Pahang (UMP), Kuantan, Malaysia, May 25-27, 2009

Sutarto, A.P., Abdul Wahab, M.N., and Mat Zin, N. 2009. *Smart Kit for Operators' Performance*. Poster session presented at the International Exposition of Research and Invention of Institutions of Higher Learning (Pecipta) 2009, Kuala Lumpur, Malaysia, October 8-10, 2009. (Bronze Medal awarded)

Sutarto, A.P., Abdul Wahab, M.N., and Mat Zin, N. 2009. *Application of Biofeebdack in Industry (Case Study in Performance Workforce)*. Poster session presented at the Bio Malaysia 2009, Kuala Lumpur, Malaysia, November 17-19, 2009. (Bronze Medal awarded)

Abdul Wahab, M.N., Sutarto, A.P., and Mat Zin, N. 2009. *A New Training Technology for Human Operators*. Poster session presented at the Seoul International Invention Fair (SIIF) 2009, Seoul, South Korea, December 3-7, 2009. (Silver Medal awarded)

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Sutarto, A.P., Abdul Wahab, M.N., and Mat Zin, N. 2010. *HRV Biofeedback Improves Cognitive Performance among Industrial Operators*. Paper presented at the 14th Annual Meeting of Biofeedback Foundation of Europe, April 13–17, 2010. Rome, Italy.

Sutarto, A.P., Abdul Wahab, M.N., and Mat Zin, N. 2010. Resonant Breathing Biofeedback for Stress Reduction among Manufacturing Operators. Manuscript submitted to the *International Journal of Occupational Safety and Ergonomics* (Indexed in Scopus). (Under review).