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Measurements of the effects of colored light on the body

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ABSTRACT

MEASUREMENTS OF THE EFFECTS OF COLORED LIGHT ON THE BODY

by

Lynne Hendrickson

Colored light is used in movies, restaurants, and other situations to create particular environments. It creates a mood and sets a stage for specific events.

This study used colored light to create relaxation and stress in order to evaluate physiological reactions in the human body. In all four studies of this paper, EEG, EKG, and peripheral blood flow were recorded and observed and in the latter two studies peripheral temperature and conductance were also recorded. An audio stressor was introduced in the first three studies to evaluate the stability of the altered mood of the individuals.

Considerable mood alterations were observed and were easily depicted in most of the signals recorded. Although the additional stressor did create a stress response with and without colored light, it was more severe in the absence of colored light. In the fourth study, the audio stressor was not used and it was found that colored light was a stressor in itself.

MEASUREMENTS OF THE EFFECTS OF COLORED LIGHT ON THE BODY

by
Lynne Hendrickson

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And to whom I owe the world, I thank my parents for guiding me through life and supporting me when I needed it the most.

Thank You All

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CHAPTER 1

INTRODUCTION

We as humans share with fish, birds, and the higher primates such as monkeys and chimpanzees, the ability to perceive images in color due to the complexity and large processing ability of our brains. The color of an object, for example, a fruit is indicative of whether or not it is ripe and ready to be eaten to us as humans. Just the same, bees are attracted to certain flowers by color indicating the ability to produce honey. Color provides a behavioral response although not always recognized as such.

In nature, absorption, refraction, and reflection produce colors. The composition of organisms is different molecularly or chemically and therefore reacts in various ways to white light. For example, green plants are made up of chlorophyll which has an absorption band at 660 nm situated in the center of the red spectrum of light; this absence of red is why we see plants as green. If the ultraviolet spectrum were visible to the human eye, we would see plants and grass as being much brighter and of different color due to chlorophyll. This type of phenomenon happens not only in plant life but also in mammalian molecular makeup. The beautiful array of colors in butterflies and peacocks and the black and brown stripes of

a tiger are created in the same manner, by means of absorption and refraction in the layers of its makeup.

1.1 Object of this Research

The purpose of this study was to explore a variety of physiological signals from the human body to determine which would best indicate the effect that colored light has on an individual. As one experiences colored light via the eye, many neural pathways are stimulated starting from the retina, traveling down the optic nerve into many areas of the brain. These stimulations influence our mood and behavior. This study was designed to influence mood alterations via a three-way mirror (for the head only) equipped with a system providing various colored light. Parameters such as an electroencephalogram (EEG), an electrocardiogram (EKG), and peripheral blood flow were recorded to understand the physiological systems supporting these mood alterations and provide a starting point for further studies.

Within the body, all systems are interconnected and therefore it is difficult to depict the exact cause and effect of each stimulus. However, one goal is to determine whether the stimulus of color can counteract the effect of stress.

Under the presumption that the visual environment alters mood, an audio stressor was introduced to determine the stability of these mood alterations. Since all external events are processed in the brain, it was of interest to add an audio stressor to stimulate certain chemical processes which are discussed later in this chapter.

Four studies were conducted to determine whether or not colored light counteracts the effects of stress. Study 1 used colored light to create an environment of both stress and relaxation. Audio stimuli was introduced to create both stress and relaxation during each colored environment. Study 2 consisted of two consecutive sessions. The first session was conducted with the subjects' eyes closed: the second session was conducted with colored light to create a relaxing environment. In both sessions an audio stressor was introduced. Study 3 was a case study used to bridge together the acquired signals of studies 2 and 4. Study 4 was conducted on a subject group of 5 patients under the advisement of Dr. R. Frenkel, Psychoanalyst. This study was conducted with a series of eight colored lights, consecutively displayed without an additional stressor.

1.2 What is Color?

The nature of color was first explained by Sir Isaac Newton

in 1672. It had already been known that passing light through a prism produced colored light. However, the explanation was incorrect until discovered by Newton. Through a series of experiments he found that the colored spectrum could be produced by splitting white light once and could not be subdivided further. He also discovered that the recombination of the entire spectrum reproduced white light. Newton realized these light rays were of different frequencies to which the *eye* is sensitive. The actual light rays were no more colored than radio waves [4].

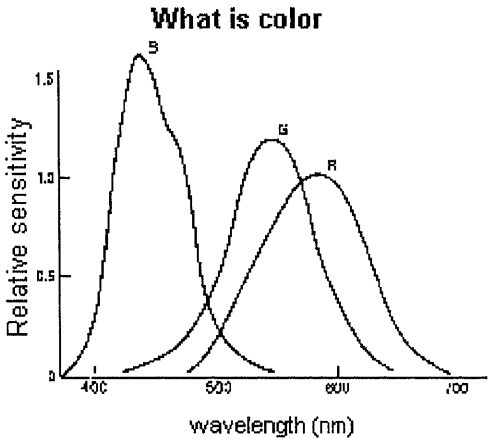


Figure 1.1 Color spectrum as seen by the eye [4].

Since we do not view life through a prism, further explanation was required which brought about the discovery of selective refraction and absorption. When white light falls on a red surface, this surface reflects the red light while absorbing the remainder of the spectrum. This is known as selective reflection. Similarly explained, selective absorption occurs when white light is directed through a red filter

and it absorbs all colors of the spectrum except red. This process can only be recognized through the mechanisms of the eye and is then transmitted to the brain via nerve signals [4].

More that a century later, Thomas Young experimented with color theory and discovered that all colors of the spectrum could be produced by means of three primary colors: red, green, and blue. He postulated that the eye had three different types of nerves and each was sensitive to one of these three colors. Also, when the eye responded to yellow, it was stimulating both the 'red' and 'green' nerves. Almost fifty years later, these theories in color vision were explored again by Herman von Helmholtz. It was he who dismissed the three-nerve theory and introduced the system of red, green, and blue receptors of the eye which could be stimulated simultaneously allowing an array of color to be viewed [4].

While many other scientists have experimented with color theories and made significant discoveries, it wasn't until 1964 that Youngs' theory was proven to be correct. This direct confirmation was produced by two groups in America, Marks, Dobelle, and MacNichol who worked on goldfish, monkey, and human retinae and by Brown and Wald who worked on human retinae. Both groups performed

microspectrophotometry on single cone receptor cells and confirmed that there existed three type of cone cells that absorbed light in different regions of the spectrum. Figure 1.1 shows the spectral responses of the three cone types as first published by Thompson and Wright in 1953 [4].

1.3 Stress

Stress is often experienced on an emotional level; for example when one is interviewing for a new job, starting a new job, involved in an automobile accident, or by merely having too much to accomplish in one day. It also occurs from physical trauma, prolonged exposure to the cold, prolonged intense exercise, infection, pain, and shock. Stress is known as a pressure, tension, or strain and is often experienced both physically as well as mentally. One might feel tension in the shoulders and neck while others may experience a headache. These are responses on a macroscopic scale, but what happens to the body on a microscopic scale?

The secretion of the glucocortcoid hormone cortisol by the adrenal cortex is increased due to all types of stress. In addition, the sympathetic nervous system will increase the release of epinephrine from the adrenal medulla.

This increased cortisol secretion due to stress is

mediated mainly by the hypothalamo-anterior pituitary system. Neural input to the hypothalamus from sections of the nervous system responding to a particular stress activates secretion of corticotropin releasing hormone (CRH). This hormone is carried by the hypothalmo-pituitary portal vessels to the anterior pituitary and stimulates adrenocorticotropic hormone (ACTH) release. The ACTH in turn circulates to the adrenal cortex and stimulates cortisol release [3].

Vascular reactivity such as the ability of vascular smooth muscle to contract to such stimuli as norepinephrine is an important effect caused by increased levels of cortisol. This increased level of cortisol also helps in organic metabolism as well as inhibiting inflammation and protecting against the damaging effects of stress [3].

CHAPTER 2

PHYSIOLOGICAL BACKGROUND

This chapter provides insight to the physiological anatomy and chemical interactions of the subsystems prevalent to the scope of this research. The areas of interest are the nervous system, the heart, blood flow, the eyes, and the brain, all of which will be discussed in detail as it applies to this study.

2.1 The Nervous System

The nervous system is responsible for sensory and motor activity, for behavior, and for regulating activities of the internal organs and systems. It is divided into two components: the central nervous system (CNS) and the peripheral nervous system (PNS).

2.1.1 The Central Nervous System

The CNS consists of the brain and the spinal cord, processes sensory information and integrates it with past experience to produce appropriate motor commands. All CNS operations are carried out by sensory, motor and association centers of the brain and spinal cord. The nerve centers of the CNS are organized in a hierarchy of higher

and lower centers where only the lower centers come in contact with the PNS structures [3].

2.1.2 The Peripheral Nervous System

The PNS is categorized into two divisions: afferent and efferent. The afferent division conveys sensory information to the brain to be processed. The efferent division carries signals via nerve fibers to muscles, glands, and organs.

The efferent division of the PNS can also be divided into two systems: the somatic and the autonomic nervous systems (ANS). The somatic nervous system (SNS) is made up of nerve fibers going from the CNS to skeletal muscle. These nerve fibers are generally large in diameter and coated with a myelinated sheath and pass without synapse to the skeletal muscle cells. Somatic neurons or motor neurons when excited by the neurotransmitter acetylcholine cause the skeletal muscle into contraction; relaxation is a function of the ANS. To sum up the SNS: it innervates skeletal muscle, leads to muscle excitation and consists of only a single neuron between the CNS and the effector organ.

The ANS consists of nerves that regulate motility and secretion in the skin, blood vessels and visceral organs by stimulating smooth muscle and exocrine glands. All efferent

innervation to tissue other that smooth muscle is done through the ANS. The ANS can be further subdivided into sympathetic and parasympathetic systems where the sympathetic is associated with stress response while the parasympathetic is associated with relaxing responses. The main neurotransmitter in these systems between pre- and post-ganglionic fibers is acetylcholine. However in the sympathetic division norepinephrine is mainly the transmitter between postganglionic fibers and the effector cell.

2.1.2.1 Sympathetic Nervous System: The sympathetic component of the ANS consists of nerve fibers that span the region of the spinal cord in the thoracic and lumbar regions and are therefore referred to as the thoracolumbar division. This division targets the visceral core, the skin, and the blood vessels of the muscles. The eyes, mainly the iris, receive sympathetic nerve innervation via the spinal nerve trunks, which are postganglionic fibers and are located on both sides of the vertebral column.

2.1.2.2 Parasympathetic Nervous System: Parasympathetic nerve fibers are orientated in the brain and sacral portion of the spinal cord and are referred to as the craniosacral

division. Cranial nerves such as the oculmotor, the trigeminal, and the vagus are also under parasympathetic influence. The most prominent parasympathetic nerve is the vagus, which innervates many visceral organs including the lungs, heart, and the digestive tract; the heart and the digestive tract receive the most profuse innervation.

2.2 The Heart

Electrically stimulated but mechanical in function, the heart pumps blood containing oxygen and other nutrients to all organs and tissues throughout the body. It is functionally divided longitudinally and subdivided laterally into two chambers: an atrium and a ventricle.

Blood is pumped from the right ventricle through the lungs into the left atrium. During this portion of the cycle the blood becomes enriched with oxygen. The blood is then pumped into the left atrium, through the left ventricle, and out into the systemic arteries. It is in this portion of the circulatory cycle that all organs, tissues, and cells, with the exception of the lungs are supplied with freshly oxygenated blood. All vessels carrying blood to the heart are called veins while all vessels leaving the heart are called arteries [3].

Between the chambers of the heart are valves that

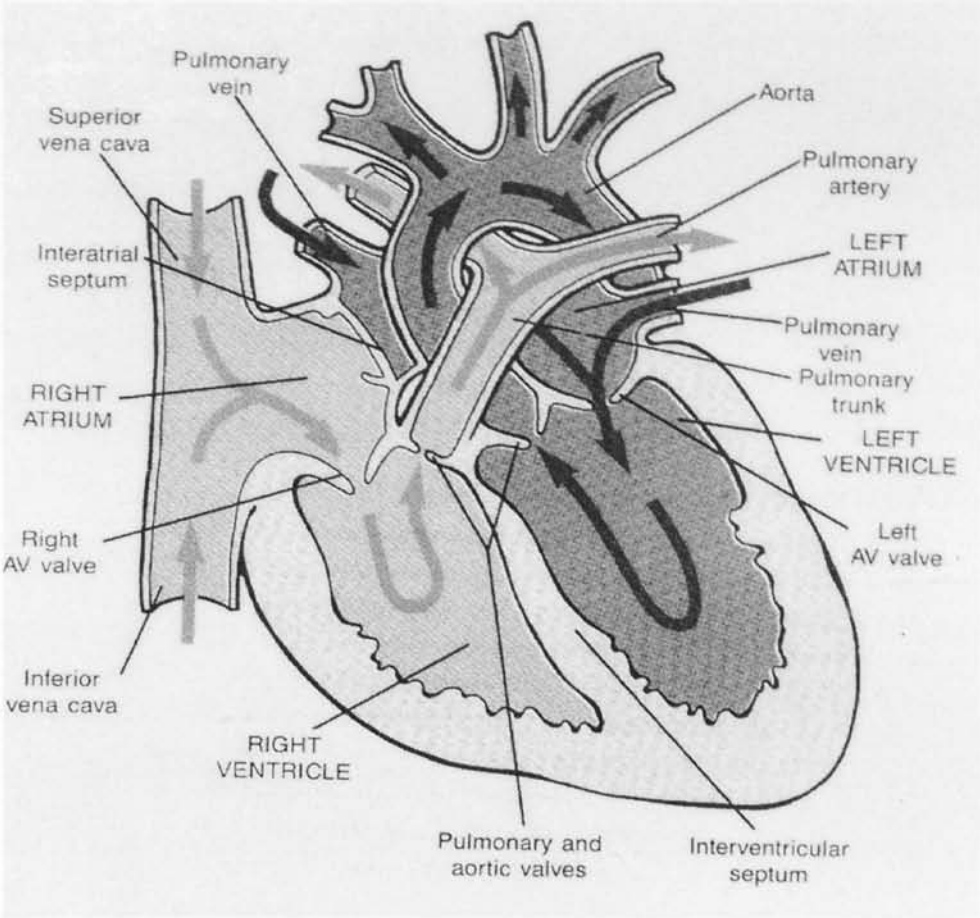


Figure 2.1 The chambers of the heart [3].

prevent the blood from flowing backwards. Located between the atrium and ventricle in each half of the heart are the atrioventricular (AV) valves. The right AV valve is called the tricuspid valve, and the left is called the mitral valve. The movement of these valves is a passive process resulting from pressure differences across the valves. When the blood is moving from the atrium to the ventricle, the valve is open. However when the ventricle contracts, the AV valves are forced closed. The pulmonary valve exists at the opening of the right ventricle into the pulmonary trunk,

and the aortic valve exists where the left ventricle goes into the aorta. These valves permit blood to flow into the arteries during ventricular contraction and prevent it from changing direction. All of these areas are electrically stimulated by means of action potentials via the nervous system.

2.2.1 Neural Control of the Heart

The pace of the heart is largely influenced through the sympathetic and parasympathetic nerves on the heart. The general physiological effects of these two nerve systems can be described rather simply; the sympathetic nerves liberate norepinephrine, which stimulates the heart causing an increase in its rate and force of contraction and the parasympathetic nerves liberate acetylcholine, which inhibits the heart, slowing its rate. Both the SA and AV nodes are affected by both sets of nerves. However, the ventricular musculature is free of any parasympathetic innervation.

2.2.2 Norepinephrine and the Heart

Norepinephrine has several effects by means of calcium transport. The rate of rise of the pacemaker potential and therefore the heart rate is increased in the SA node due to

the increase of calcium permeability caused by norepinephrine. Ventricular contraction becomes stronger due to increased amounts of calcium entering the muscle with each beat. This triggers calcium release while also storing some to be released with up coming beats thus causing a stronger contraction. Norepinephrine also increases the reuptake of calcium by the sarcoplasmic reticulum which speeds up the relaxation process and in turn shortens the duration of contraction.

2.2.3 Acetylochline and the Heart

The vagus nerve liberates acetylocholine, which acts on the SA node by increasing its permeability to potassium. This causes the resting potential of the SA node to become more negative, pushing it further away from the threshold potential. Outward moving potassium slows the normal rate of depolarization caused by inward moving calcium. This slows the heart by lengthening the time needed to reach threshold. This inward moving potassium impedes excitability of other cells, which slows conduction of the impulse through the atrium and AV node.

2.2.4 The ECG Recording

A typical Electrocardiogram (ECG) is an electrical

recording of the heart's activity. Figure 2.2 shows a series of action potentials (electrical activity) occurring at the heart that get summed up during an EKG resulting in a composite wave. Various cells are orientated in different directions, and are excited at different times and recovering at others. Due to this variety, the composite ECG bears no obvious resemblance to the action potential of any single cell. The landmarks on a typical recording are designated by the letters P, QRS, and T. Their physiological correlates are:

P WAVE: The P wave signals the beginning of a single heartbeat. It corresponds to the spread of excitation over both atria.

QRS COMPLEX: This corresponds to the invasion of ventricular muscle by excitatory impulses. It is higher than the P wave because the ventricular mass is much larger than the atria. The duration of the QRS complex is shorter that the P wave because impulse conduction through the ventricle is very rapid.

T WAVE: The T wave results from the ventricular repolarization as different parts of the ventricle repolarize at different times.

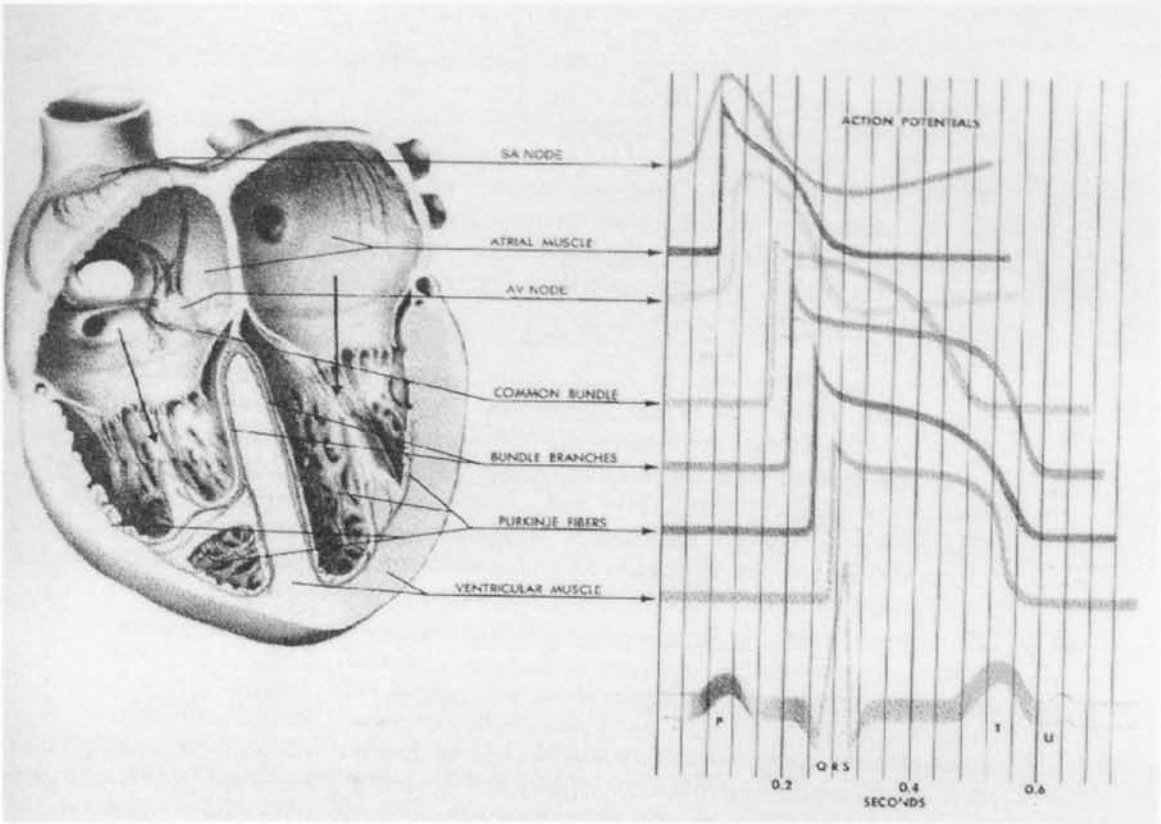


Figure 2.2 Components of the EKG [27].

2.2.5 Heart rate variability (HRV)

A large degree of heart rate variability (HRV) can be found in healthy hearts and is described as the standard deviation of all time intervals of the QRS complex. It has been found that increased sympathetic activity and decreased parasympathetic activity decreases HRV [22]. The studies comprising this thesis use HRV as a tool to measure the effect of color and audio stimuli as active stressors.

The ECG signal was used to derive the interbeat interval (IBI) signal. First, the R waves were detected. The time interval between R waves was used to determine a

discrete IBI sequence. The IBI sequence was then interpolated using a backward step method to produce the interpolated IBI (or IIBI). This signal was detrended, removing naturally occurring slow patterns of the ECG signal. Fourier analysis (FFT) was then performed on the IIBI which splits the signal into its frequency components. The FFT of the signal was then plotted on a frequency axis: this plot is called a power spectrum and is a useful tool in determining the activity of the sympathetic and parasympathetic nervous systems [19]. When a power spectrum is done on an HRV signal, there are usually three peak areas that are of interest: the very low frequency peak (below 0.05 Hz), the low frequency peak (0.05-0.15 Hz), and the high frequency peak (0.15-0.40 Hz). This thesis is most concerned with the low and high frequency peaks because these are the two peaks known to be under sympathetic and parasympathetic control [23].

The ratio of the low to high frequency power was computed as an indicator of sympathovagal balance [23]. Plots of the HRV spectral analysis can be viewed in plots 5.13 through 5.20.

2.3 Blood Volume

The heart pumps blood intermittently; during systole, some 70 mL of blood is thrust into the aorta, but during diastole, no blood leaves the heart. Despite this choppy, discontinuous flow of blood through the root of the aorta, blood flows out of the arteries into the capillaries in a smooth and continuous motion. This is possible because the aorta and other arteries are not rigid pipes; they have elastic walls, which can expand or recoil.

2.3.1 Smooth Muscle

The elastic walls are controlled by smooth muscle that uses cross-bridge movement between actin and myosin filaments to generate force, and calcium ions to control cross-bridge activity. This cross-bridge activity is turned on by calcium mediated changes in the thick filaments of the muscle. The calcium concentration of extracellular fluid is ten thousand times greater than the cytosolic calcium concentration. When the calcium channels of the plasma membrane open, an influx of calcium occurs. The greater the increase of calcium concentration, the greater the number of cross-bridges activated and the greater the contraction [3].

The removal of calcium from the cytosol, to bring

about relaxation, is achieved by the active transport of calcium back into the sarcoplasmic recticulum as well as out of the cell across the plasma membrane. The rate of calcium removal in smooth muscle is much slower than in skeletal muscle, with the result that a single twitch lasts only a fraction of a second in skeletal muscle but may last several seconds in smooth muscle [3].

2.3.2 Neural Regulation

In addition to local chemical control, smooth muscle in

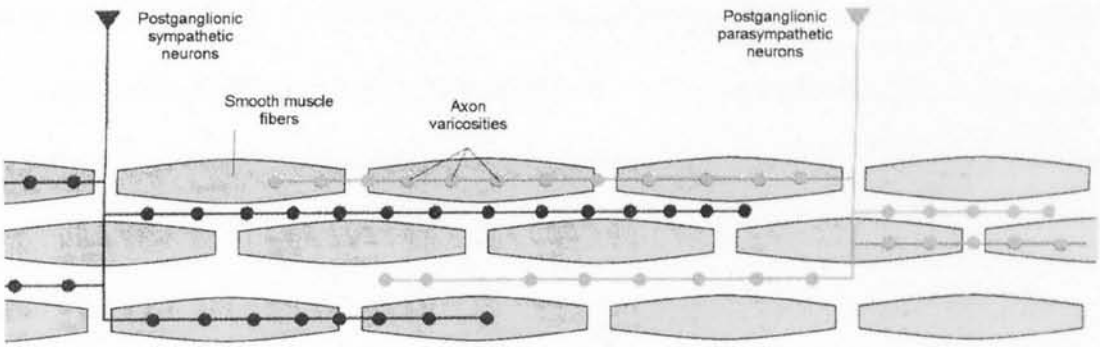


Figure 2.3 Neural control of blood flow [3].

blood vessel walls is also controlled by sympathetic nerve endings as shown in Figure 2.3. The neuron, at the intersection with the smooth muscle fibers, divides into numerous branches, each branch containing a series of

swollen regions called varicosities. When the nerve axon transmits an action potential, neurotransmitters are released from vesicles contained within these varicosities.

Whereas some neurotransmitters depolarize smooth muscle membranes, others produce a hyperpolarization which leads to decreased cytosolic calcium concentration, producing a lessening of contractile activity. Thus, in contrast to skeletal muscle which receives only excitatory input from its motor neurons, smooth muscle tension can be either increased or decreased by neural activity [3].

Sympathetic nerves are generally active, constantly sending to the blood vessel impulses that liberate norepinephrine, causing depolarization and thus contraction. When the frequency of sympathetic impulses increase, blood vessel contraction is more intense; when the frequency decreases, the smooth muscle is more relaxed and blood vessels dilate. The density of sympathetic innervation varies widely from tissue to tissue. Arterioles and veins of the skin have a rich supply of nerves and show intense vasoconstriction upon sympathetic stimulation.

Sympathetic nerves are activated in response to low blood pressure causing vasoconstriction. At the same time, the deprived organ innervated by the sympathetic nerves begins producing vasodilator substances. Although the net

result depends on the particular organ, the vasodilator response often predominates. In fact, there is evidence that vasodilator substances act not only on blood vessels but also directly on sympathetic nerve endings to inhibit the amount of norepinephrine released by sympathetic impulses [3].

2.3.3 Blood Volume Recordings

As stated in the previous section, the arterioles of the skin are richly supplied by nerves, which are mainly of sympathetic origin. In situations of stress, sympathetic regulation of vascular tone is highly activated and is a large contributor of blood volume. Due to this high nerve activity region, a good surface area is established from which to record blood volume. Photoplethysmography is a method of detecting blood volume by means of a light emitting diode and a phototransistor. This was the method used for measuring blood volume in this thesis and is described in detail in section 3.4.3.

Vasoconstriction caused largely by stress can easily be seen by means of blood volume waveform recordings taken at the finger. The raw or unprocessed blood volume data shows a smaller peak to peak waveform during vasoconstriction. The peak to peak waveform climbs back to

a normal baseline value when a person is more relaxed: this value varies for the individual and is partially dependent on circulatory function and peripheral body temperature. Figures 5.5 through 5.12 in Appendix A illustrate the changes discussed here.

2.4 The Eye

The eye is a complex organ designed to perform both optical functions for image formation and nervous functions for photoic transduction, image analysis, and image transmission to the brain. The eye's optical apparatus forms

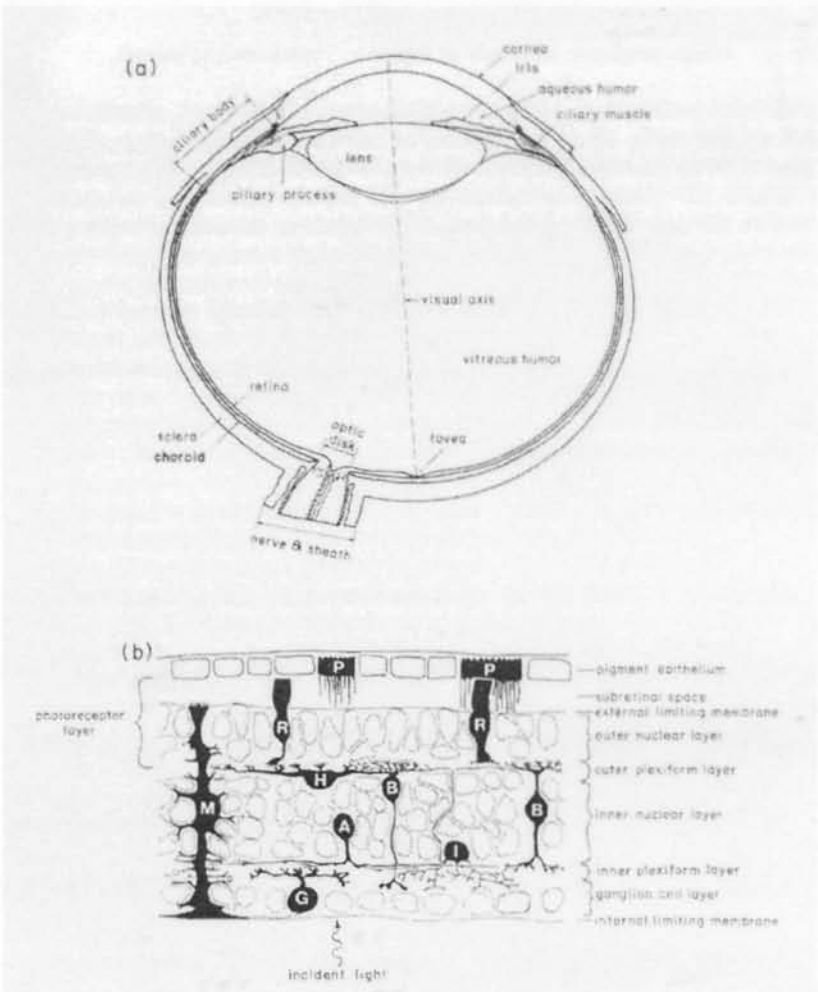


Figure 2.4 The structure of the eye [4].

and maintains sharp focus of an object image on the retina as shown by the visual axis in Figure 2.4. Photoreceptors on the retina convert the incident photons into nerve signals and transmit them via integrative neural elements to the brains visual centers as indicated in Figure 2.5.

Light enters the eye at the cornea, the only part of the optical system that touches the air. It is here, at the intersection of the air and the cornea, where an appreciable change of refractive index occurs; light rays bend more in air that in any transparency of the eye. It is the high curvature of the cornea that permits light rays hitting it at different angles to be delivered through the lens to the retina forming a precise image. The lens plays a smaller role in focusing. However, it makes all the adjustments for distance by its shape [3, 4].

The ciliary muscle and the tension it applies to the zonular fibers, which attach this smooth muscle to the lens, controls the shape of the lens. The zonular fibers pull the lens into a flattened, oval shape, and when this pull is removed, the natural elasticity of the lens causes it to become more spherical. This more spherical shape provides additional bending of the light rays, which is important when near objects are viewed. The ciliary muscle, which is controlled by parasympathetic nerves, is circular

like a sphincter, so it draws nearer to the lens as it contracts and therefore removes tension on the zonular fibers [3].

The ringlike colored muscle that controls the amount of light entering the eye is called the iris. This muscle is composed of smooth muscle tissue, which is innervated by the autonomic nerves. The iris contracts and the pupil enlarges under sympathetic stimulation while under parasympathetic stimulation, the sphincter muscles surrounding the outer radius of the iris contract making the pupil smaller. These neurally induced changes occur in response to light sensitive reflexes [3].

2.4.1 The Retina

It is on the retina that the lens focuses all images. The central region of the retina is called the fovea which has subdivisions of the foveola, the fixation spot, and the foveola pit. This pit is a depression. Only cones are found at the base of this depression in the foveola and there are more direct connections from each cone to the bipolar and ganglion cells than are found in the peripheral retina. In addition, the cones are more closely packed and more elongated than elsewhere in the retina. Thirdly, the bipolar and ganglion cells are displaced towards the edge

of the depression. Each of these factors contributes to the special properties of the central fovea. More light quanta can reach the receptors unobstructed by other structures and the ganglion cells respond only to a small retinal area or pool of receptors. Consequently, the central fovea corresponds to the retinal area of maximum visual acuity. This also defines the fixation point, namely the region where an image is formed, by means of eye and head movements when a stimulus detail needs to be seen most clearly [4].

2.4.2 Receptor Cells

Before light can influence the eye, it must be absorbed. This is done by the receptor cells rods and cones; each of which contains photopigments that absorb light. There are four different photopigments in the retina, rhodopsin in the rods and one in each of the three cone types. Opsin, a group of integral proteins which is found in each photopigment, surrounds and binds a chromophore molecule which is the actual light sensitive part of the photopigment. The opsin protein, which is different for each photopigment, filters the light reaching the chromophore causing a variation in response to areas in the visual spectrum. Within the photoreceptor cells, the

photopigments are arranged in stacks parallel to the retina for repeated layers causing an effective trap for light [3].

When light activates a molecule, it changes shape. This change facilitates the binding of opsin to a G-protein, which activates the enzyme phosphodiesterase, which in turn hydrolyzes cyclic GMP. The GMP concentration becomes low and plasma membrane ion channels close. However, calcium continues to be pumped out of the photoreceptor causing the cell to hyperpolarize. This hyperolarization is conducted down the photoreceptor causing a decrease in neurotransmitter released from the cell. This decrease in neurotransmitter transmission signifies to the synapsing neurons that light has been absorbed.

In darkness, the cyclic GMP in the photoreceptors is high. The plasma-membrane ion channels are open, permitting sodium and calcium to enter the cell and depolarize the membrane. Transmitter release is then high in the dark [3].

2.4.3 Phototransduction

Visual information is conveyed from the receptors to bipolar and ganglion cells where it is then sent along the optic nerve, to the lateral geniculate body, and then to

the visual cortex. Bipolar cells are second order neurons and are responsible for various characteristics of the visual image such as color, intensity, form, depth, and movement. They synapse with parallel neural pathways and ganglion cells processing major amounts of information while still in the retina. Figure 2.6 shows a diagram of the pathway from the eye to the brain.

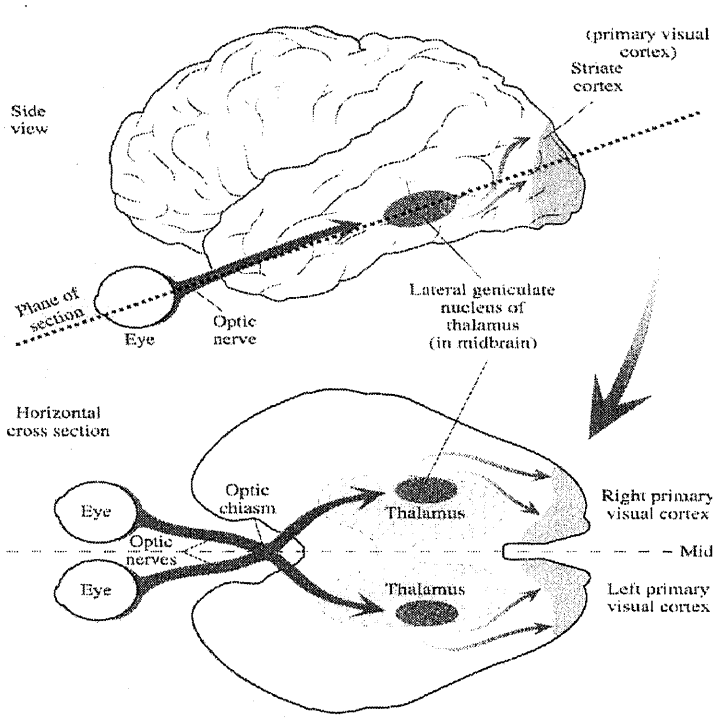


Figure 2.5 The pathway from the eye to the brain [1].

There are two types of ganglion cells, the magnocellular or M cell which is responsible for movement and the large outer parts of the visual image, and the parvocellular or P cell which is responsible for small stationary stimuli, fine detail, and color.

All synaptic potentials are due to depolarization and hyperpolarization or graded potentials up until the ganglion cells where it becomes an action potential. This

is due to the fact that the ganglion cells make up the optic nerve that feeds the brain information and must therefore travel long distances. It is however, the inhibitory and excitatory synaptic interactions from the bipolar cells that cause the change in action potential firing [3].

2.4.4 Color Vision

The cone photoreceptors differ from the rod photoreceptors not only morphologically, but also in the types of photopigment molecules they contain. The rod photoreceptors contain the photopigment rhodopsin. Each of the three cone types contains a unique photopigment in its outer segments. The wavelength that is best absorbed by each of the cone types depends on the interaction of the

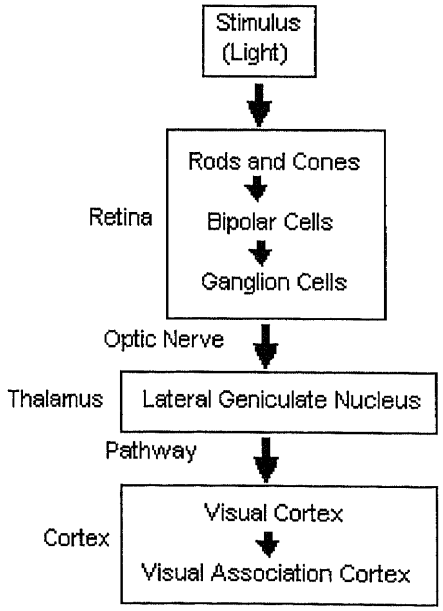


Figure 2.6 The visual pathway.

photopigment and the different opsin protein, each producing a different spectral sensitivity. S-cones or short-wavelength cones (blue) have the highest sensitivity at 420 nm; M-cones or middle-wavelength cone (green) have the highest sensitivity at 530 nm; L-cones or long-wavelength cones (red) have the highest sensitivity at 560 nm. Although the cones are named after the pigment that they best absorb, all can detect and respond to other pigments, however not as much [3,4].

2.5 The Brain

Housed in the skull, the brain consists of all parts of the central nervous system above the spinal cord. Anatomically, it can be divided into two parts, a higher forebrain and a lower brain stem, both of which are composed of six subdivisions. All proposed divisions within the brain are rather artificial and are based on the need to separate it into neat and understandable units; however, the brain functions as a whole.

2.5.1.The Forebrain

The forebrain consists of two nearly symmetrical cerebral hemispheres each comprised of the cerebral cortex, the

basal ganglia, and the limbic system. The two hemispheres are connected by a massive bundle of nerve fibers, the corpus callosum being the largest.

The cerebral cortex is an outer shell of gray matter that is highly folded creating a large surface area. This large area is densely populated with cortical neurons relaying sensory information to be processed. This information comes from a variety of places but particularly from the thalamus, the cortex, and from the brainstem reticular formation.

The cortex of each hemisphere is divided into four lobes: the frontal, parietal, occipital, and temporal. The frontal lobe specializes in motor functions, while some areas of the lobe are involved in learning, planning, and some psychological processes. The occipital lobe is mainly involved in visual operations and the parietal lobe specializes in somatic sensory functions such as skin senses. The temporal lobe comprises the hearing center and related association areas, including some speech centers. Other areas are active in memory, smell, and other functions related to the limbic system [3].

Another brain system found in the forebrain is the basal ganglion, which consists of structures mainly involved in motor processes. The structures of the basal

ganglion work in conjunction with the motor areas of the cortex and cerebellum for planning and coordinating gross voluntary movements and also in more complex aspects of behavior.

An area of the forebrain that includes both gray and white matter is the limbic system. This is an interconnected group of brain structures, taking in portions of frontal lobe cortex, temporal lobe, thalamus, and hypothalamus, as well as circuitous fiber pathways that connect them. The limbic system is associated with learning, emotional experience and behavior, and a wide variety of visceral and endocrine functions. Besides being connected with each other, the parts of the limbic system are connected with many other parts of the central nervous system [3].

The second component of the forebrain consists of the thalamus and the hypothalamus and is called the diencephalon. The thalamus sits at the center of the brain and serves as an important synaptic relay station for the cortex and responds to all the senses except smell.

Just below the thalamus sits the hypothalamus. Although the hypothalamus is less than one percent of the total brain volume, it is the critical link between the cerebral cortex, the limbic brain, and the hormonal output

of the pitutary gland. It is critical to hemostatic regulation and it is the principal site for regulation of behavior needed for survival. It serves to balance the internal levels of water, temperature, and hormones and regulates appetite, sexual behavior, and emotion [1].

2.5.2 The Brain Stem

The brain stem is situated directly above and has extensive connections with the spinal cord. It is the most primitive part of the brain and consists of several parts: the medulla, pons, and midbrain.

The brain stem structures carry out many vital somatic, autonomic, and reflexive functions that deal with vegetative functions for body maintenance and survival. The centers for control of respiration, cardiovascular, and digestive functions are located in the medulla while the pons has structures involved in the function of cerebellum and motor control, in addition to other inhibitory control centers for respiration.

Running through the core of the brain stem and consisting of loosely arranged neuron cell bodies intermingled with bundles of axons is the reticular formation, which is the one part of the brain absolutely essential for life. It receives and integrates input from

all regions of the central nervous system and is also responsible for outputting a great deal of neural information. Most reticular formation neurons send axons for considerable distances up or down the brain stem and beyond, to most regions of the brain and spinal cord. This pattern indicates the very large scope of influence the reticular formation has over other parts of the central nervous system [3].

In the brainstem located below the diencephalon and above the pons sits the midbrain. It has bi-directional neural pathways with the forebrain: controlling information is sent from the forebrain to the midbrain, processed and distributed back to the appropriate areas of the forebrain for further processing.

The midbrain has two important subdivisions: the inferior colliculus and the superior colliculus, both of which form protrusions on the dorsal surface of the midbrain. The inferior colliculus serves as a relay and processing station for auditory information, while the superior colliculus involves integration of visual information with motor output in the neural systems that control eye movement [1].

The axons of the retinal ganglion cells project to multiple targets in the brain via the geniculostriate

pathway, which sends optic projections to the thalamus and from there to the striate cortex or primary visual cortex. The striate cortex gets its name from the conspicuous stripe caused by the abundant amount of thalamic synaptic inputs.

The optic nerves from the two eyes merge at the base of the brain, forming a structure called the optic chiasm. The axons of the retinal ganglion cells then separate again to form the two optic tracts, which project to the lateral geniculate nuclei on both sides of the brain. There, the axons of the ganglion cells end, making synaptic connections with the neurons of the lateral geniculate nucleus. The thalamic neurons in turn send their axons to the primary visual cortex in the occipital lobe at the back of the brain [1].

2.5.3 The Cerebellum

The cerebellum is a complex structure that receives a wide variety of sensory information from muscles, joints, skin, eyes, and ears as well as signals from motor control areas of the forebrain. It is mainly involved in skeletal muscle control making it an important center for coordinating and learning movements and for controlling posture and balance.

The cerebellum appears to have evolved as an adjunct to the brainstem locomotor command center. One of the main sensory inputs comes from sensory information about the orientation and the acceleration of the body during locomotion. Much of the fine tuning of motor output occurs here in the cerebellum [1].

2.5.4 Brain Potentials

An electroencephalogram (EEG) is an electrical recording of the continuous activity occurring within the brain as measured from the surface of the head. This measured potential is the result of cell bodies and dendrites of cortical cells systemically arranged. The amplitude of the waves range from 1 millivolt to 100 microvolts in the frequency range of 0.5 to 100 Hz. The patterns and characteristics of the waves change between states of wakefulness and sleep and can be broken down into four groups classified as alpha, beta, theta, and delta.

The breakdown is as follows:

Alpha waves occur between 8 and 13 Hz while a person is awake in a quiet resting state and completely disappear during sleep.

Beta waves occur between 14 and 30 Hz and are active during intense mental activity, tension, and activation of the central nervous system.

Theta waves occur between 4 and 7 Hz during emotional stress.

Delta waves occur in the frequency region below 3.5 Hz during deep sleep.

CHAPTER 3

METHODS

This chapter will help the reader to understand the procedures used, the equipment necessary, and the techniques employed.

3.1 Data Acquisition System

Recording was done by an IBM compatible computer with a 486DX2 CPU running at 66MHz. The hard drive was 540MB with 16M of RAM. This computer was equipped with an AT-MIO-16 data acquisition board [National Instruments, Valley View, OH]. Set in a bipolar range with a board gain of 0.5 an output range of +/-10 volts is obtained. With a sampling capability of 500KS/s, a FIFO buffersize of 2048, and a clock speed of 20MHz, this board well exceeds the specifications needed for this thesis. Signals were fed to the board by a CB-50 I/O connector block and a 50 pin connector cable [National Instruments].

3.2 Data Acquisition Software

The data was collected by a software package LabVIEW (Laboratory Virtual Instrument Workbench): a powerful icon driven package with capabilities to collect and analyze data [National Instruments]. A virtual instrument provided

by the manufacturer called " Continuous Acquisition to Spreadsheet File" was used for data collection. The front diagram allows the user to change the number of channels to record, the scan rate, the number of scans to write at a time, and the buffer size. The scan rate is the number of data points to be recorded per second. These scans get written to a file to be saved and each time this writing takes place, it requires the full attention of the central processor of the computer and therefore must be written in small pieces not to interrupt the data acquisition. The scans also need to be saved a block at a time because the buffer does not have the capacity to hold an entire file of data: to allocate that much memory to the buffer would drastically slow down the computer.

The data collection program also indicates on the front panel the scan backlog, the number of scans written to file as well as displays the signals being recorded. The scan backlog indicates the number of scans being held in the buffer not yet written to the file while the number of scans written to file indicates the portion of the recording already saved. For this experiment, the scan rate used was 200 samples/second.

3.3 Medical Instrumentation

Instrumentation used for signal enhancing, conditioning, and acquisition is described in the following sections.

3.3.1 Signal Conditioning of EEG and EKG

Electrical type signals taken from the body are in the millivolt range for EKG and in the microvolt range for EEG. In order to be able to distinguish the signals, they must first be conditioned. For the cases of EEG and EKG, Gould Universal Amplifiers (model 13-4615-58, Gould Inc., Valley View, OH) were used. The following sections will describe the settings used for each application.

3.3.2 Skin Preparation

Skin surfaces have high impedance and are slightly oily. To help protect the integrity of the signals a few steps were taken. The skin was first washed with an alcohol swab to remove dirt and oil residing in the areas where the electrodes would be attached to the subject. An abrasive scouring pad was rubbed lightly on the skin to break or scratch the epidermis to lower the impedance.

Copper electrodes were used in the case of acquiring EEG and EKG. The copper cups were filled and leveled off with Lectron II conductivity gel [Pharmaceutical

Innovations, Inc.,] and taped into place with one-inch medical tape.

3.3.2.1 EEG Procedures: After skin preparation, electrodes were placed at Fp1, Fp2, and A1 in conformance with the 10-20-electrode system as recommended by the International Federation of EEG Societies [6]. Fp1 and Fp2 are positioned on the forehead above the inner corner of the eyes as shown in Figure 3.1, and A1 is on the left earlobe. The electrodes were fed into the Gould universal amplifier at a gain setting of 0.05full scale creating the magnitude of the wave to be 1-2 volts. This allows a wide enough range for the DC level of the signal to change without exceeding the limitations of the DAQ board (+/- 10 volts) and thus does not clip the signal This is not a typical scenario; however, it does occur to some degree when a subject moves. Bandpass filtering was used from 0.5 to 30 Hz allowing the range of 4 to 28 Hz to

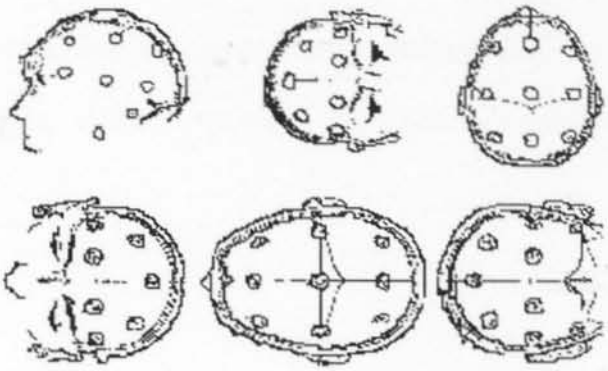


Figure 3.1 EEG electrode placement Standard, 10-20 system [27].

pass through without attenuation at either end of the spectrum of interest.

3.3.2.2 EKG Procedures: In obtaining EKG recordings, there are several configurations for electrode placement. In this case, electrode placement was chosen directly under the

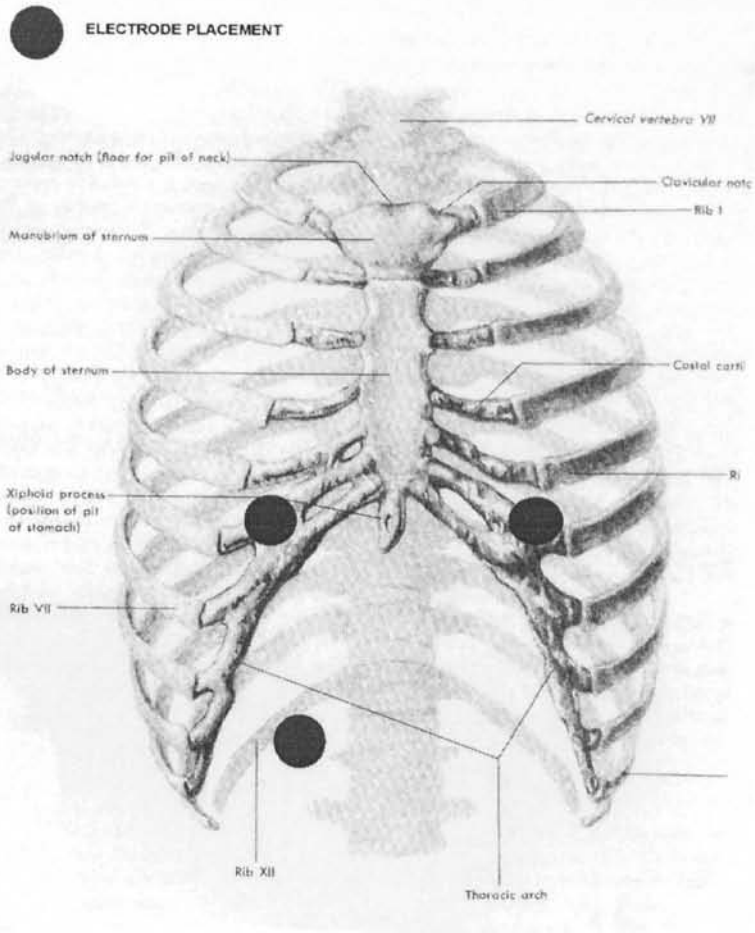


Figure 3.2 EKG placement [28].

breast line using a two-electrode system in addition to a ground. For the purpose of this thesis the full P and T pertinent for the analysis and is discussed in detail in section 4.2.2. Electrodes were placed symmetrically across the sternum on the thoratic arch at the sixth rib. Ground was placed three inches below on the right side, see Figure 3.2. The acquired signal was sent through a Gould universal amplifier with a gain setting of 0.1 maximum scale creating a signal magnitude of 2-3 volts. A passband filter of 1 to 30 Hz was used to eliminate noise yet allow all components of the heart's activity to be recorded.

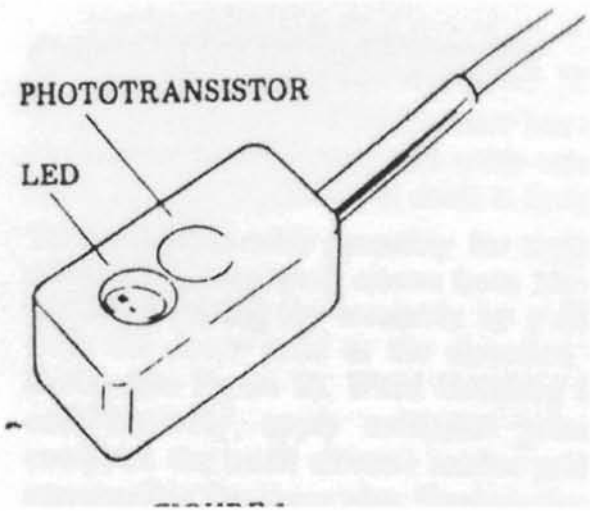


Figure 3.3 Blood flow transducer [5].

3.4.3 Blood Volume Conditioning

Changes in arterial pulsing can be detected by means of blood flow in a finger or toe. A MedaSonics

photoplethysmograph model PPG13 [Kendall Hospital, Mountain View, CA] was used to detect these changes in the microcirculation near the skin surface.

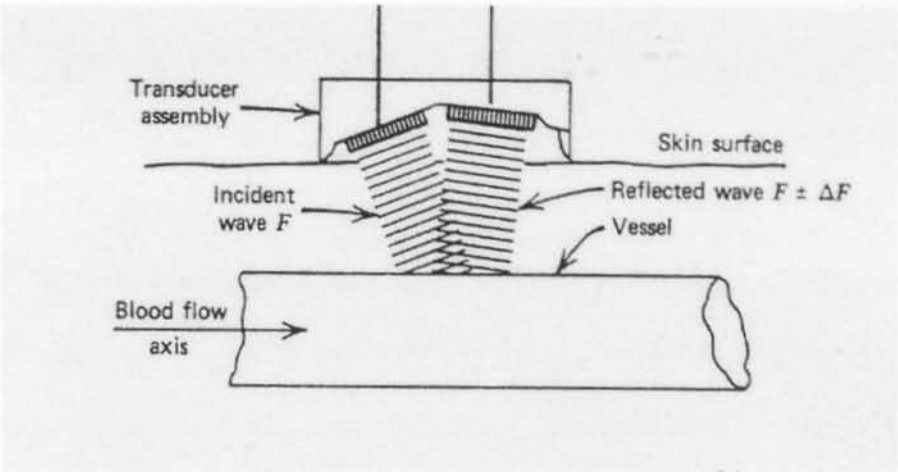


Figure 3.4 Blood flow device [5].

A PH77 Photo Pulse Sensor (Figure 3.3) detects the blood volume by a light emitting diode (LED). When the infrared light is transmitted back to the phototransistor (as shown in Figure 3.4) the signal is converted to an electrical signal. It is important to have the sensor taped securely, not too loose or tight, for a quality signal. When in the AC coupling mode (or arterial mode) the peak to peak amplitude of the waveform is indicative of vasoconstriction or vasodilation.

The amplifier of the photoplethysmograph is AC coupled and has a frequency response of 0.5 to 16 Hz, which is suitable for detecting, and recording the rapidly changing

pulsatile signals produced by arterial blood volume change in the microcirculation [5]. The AC gain is set for approximately 220, which can lead to outputs of up to and above seven volts.

A replica of the PPG13 had been constructed prior to this study and was the first choice of the two devices because it delivered a higher quality signal. The infrared sensor was mounted in hardening clay in the form of a hand. It was set to the size of a grown man's hand so that the platform was large enough to accommodate all subjects. However, on occasion a subject's hand was too small and it was necessary too use the original device. The sensor was set at the middle finger. A four ounce weight was inserted into the end of a piece of rubber tubing and was set on the middle finger to keep the finger firmly in contact with the sensor and also as a reminder not to move the finger.

CHAPTER 4

DATA ANALYSIS

In order to determine what is happening in the recorded data, it must be viewed in a way other than its raw form; therefore analysis techniques are used. Analysis consists of manipulating the data mathematically into a form in which the data can better be understood. Many of the routines and techniques used in this thesis have been developed by other researchers.

4.1 Data Transfer

LabVIEW has the capability to collect data in a number of formats. The program "Continuous Acquisition to Spreadsheet File" creates a spreadsheet in ASCII format with a column dedicated to each channel or signal collected and a row for each scan. For this thesis each file had three channels collected at 200 samples per second and therefore three columns and 200 rows per second of data collected creating files of 2.2 megabytes in size. The files were transferred to a faster computer for analysis purposes. However, due to their size they needed to be compressed in order to fit on a floppy disk. PKZIP v2.04g [PKWARE Inc.] was chosen to handle the task. This program takes files in ASCII and

converts them to binary format. This reduces the original file size by a factor of approximately 5.

All data were compressed from the DOS prompt, transferred to floppy disk, and loaded onto the hard drive of the computer used for analysis. PKUNZIP, the counterpart of PKZIP was used to restore the data back to ASCII format.

4.1.1 Data Separation

The data was to be split into time segments corresponding to each protocol and is explained in detail in Chapter 5 for each study.

File separation was done manually in Microsoft Excel. When saving a data file, LabVIEW saves the scan rate as line one, skips a line, and then begins data recording. The first two lines of the file must be eliminated because the analysis software Matlab does not accept a file formatted in this way. Excel allows the user to begin importing a file from line 1 to 32000. The spreadsheet program will load up to 65000 lines of data allowing a total of 97000 lines of data to be imported and saved as different segments.

The two channels of EEG and blood flow, the first two columns of data were separated identically and saved as one file. The analysis programs allows the user to choose which

column of data is desired to be processed. ECG files were handled differently since the analysis program would analyze a file containing only one column of data.

4.2 Signal Processing

Analysis was performed on an IBM compatible computer. After the data files were unzipped and separated, they were imported into MATLAB v4.2 [The Math Works Inc., Natick, MA]. This software package permits the custom writing of programs for engineering design and analysis while offering a significant preexisting toolbox loaded with algorithm scripts for windowing, filtering, and transforms.

4.2.1 EEG Analysis

Time frequency analysis quantifies the time evolution of the frequency rhythm of a signal and describes the frequency behavior over a time period. A program called "tf.m" written by Newandee [8] was used to calculate the time frequency spectrum of the EEG waves. A listing of the MATLAB code appears in Appendix A. The user indicates the data to be analyzed, window length (WL), and sliding window length (SWL). WL depicts the period of time to analyze as a single period and for this thesis 5 second periods were chosen. SWL describes to the program how far to advance

before accessing the next epoch of data. The data is fed in sections of length WL through a loop; the mean is extracted, and then normalized to the extracted mean. At this point the new data is stored in matrix form and a fast Fourier transform (FFT) is performed with zero padding at 1024 points. The data loop is then incremented by the SWL and this procedure continues until the end of the data file. This author suggested that the program provided the best results when a WL of 512 and a SWL of 1024 is used. After spending some time experimenting with various settings, it was found that Newandee's suggestion was a good one. The only change to the program was the frequency of interest: instead of looking between 0.05-50 Hz, 4-28 Hz was investigated.

4.2.2 EKG Analysis

Appendix A lists a program called "ps1.m" which was supplied from the Wigner Library. Ps1 calls multiple subroutines to interact in calculating the PSD (power spectral density) of the HRV wave. This routine has the ability to investigate respiration; however that particular signal is beyond the scope of this thesis and therefore the requests for respiration signals within the routines are commented out.

Ps1 begins by loading in the file and detecting the peaks of the QRS complex. The user has the option to scroll through the entire file to verify that all peaks were detected and if not, they can be corrected. All buttons and options in this window or portion of the program are written within the "control.m" script. Within this file "pslwsu.m" is called and from this script all other functions are called to perform various tasks on the data. "Grep.m" is the first routine called. It determines the number of samples between each peak detected, ie: ibi (interbeat interval). The iibi (interpolated interbeat interval) is then calculated from the ibi. This routine reads the number of samples between each beat and writes that number for that many times as if to resemble a step function. For instance, if there were five samples between two consecutive beats, the program would write 5 five times in a row. This is then decimated by ten through the "seq.m" script. The data is then detrended by "sqdt.m" and is finally ready for finding the spectrum. A script called "rspect.m" handles the FFT analysis.

When a power spectrum is done on an EKG signal, there are usually three peak areas that are of interest: the very low frequency peak (below 0.05 Hz), the low frequency peak (0.05-0.15 Hz), and the high frequency peak (0.15-0.40 Hz).

This thesis is most concerned with the low and high frequency peaks because these are the two peaks known to be under sympathetic and parasympathetic control and will be discussed in the results section. A Matlab script "apow" was written to calculate the area in each of these two frequency ranges. This program first calculates the FFT from the iibi then sums the magnitudes between the frequency range of interest.

4.2.3 Blood Volume Analysis

After trying various methods of analyzing the signals, it was found best suited to inspect the raw signals. This allows viewing changes in the peak to peak waveform as well as any disturbances such as finger movement.

A program called "abf" was written to calculate the average peak value over a time period of 30 seconds for the first two studies and a period of 20 seconds for the second two studies. The reason for the two different time intervals was due to the length of the files and will be explained in the result section for each study.

CHAPTER 5

PROTOCOLS AND RESULTS

In this chapter each study is discussed in detail: the specific protocol, the handling of data files, the experimental data, and the discussion of the results.

5.1 Study 1

Study 1 was designed to determine the differences that stressful and relaxing colored light environments cause on a subject. This experiment was run with a group of 17 subjects, eleven women and six men ranging from the age of 23 to 40. All subjects were without heart condition and considered healthy.

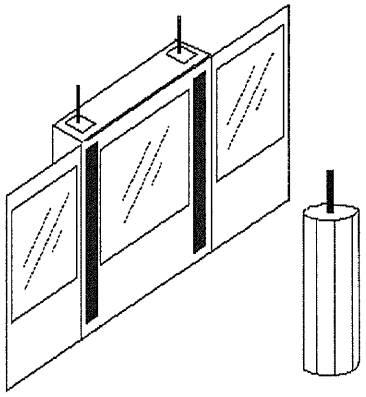


Figure 5.1 Light box used to create colored environments.

The first stage of the experiment required the subject to sit in front of a light box and determine subjectively the one color out of seven which felt the most relaxing and the one color that felt the most stressful. The light box was a three-way mirror designed for head reflection only with a light on either side of the middle mirror. Each colored light was

produced by a cellophane skin on a circular rotating cover over a florescent light bulb 12 inches in length situated on either side of the middle mirror as shown in Figure 5.1. When the circular covers were simultaneously rotated, the illuminating color changed producing a different environment.

There were several stimuli for this protocol: the light, a relaxor, and a stressor. The light was described above. The relaxor was a two minute segment from Reflections of Nature by Pachelbel "In Harmony with the Sea" and the stressor was a two minute period created by an alarming device from Radio Shack that consists of a dual frequency oscillator of 3 and 16 Hz played at 95 db which was measured with a Realistic sound meter. The audio tape was played through a portable cassette player by Awia through a quality set of Koss headphones.

The first recordings were done while the subject was seated comfortably in front of the mirror with the stressful color illuminating the face while the rest of the room was dark. The recording was a total of thirteen minutes consisting of a 5-minute baseline period, a 2-minute relaxor period, a 2-minute recovery period, a 2-minute stressor period, and another 2 minute recovery period.

The second half of the experiment was conducted with the subject in front of the light box illuminated with the relaxing color and the same audio tape was played. Table 1 lists the colors, the wavelengths, and the number of subjects who chose each color as relaxing. Another thirteen-minute period of data was recorded: 5-minutes of baseline, 2- minutes of relaxor, 2-minutes of recovery, 2-minutes of stress, and 2-minutes of recovery.

Table 5.1. Colors, wavelengths and number of subjects who chose each color as relaxing and stressful.

Color	**λ (nm)**	**relaxing**	**Stressful**
Red	648	2	2
Orange	592	0	4
Yellow	580	0	11
Green	558	6	0
Blue	491	7	0
Violet	407	2	0
white		0	0

5.1.1 Explanation of Protocol

Five minutes of baseline in the beginning of the session was recorded to establish normal patterns for the

individual in the particular environment of color. It also served the purpose to dissolve any stress associated with the white coat syndrome (stress involved with clinical environments and doctors). The relaxor and stressor were put into the experiment to show some indication of how stable the subject's mood had become in the present environment. The two-minute recovery period was incorporated after the relaxor period to allow for any residual changes to dissipate. It also served as an indicator to show long it took a subject to recover.

5.1.2 Data Separation

It was advantageous to separate the data files into sections due to the length of the files and also to view the audio stimulus sections separately. The first five-minute period was taken as baseline. The next section consisted of the two-minute relaxor period with a one-minute pre- and post- stimulus. The two-minute stressor period also contained a one-minute pre- and post- stimulus section. This allows for continuity when viewing the plots and offers the advantage of seeing changes occurring prior to and after the stimulus: time delays occur within most systems of the body.

The files were loaded into a Unix based system and run by a program called 'lhsplit' as listed in Appendix E, which split the files into sections as described above. All data was saved onto a zip disk through an Iomega zip drive and loaded into a Compaq Presario computer with a processor speed of 266 MHz which was used for the analysis of the data.

The analysis techniques described in Section 4.2 were applied to the data. The following pages show a sample of the data collected.

5.1.3 Results

After viewing the analyzed data, it was discovered that although the subjects recognized the stressor as stressful, the data did not show that to be true. For example, Figure 5.2 in Appendix A shows the arterial blood flow of one subject. Notice that the peak-to-peak amplitude of the waveform does not change during the stress or the relaxation period. Figure 5.3 in Appendix A shows the HRV spectrum. The boxes to the left of the plots indicate numerically the power in the low and high frequency bands. The powers do not change significantly during any of the three periods indicating there were no changes in behavioral response.

All of the subjects were run one after another over a two-day period. This did not allow for enough time to look closely at the data to interpret that the stressor was not effective. Therefore all seventeen subjects were run.

In response to this error, a few short studies (two-minutes in length) of a few subjects were run to decide on a new stressor. Another Radio Shack warble oscillator device with a high pitch and 102 dB output was tested alone and in conjunction with the device used in Study 1. The result was still not stressful enough. Under the suggestion of Dr. S. Reisman, a radio delivering static was tested on a group of subjects and showed positive results: the subjects showed signs of stress in both the pbf and HRV and therefore it was chosen as the stressor.

5.2 Study 2

After running the first study, it was decided that a true relaxed baseline would be best ascertained during an interval with the eyes closed and therefore part one of Study 2 was conducted with the eyes closed. The stressor was incorporated during part one of Study 2 to act as a comparator to part 2 of this study during which the subject's eyes were open in the colored light environment.

This experiment was run with group of 8 subjects, six women and two men ranging from the age of 23 to 40. All subjects were without heart condition and considered healthy.

The stimulus for this study was the light box and an audio stressor, which was induced unannounced by a radio delivering static at 95 dB measured with a Realistc sound meter.

The experiment consisted of two parts each occurring in a dark quiet room while the subject was comfortably seated. During part one, the subject was instructed to sit quietly with the eyes closed. Eight minutes of data was collected: 4 minutes of baseline, two minutes of auditory stress, and two minutes of recovery.

The first stage of part two required the subject to sit in front of a light box and determine subjectively the color, which felt the most relaxing. The second stage of part two of the experiment was conducted with the subject, eyes opened in front of the light box illuminated with that relaxing color. Table 2 lists the colors, the wavelengths, and the number of subjects who chose each color as relaxing. Another eight-minute period of data was recorded: 4 minutes of baseline, 2 minutes of stress, and 2 minutes of recovery.

Table 5.2. Colors, wavelengths and number of subjects who chose each color as relaxing.

Color	λ (nm)	Relaxing
Red	648	0
Orange	592	0
Yellow	580	0
Green	558	4
Blue	491	3
Violet	407	1
white		0

5.2.1 Data Separation

The files for this protocol were eight minutes in length, 96000 data points, and could therefore be separated in Microsoft Excel 97. After loading the data files into the computer for analysis, they were unzipped, and loaded into Excel. A baseline section was taken for the first 4-minutes and a stress section was taken one-minute pre- and post- the stimulus period. This was done for both parts of Study 2 for both peripheral blood flow (pbf) and EEG. The EKG signal was separated by taking two 2-minute segments: one for baseline and one for the stress period only. This insured heart rate information for the stress period only

and could be compared to an equivalent time segment of baseline data.

5.2.2 Results

The pbf turned out to be a good measure of stress: the amplitude during the stress period of the pbf wave decreased in magnitude in seven of the eight subjects. The stress plots b and d of Figures 5.5 in Appendix B show that there is a delay time in response to the stimulus. The onset of the stressor occurs at point 12000; however, the actual response to the stress occurs around 14000, five seconds later. The subject of BLD illustrates the ideal response scenario. The pbf amplitude is largest when the eyes are closed and decreases when the stressor is applied. Under the influence of colored light with the eyes opened, the amplitude of the pbf is not as large and while the stressor is applied, the amplitude again decreases, however, to a lesser degree than as with the eyes closed. This would indicate that the colored light has a relaxing effect on the subject; however, only 5 of the 8 subjects have responded in this way.

Studying the work of many others who have done heart rate variability research [12,18,19,22], the results of this study are similar. It has been found that the high

frequency peak (0.15 - 0.4) Hz is significantly higher when a person is relaxed (see Appendix B: Figures 5.13 through 5.20 in plots a and c). This peak controlled by the parasympathetic nervous system significantly changes during mental stress [10] and decreases in power when inspecting the power spectrum. This was consistent through this study with few exceptions however, the ratio of low frequency area to high frequency area (LFA/HFA) did not always increase. This could be due to the partial sympathetic activity occurring in the LFP (0.05 - 0.15) Hz range.

The estimation of power spectra was used in processing the EEG data. The output was a 3-D mesh plot as shown in Appendix B in Figures 5.21 through 5.28. Overall, the plots do not follow the results of the other data collected per subject. For most subjects there was a large amount of activity between 3.5 - 8 Hz. Normally this is indicative of emotional stress. However, since the plots per subject do not vary per intervention (ie: eyes closed, stress) it was considered to be of irrelevant origin to this research. There is EEG activity present in the plots; however, not substantial enough to draw conclusions on what is occurring. Electrode placement within the hairline is rather cumbersome and messy yet would probably provide better insight to the activity within the brain.

5.3 Study 3

This case study was incorporated to act as a link between Studies 2 and 4. In Study 2, temperature and conductivity were not recorded due to the lack of instrumentation available. Studies 3 and 4 were conducted in White Plains, New York under the advisement of Dr. Frenkel who provided the equipment for the additional two signals. Dr. Frenkel had been working with patients and colored light therapy for a number of years.

This study acted as a bridge to determine the relationship between both sets of signals (EKG, EEG, blood flow and temperature, conductivity) under the influence of the same stress stimulus. Study 4 did not use this stressor for reasons discussed in Study 4.

This study was set up as an eight-minute recording run on a single person sitting with his eyes closed. The colored light was not involved; however, the audio stressor was introduced for two minutes at the beginning of the fifth minute of recording. The stress period was followed by a two minute recovery period. EKG, EEG, and pbf were recorded in addition to finger temperature and conductivity.

5.3.1 Temperature and Conductance Acquisition

Temperature and skin conductance were recorded in Studies 3 and 4 as additional indicators of stress. A second computer, an IBM compatible computer with a 33 MHz processor was used to collect the peripheral temperature and conductance measurements at the fingers. Both signals were conditioned by a J&J Personal Computer Physiological Monitoring System (J&J Enterprises, Poulsbo, Wa., 1988). A program called "Protool4" was used for data acquisition and is listed in appendix E. Both the temperature and skin conductance were sampled at 0.5 samples/second.

Temperature was measured with a thermistor that was taped to the subject's middle finger. Peripheral temperature gives indication of stress by means of vasoconstriction. Vasoconstriction causes the arterioles to pass less blood, which in turn causes the skin temperature to decrease.

The conductance was measured with a two-electrode system strapped with Velcro to the subject's index and middle fingers. Skin conductance can indicate stress caused by neural and chemical activity occurring in the dermis of the skin. Under the influence of stress, this activity increases causing the skin conductance to also increase.

5.3.2 Data Separation

After being loaded into the computer, the file was unzipped and loaded into Microsoft Excel. The entire file was split into two minute segments: the first two segments were baseline data, the third was the stress period, and the fourth was the recovery-period.

5.3.3 Results

After studying the data set of this subject (DRF) which is listed in Appendix C, it was determined that temperature and conductivity were not advantageous measures of stress for this subject. The changes in skin temperature take too long to become visible and the conductance for this subject showed no changes at all (Figure 5.32). The pbf (Figure 5.29) indicated a stressed subject at the time of the stimulus and while the HRV (Figure 5.30) did not, it may have been a result of the large amount of noise in the EKG signal discovered during the processing.

When viewing the pbf in conjunction with the EEG (Figures 5.29 and 5.30), some interesting things have been noted. At points 6000 and 10000 on the last blood flow plot of DRFT an irregularity (a sudden rise in the DC level) in the waveform has occurred and there is activity across the entire range of the frequency spectrum of the EEG at these

times. The amplitude of these occurrences appears to vary similarly to the blood flow variation. The exact nature of these occurrences is not known; however, it has been thought to be a phenomenon of pure relaxation. However, if this were true, it would be probable to see these occurrences more often during the periods when the subjects' eyes were closed.

5.4 Study 4

All five of the subjects of this study were under the treatment of Dr. Frenkel and have been exposed to the light box prior to this study. Prior testing showed that these subjects responded to colored light in stressful and relaxed manners and sometimes severely. It was decided to eliminate any additional stimuli for the well being of the subjects and also because prior testing showed a response from the colored light alone. Therefore colored light was the sole stimulus of this protocol.

The subjects were seated comfortably at a light box which was different from the previous studies. This light box was constructed for Dr. Frenkel's therapy analysis. The subject's head rests on a rectangular opening exposing only the face to a mirror. The mirror is then lit with colored light bulbs to illuminate the face in that particular

environment. The color of the light was variable as well as the intensity.

The recording began with white light and went through a series of eight colors continuously, each for two minutes. They were white, red, orange, brown, green, yellow, blue, and violet. The colors were sequenced by Dr. Frenkel by means of a control box which was cabled long enough for him to be out of view of the subject. The signals recorded were EKG, EEG, blood flow, temperature, and conductance.

5.4.1 Data Separation

The files were loaded into a Unix based system and run by a program called 'drfsplit' as listed in Appendix A, which split the files into two sections. All data was saved onto a zip disk through an Iomega zip drive and loaded into a Compaq Presario computer with a processor speed of 266 MHz which was used for the analysis of the data. The files were loaded into Microsoft Excel and split into two minute segments that corresponded to each color.

5.4.2 Results

The discussion of results of Study 4 will be presented on an individual subject basis. The results vary significantly

from one subject to the next and are shown in Appendix D. One possible reason for the lack of response may have been that the intensity of light within the light box was too intense to get an accurate response from the subject. Too bright of a light causes stress and therefore a relaxed response may never have been able to occur. Two of the six subjects (DRF1 and DRF2) were run with this possible error. DRF2 was run a second time with the light intensity at 65%. This file is DRF5 and will be discussed in conjunction with DRF1.

DRF1 and DRF5

The files of DRF1 and DRF5 are both of the same subject. DRF1 was run with the light intensity at 100 %, which seemed to neutralize any expected response. The opportunity to run this subject for a second time allowed for comparison of the signals under both light intensities (100 % and 65 %) however, the results were not as would be expected. In DRF5 there were no significant changes in the pbf (Figures 5.40 and 5.41) although there was a lot of movement indicating an uncomfortable or fidgety subject. This was noted at the time of recording and it was also observed that the subject's eyes were opening and closing as if very sleepy during the latter part of the recording.

This may have been occurring throughout the entire recording; however it was not noticed. The HRV for DRF1 (Figures 5.35 and 5.36) showed no major changes in frequency ranges while the HRV for DRF5 (Figures 5.43 and 5.44) followed the known pattern more closely. The stress color for this subject is orange and is indicated in the second plot of the First 4 colors. The HFA is low and the LFA/HFA is high which would be expected for a stressed person.

The EEG in DRF1 indicates no significant changes throughout the entire test; however, DRF5 does. The spectrum shows many areas of high activity in the low frequency areas and often across the entire frequency range. There was correlation between this activity and the activity in the pbf.

Visually, the temperature and conductivity oppose each other: the magnitude of the conductance increases during stress while the magnitude of the temperature decreases. The plots of DRF1 are what would be expected to see as an average plot: at the beginning of each change of color, the conductance increases then follows the mood of the subject. However, for this subject the response for the relaxed and stressed colors are very similar and act opposite to the norm.

DRF2

This subject was run with the light intensity at 100 % and shows no significant behavioral response in any of the plots. Although this is true, there is correlation between the pbf and the EEG. At the times of irregularities in blood flow (figures 5.47 and 5.48), there are bands across the frequency range in the EEG spectrum (Figures 5.51 and 5.52). These occurrences are not as prominent for this subject in comparison to the other subjects, which could be due to the high light intensity therefore suppressing the phenomena. This would make sense if the occurrences are pure relaxation.

DRF3

The pbf (Figures 5.45 and 5.55) shows that there was some initial stress with this subject which disappeared after three minutes. The blood flow wave averaged between 7-8 volts except in the last plot which seemed to cause this subject's stress.

At the end of the fifth color, the EEG electrodes began to slip off (as advised by the subject). Both the EEG and the pbf show this: the EEG (Figures 5.48 and 5.59) goes to a minimum and the pbf wave indicates stress for about 20 seconds until the problem was fixed. The EEG also shows

high activity between 3-6 Hz just after the stress period is ending in the pbf.

In the EKG spectrum for this subject it was very hard to be quantitative (Figures 5.56 and 5.57): the spectrum showed major inconsistencies in all 8 plots and appeared to show nothing of importance.

The temperature plot shows no sudden or drastic changes; however, the conductance follows the pbf. The conductance shows small peaks where the peak-to-peak blood flow wave decreases. This is especially evident at the time when the electrodes came loose. The conductance reaches a maximum during the last color of the experiment, which was the subject's stressful color.

DRF4

Of all the subjects run, this one was the most astonishing. The behavioral response entailed fidgeting, sniffling, and crying during certain colors and at times it was necessary to end the session of one color and continue to the next: This is the reason for the shortness of some data trials. This subject was extremely sensitive to the red family. During the second and into the third color the subject was crying. The pbf (Figures 5.61 and 5.62) shows stress and irregularities during these times and becomes more normal

during colors six and seven. The recovery time seemed to be prolonged both by observation during recording and also in viewing the processed data. All of the EKG files cannot be considered accurate due to the length of the segment: under two minutes of data does not provide enough information for proper assessment. However, the power under the specific frequency bands of interest have been scaled as if the time segment were two minutes. Referring to Figures 5.63 and 5.64, the power in the bands show signs of stress as well as the LFA/HFA sympathovagal balance. The EEG data collected on this subject does not provide any additional insight: there appears to be no changes which might have been due to electrode placement since all of the other signals collected for this subject have indicated response.

The temperature shows changes at the stressful colors and levels off toward the latter part of the entire session (Figure 5.67). The conductance indicates best what was known to be true of this subject. It increases drastically during the second color, remains high during the third, and then slopes down rather linearly to the sixth color where it reduces further but very slowly as if it were remaining constant. It was known that reds were stressful to this subject while blues were relaxing.

DRF6

This subject was interesting. She had been working with Dr. Frenkel to desensitize herself from colors. Her relaxing color was gray which was not one of the eight colors of the test. Due to this process of desensitizing, the pbf (Figure 5.68 and 5.69) showed only a few changes and not enough to evaluate stress or relaxation. There was also a problem with her heart that was discovered during the recordings and therefore the HRV spectrum is not very informative. The EEG (Figures 5.72 and 5.73) correlates with the few changes in the pbf and also shows something else occurring in the 3-6 Hz frequency range. Activity varying in time and magnitude occur throughout the entire recording. Normally it would not be considered so seriously; however, at the end of the recording the subject spoke of spiritual visions she experienced during each of the colors. This may be the origin of the low frequency activity present in the plots.

The temperature plot does not show changes. The conductance plot shows a stress correlation with the pbf and EEG during the third color and again during the seventh color.

5.5 Conclusions and Future Research

These studies collectively served as a pilot study for future research. Color has been known to create mood changes for years. To what extent is now being investigated. From this study it seems to be highly effective in people who have some form of chemical deficiency or imbalance.

It was found that it is better to collect a number of different signals because not all people respond in exactly the same way. However, some measures are more revealing. For example, the pbf is a good and easily assessed measure of stress. The signal processing can and should be taken a step further than what was presented in this study. The peak-to-peak amplitude per individual waveform proves to be a beneficial tool. The EKG becomes important when interest lies in the sympathetic and parasympathetic nervous systems and their interaction with stress and was a good indicator of stress for this study. The EEG provides insight on the mechanisms of the brain to which there is still so much to be discovered. However, a method should be used that provides more information than what was used in this study. Perhaps an EEG cap which uses microneedle electrodes at all 20 locations as standardized by the International Federation of EEG Societies would better capture the

activity occurring within the brain. The EEG information recorded within the studies does not provide a significant amount of information. It was interesting, however, to see that during the EEG when the entire frequency range became active, there was also a concurrent event in the pbf. Although the exact nature of the occurrences is unclear, something is happening that should be investigated further. The occurrences do not happen at any particular onset or offset of a stimulus and do appear to occur randomly.

Skin conductance provided additional insight and tied together events that were occurring in one or more of the other signals collected and therefore was helpful. Temperature was not a helpful tool in assessing the outcome of the tests: this parameter changes too slowly to catch immediate changes that occur during the switching of colors.

One of the goals of this thesis was to determine whether colored light could counteract the effects of stress. Study 2 was conducted with normal subjects and was directed to answering this question. There were not enough subjects participating in this study to conclude a positive answer. However, the data collected does appear to support this to be true. The average peak to peak baseline amplitude is larger with the eyes closed yet during the

stress period, the peak to peak value largely decreases. During the session with the eyes open the average peak to peak baseline value was smaller than with the eyes open and during the stress period, the waveforms peak to peak value decreased less than had occurred with the eyes open. Another study should be conducted with a larger n and analyzed statistically: this study did not have enough subjects to do so.

Further studies should also be conducted on many different subject groups: the severely depressed, the hypertensive, the anxious, just to name a few. A pair of tinted glasses could end up replacing many prescription drugs leaving the patient with many less side effects.

APPENDIX A

ARTERIAL BLOOD FLOW OF BASR

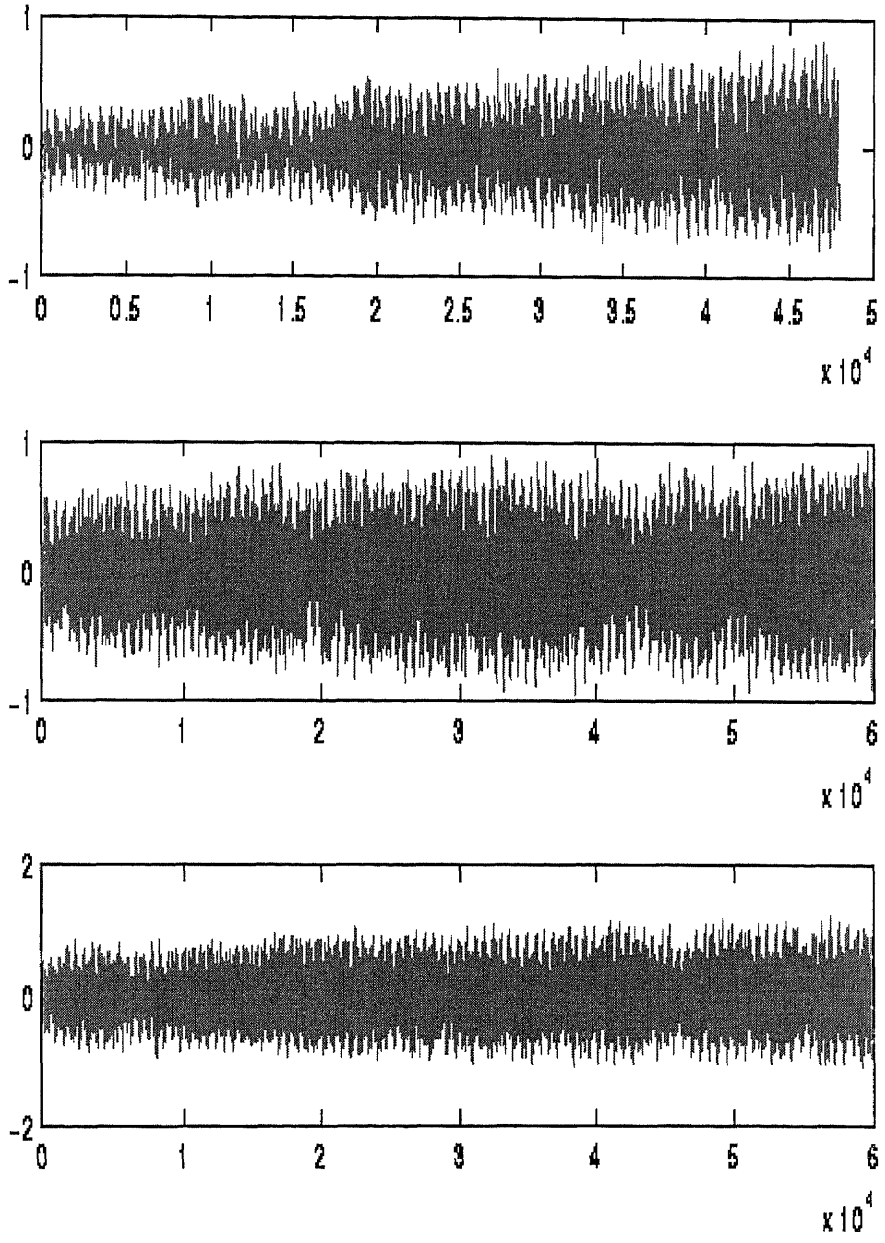


Figure 5.2: Under the influence of relaxing colored light: a)baseline b) during relaxor c) during stressor.

ECG SPECTRAL ANALYSIS - BASR

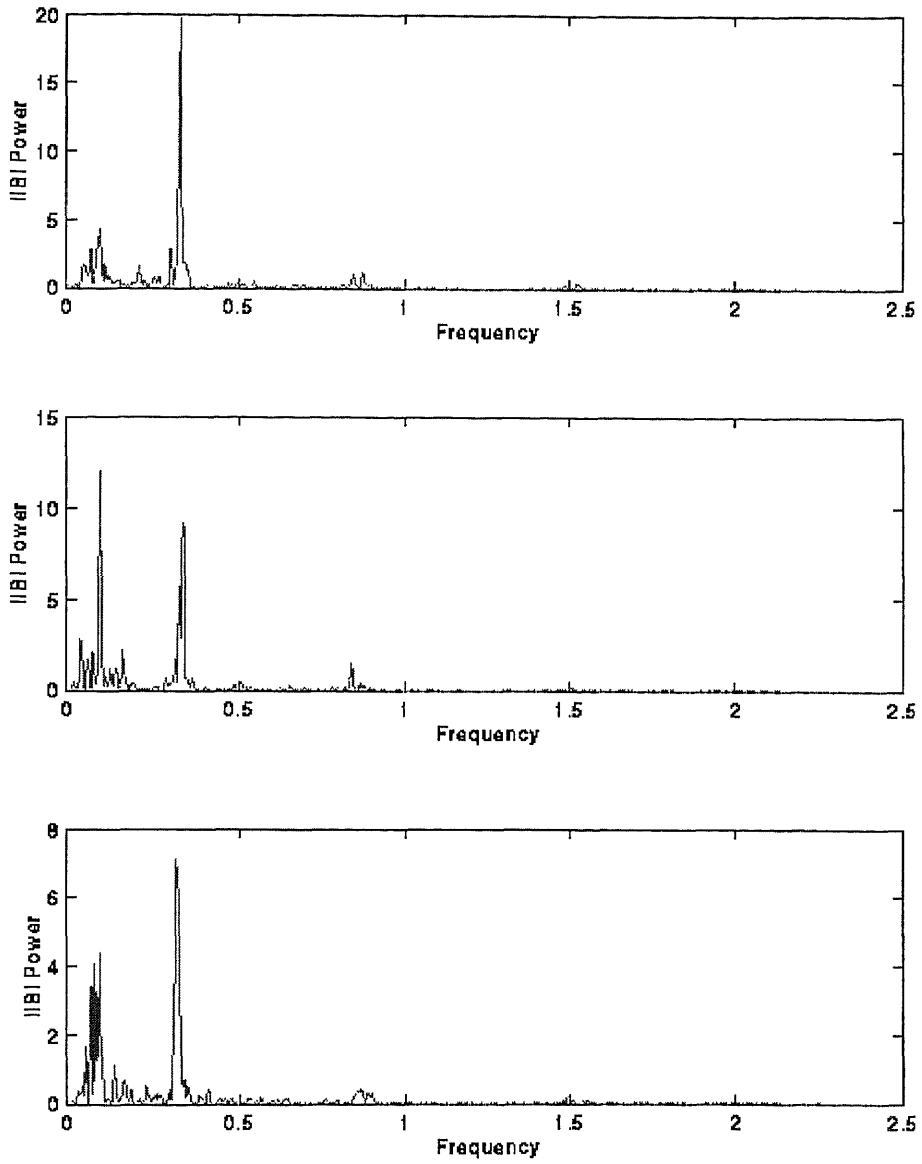


Figure 5.3: Under the influence of relaxing colored light: a)baseline b) during relaxor c) during stressor.

EEG SPECTRUM OF BASR

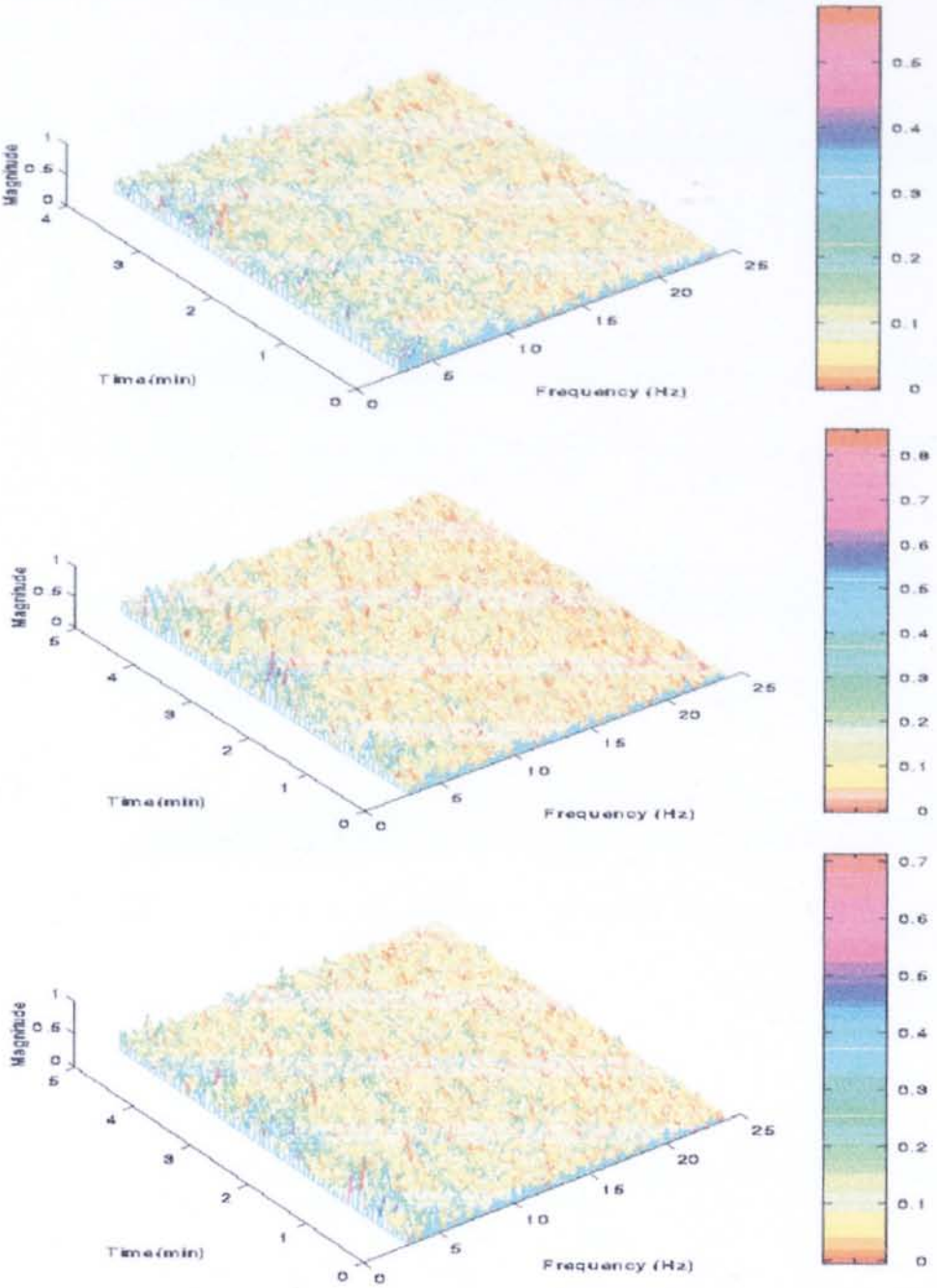
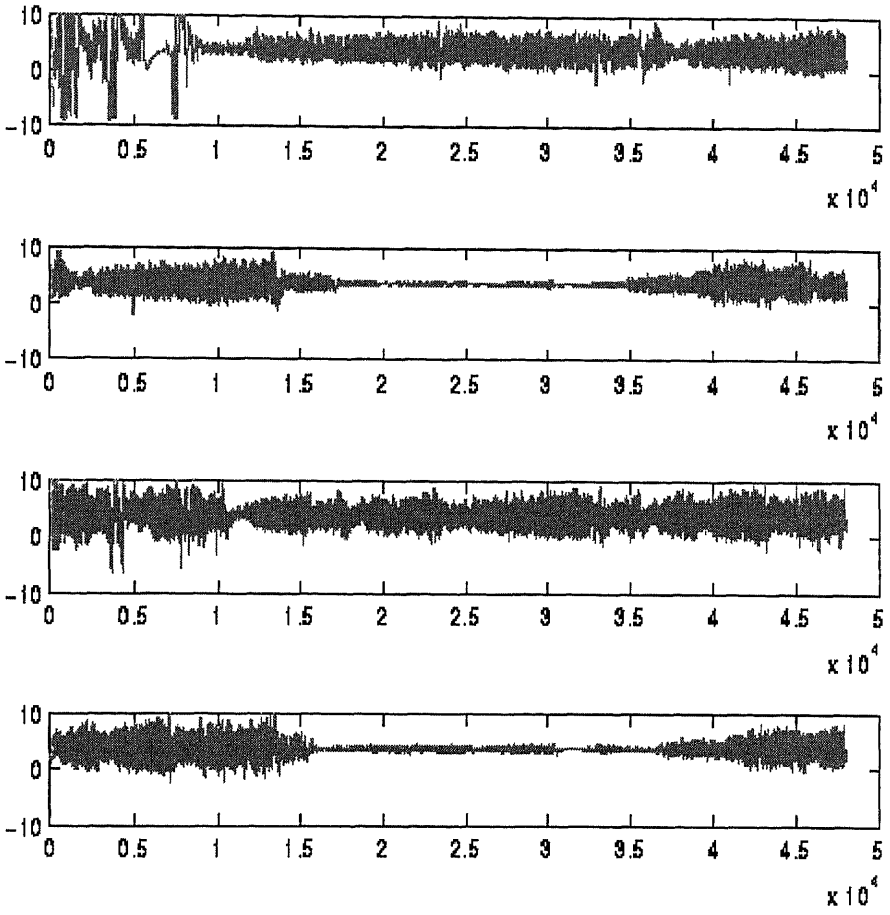


Figure 5.4: Under the influence of relaxing colored light: a)baseline b) during relaxor c) during stressor.

APPENDIX B

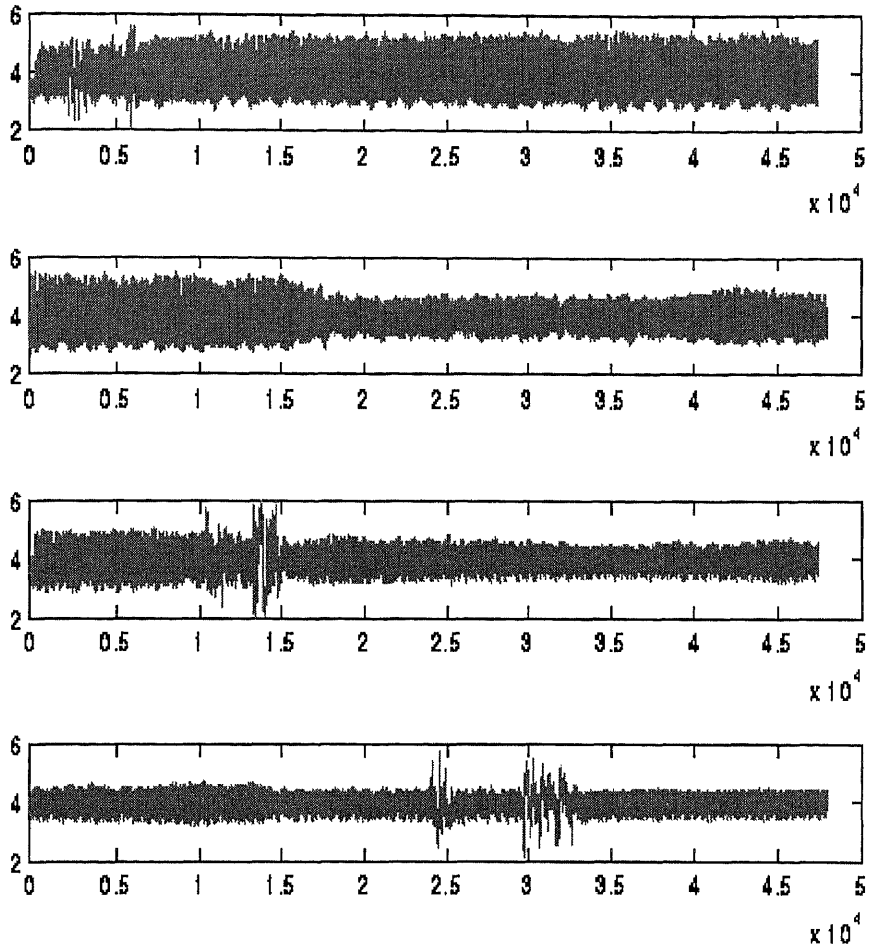
ARTERIAL BLOOD FLOW OF BAS



BAS	1-6K	6K-12K	12K-18K	18K-24K	24K-30K	30K-36K	36K-42K	42K-48K
BAS1	7.73	2.21	3.84	4.20	5.58	5.47	3.30	6.70
BAS2	4.15	4.87	3.72	1.29	1.32	1.98	3.51	5.93
BAS3	9.18	8.78	4.92	5.98	6.39	8.14	7.20	7.89
BAS4	6.74	8.47	4.52	1.31	1.24	0.95	2.63	4.56

Figure 5.5: A) a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period **B)** table of average wave amplitudes for 30 second periods.

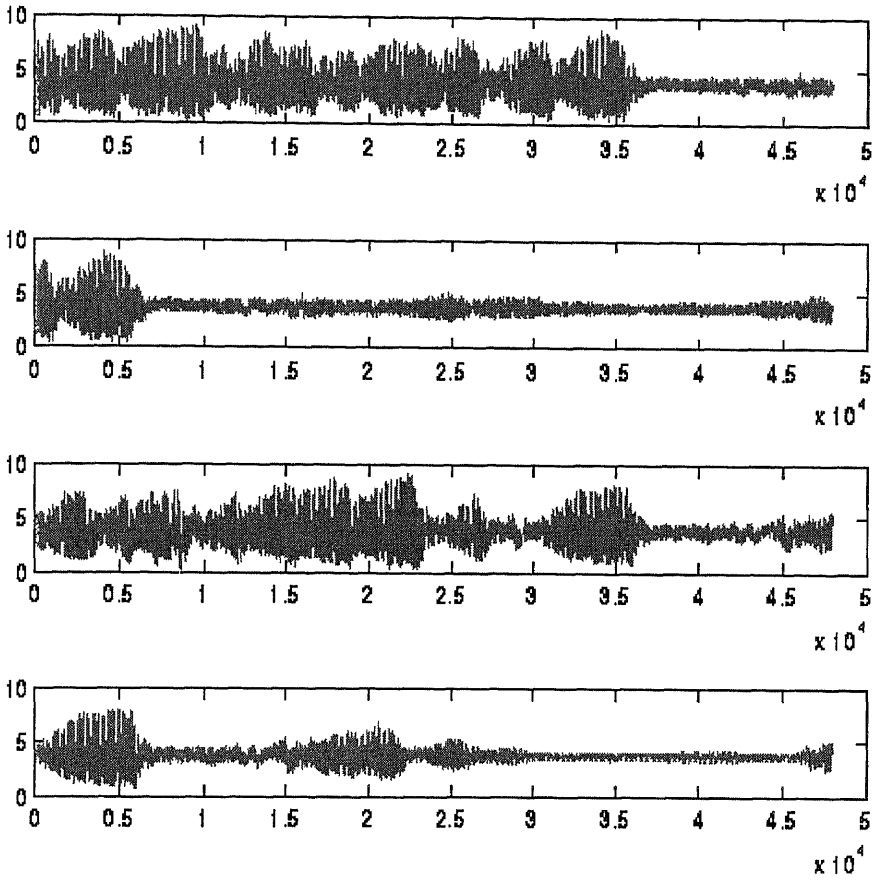
ARTERIAL BLOOD FLOW OF BLD



BLD	1-6K	6K-12K	12K-18K	18K-24K	24K-30K	30K-36K	36K-42K	42K-48K
BLD1	1.91	2.26	2.20	2.24	2.30	2.29	2.35	2.32
BLD2	2.35	2.32	2.11	1.30	1.36	1.33	1.46	1.66
BLD3	2.00	1.88	1.79	1.45	1.29	1.13	1.11	1.25
BLD4	1.12	1.25	1.07	0.99	1.23	1.23	0.96	0.95

Figure 5.6: A) a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period **B)**) table of average wave amplitudes for 30 second periods.

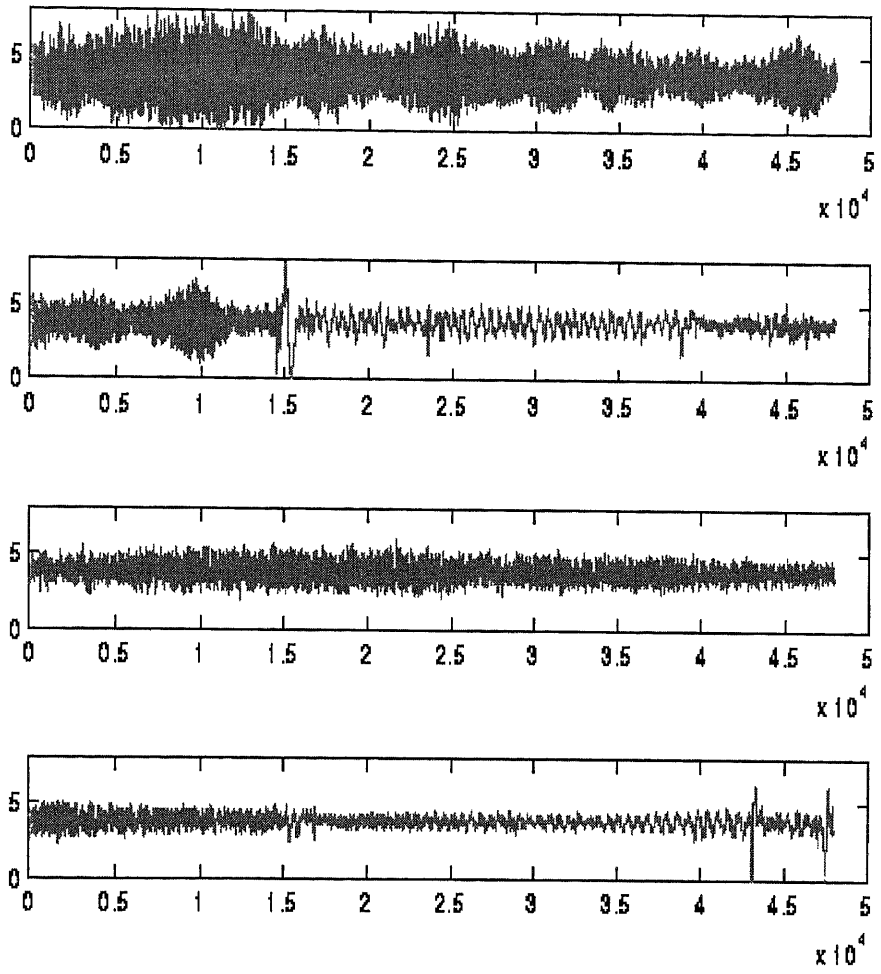
ARTERIAL BLOOD FLOW OF DAB



DAB	1-6K	6K-12K	12K-18K	18K-24K	24K-30K	30K-36K	36K-42K	42K-48K
DAB1	5.90	6.53	5.29	5.35	4.98	5.97	1.24	1.28
DAB2	5.97	1.24	1.28	1.30	1.79	1.04	0.85	1.44
DAB3	4.42	4.49	5.86	6.33	2.93	5.22	1.56	1.95
DAB4	5.22	1.56	1.95	3.12	1.64	6.59	0.74	1.05

Figure 5.7: A) a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period **B)** table of average wave amplitudes for 30 second periods.

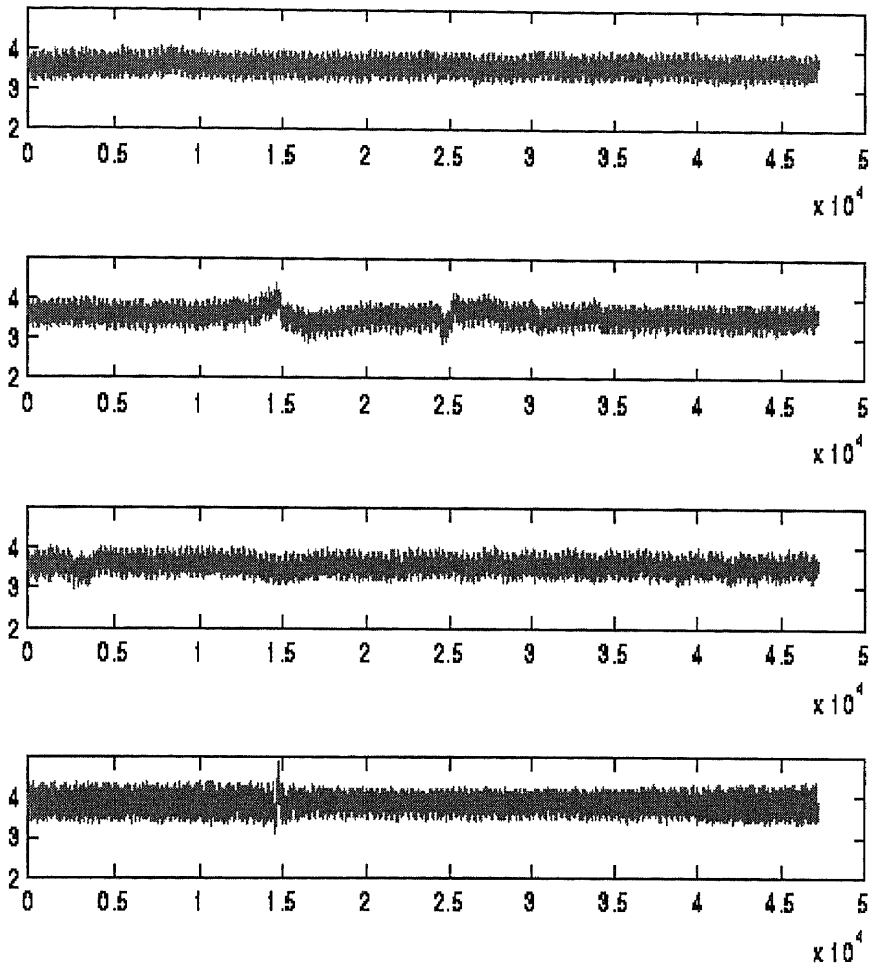
ARTERIAL BLOOD FLOW OF JLB



JLB	1-6K	6K-12K	12K-18K	18K-24K	24K-30K	30K-36K	36K-42K	42K-48K
JLB1	4.58	6.38	5.09	4.00	4.22	3.64	2.66	3.19
JLB2	2.66	3.19	1.88	1.17	1.20	1.01	0.93	1.07
JLB3	1.82	2.43	2.50	2.58	1.93	2.00	1.84	1.40
JLB4	1.84	1.40	1.16	0.85	0.79	0.65	0.81	1.59

5.8: A) a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period **B)** table of average wave amplitudes for 30 second periods.

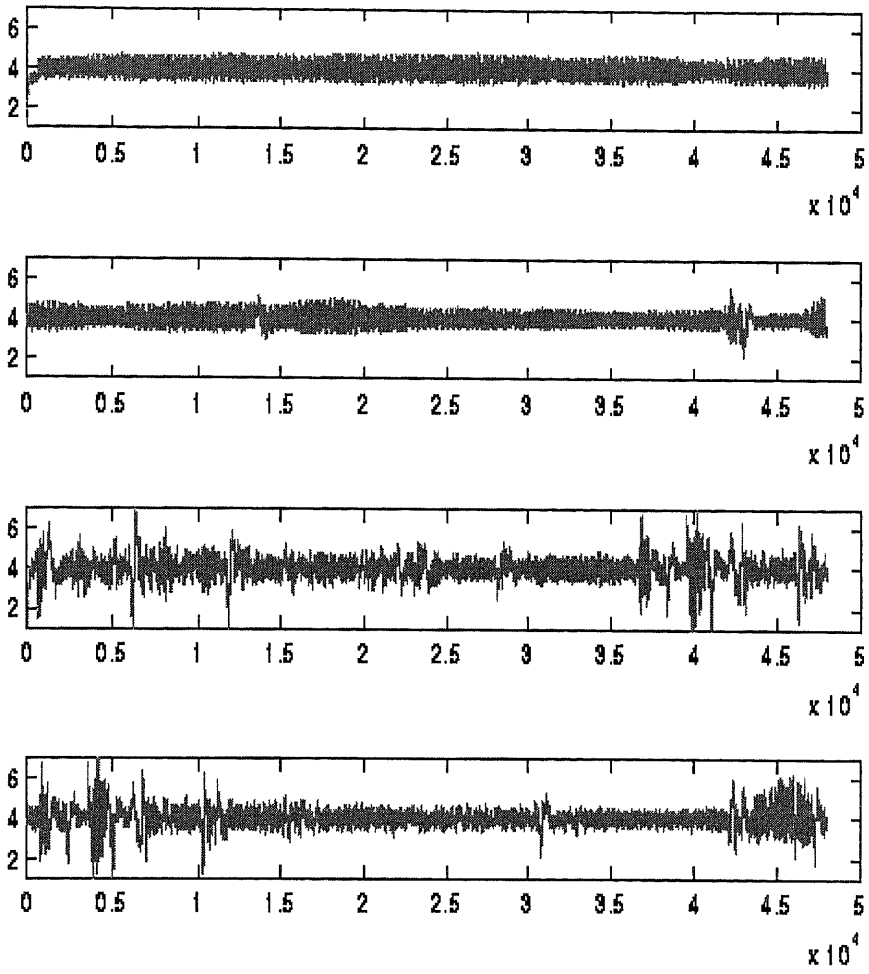
ARTERIAL BLOOD FLOW OF SGL



SGL	1-6K	6K-12K	12K-18K	18K-24K	24K-30K	30K-36K	36K-42K	42K-48K
SGL1	0.93	0.94	0.85	0.90	0.95	0.84	0.90	0.85
SGL2	0.90	0.85	0.86	0.73	0.73	0.72	0.78	0.76
SGL3	1.03	0.97	1.04	0.98	0.90	0.98	0.90	0.89
SGL4	0.67	0.66	0.66	0.66	0.65	0.66	0.66	0.67

Figure 5.9: A) a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period **B)** table of average wave amplitudes for 30 second periods.

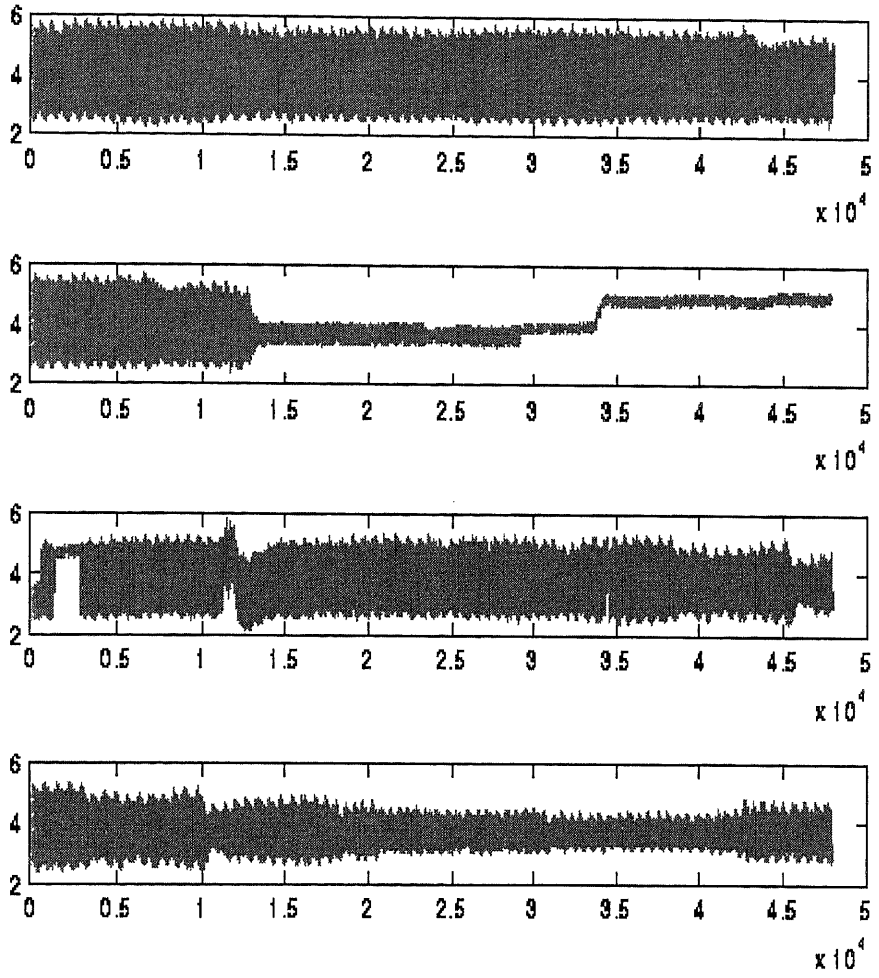
ARTERIAL BLOOD FLOW OF SJC



SJC	1-6K	6K-12K	12K-18K	18K-24K	24K-30K	30K-36K	36K-42K	42K-48K
SJC1	1.11	1.22	1.22	1.33	1.35	1.23	1.15	1.27
SJC2	1.15	1.27	1.41	1.32	0.96	0.85	0.87	1.12
SJC3	1.85	2.11	1.45	1.46	1.26	1.27	2.32	1.91
SJC4	2.32	1.91	1.37	1.10	1.01	1.02	0.93	2.42

Figure 5.10: A) a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period **B)** table of average wave amplitudes for 30 second periods.

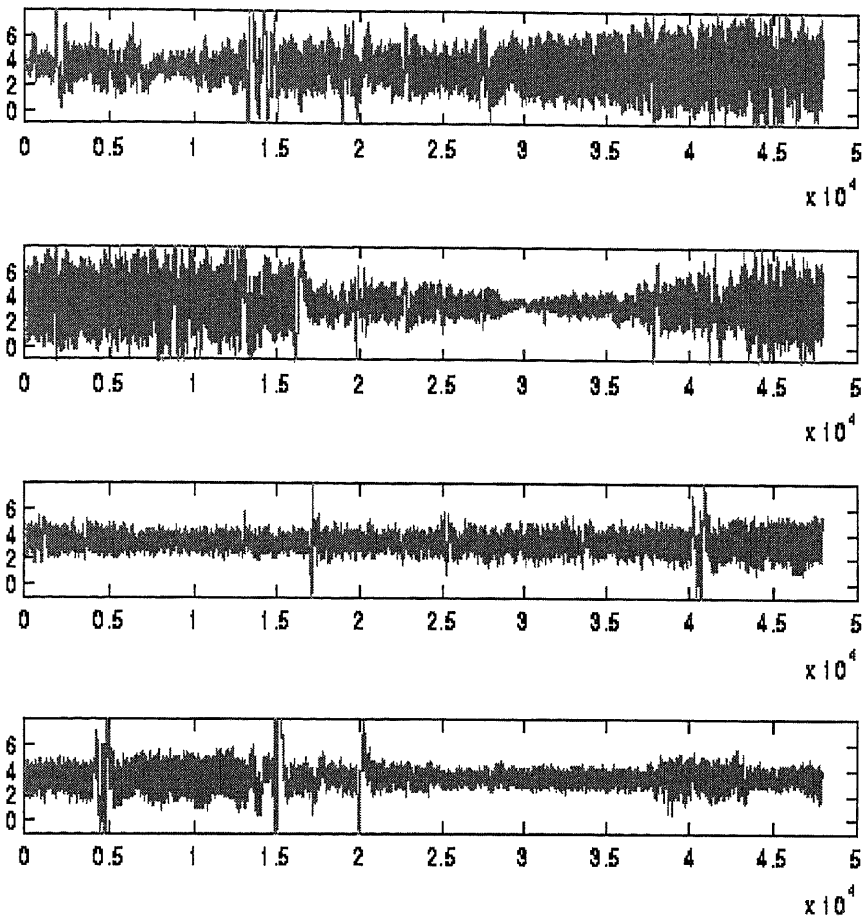
ARTERIAL BLOOD FLOW OF SMM



SMM	1-6K	6K-12K	12K-18K	18K-24K	24K-30K	30K-36K	36K-42K	42K-48K
SMM1	3.06	3.14	2.88	2.88	2.92	2.96	2.83	2.65
SMM2	2.83	2.64	1.01	0.68	0.56	0.33	0.34	0.33
SMM3	1.88	2.48	2.38	2.49	2.50	2.44	2.35	2.01
SMM4	2.42	2.04	1.96	1.50	1.29	1.10	1.13	1.71

Figure 5.11: A) a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period
B) table of average wave amplitudes for 30 second periods.

ARTERIAL BLOOD FLOW OF TSK



TSK	1-6K	6K-12K	12K-18K	18K-24K	24K-30K	30K-36K	36K-42K	42K-48K
TSK1	4.86	4.85	4.56	5.15	4.80	5.01	4.59	5.05
TSK2	4.59	5.05	4.42	4.36	5.16	4.45	5.24	4.61
TSK3	1.97	1.91	1.97	2.05	2.13	1.86	1.95	1.94
TSK4	1.95	1.94	1.91	1.86	1.96	1.84	2.04	2.88

Figure 5.12: A) a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period
B) table of average wave amplitudes for 30 second periods.

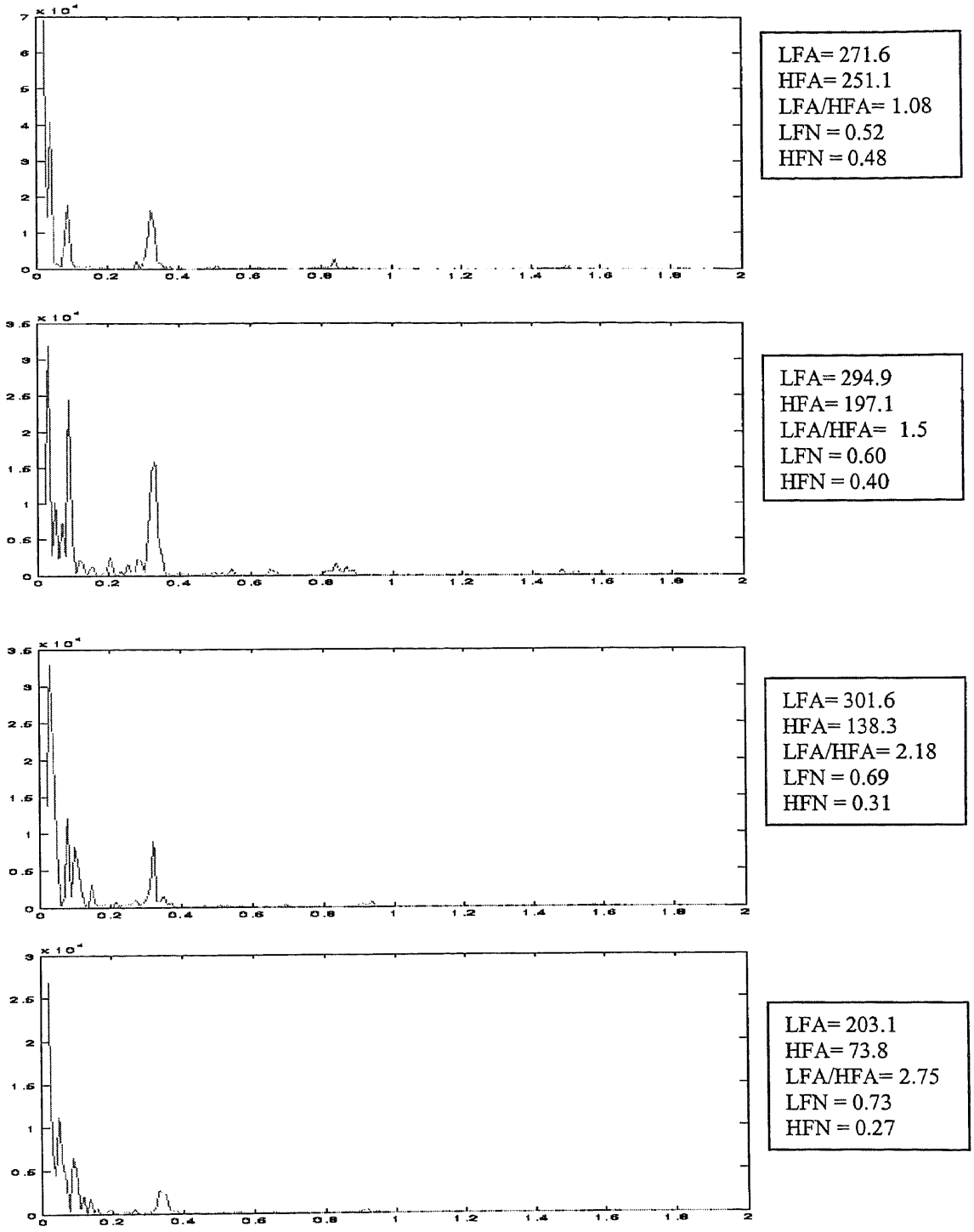


Figure 5.13: a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period.

HRV SPECTRAL ANALYSIS - BLD

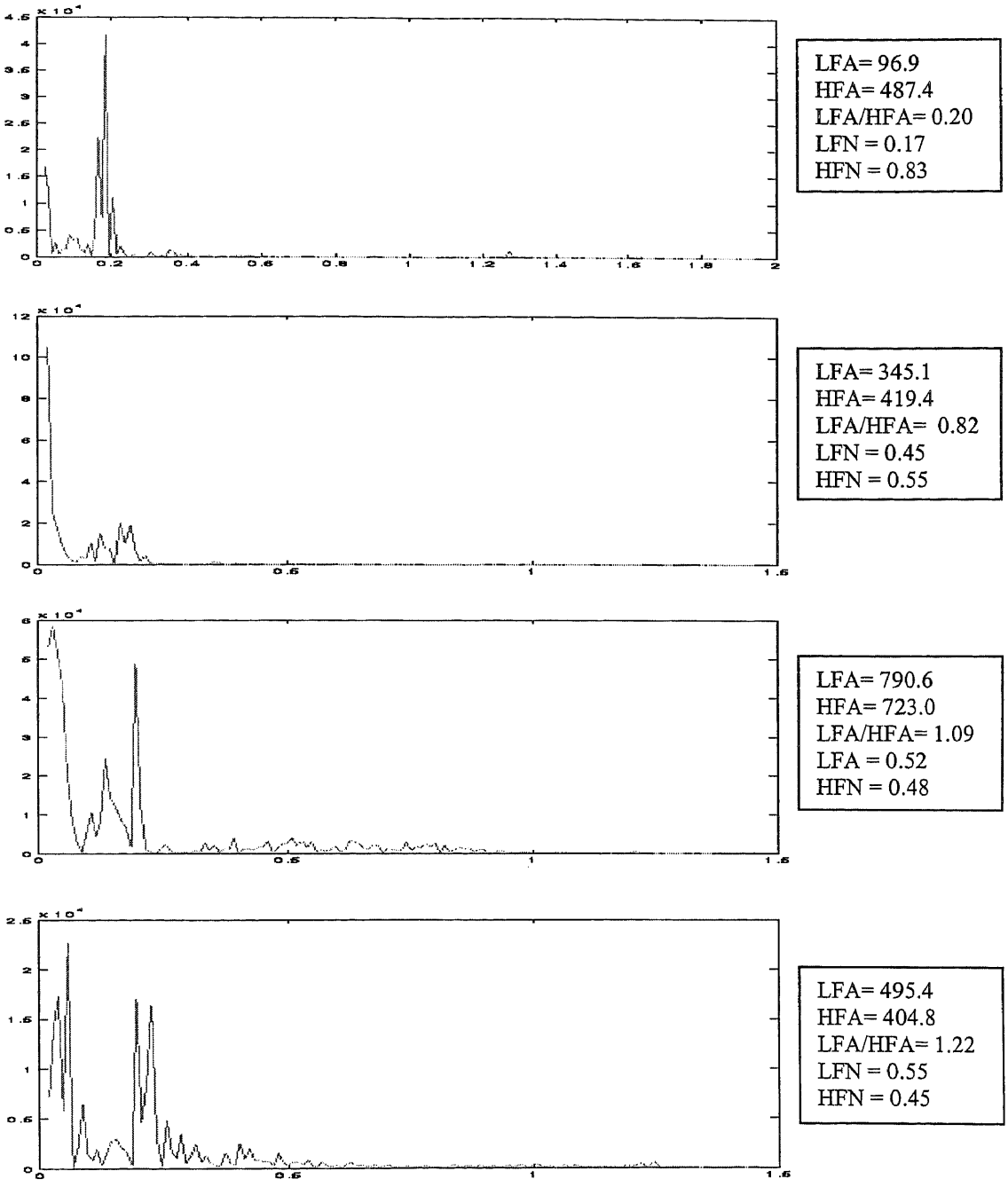


Figure 5.14: a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period

HRV SPECTRAL ANALYSIS - DAB

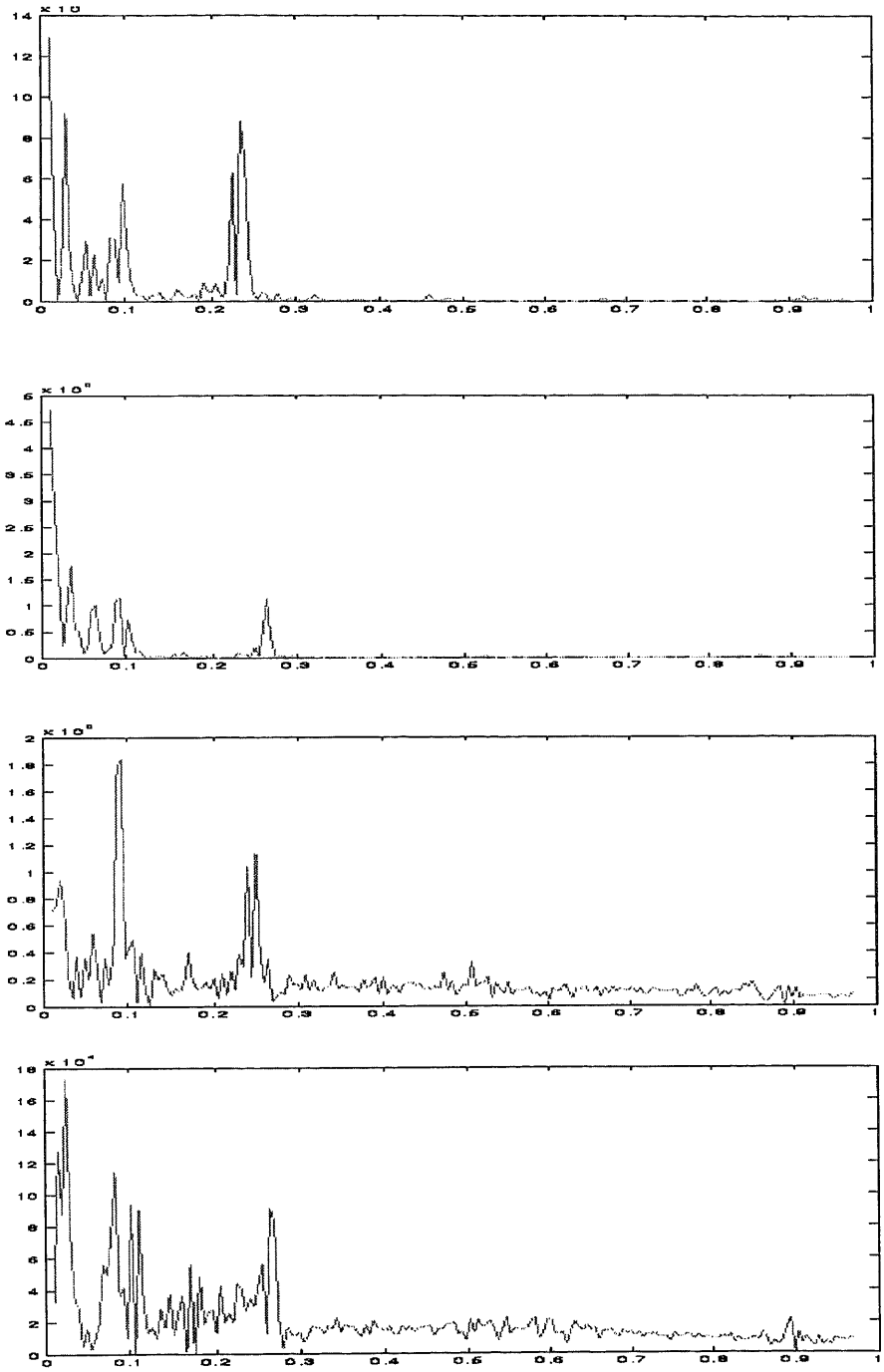
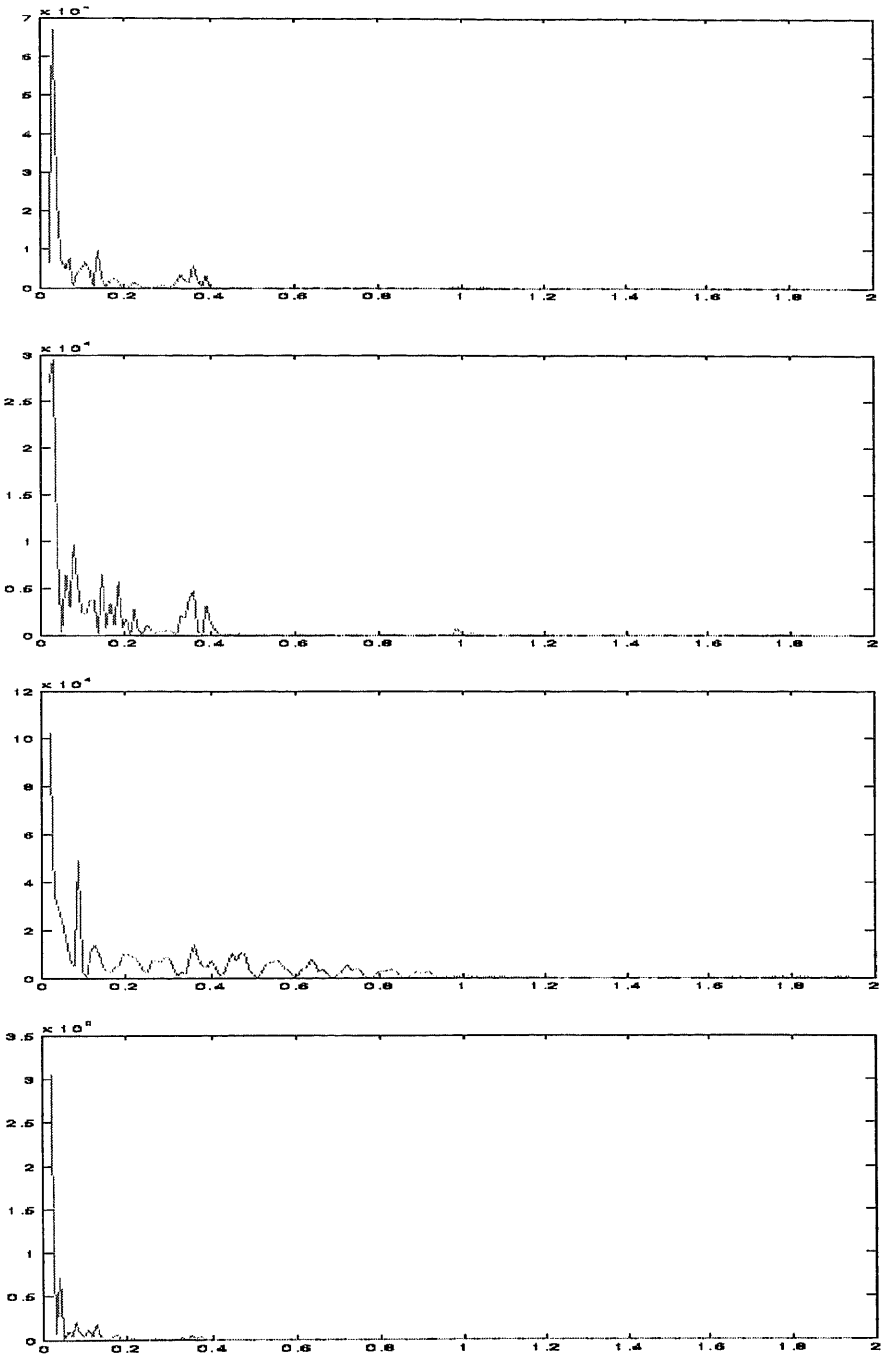


Figure 5.15: a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period

HRV SPECTRAL ANALYSIS - JLB



LFA= 319.7
HFA= 209.7
LFA/HFA= 1.52
LFN = 0.60
HFA = 0.40

LFA= 232.0
HFA= 205.4
LFA/HFA= 1.13
LFA = 0.53
HFA = 0.47

LFA= 792.6
HFA= 819.1
LFA/HFA= 0.97
LFN = 0.47
HFA = 0.53

LFA= 786.8
HFA= 208.3
LFA/HFA= 3.78
LFN = 0.79
HFN = 0.21

Figure 5.16: a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period

HRV SPECTRAL ANALYSIS - SGL

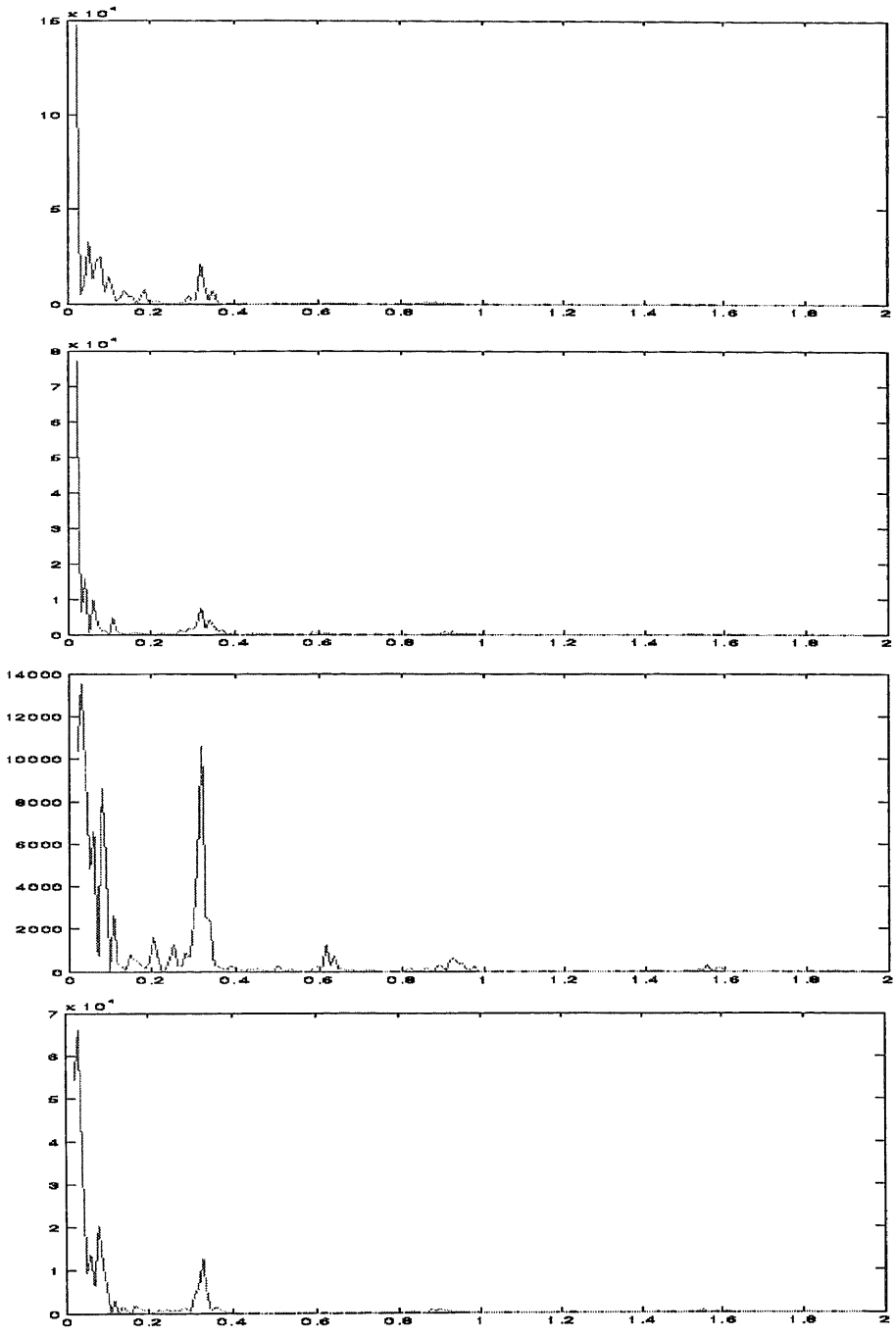


Figure 5.17: a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period

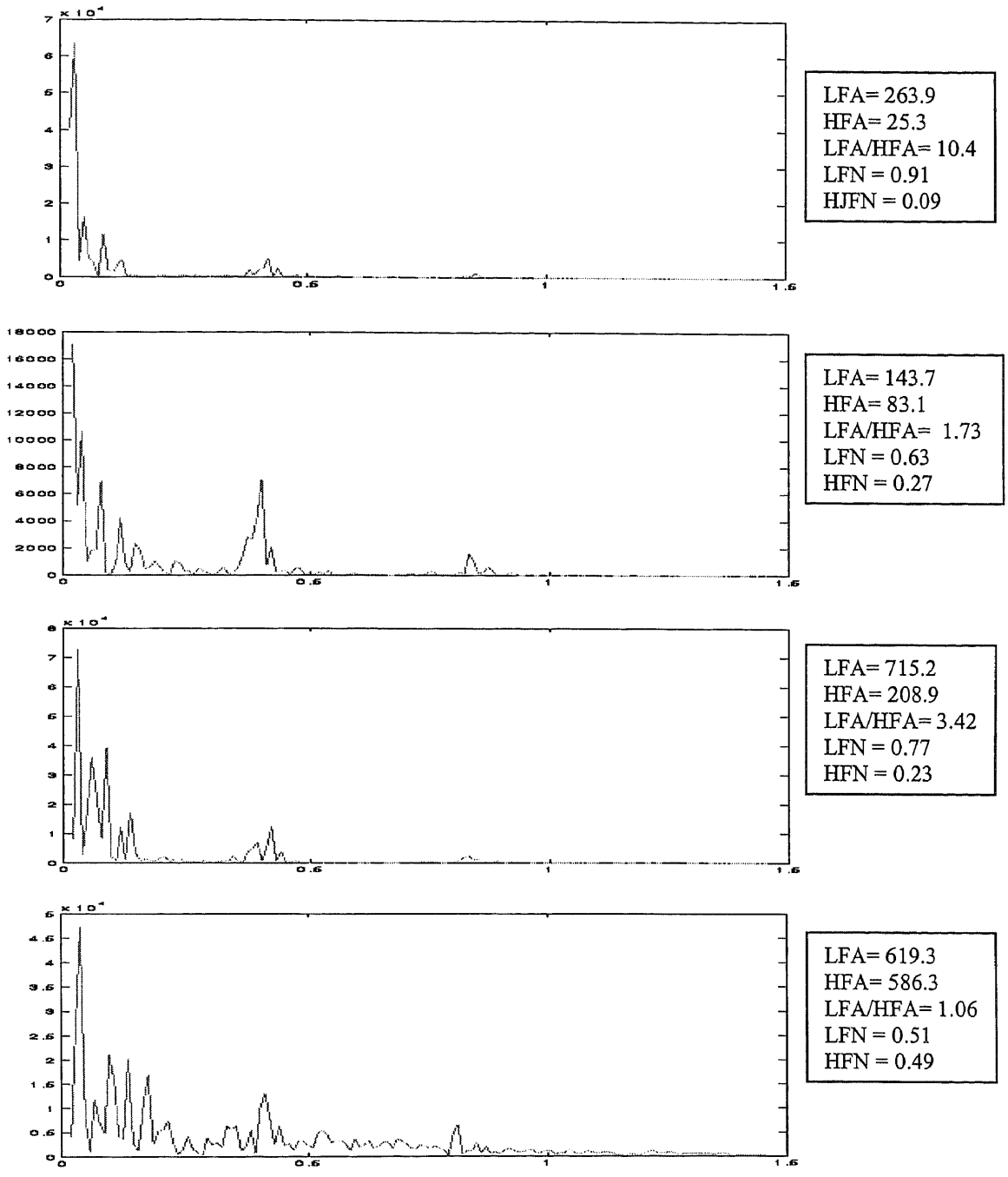


Figure 5.18: a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period

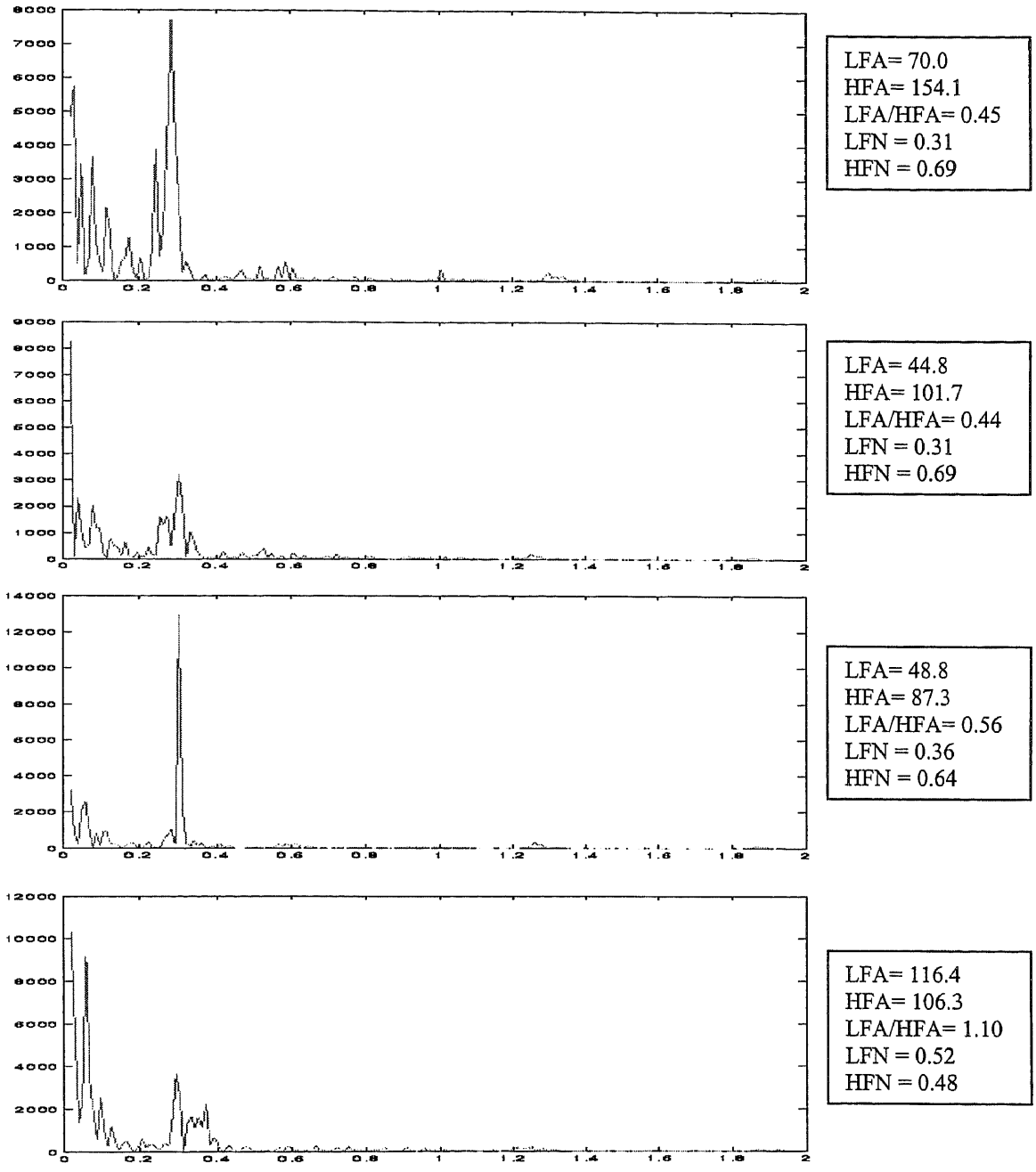


Figure 5.19: a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period

HRV SPECTRAL ANALYSIS - TSK

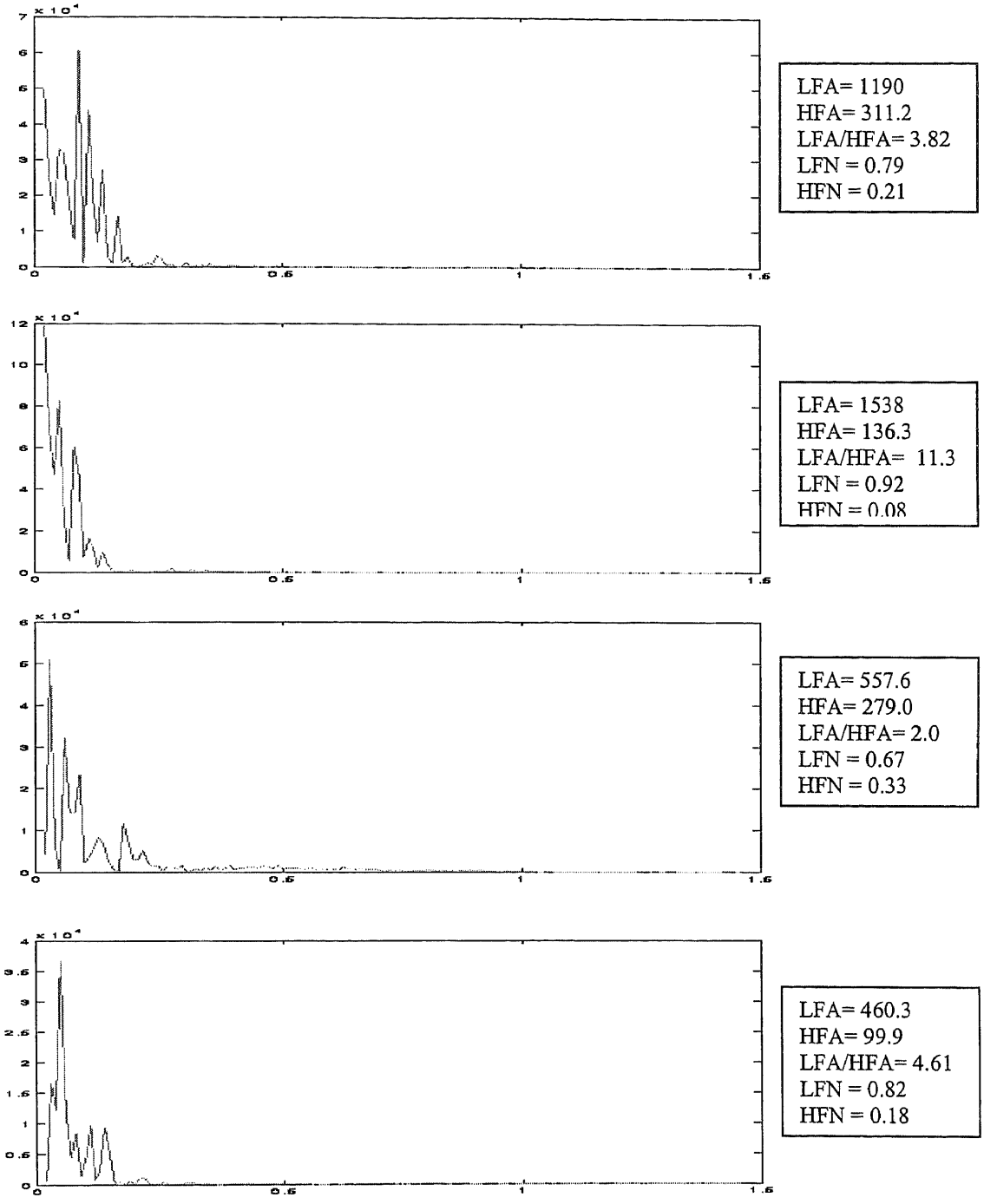


Figure 5.20: a) baseline with eyes closed b)stress period with eyes open. Under the influence of relaxing colored light with eyes open: c) baseline d) during stress period

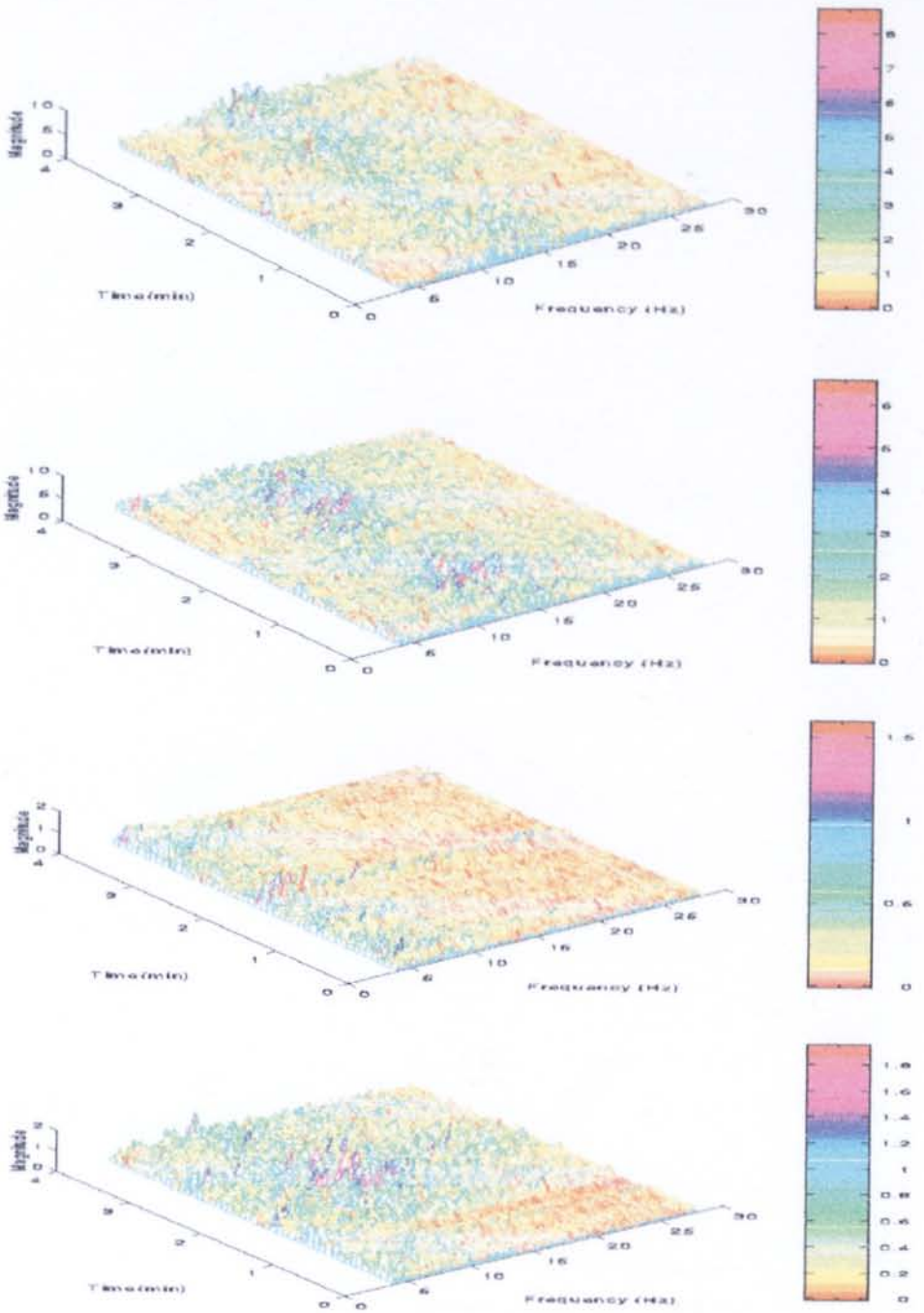


Figure 5.21: EEG Spectrum a) resting with eyes closed b) during 2 minute stress period (stress introduced during minutes 1 – 3) c) eyes open during colored light d) stress period during colored light.

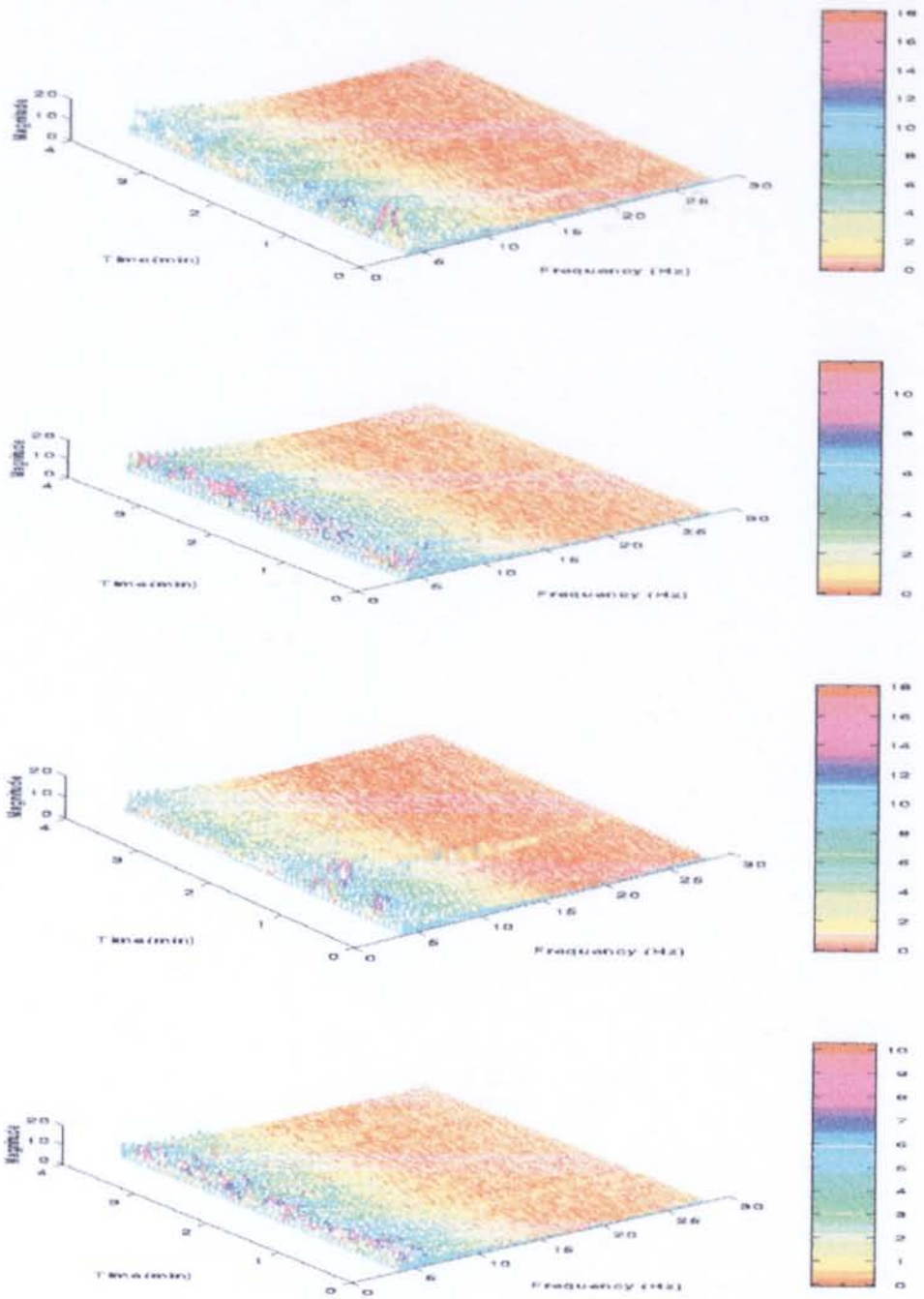


Figure 5.22: EEG Spectrum a) resting with eyes closed b) during 2 minute stress period (stress introduced during minutes 1 – 3) c) eyes open during colored light d) stress period during colored light.

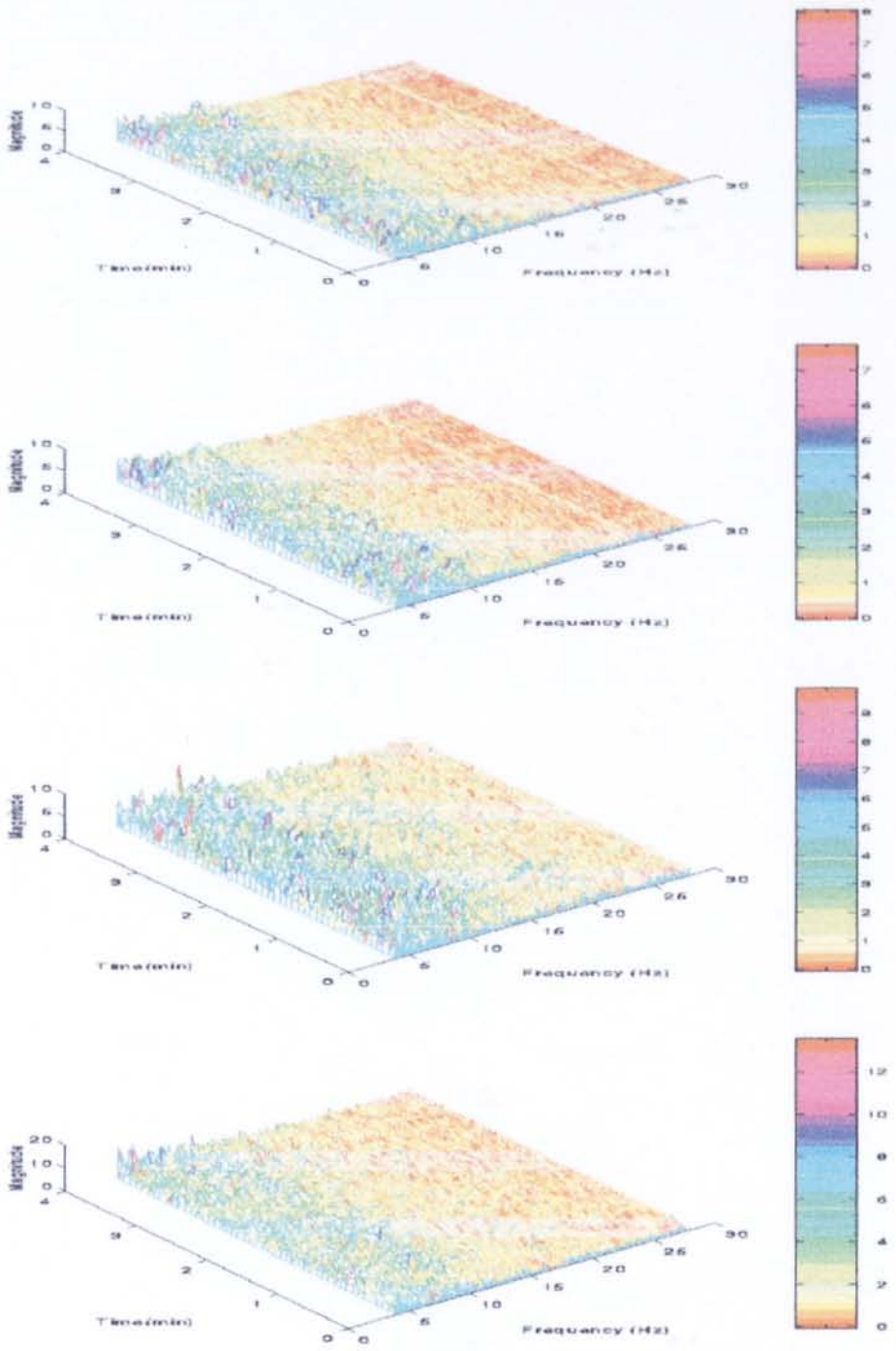


Figure 5.23: EEG Spectrum a) resting with eyes closed b) during 2 minute stress period (stress introduced during minutes 1 – 3) c) eyes open during colored light d) stress period during colored light.

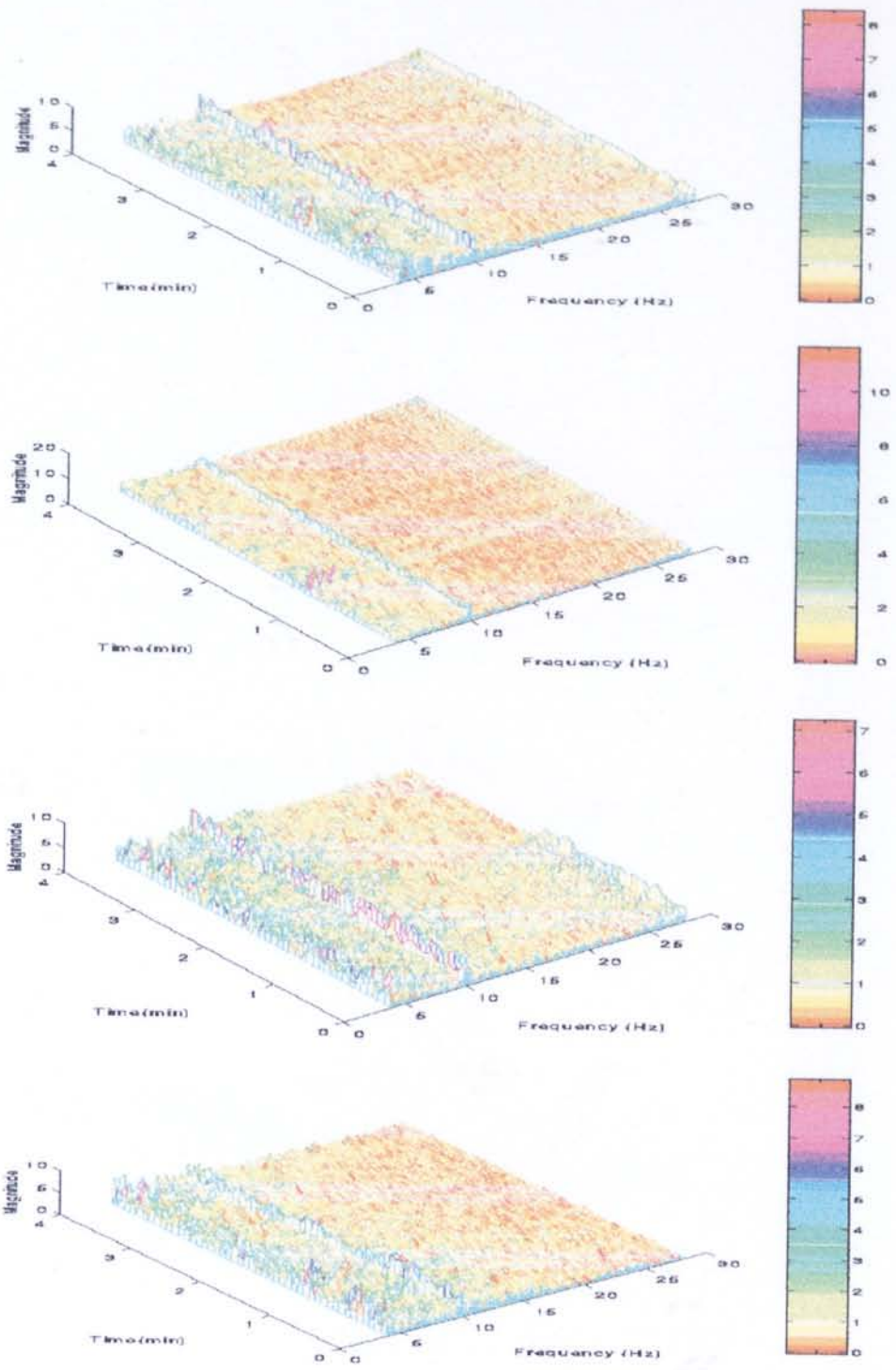


Figure 5.24: EEG Spectrum a) resting with eyes closed b) during 2 minute stress period (stress introduced during minutes 1 – 3) c) eyes open during colored light d) stress period during colored light.

EEG SPECTRUM OF SGL

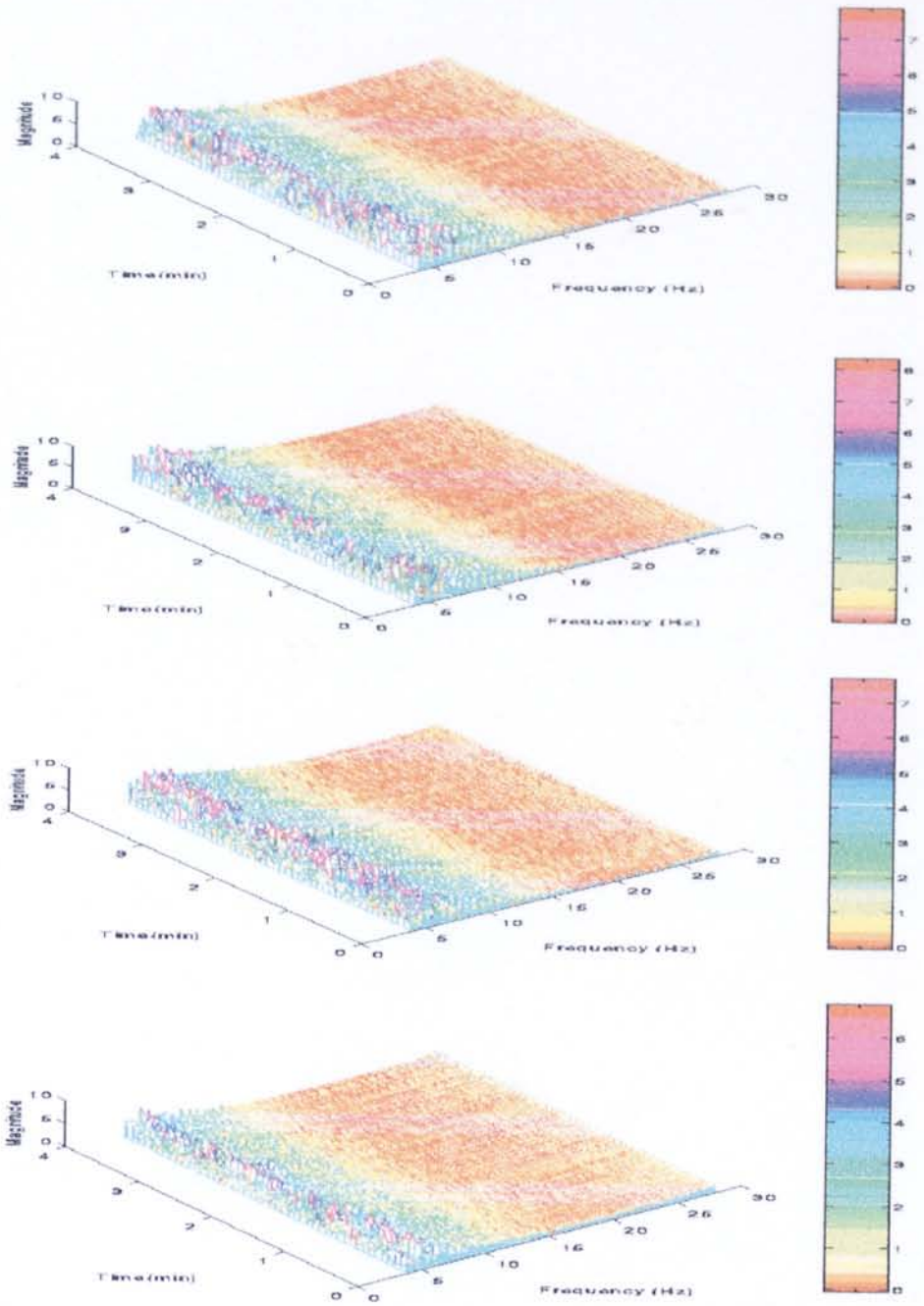


Figure 5.25: EEG Spectrum a) resting with eyes closed b) during 2 minute stress period (stress introduced during minutes 1 – 3) c) eyes open during colored light d) stress period during colored light.

EEG SPECTRUM OF SJC

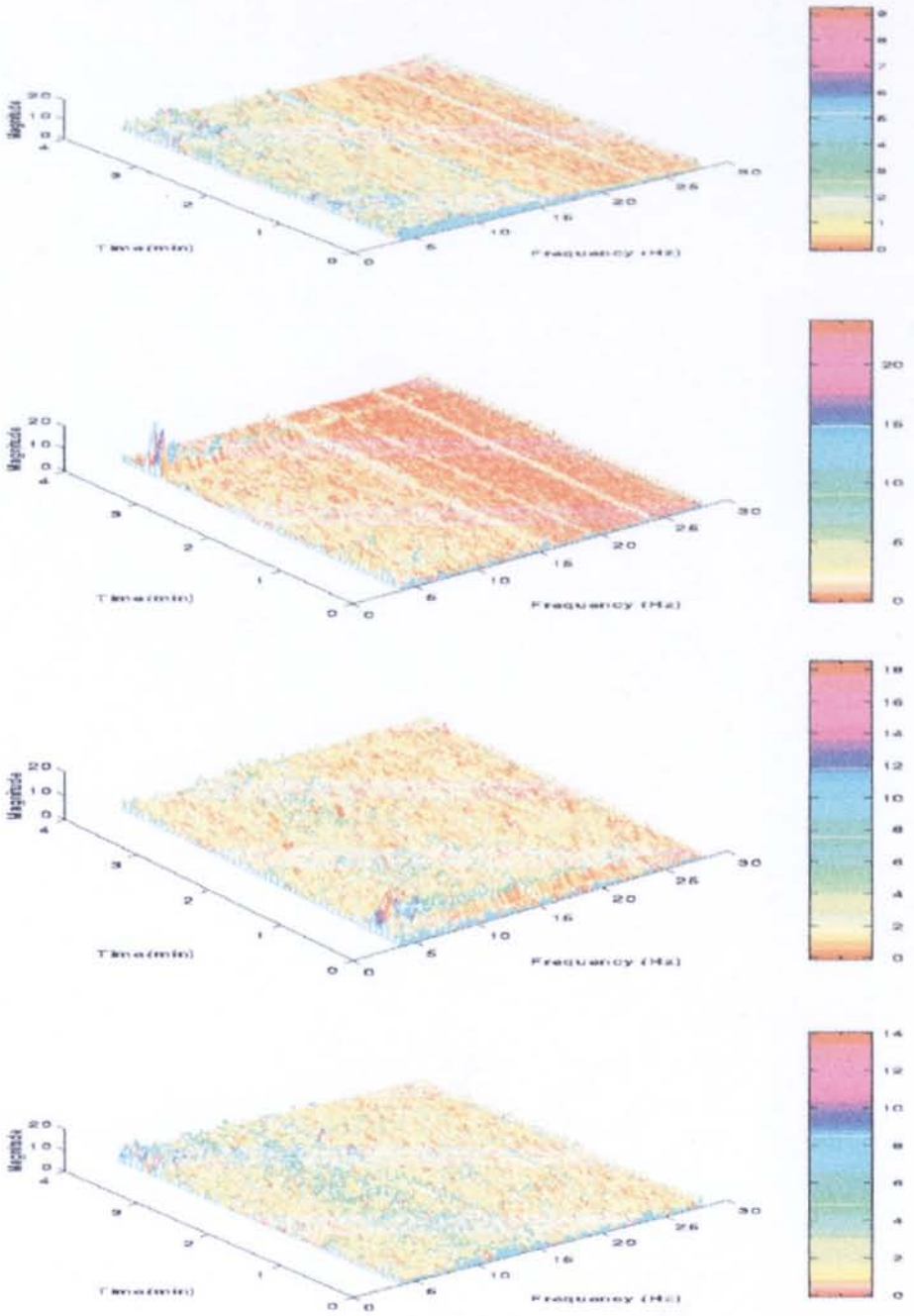


Figure 5.26: EEG Spectrum a) resting with eyes closed b) during 2 minute stress period (stress introduced during minutes 1 – 3) c) eyes open during colored light d) stress period during colored light.

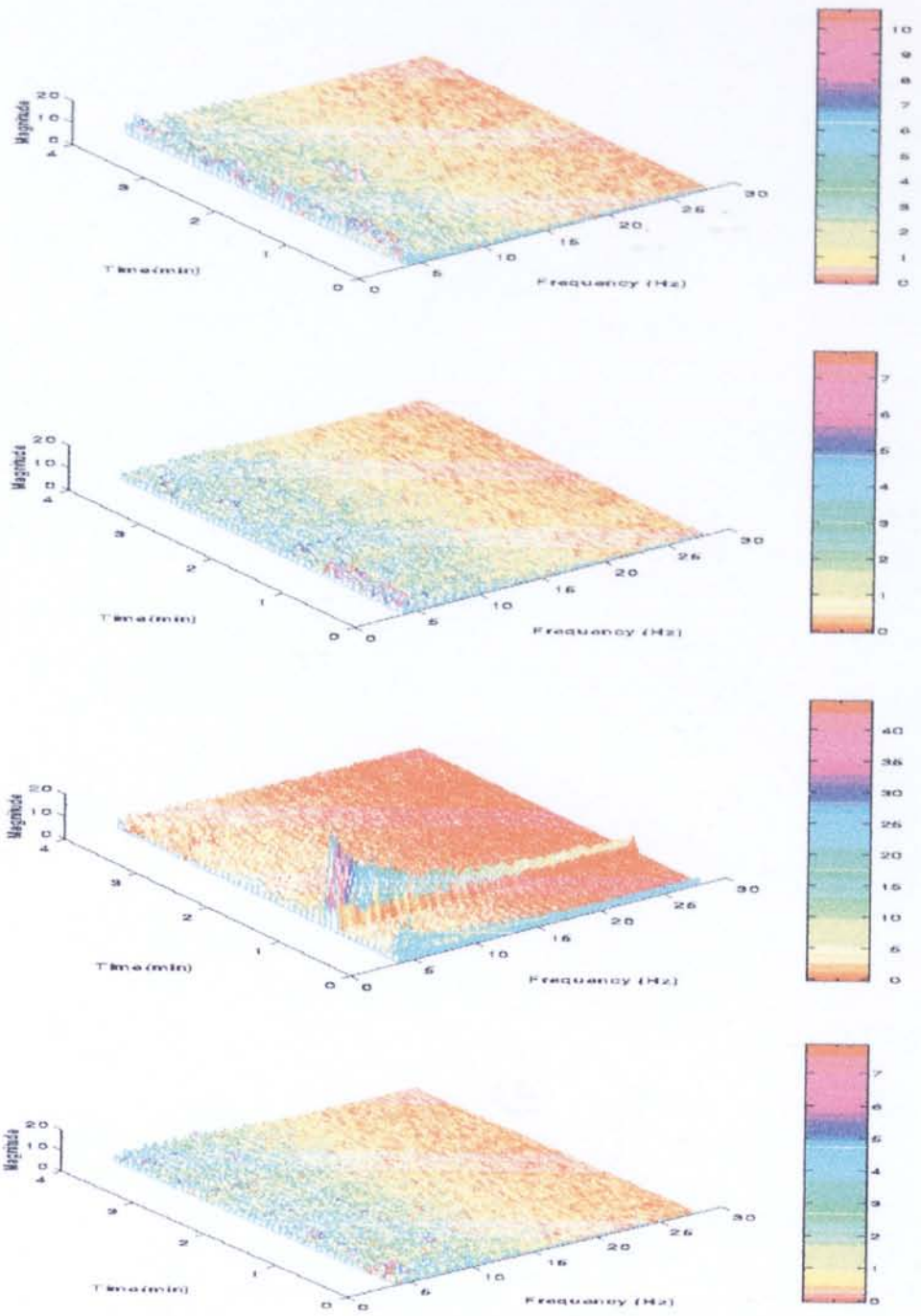


Figure 5.27: EEG Spectrum a) resting with eyes closed b) during 2 minute stress period (stress introduced during minutes 1 – 3) c) eyes open during colored light d) stress period during colored light.

EEG SPECTRUM OF TSK

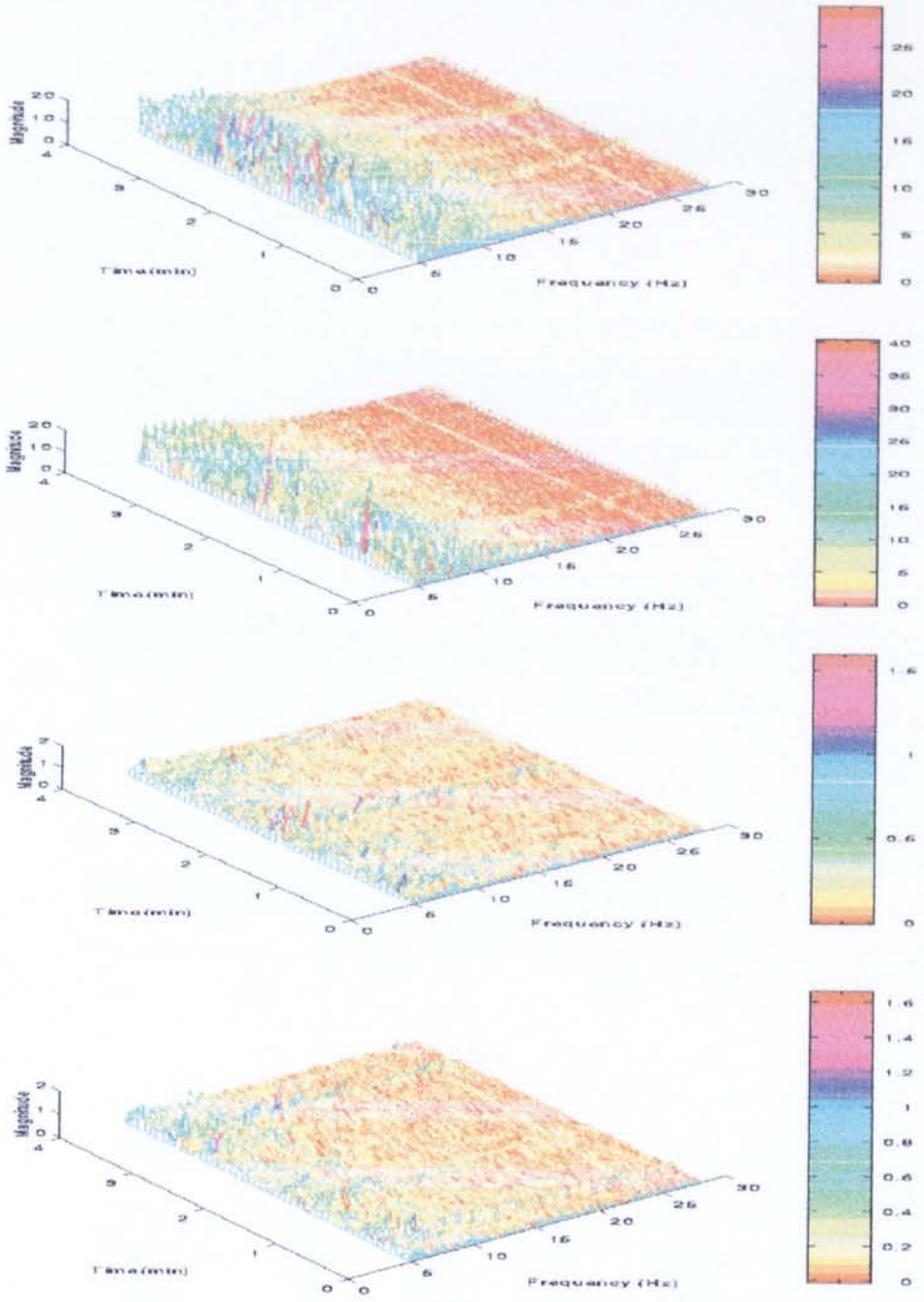
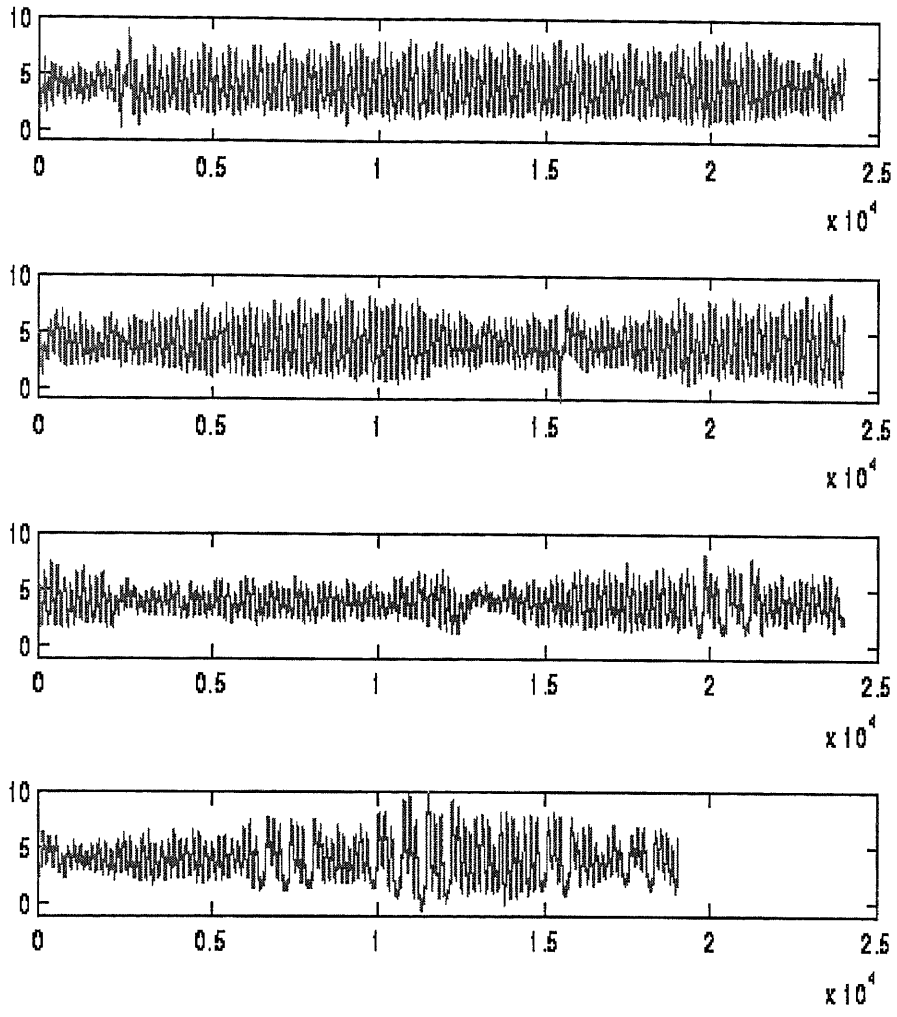


Figure 5.28: EEG Spectrum a) resting with eyes closed b) during 2 minute stress period (stress introduced during minutes 1 – 3) c) eyes open during colored light d) stress period during colored light.

APPENDIX C

ARTERIAL BLOOD FLOW OF DRF



DRF

	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRFT1	4.91	5.55	6.44	6.2	6.43	4.47
DRFT2	4.48	6.13	5.06	4.39	6.24	6.32
DRFT3	2.85	3.22	5.38	4.69	5.35	3.12
DRFT4	4.31	2.2	7.92	4.49	4.61	NA

Figure 5.29: a)Two minute plots, each plot is a two minute segment. The third plot is the stress period and the fourth is the recovery period. b) table of average values for 20 second periods.

ECG SPECTRAL ANALYSIS - DRF

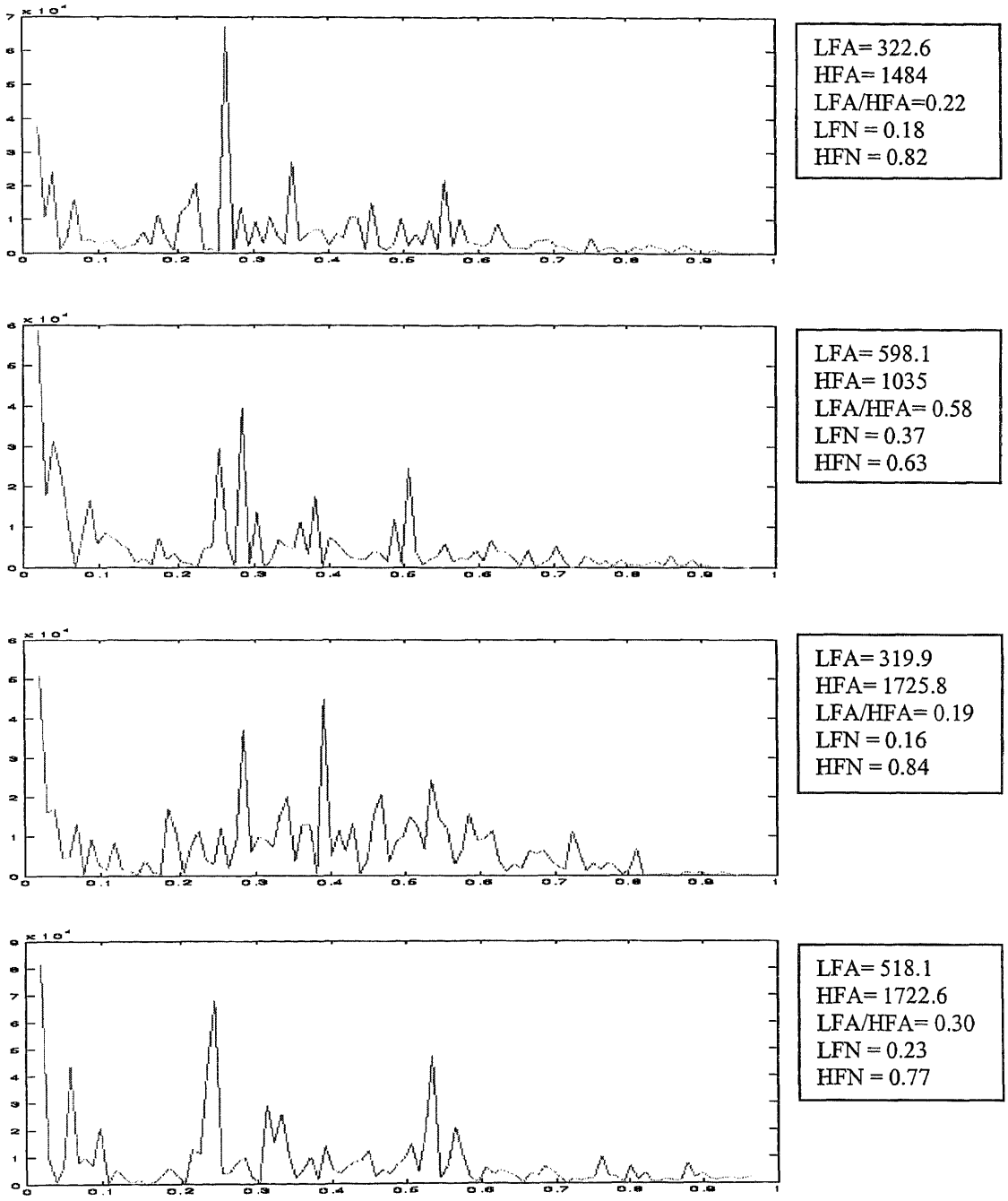


Figure 5.30: a) & b) baseline with eyes closed - 2 minute period each c) during stress period - 2 minute period d) recovery 1.5 minute period

EEG SPECTRUM OF DRF

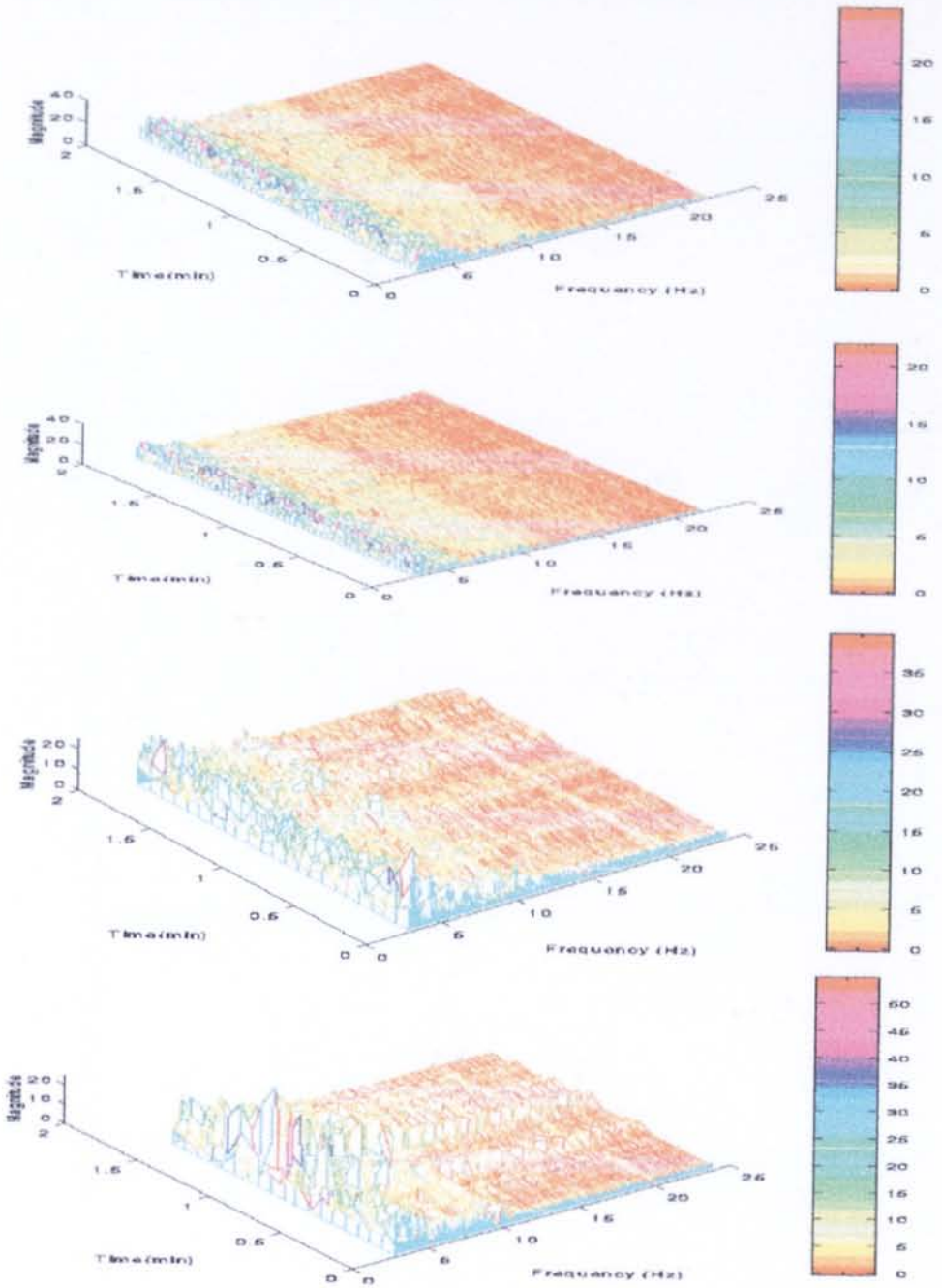


Figure 5.31: EEG Spectrum : each plot represents a 2 minute plot .

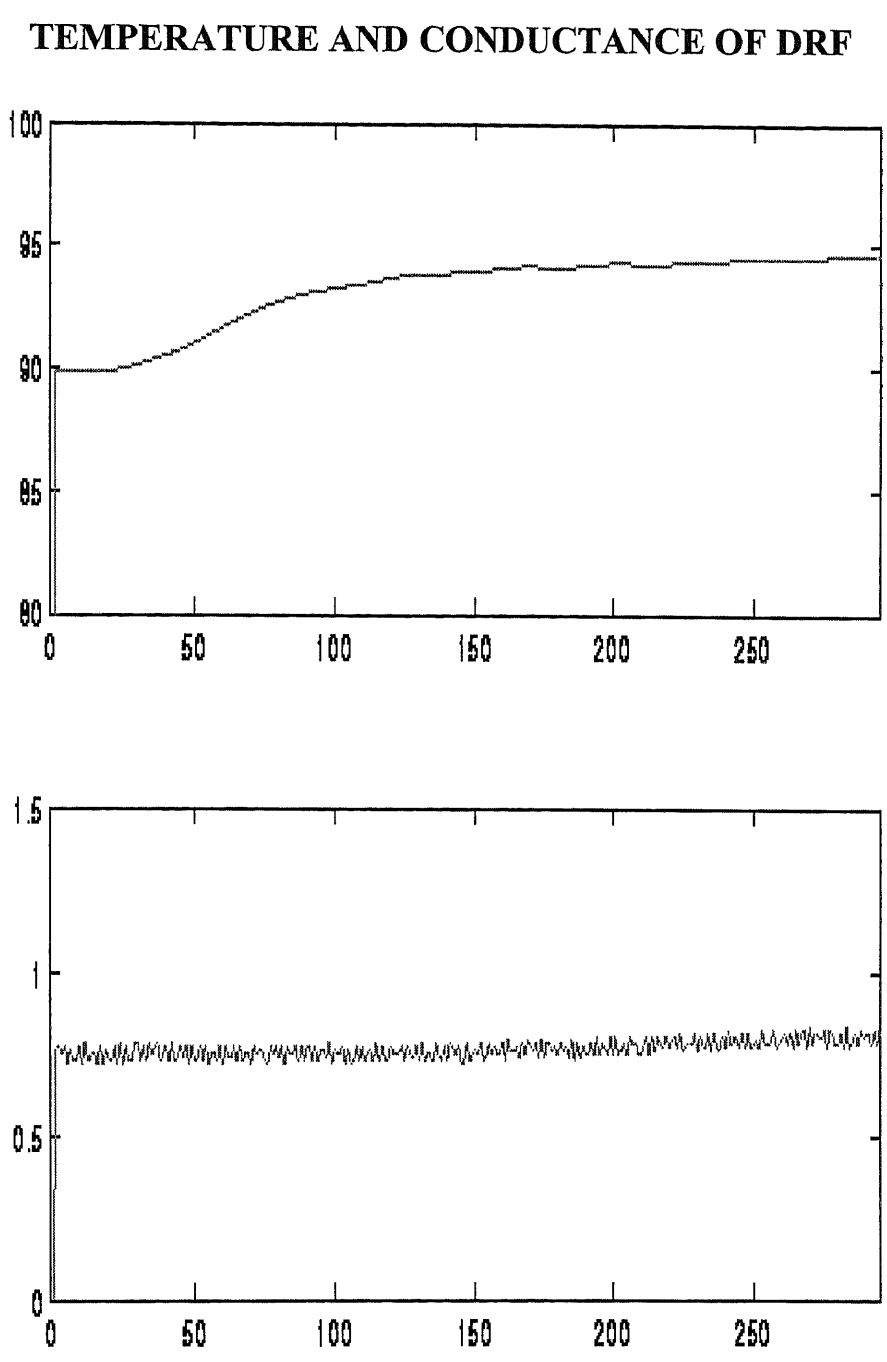
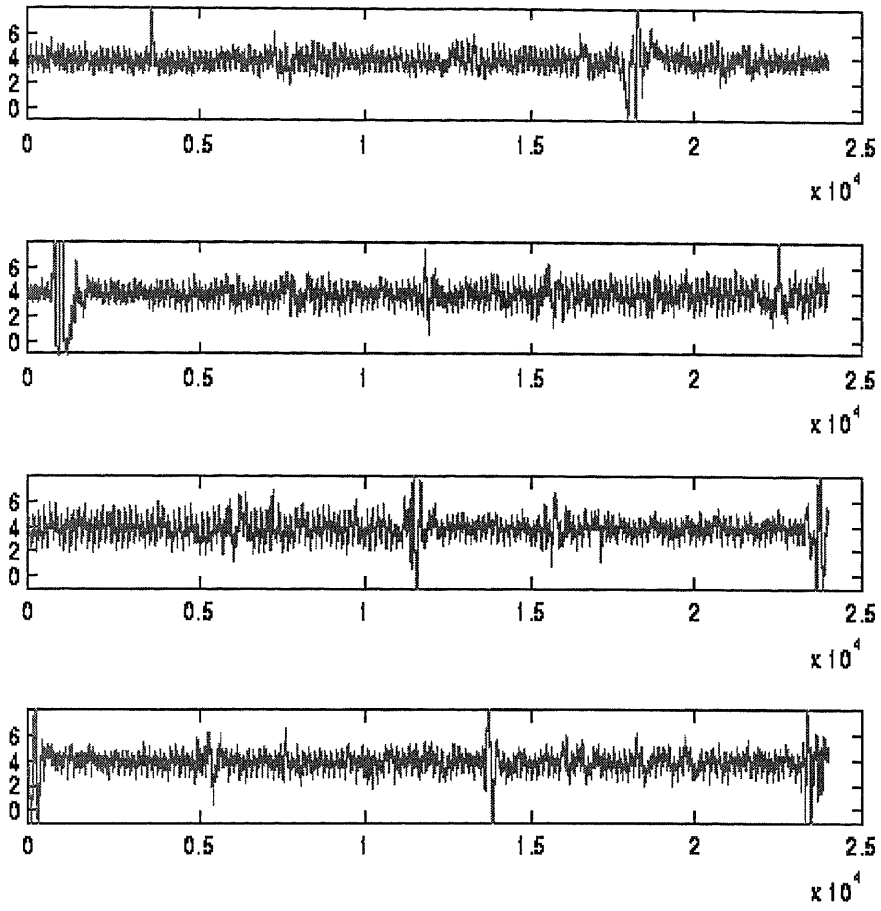


Figure 5.32: Temperature and conductivity plots respectively.

APPENDIX D

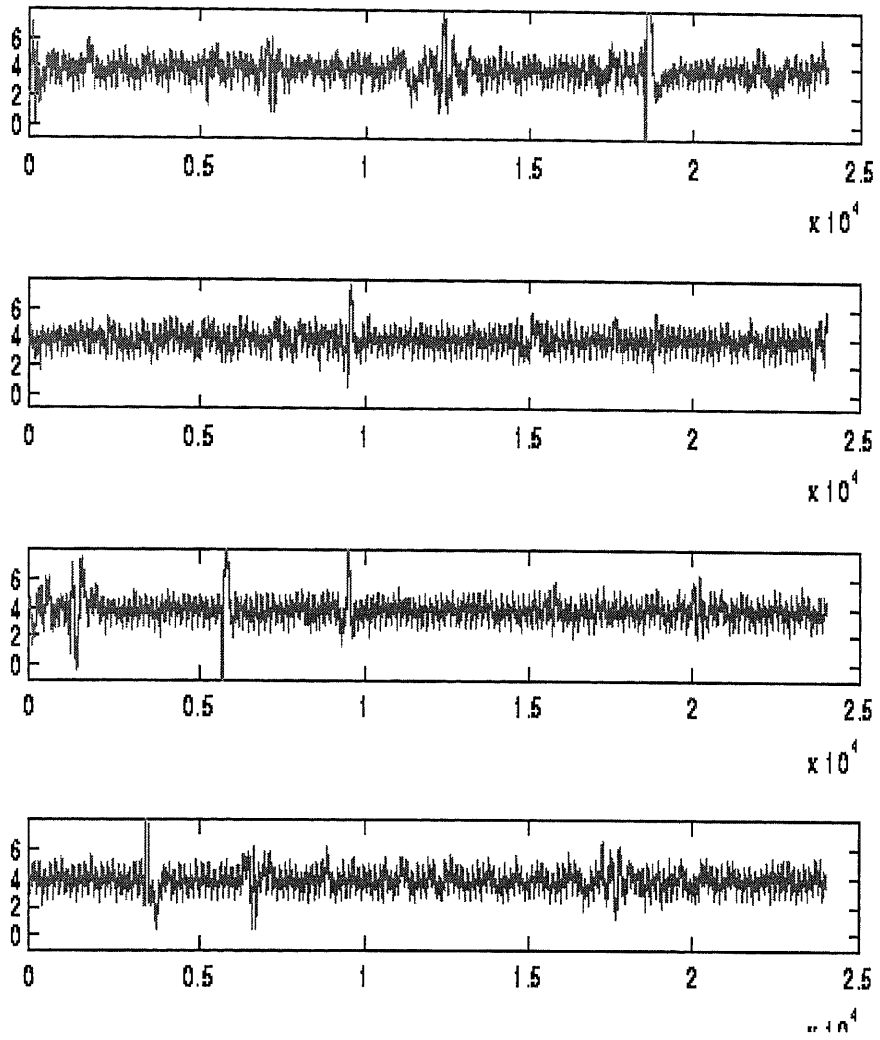
ARTERIAL BLOOD FLOW OF DRF1 (FIRST 4 COLORS)



DRF1	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRF11	2.18	2.05	2.12	2.16	3.6	2.03
DRF12	3.52	2.38	2.63	2.63	2.89	3.17
DRF13	3.05	3.5	3.63	2.56	2.27	3.08
DRF14	2.94	2.51	2.38	2.92	2.59	3.32

Figure 5.33: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

ARTERIAL BLOOD FLOW OF DRF1 (SECOND 4 COLORS)



DRF1	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRF15	2.57	2.57	2.13	2.74	3.56	2.09
DRF16	2.21	2.33	2.56	2.37	2.4	2.43
DRF17	3.03	2.78	2.55	2.43	2.42	2.61
DRF18	2.71	2.69	2.48	2.33	2.8	2.45

Figure 5.34: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

HRV SPECTRAL ANALYSIS - DRF1 (FIRST 4 COLORS)

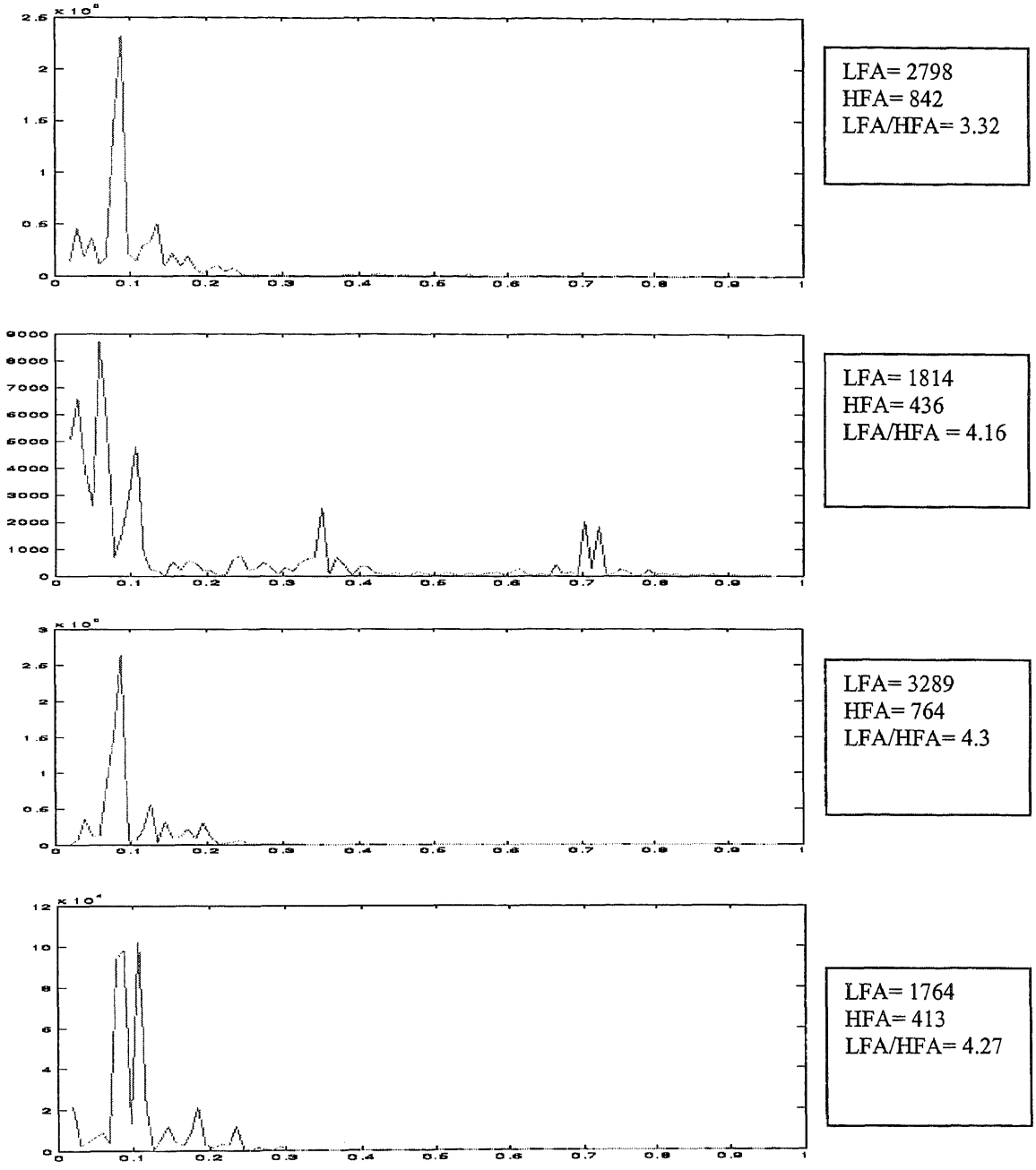
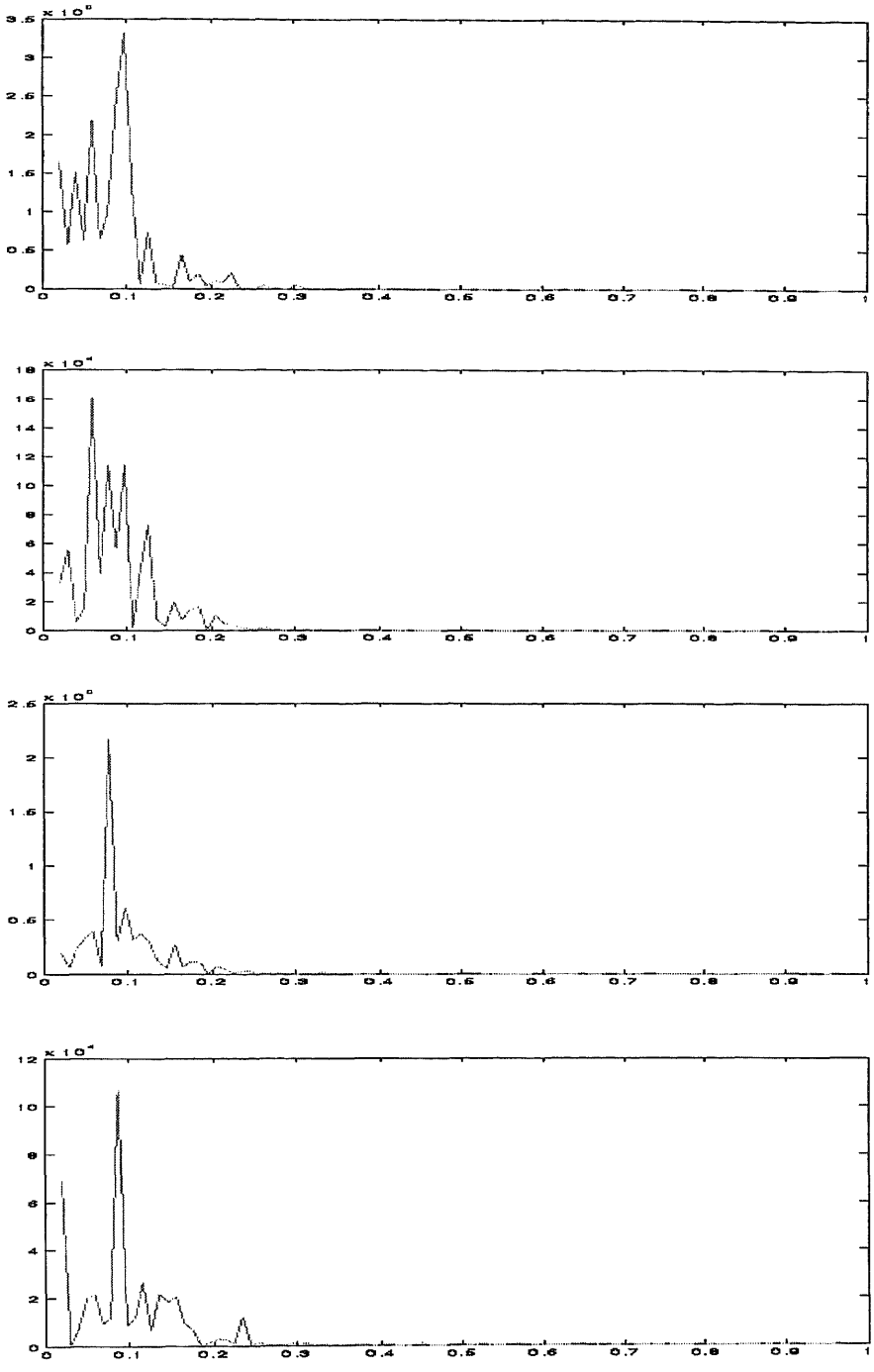


Figure 5.35: Each plot represents a two minute period with the subject under the influence of a different color

HRV SPECTRAL ANALYSIS - DRF1 (SECOND 4 COLORS)



LFA= 6893
HFA= 762
LFA/HFA= 9.05

LFA= 3114
HFA= 492
LFA/HFA = 6.33

LFA= 2564
HFA= 502
LFA/HFA= 5.11

LFA= 1154
HFA= 525
LFA/HFA= 2.20

Figure 5.36: Each plot represents a two minute period with the subject under the influence of a different color

EEG SPECTRUM OF DRF1 (FIRST 4 COLORS)

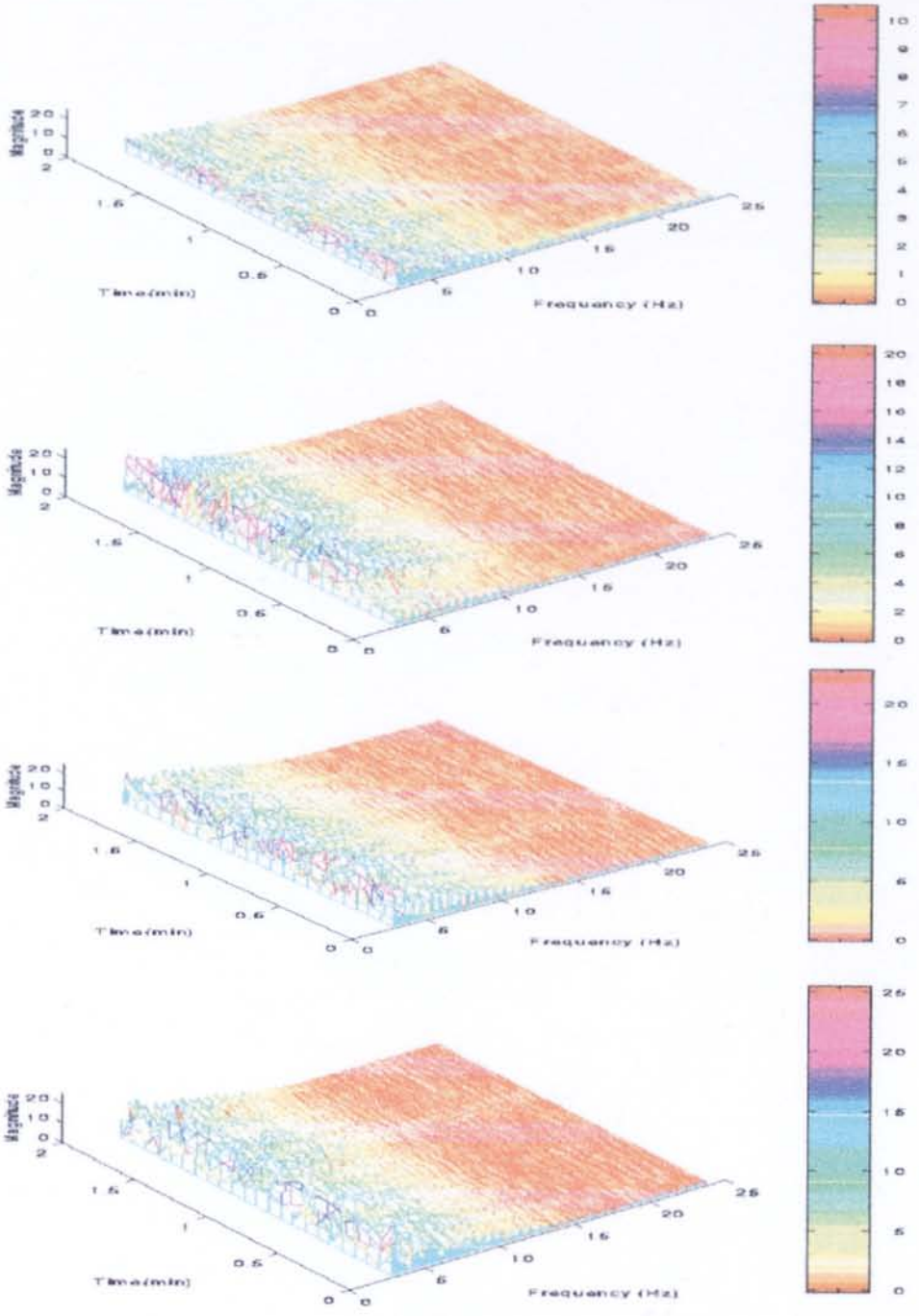


Figure 5.37: EEG Spectrum : each plot represents a 2 minute plot during a single color session.

EEG SPECTRUM OF DRF1 (SECOND 4 COLORS)

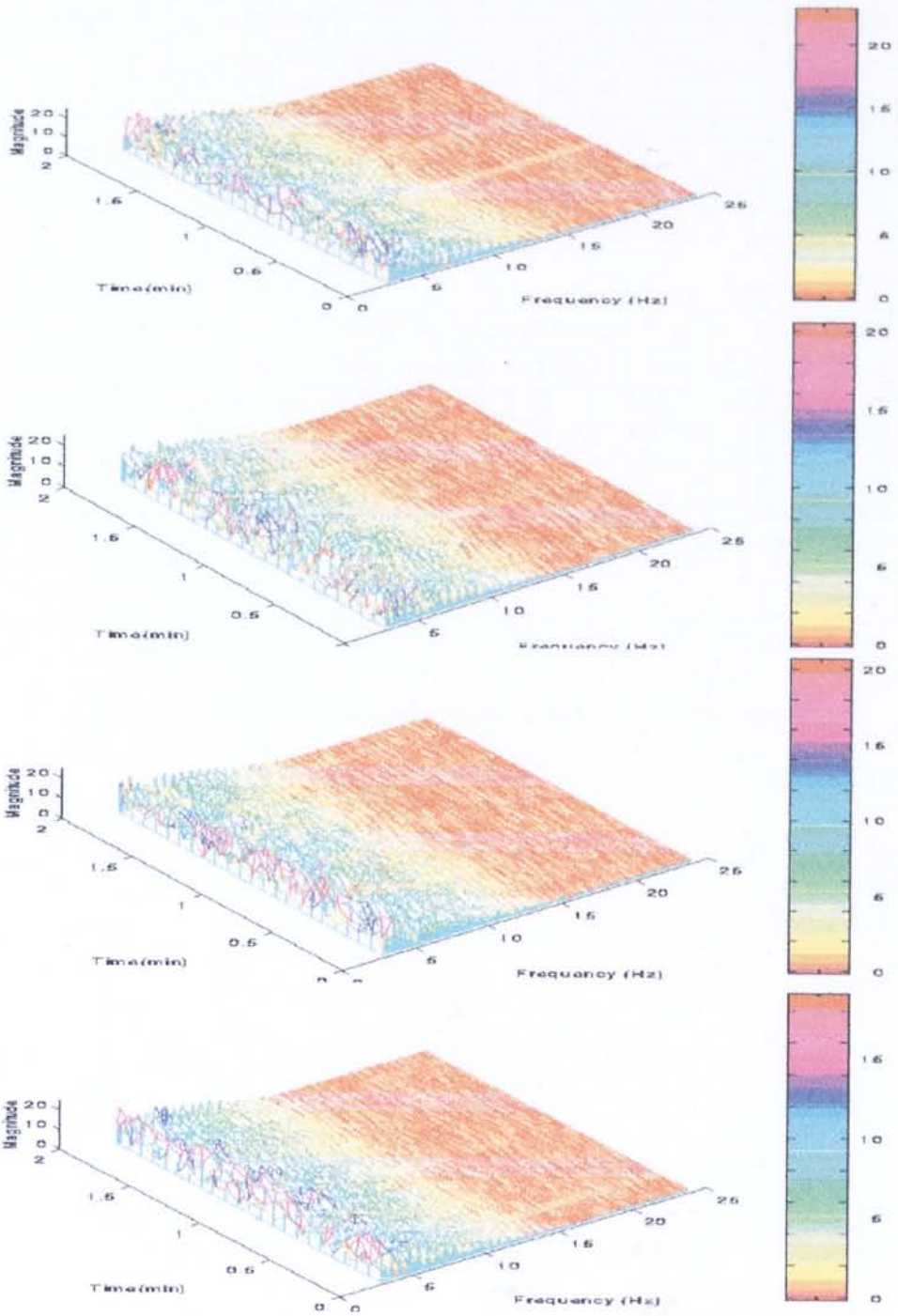


Figure 5.38: EEG Spectrum : each plot represents a 2 minute plot during a single color session.

TEMPERATURE AND CONDUCTANCE OF DRF1

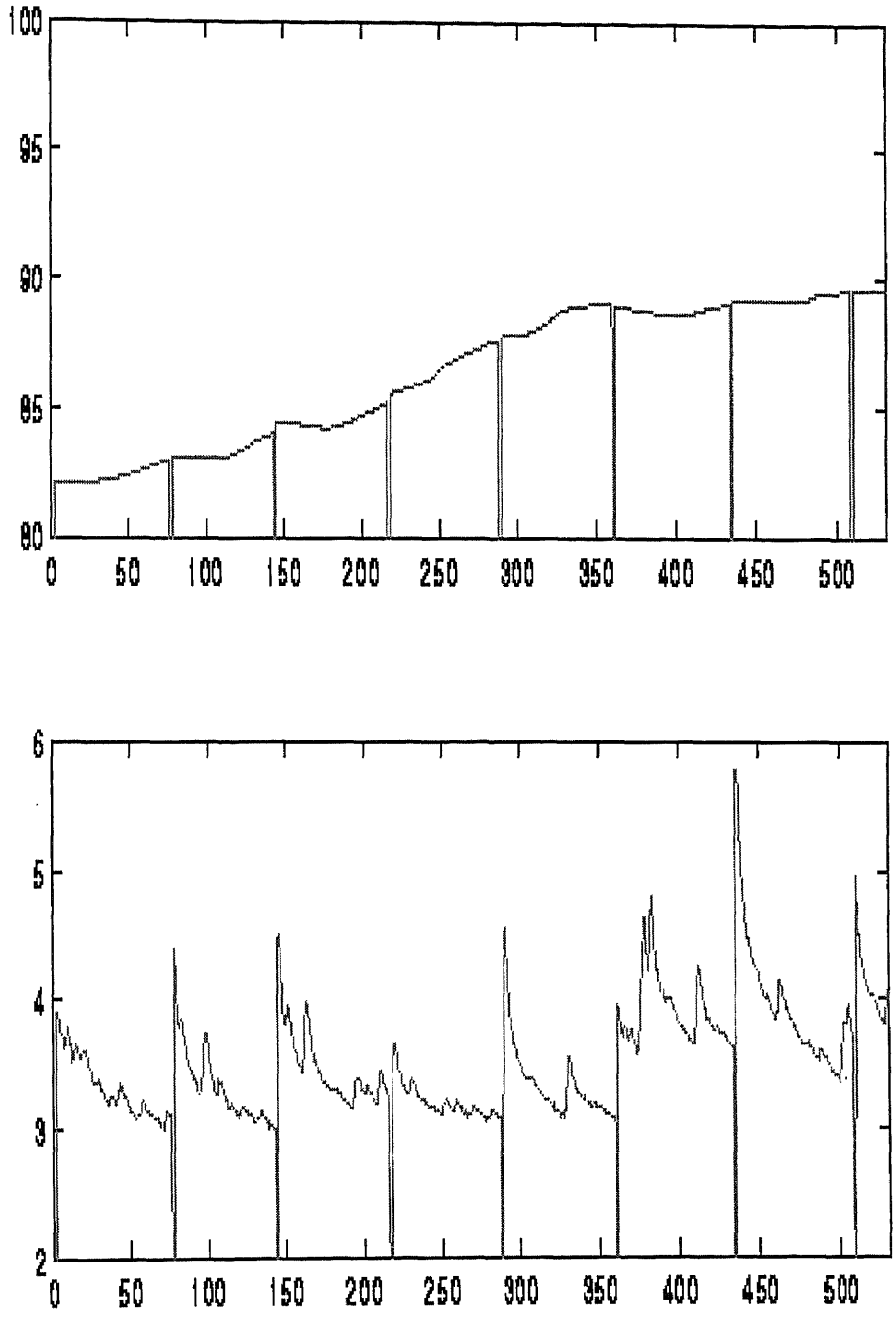
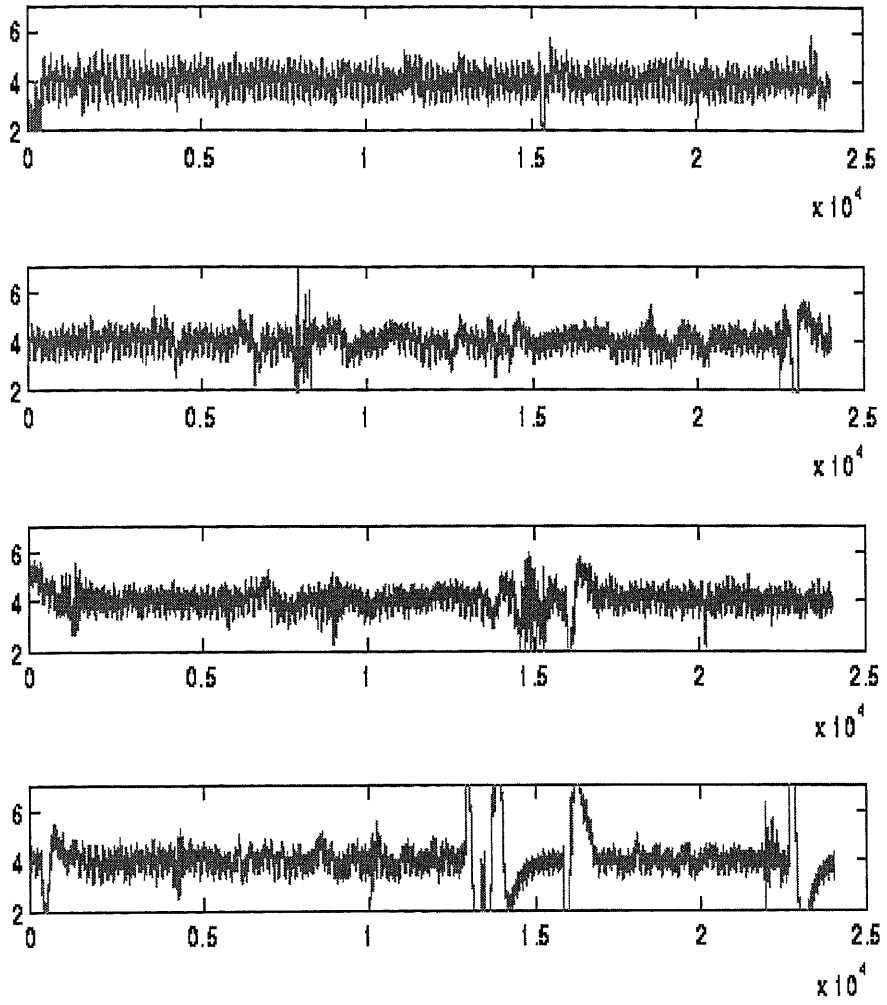


Figure 5.39: Temperature and conductivity plots respectively. Each section represents a different color.

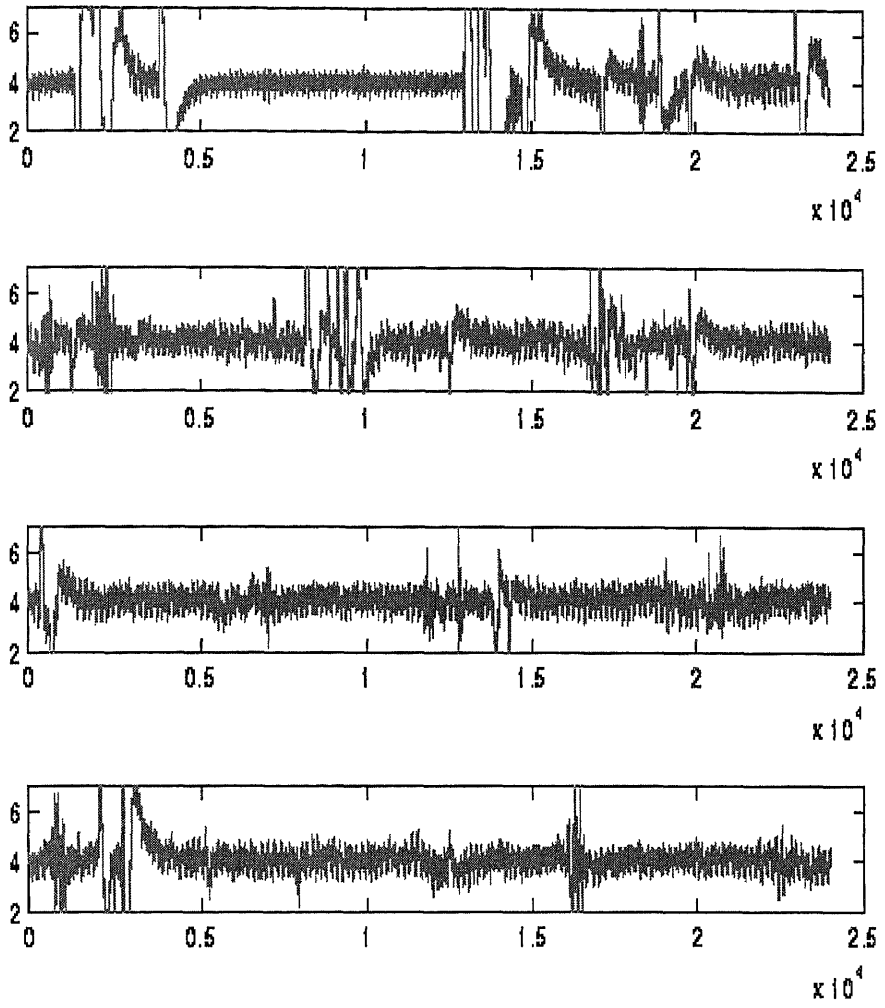
ARTERIAL BLOOD FLOW OF DRF5 (FIRST 4 COLORS)



	1-4K	4K-8K	8K-12K	12K-16K	16-20K	20K-24K
DRF51	1.98	1.66	1.64	1.79	1.68	1.57
DRF52	1.51	1.68	1.52	1.4	1.45	1.74
DRF53	1.49	1.37	1.39	2.06	1.57	1.43
DRF54	1.57	1.47	1.44	3.68	1.58	2.12

Figure 5.40: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

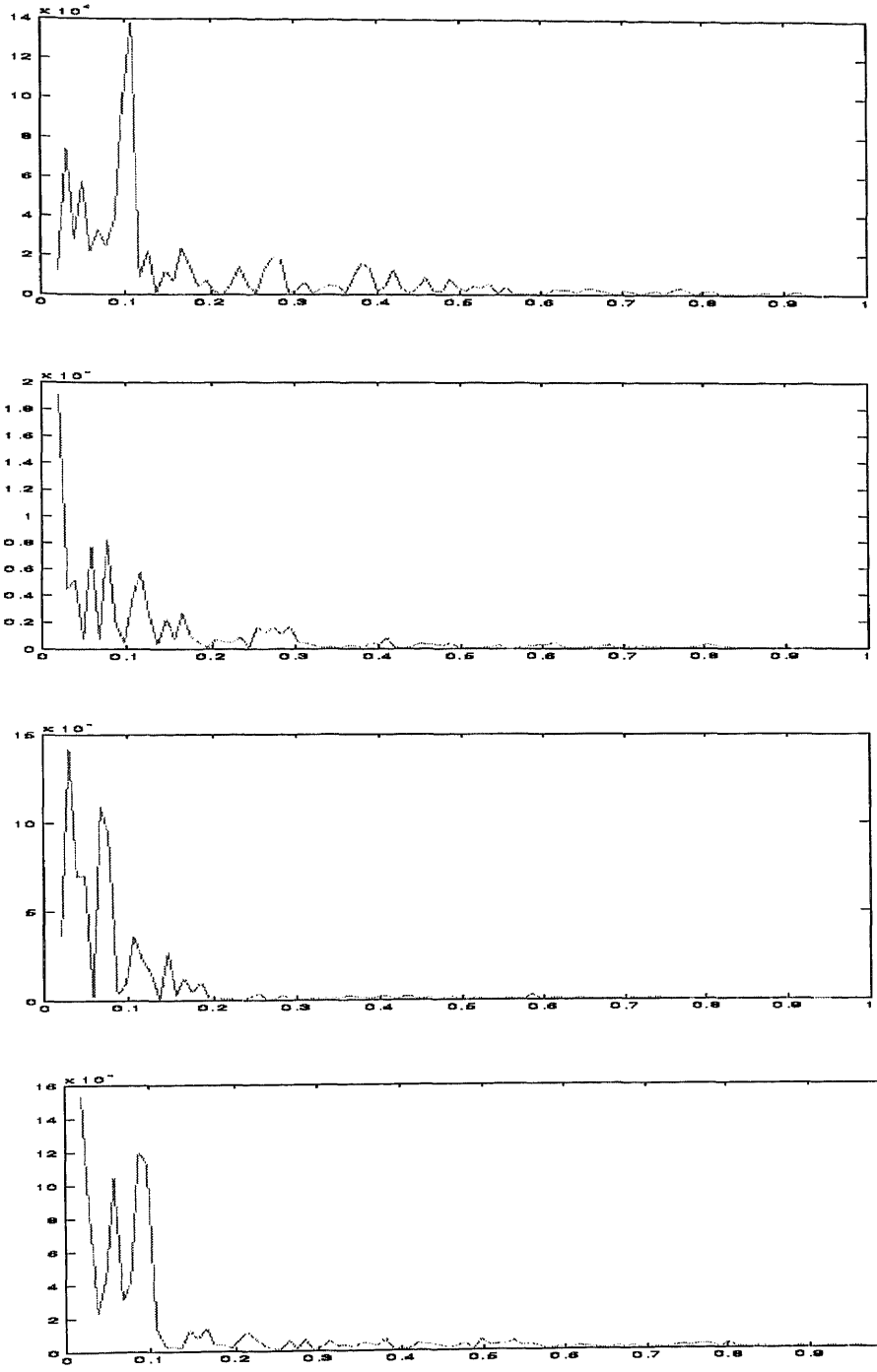
ARTERIAL BLOOD FLOW OF DRF5 (SECOND 4 COLORS)



	1-4K	4K-8K	8K-12K	12K-16K	16-20K	20K-24K
DRF55	4.4	1.14	1.02	5.63	3.1	2.57
DRF56	2.62	1.5	4.3	1.81	3.67	1.42
DRF57	2.43	1.56	1.51	2.05	1.67	1.82
DRF58	4.24	1.57	1.57	1.47	1.92	1.57

Figure 5.41: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

HRV SPECTRAL ANALYSIS - DRF5 (SECOND 4 COLORS)



LFA= 2345.7
HFA= 1213.1
LFA/HFA= 1.93

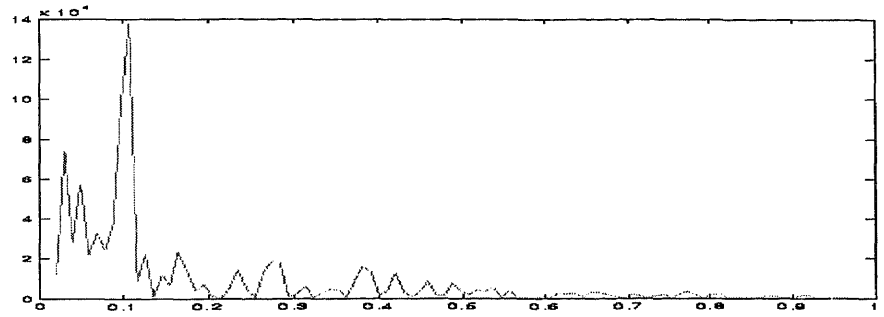
LFA= 1841.9
HFA= 1113.2
LFA/HFA = 1.65

LFA= 2173
HFA= 459.3
LFA/HFA= 4.73

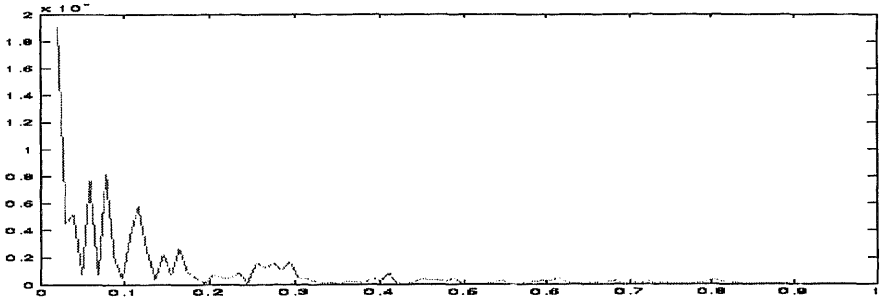
LFA= 2477.8
HFA= 737.1
LFA/HFA= 3.36

Figure 5.42: Each plot represents a two minute period with the subject under the influence of a different color.

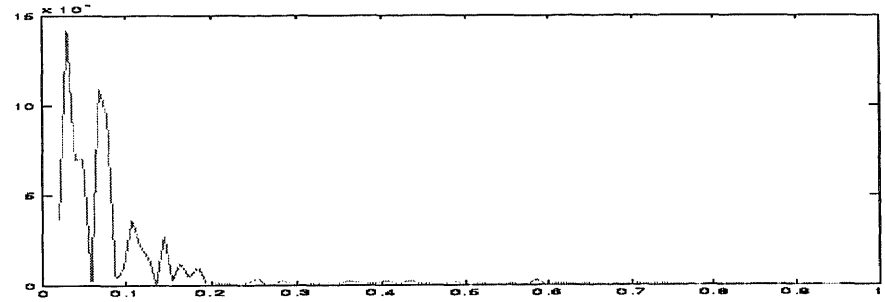
HRV SPECTRAL ANALYSIS - DRF5 (SECOND 4 COLORS)



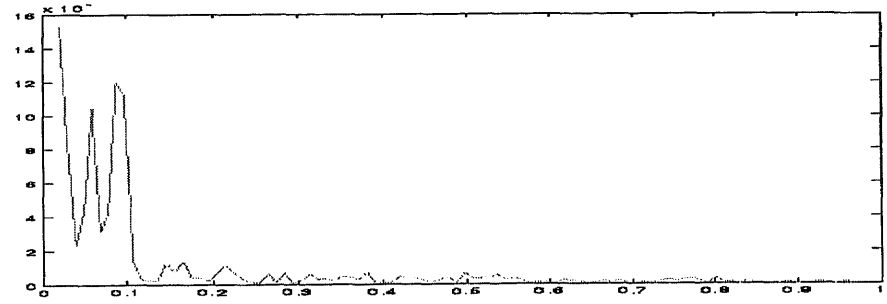
LFA= 2345.7
HFA= 1213.1
LFA/HFA= 1.93



LFA= 1841.9
HFA= 1113.2
LFA/HFA = 1.65



LFA= 2173
HFA= 459.3
LFA/HFA= 4.73



LFA= 2477.8
HFA= 737.1
LFA/HFA= 3.36

Figure 5.43: Each plot represents a two minute period with the subject under the influence of a different color.

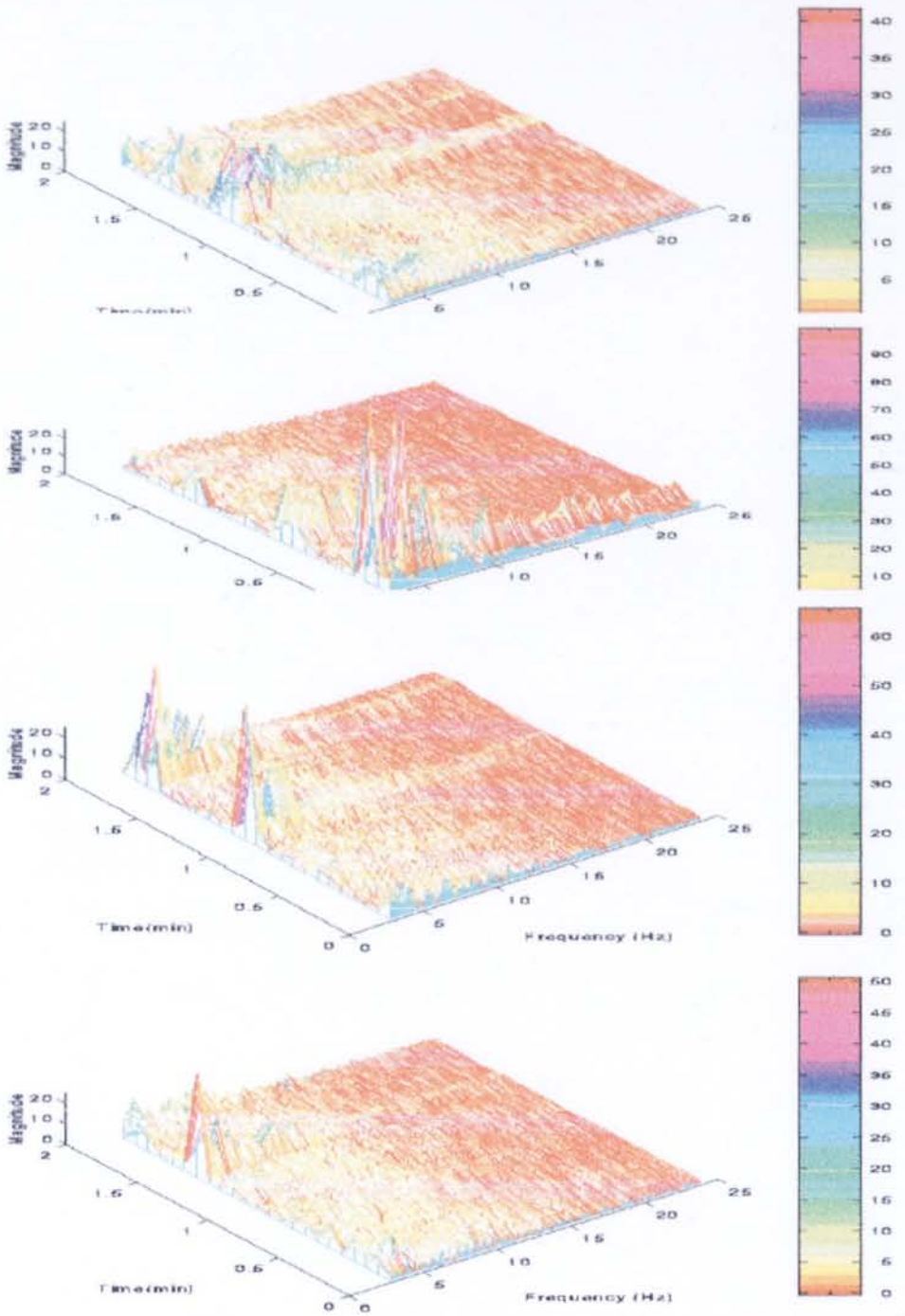


Figure 5.44: EEG Spectrum : each plot represents a 2 minute plot during a single color session

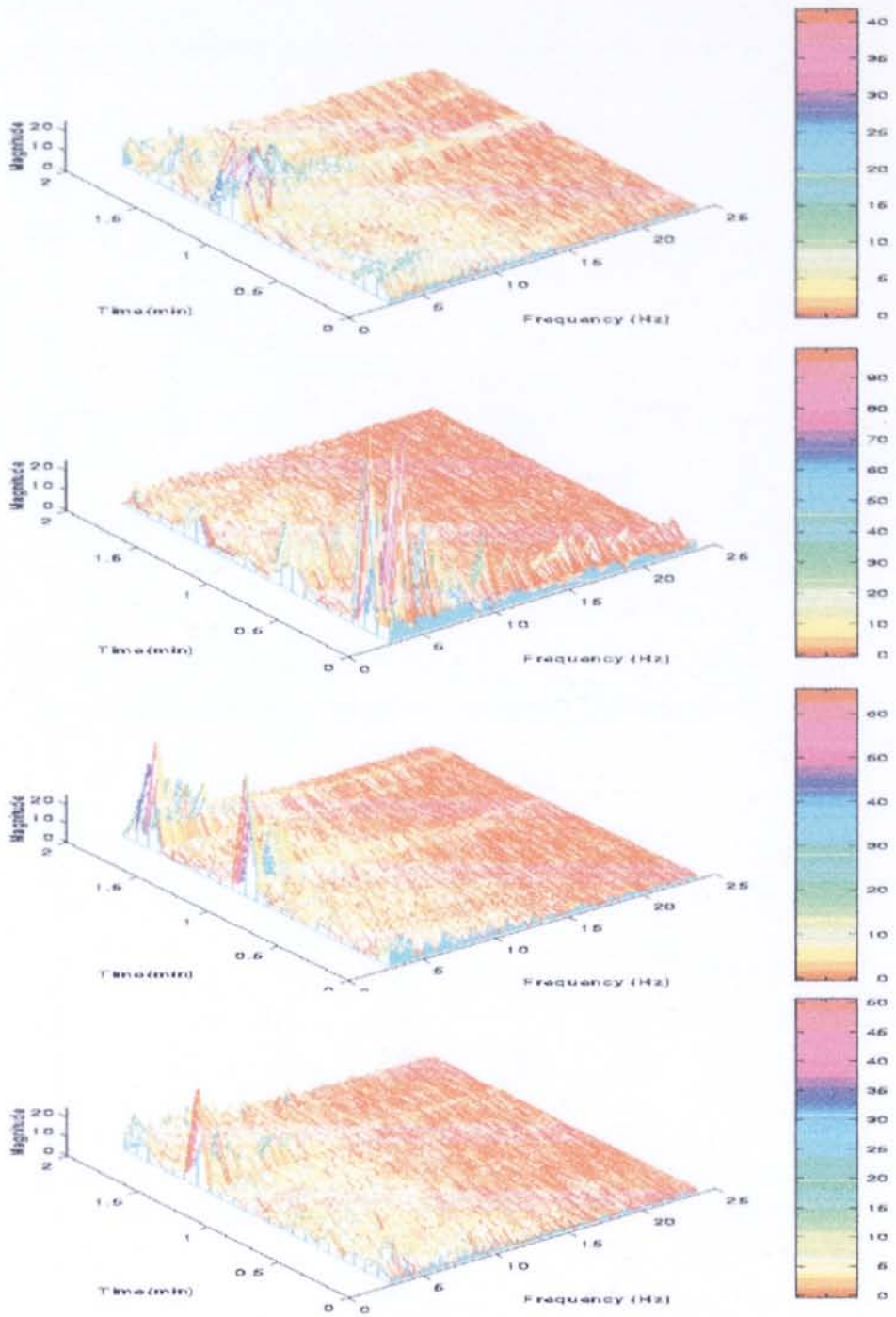


Figure 5.45: EEG Spectrum : each plot represents a 2 minute plot during a single color session

TEMPERATURE AND CONDUCTANCE OF DRF5

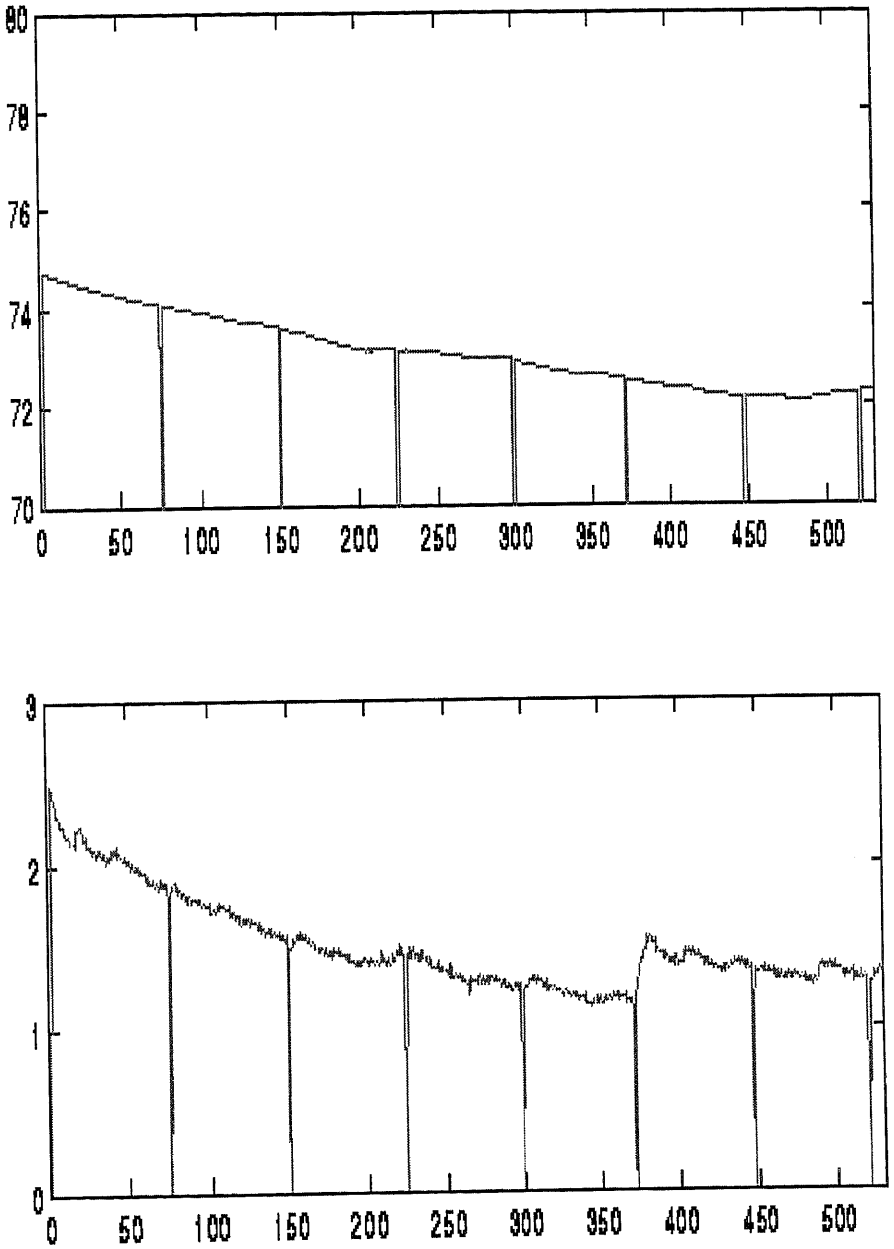
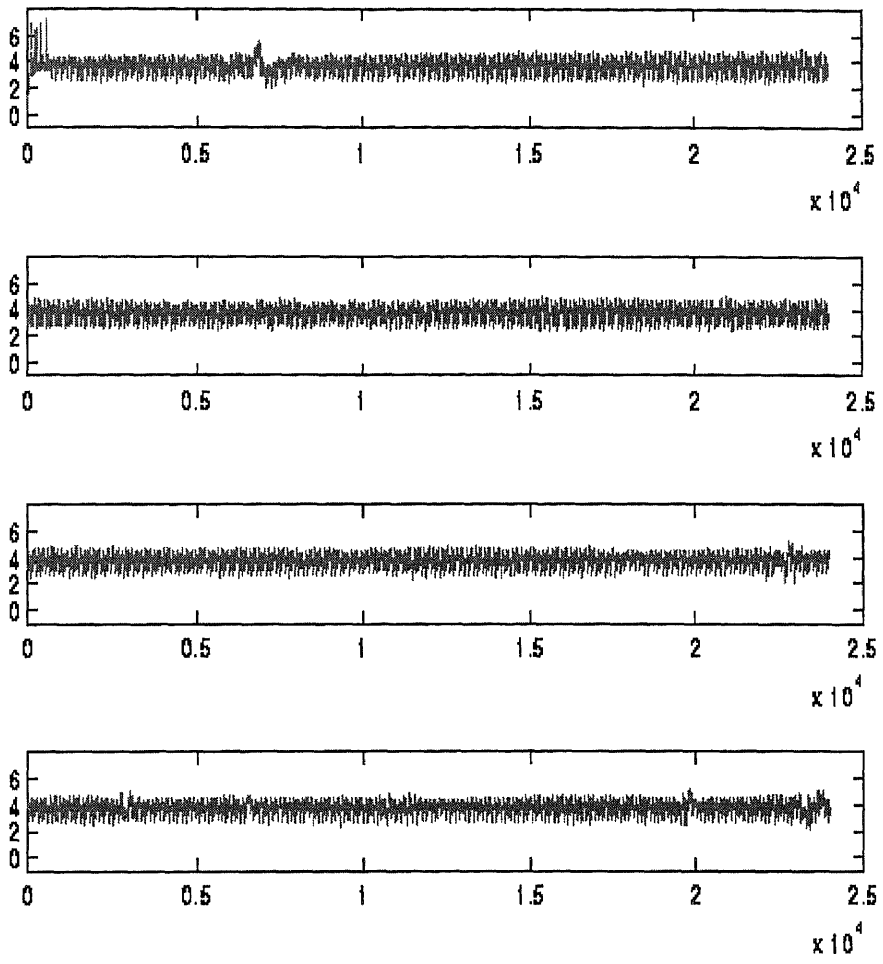


Figure 5.46: Temperature and conductivity plots. Each section represents a different color.

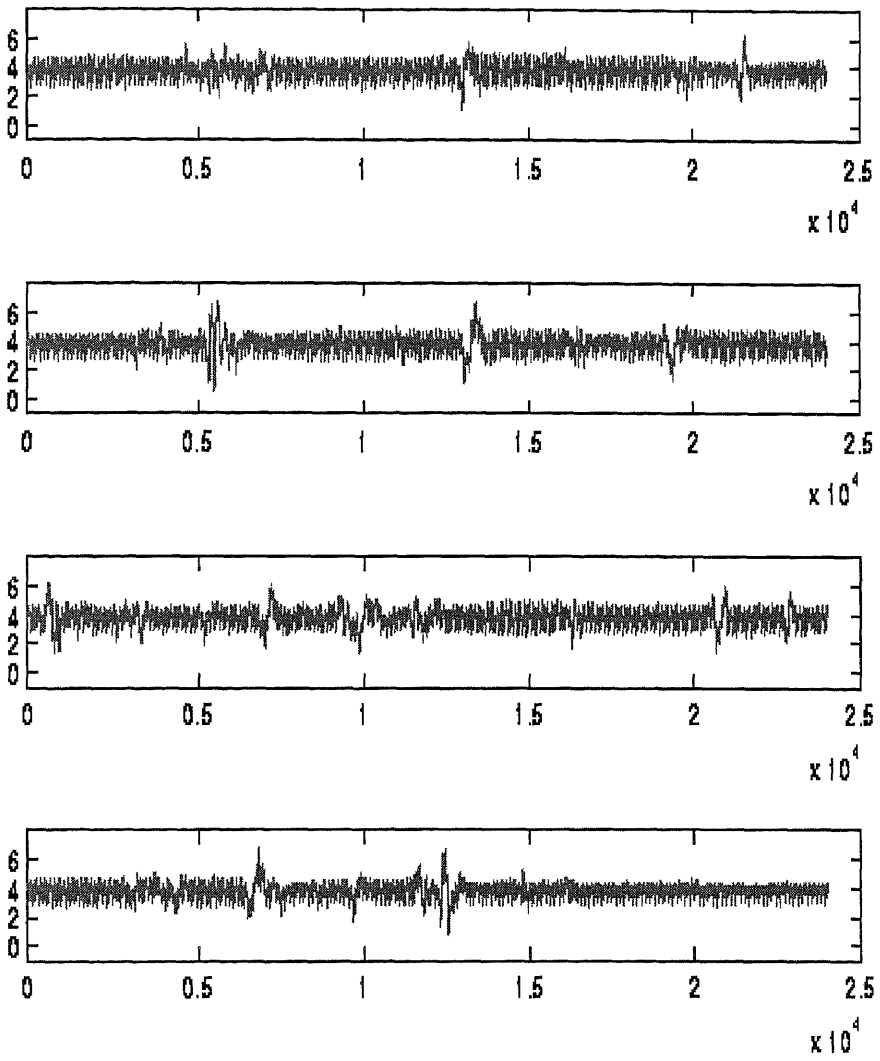
ARTERIAL BLOOD FLOW OF DRF2 (FIRST 4 COLORS)



DRF2	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRF21	2.02	1.82	1.80	1.97	2.03	2.12
DRF22	1.94	1.85	1.84	2.03	2.13	2.02
DRF23	2.03	1.93	1.93	2.04	1.83	1.96
DRF24	1.88	1.82	1.88	1.78	1.92	1.88

Figure 5.47: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

ARTERIAL BLOOD FLOW OF DRF2 (SECOND 4 COLORS)



DRF2	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRF25	1.95	2.01	1.89	2.25	2.13	1.89
DRF26	1.84	2.24	2.00	2.20	1.94	2.02
DRF27	2.04	1.97	2.05	2.10	2.01	2.24
DRF28	1.85	2.00	1.87	2.00	1.47	1.41

Figure 5.48: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

HRV SPECTRAL ANALYSIS - DRF2 (FIRST 4 COLORS)

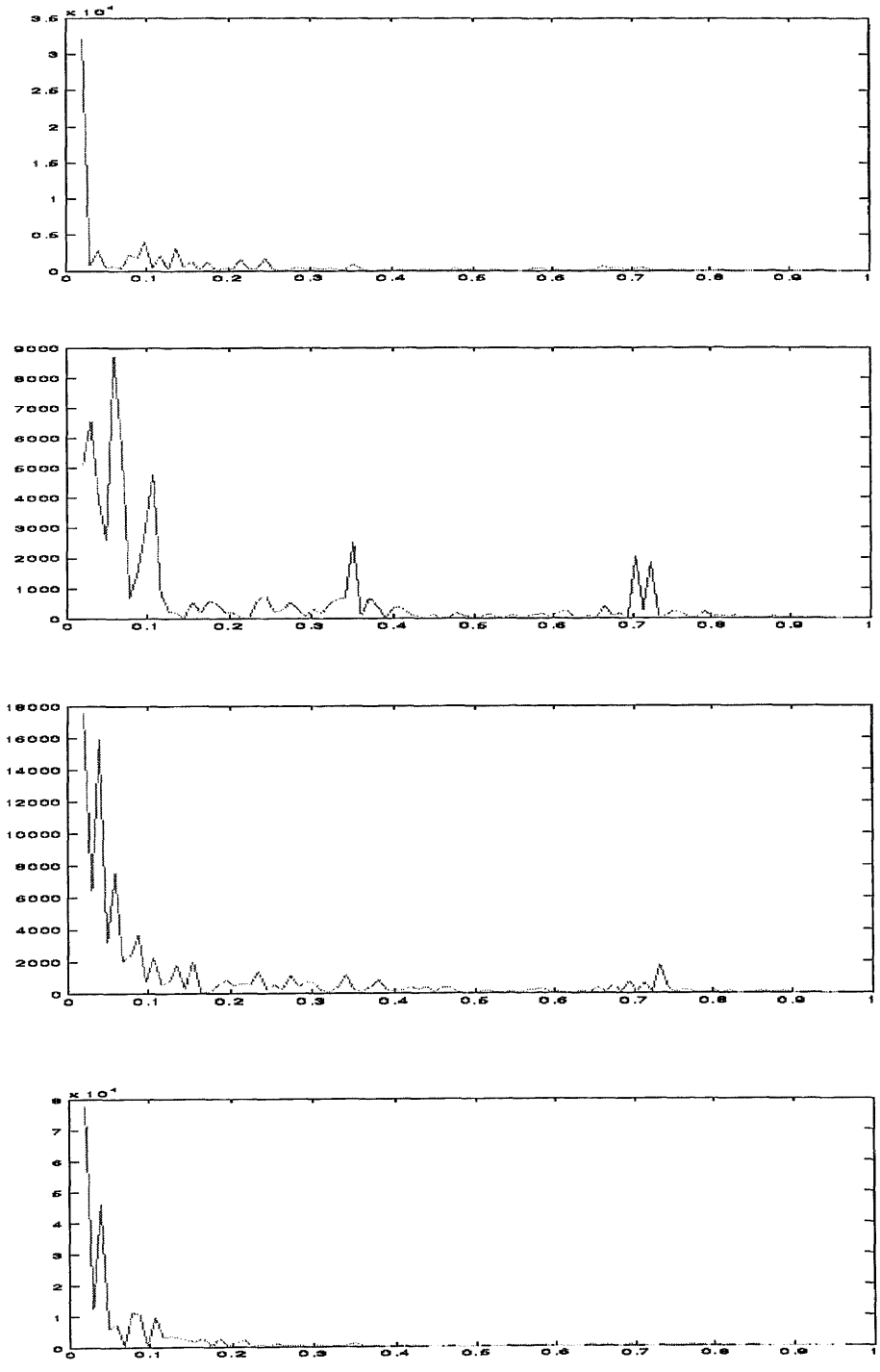


Figure 5.49: Each plot represents a two-minute period with the subject under the influence of a different color

HRV SPECTRAL ANALYSIS - DRF2 (SECOND 4 COLORS)

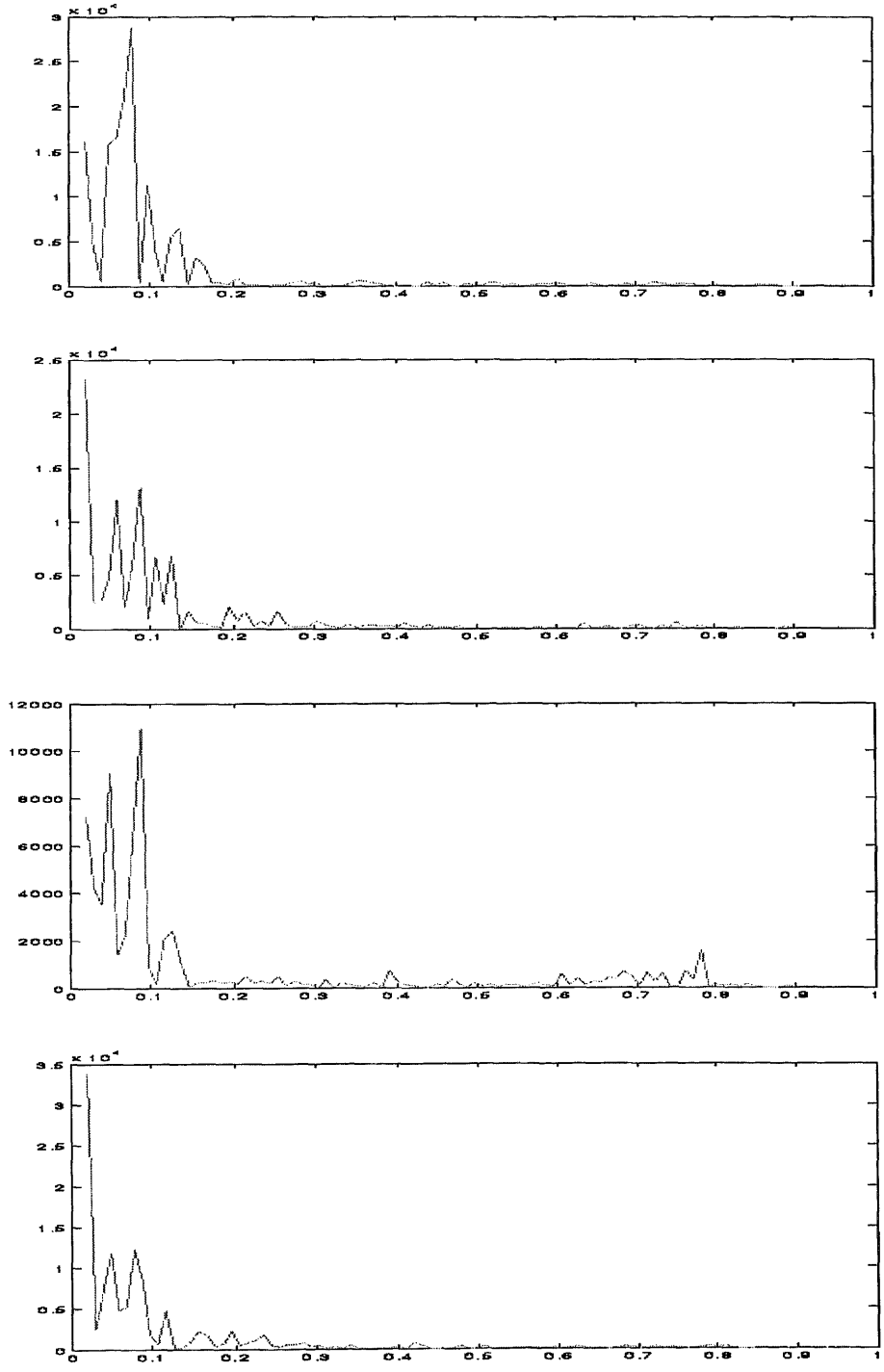


Figure 5.50: Each plot represents a two minute period with the subject under the influence of a different color

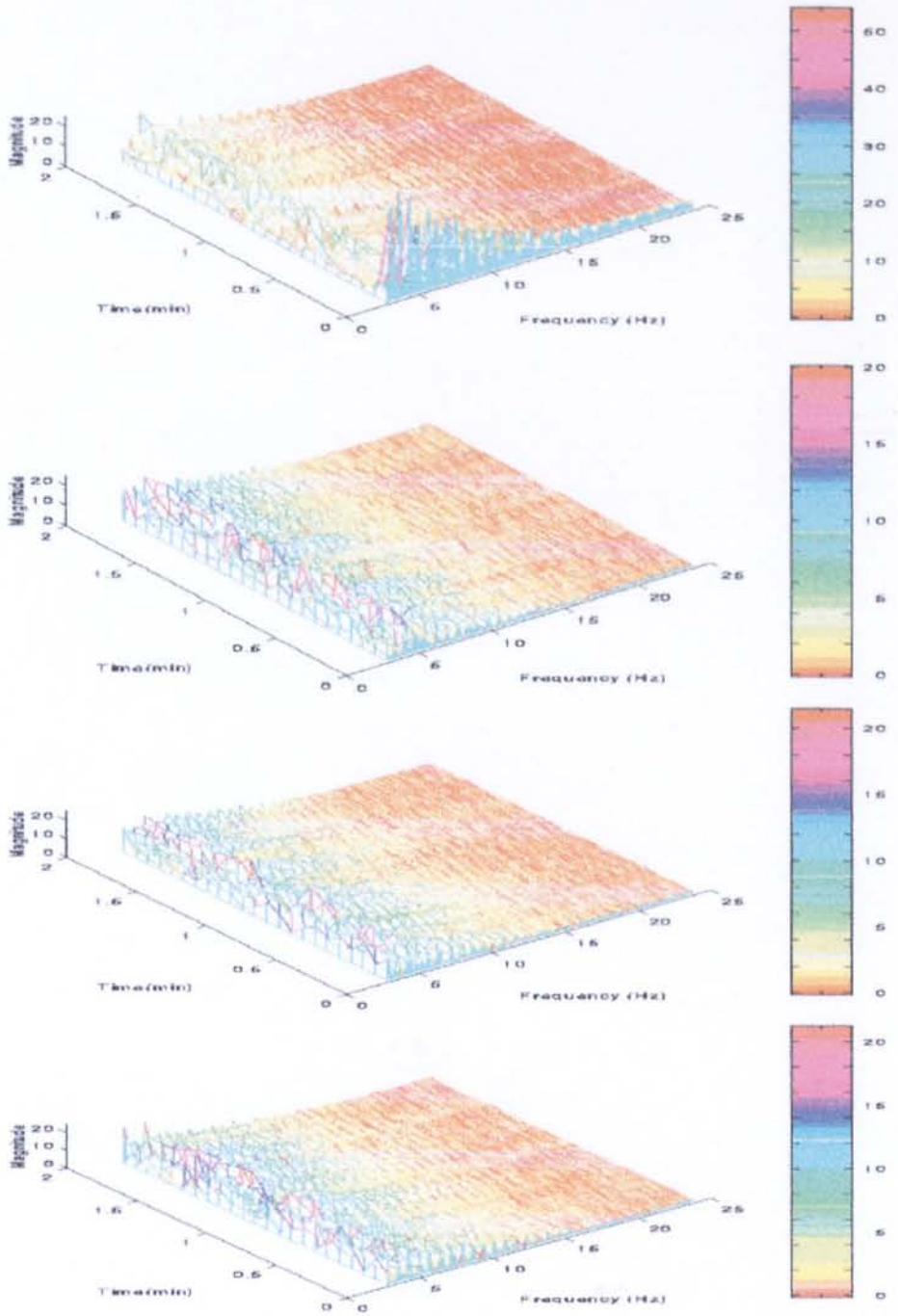


Figure 5.51: EEG Spectrum : each plot represents a 2 minute plot during a single color session

EEG SPECTRUM OF DRF2 (SECOND 4 COLORS)

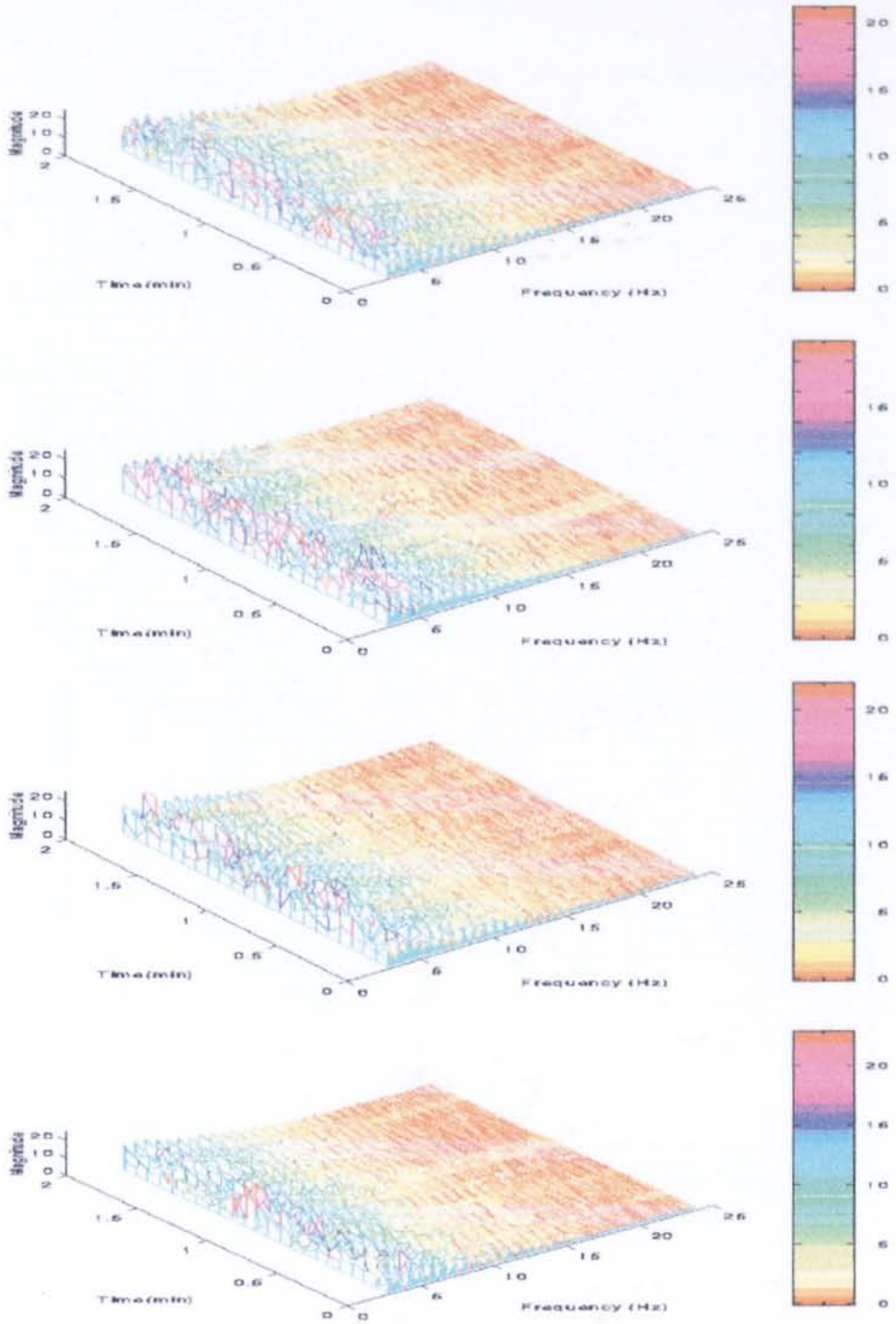


Figure 5.52: EEG Spectrum : each plot represents a 2 minute plot during a single color session

TEMPERATURE AND CONDUCTANCE OF DRF2

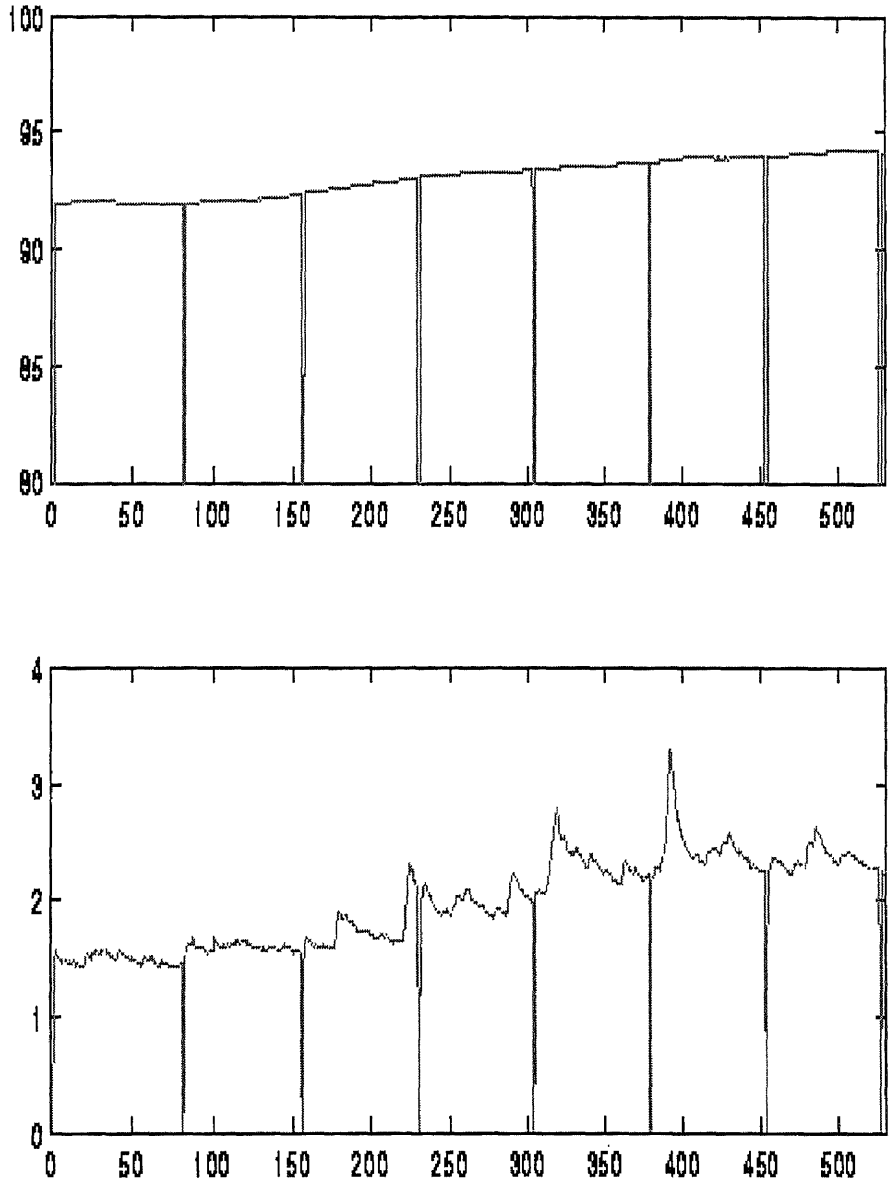
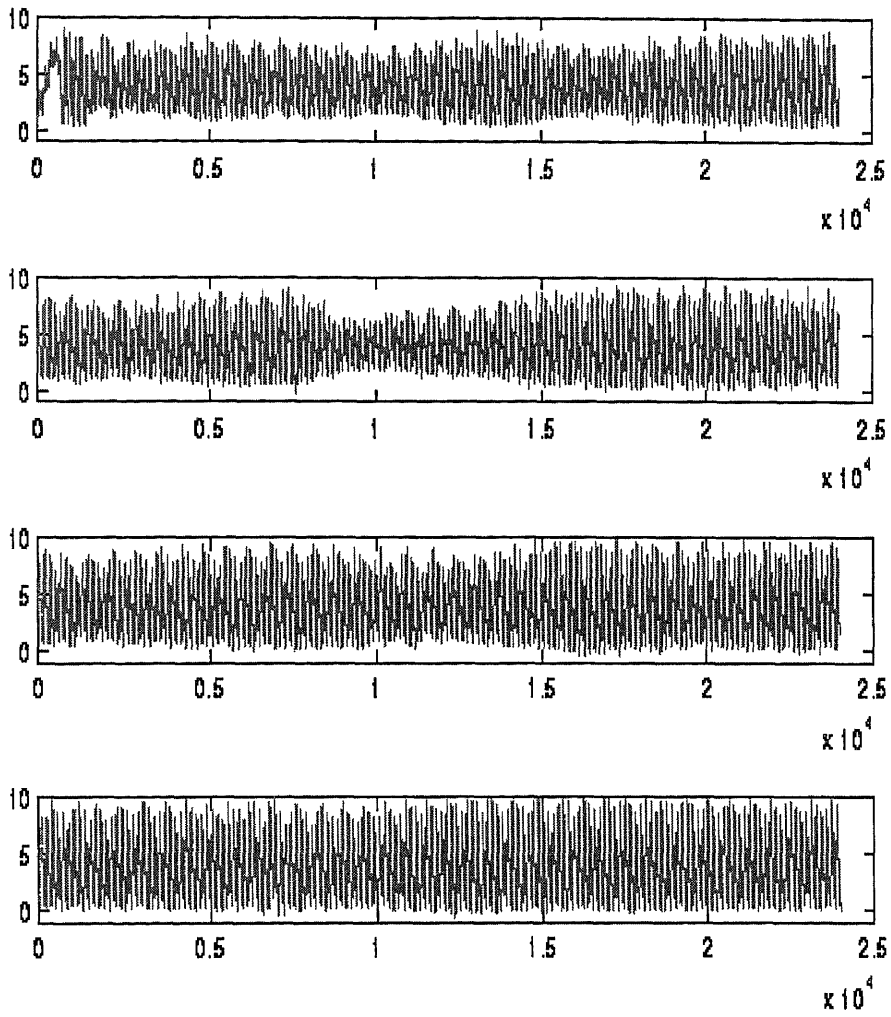


Figure 5.53: Temperature and conductivity plots respectively. Each section represents a different color.

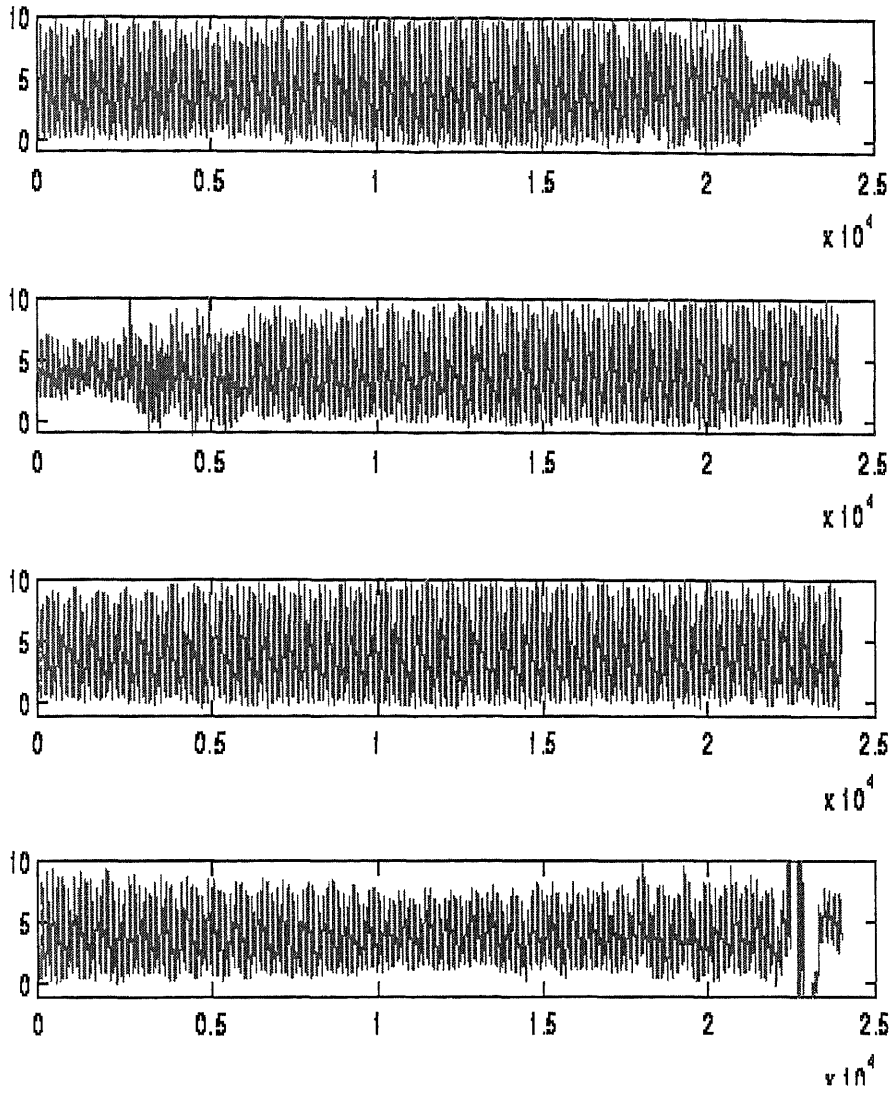
ARTERIAL BLOOD FLOW OF DRF3 (FIRST 4 COLORS)



DRF3	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRF31	5.73	6.2	5.64	6.88	6.2	7.48
DRF32	6.38	7.44	5.02	6.53	8.07	7.89
DRF33	7.38	8.06	7.56	7.94	8.89	8.7
DRF34	8.64	8.8	8.54	9.43	9.32	9.16

Figure 5.54: a) Two minute plots, each plot the subject is under the influence of a different color b) table of average wave amplitudes for 20 second periods.

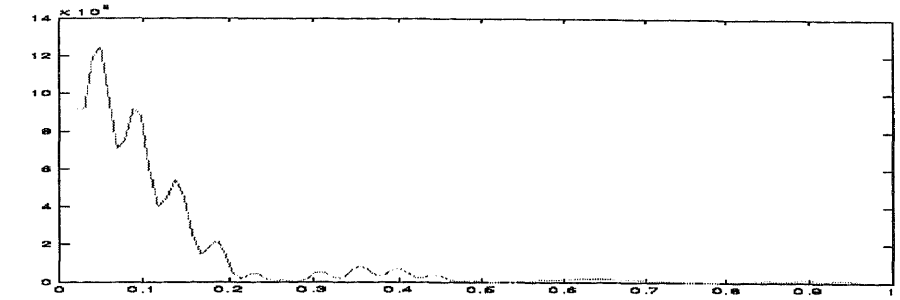
ARTERIAL BLOOD FLOW OF DRF 3 (SECOND 4 COLORS)



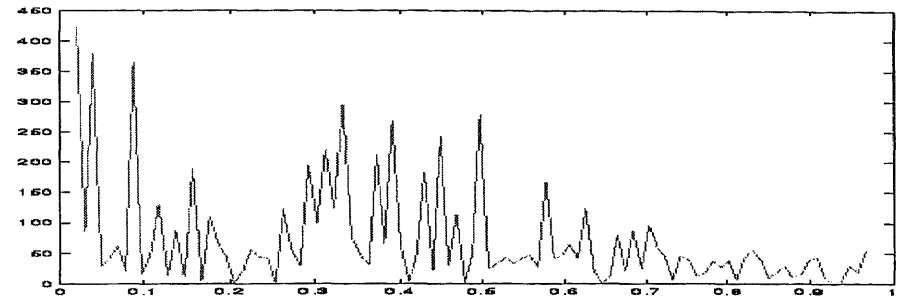
DRF3	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRF35	8.98	8.66	9.54	9.85	9.32	5.91
DRF36	5.49	8.21	8.47	9.28	9.57	9.62
DRF37	8.47	9.28	9.51	9.62	9.19	9.1
DRF38	7.84	7.1	6.19	6.13	6.81	7.48

Figure 5.55: a) Two minute plots, each plot the subject is under the influence of a different color b) table of average wave amplitudes for 20 second periods.

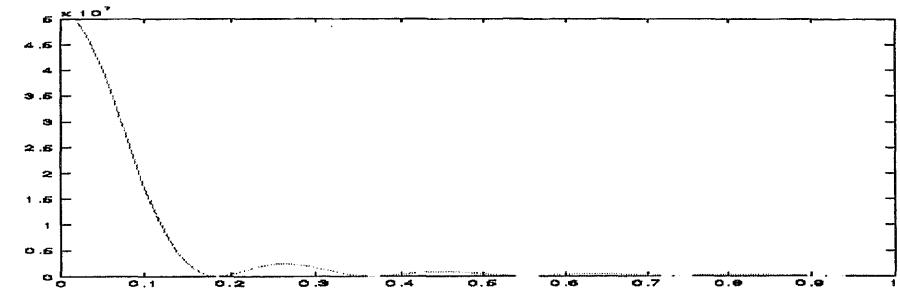
HRV SPECTRAL ANALYSIS - DRF3 (FIRST 4 COLORS)



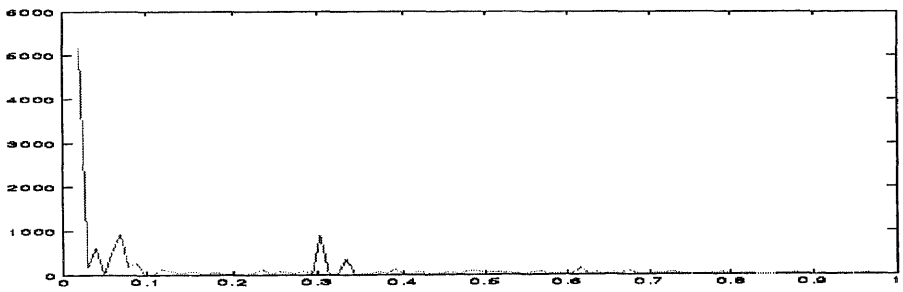
LFA= 406980
HFA= 145860
LFA/HFA= 2.79
**



LFA= 5.5
HFA= 16.1
LFA/HFA = 0.34



LFA= 1264600
HFA= 194150
LFA/HFA= 6.5
**



LFA= 14.1
HFA= 13.2
LFA/HFA= 1.07

Figure 5.56: Each plot represents a two minute period with the subject under the influence of a different color.
** the file had a period of maxing out ie: recording at 10 volts without heart waveform and thus error.

HRV SPECTRAL ANALYSIS - DRF3 (SECOND 4 COLORS)

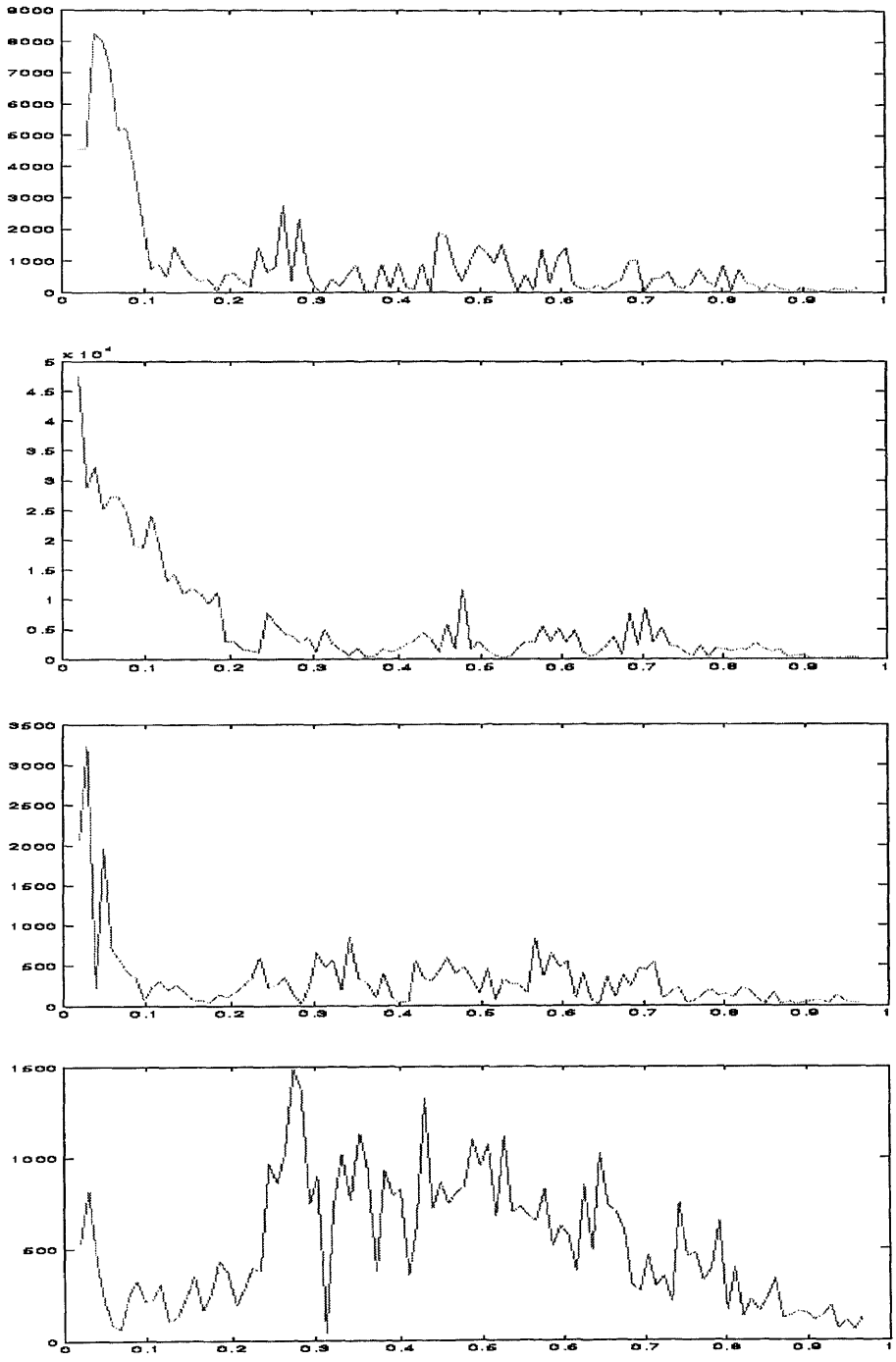


Figure 5.57: Each plot represents a two minute period with the subject under the influence of a different color.

** the file had a period of maxing out ie: recording at 10 volts without heart waveform and thus error.

EEG SPECTRUM OF DRF3 (FIRST 4 COLORS)

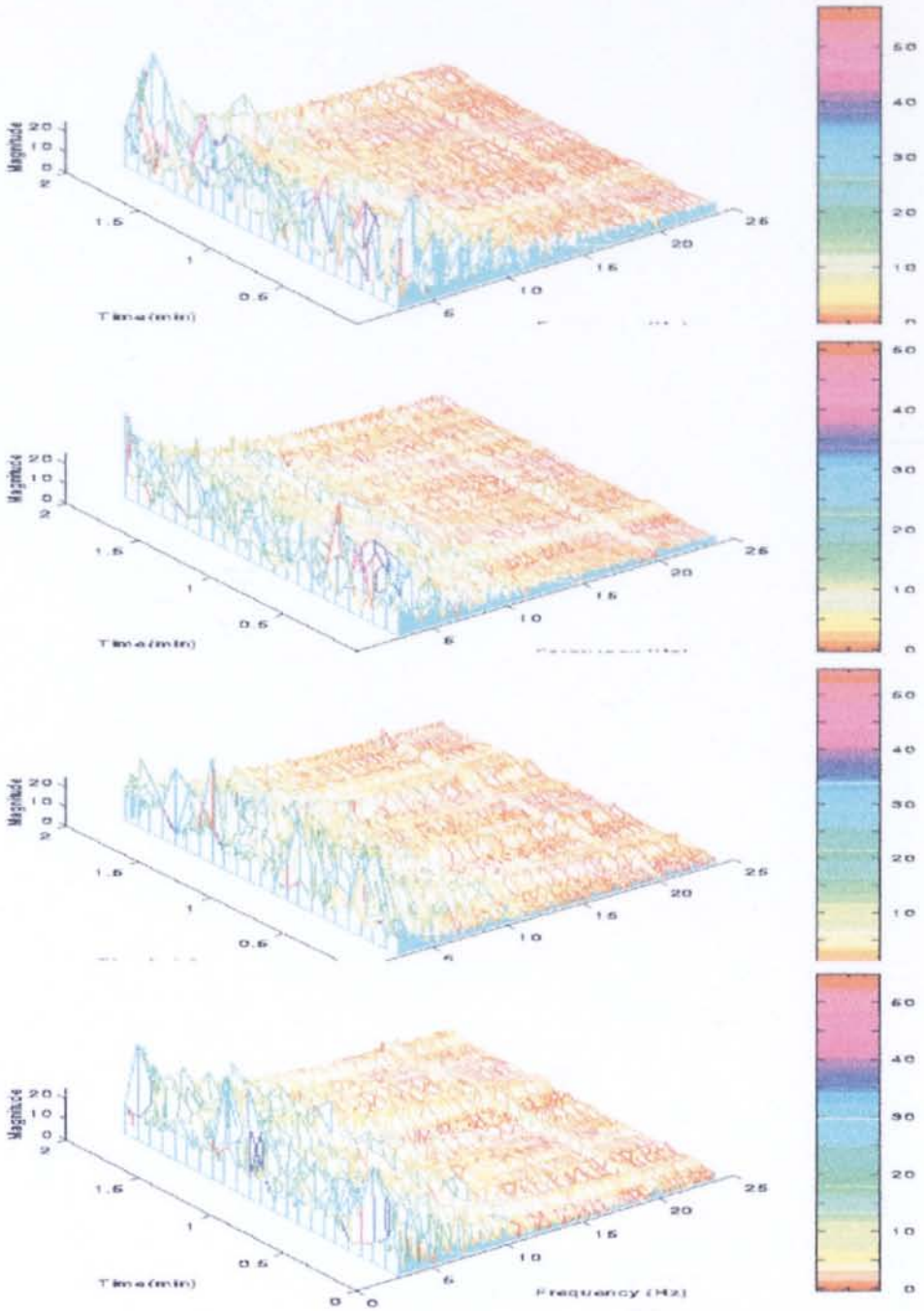


Figure 5.58: EEG Spectrum : each plot represents a 2 minute plot during a single color session

EEG SPECTRUM OF DRF3 (SECOND 4 COLORS)

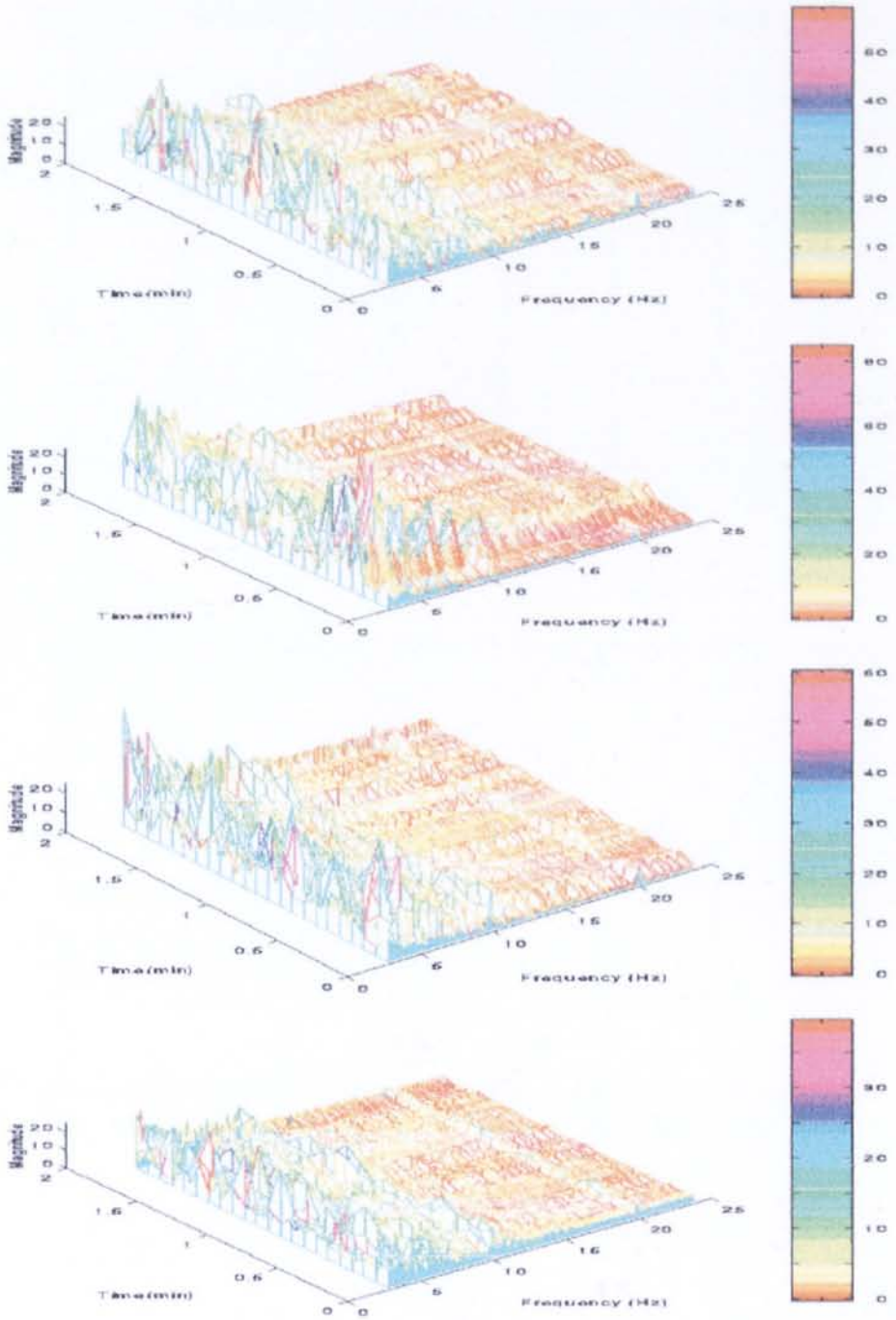


Figure 5.59: EEG Spectrum : each plot represents a 2 minute plot during a single color session

TEMPERATURE AND CONDUCTANCE OF DRF3

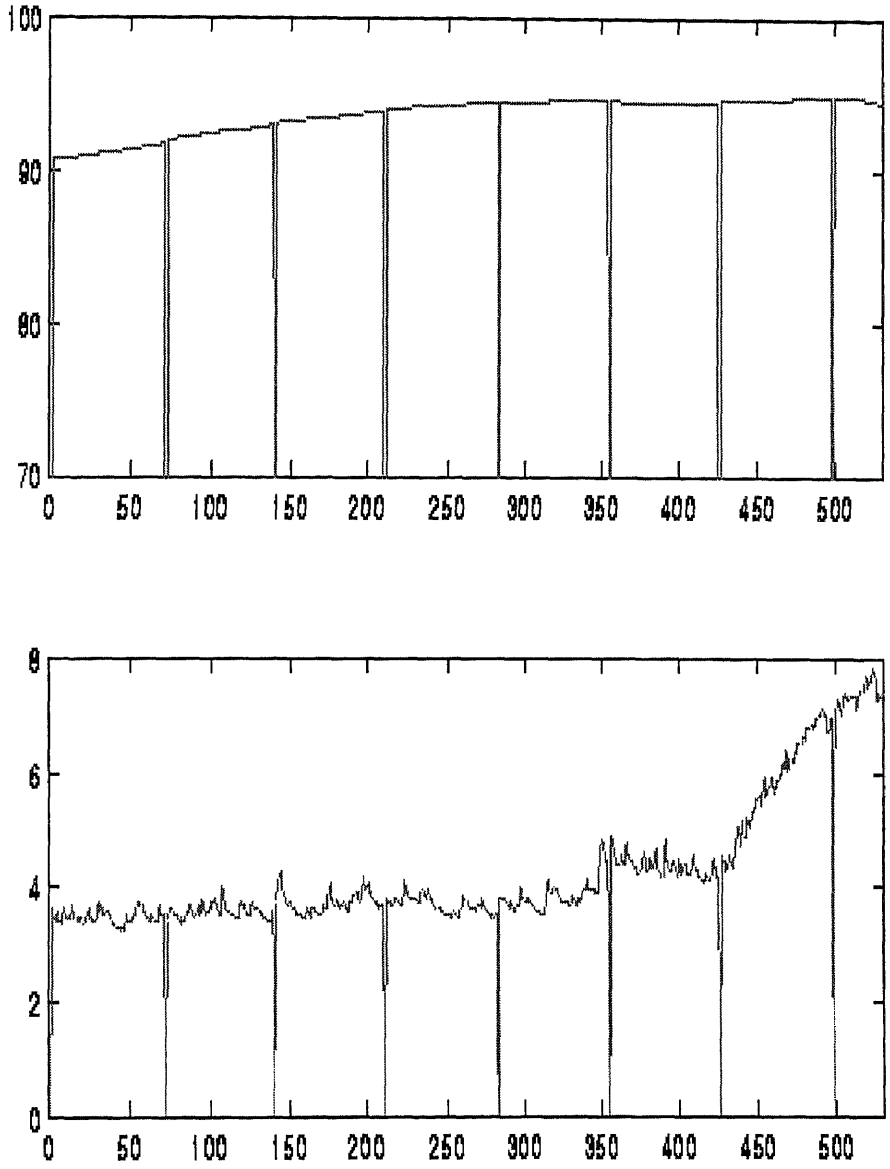
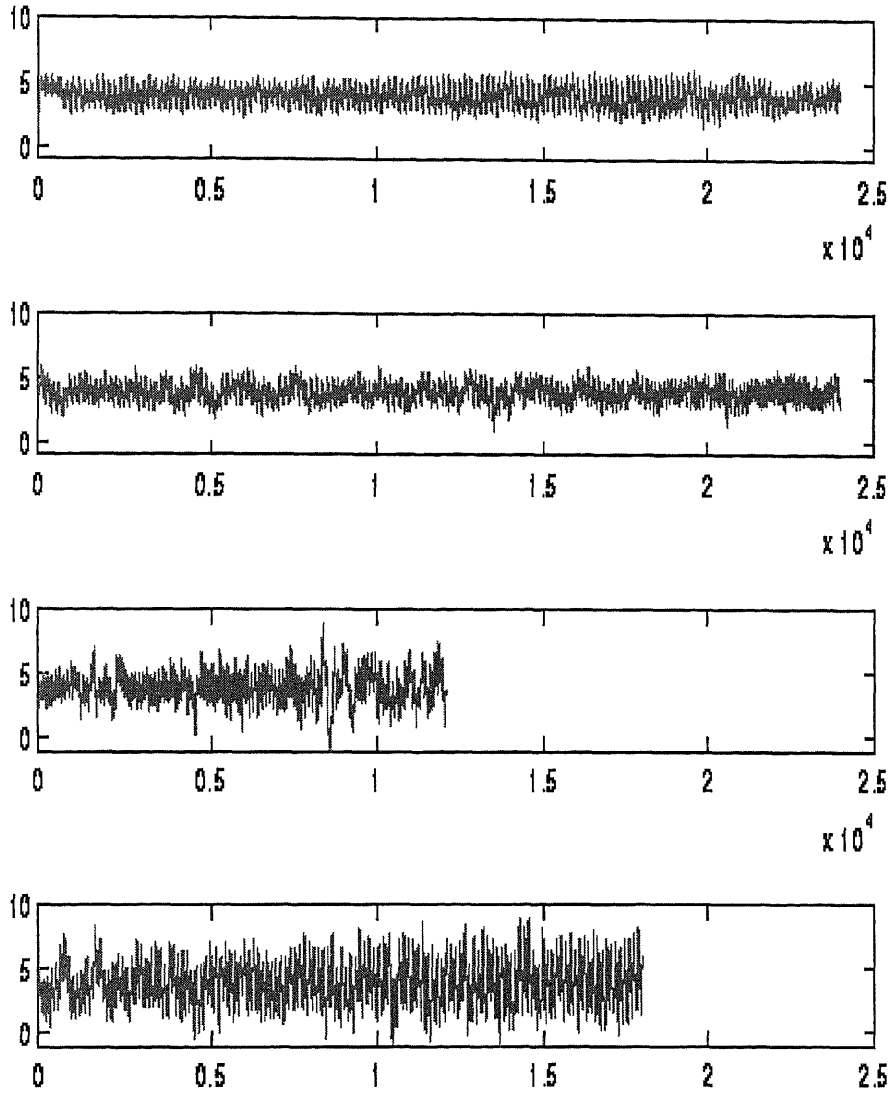


Figure 5.60: Temperature and conductivity plots respectively. Each section represents a different color.

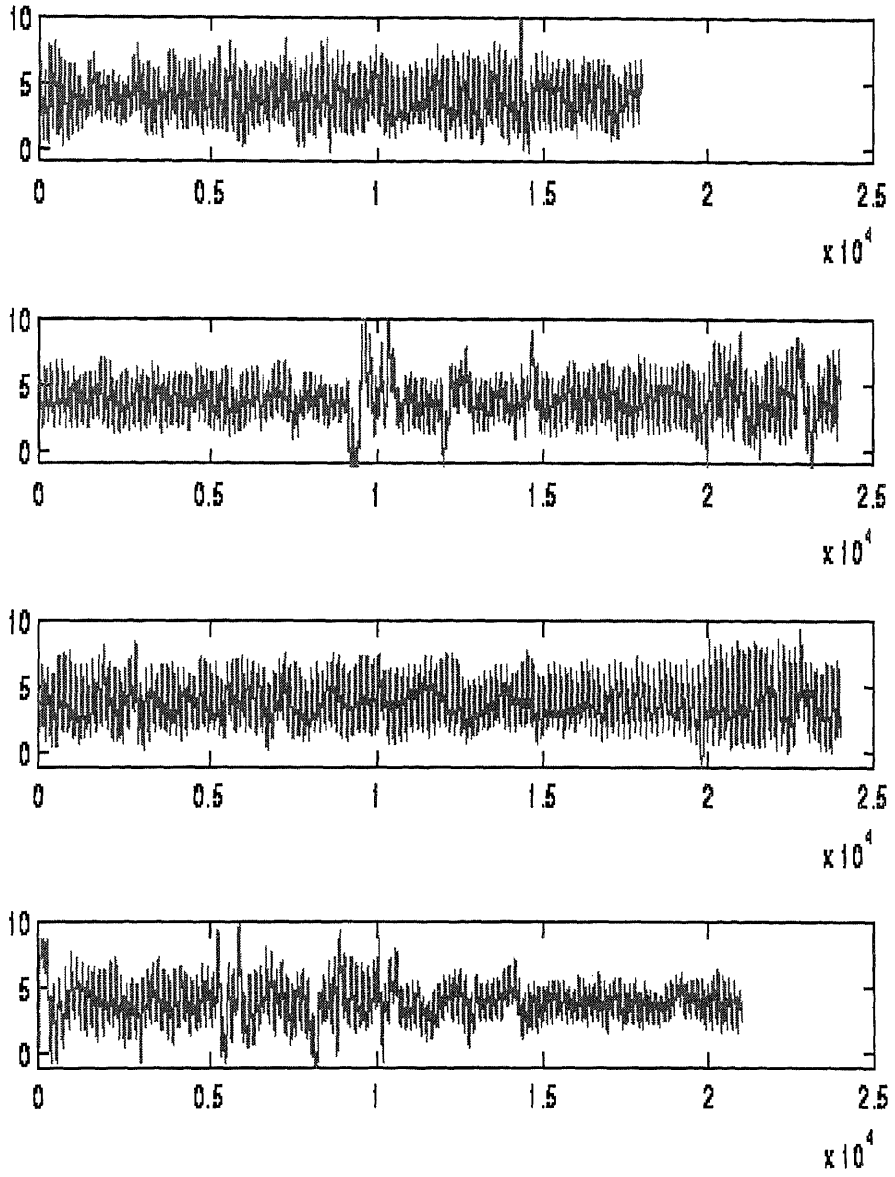
ARTERIAL BLOOD FLOW OF DRF4 (FIRST 4 COLORS)



DRF4	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRF41	2.36	2.24	2.45	2.91	3.13	2.41
DRF42	2.3	2.41	2.26	2.45	2.32	2.36
DRF43	3.01	3.87	4.44	NA	NA	NA
DRF44	4.47	5.08	5.87	6.03	6.61	NA

Figure 5.61: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

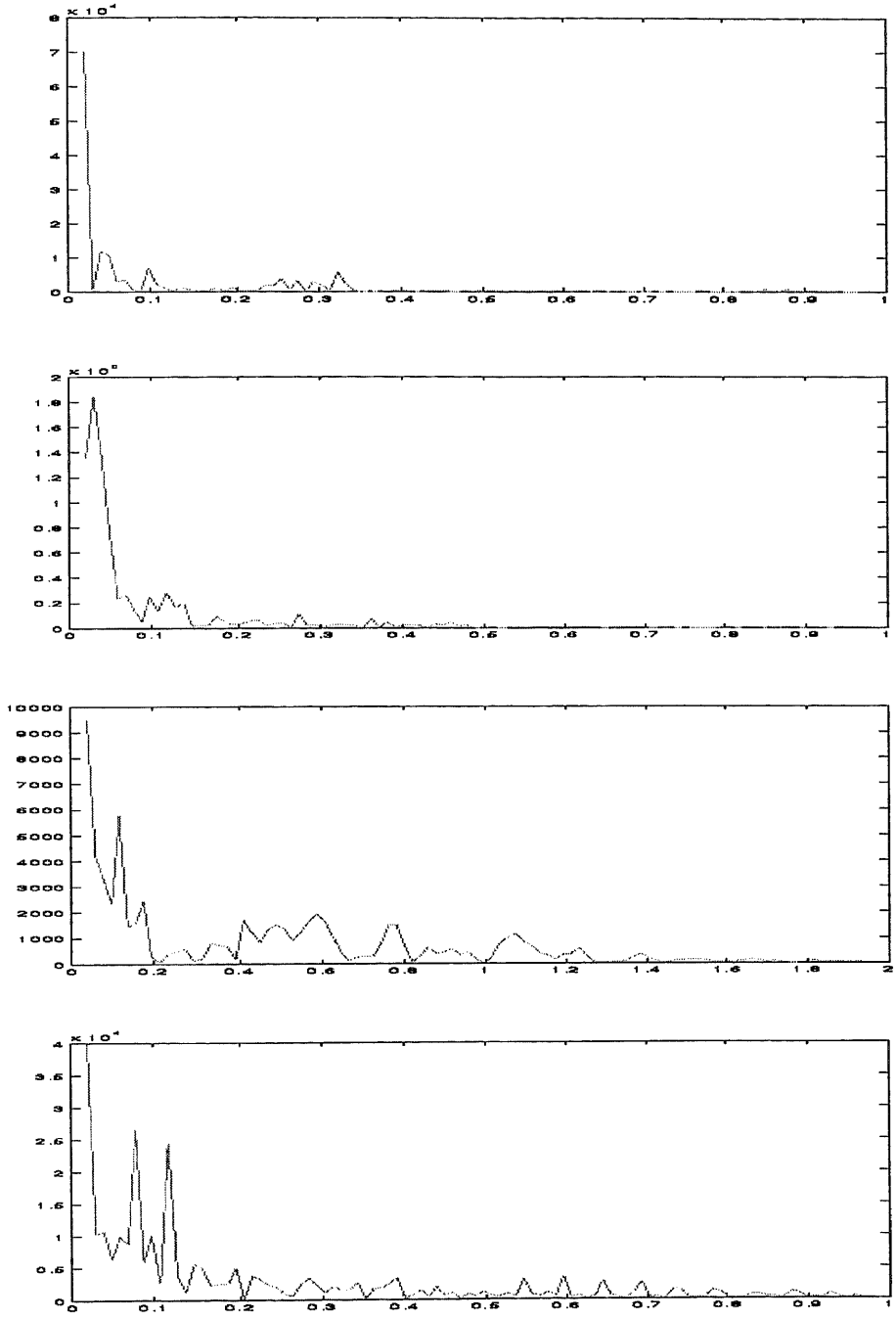
ARTERIAL BLOOD FLOW OF DRF4 (SECOND 4 COLORS)



DRF4	1-4K	4K-8K	8K-12K	12K-16K	16K-20K	20K-24K
DRF45	4.86	5.4	5.42	6.04	4.84	NA
DRF46	4.34	3.96	4.92	4.22	5.07	6.16
DRF47	5.53	5.07	5.33	4.79	5.46	6.95
DRF48	5.38	5.37	4.65	3.73	3.11	NA

Figure 5.62: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

HRV SPECTRAL ANALYSIS - DRF4 (FIRST 4 COLORS)



LFA= 202.6
HFA= 152.5
LFA/HFA= 1.33

LFA= 1818.0
HFA= 644.0
LFA/HFA = 2.82
** *!

LFA= 786
HFA= 194.8
LFA/HFA= 4.03
*!

LFA= 727.2
HFA= 461.1
LFA/HFA= 1.58
*!

Figure 5.63: Each plot represents a two minute period with the subject under the influence of a different color.
** the file had a period of maxing out ie: recording at 10 volts without heart waveform and thus error.
*! See additional note on page 66

HRV SPECTRAL ANALYSIS - DRF4 (SECOND 4 COLORS)

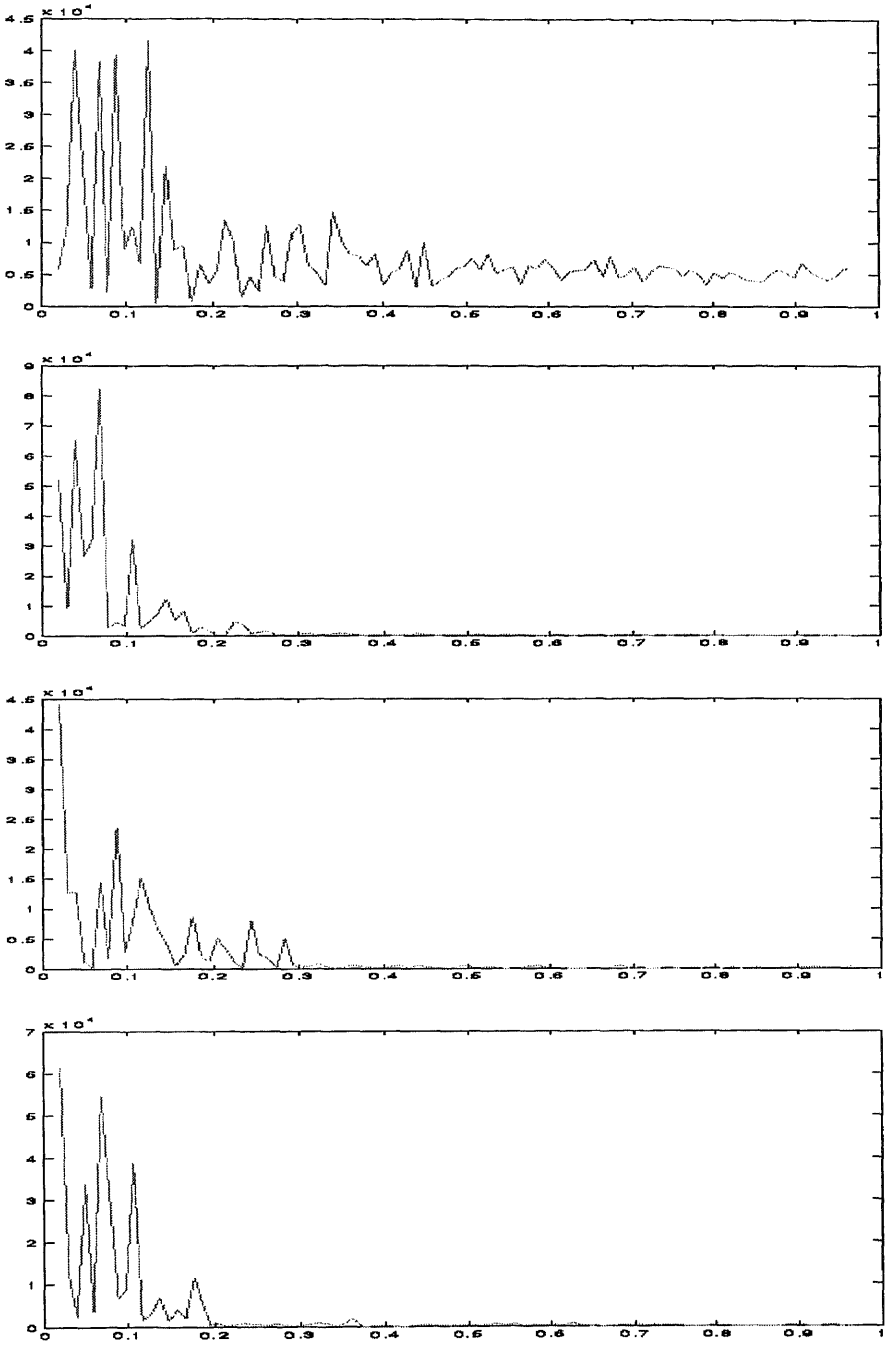


Figure 5.64: Each plot represents a two minute period with the subject under the influence of a different color.

** the file had a period of maxing out ie: recording at 10 volts without heart waveform and thus error.

*! See additional note on page 66

EEG SPECTRUM OF DRF4 (FIRST 4 COLORS)

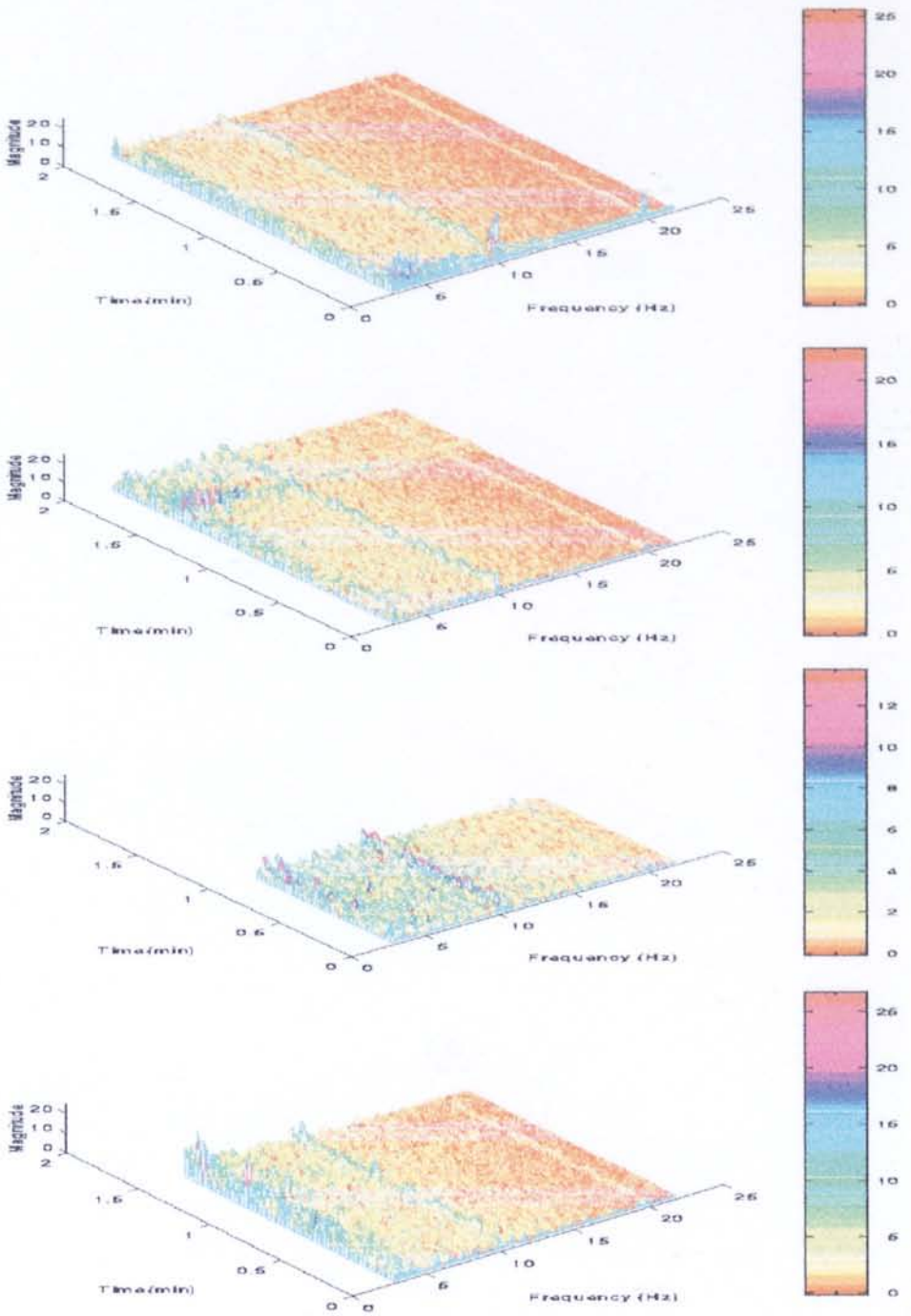


Figure 5.65: EEG Spectrum : each plot represents a 2 minute plot during a single color session

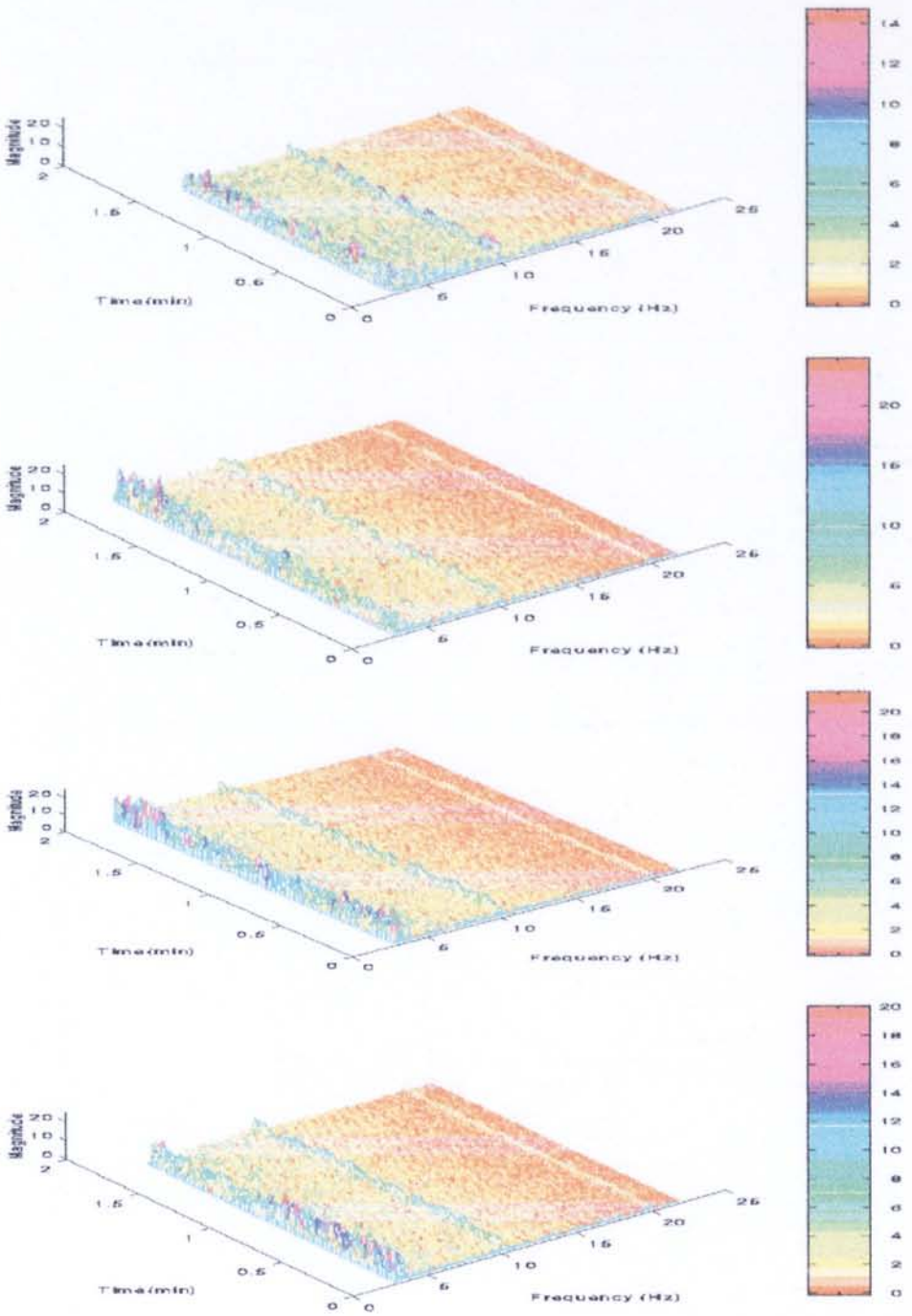


Figure 5.66: EEG Spectrum : each plot represents a 2 minute plot during a single color session

TEMPERATURE AND CONDUCTANCE OF DRF4

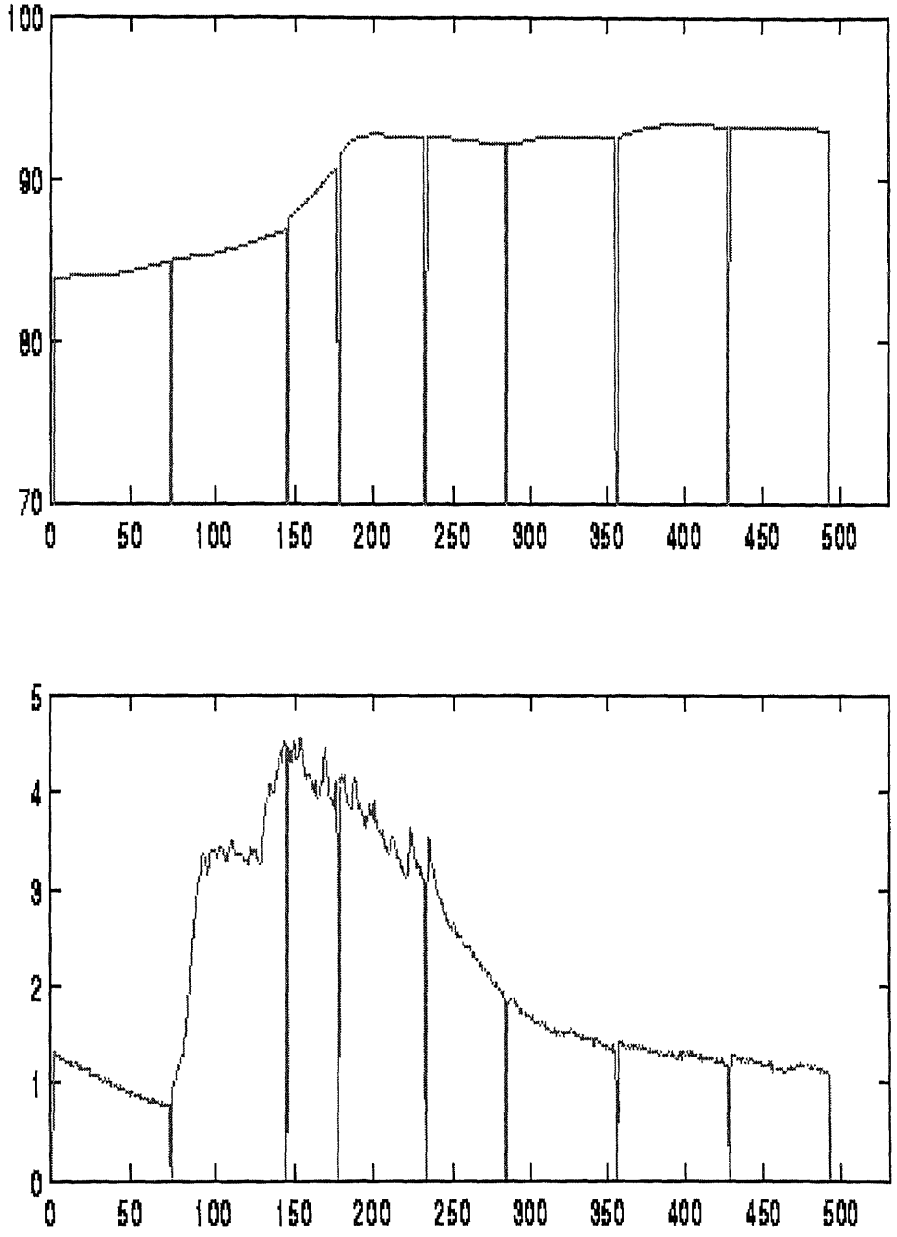
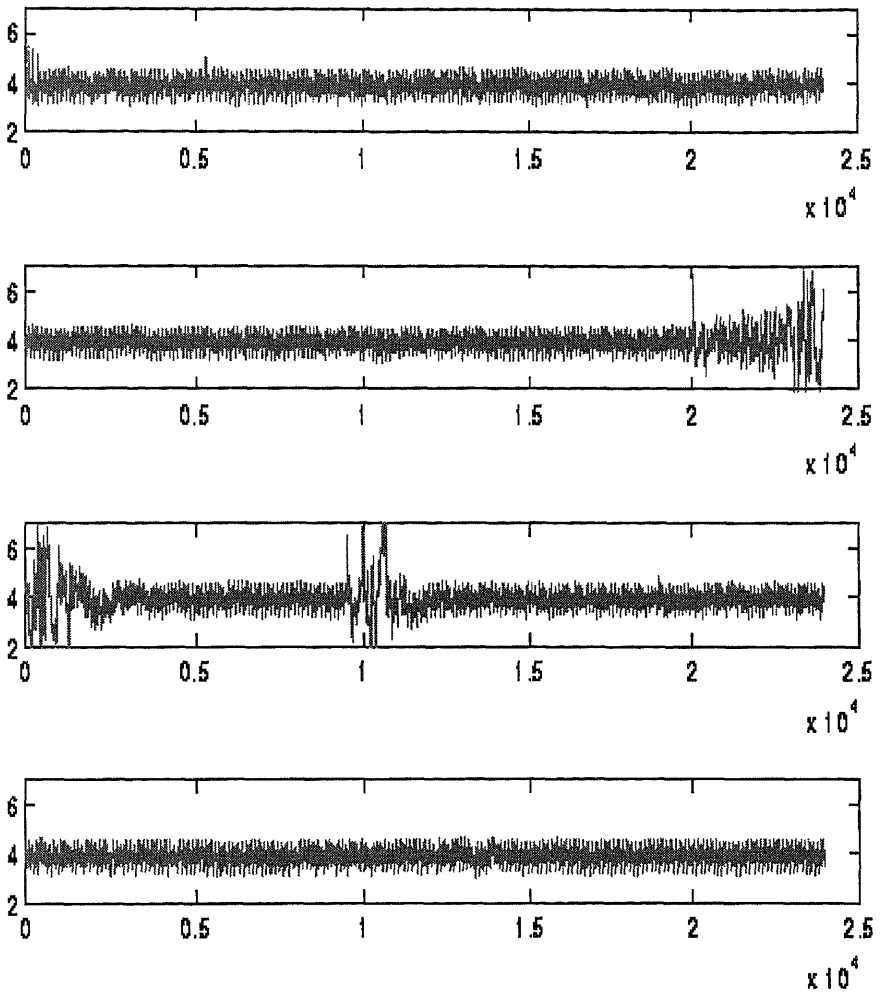


Figure 5.67: Temperature and conductivity plots respectively. Each section represents a different color.

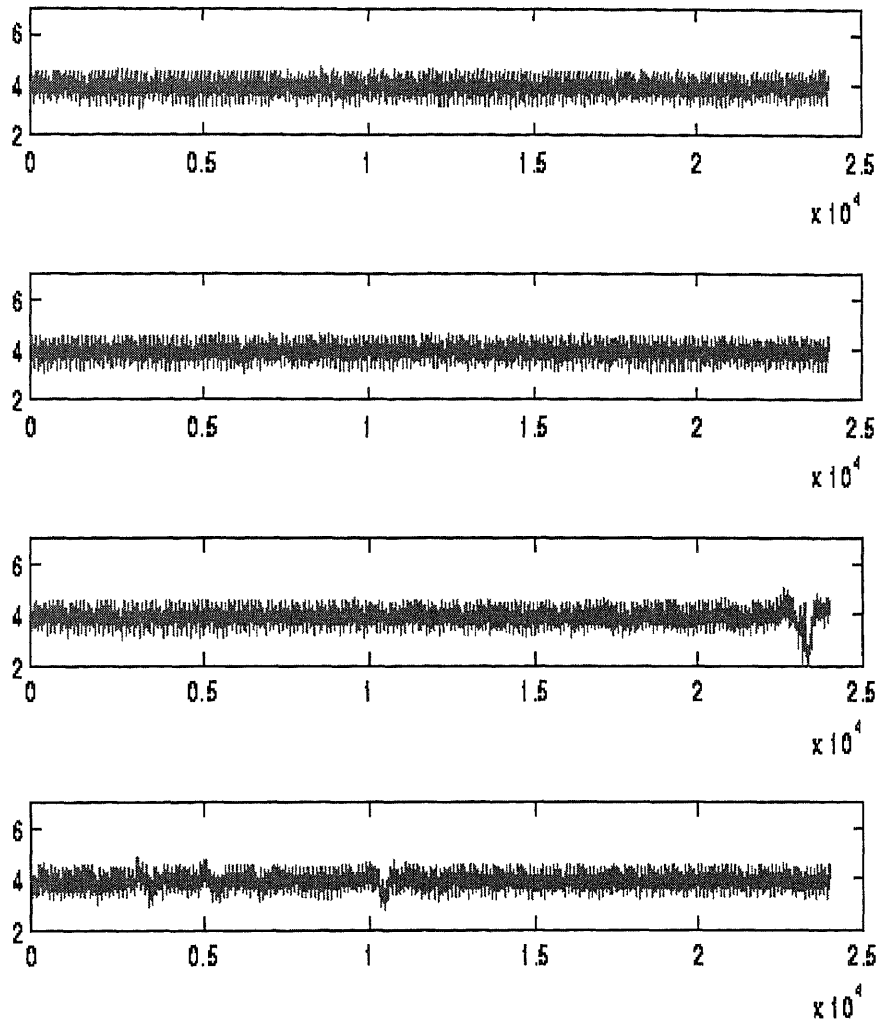
ARTERIAL BLOOD FLOW OF DRF6 (FIRST 4 COLORS)



	1-4K	4K-8K	8K-12K	12K-16K	16-20K	20K-24K
DRF61	1.29	1.24	1.13	1.24	1.18	1.17
DRF62	1.2	1.18	1.14	1.17	1.14	2.39
DRF63	2.19	1.28	2.13	1.21	1.18	1.17
DRF64	1.21	1.31	1.21	1.23	1.32	1.31

Figure 5.68: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

ARTERIAL BLOOD FLOW OF DRF6 (SECOND 4 COLORS)



	1-4K	4K-8K	8K-12K	12K-16K	16-20K	20K-24K
DRF65	1.2	1.24	1.17	1.31	1.15	1.18
DRF66	1.24	1.21	1.23	1.14	1.25	1.15
DRF67	1.22	1.21	1.15	1.12	1.12	1.27
DRF68	1.15	1.07	1.11	1.13	1.08	1.1

Figure 5.69: a) Two minute plots, each plot the subject is under the influence of a different color b) average wave amplitudes for 20 second periods.

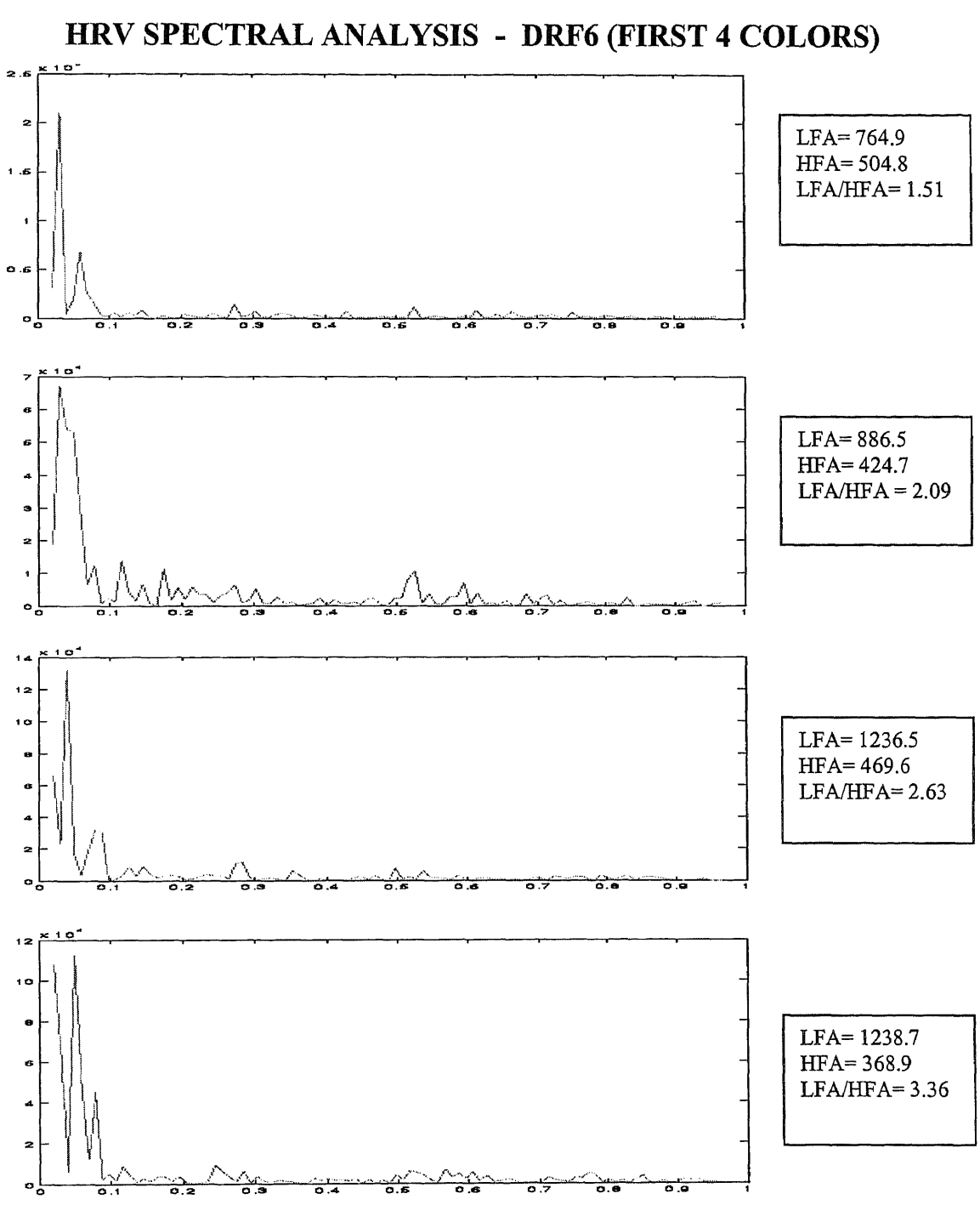


Figure 5.70: Each plot represents a two minute period with the subject under the influence of a different color.

HRV SPECTRAL ANALYSIS - DRF6 (SECOND 4 COLORS)

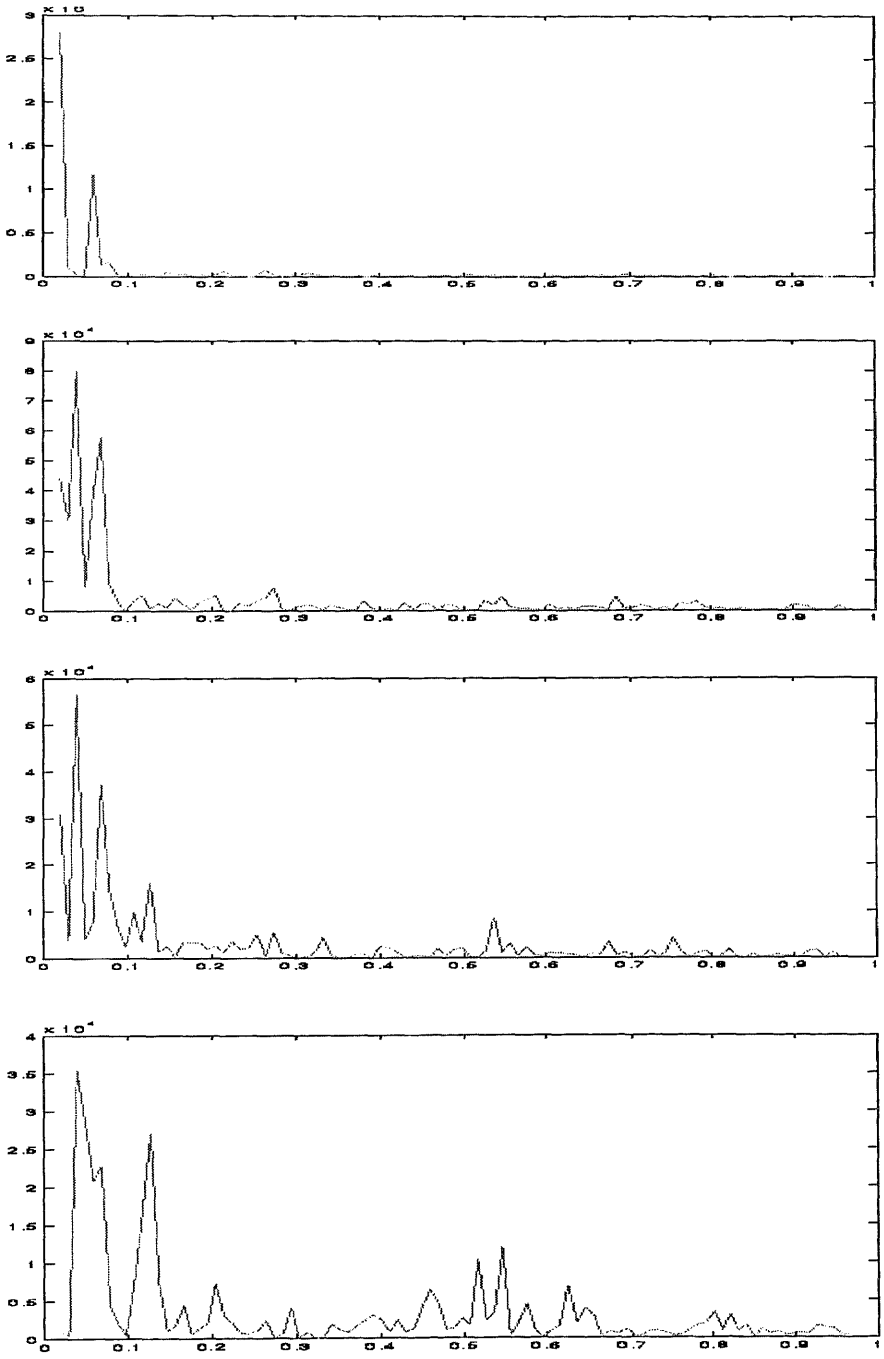


Figure 5.71: Each plot represents a two minute period with the subject under the influence of a different color.

EEG SPECTRUM OF DRF6 (FIRST 4 COLORS)

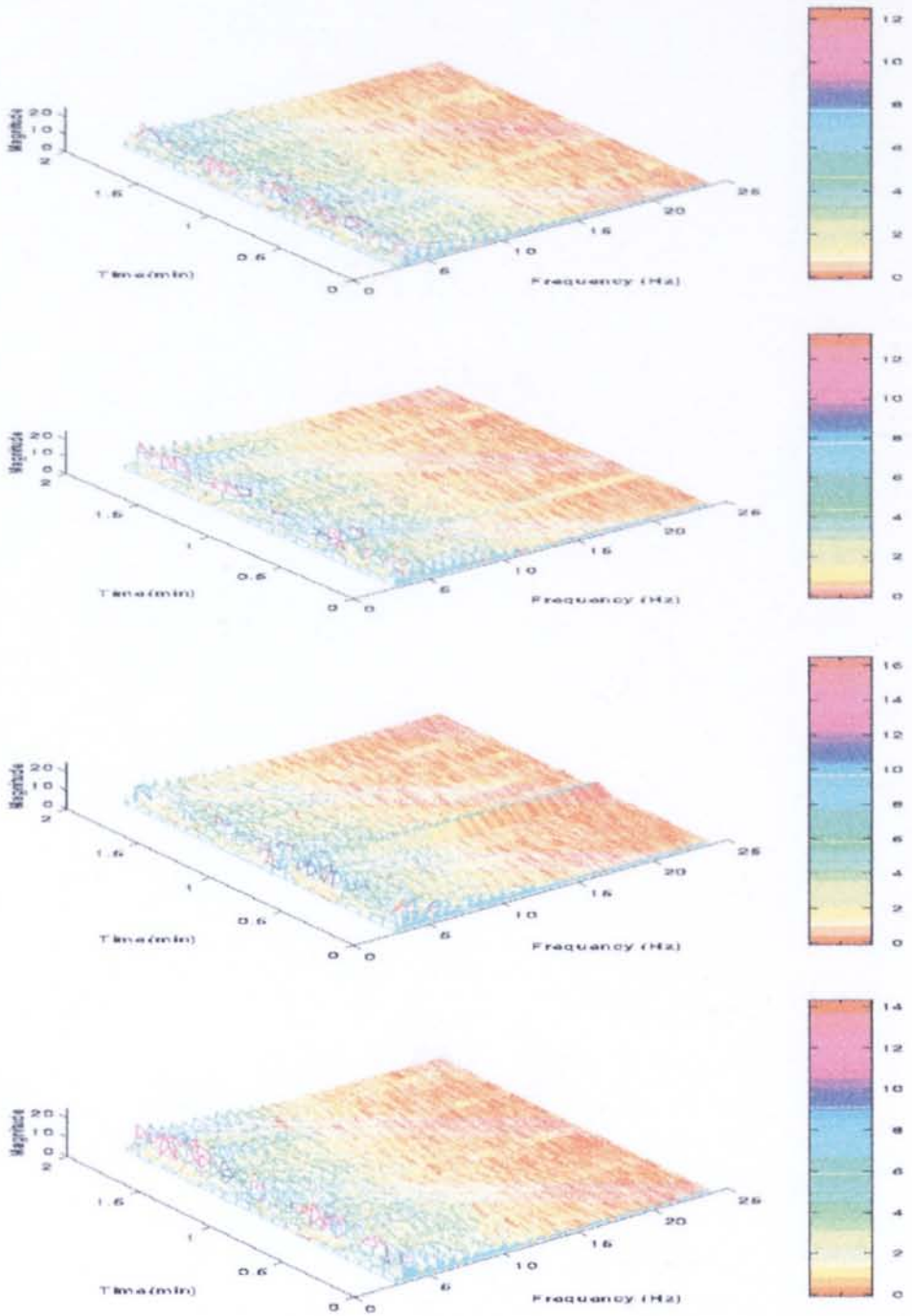


Figure 5.72: EEG Spectrum : each plot represents a 2 minute plot during a single color session

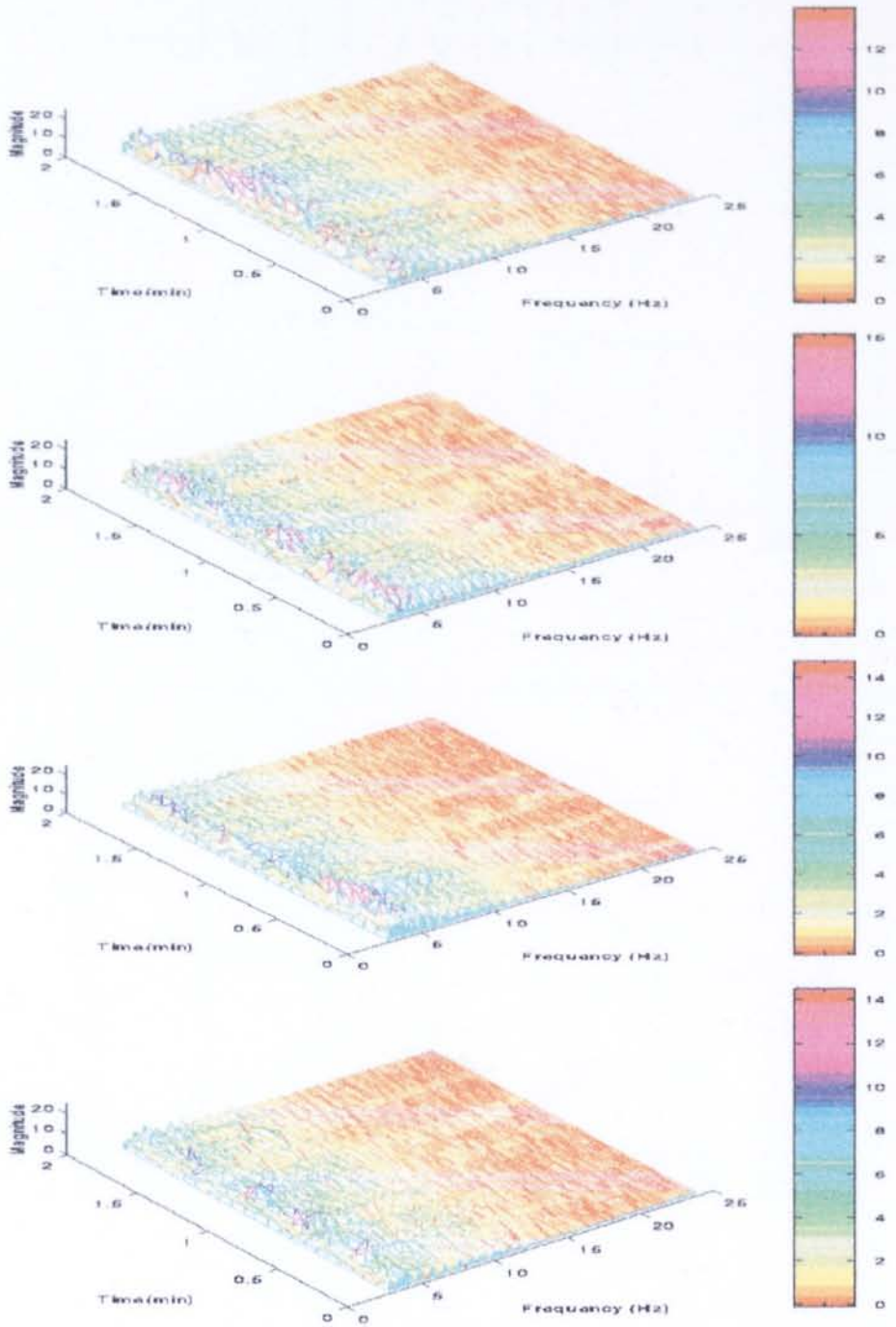


Figure 5.73: EEG Spectrum : each plot represents a 2 minute plot during a single color session

TEMPERATURE AND CONDUCTANCE OF DRF6

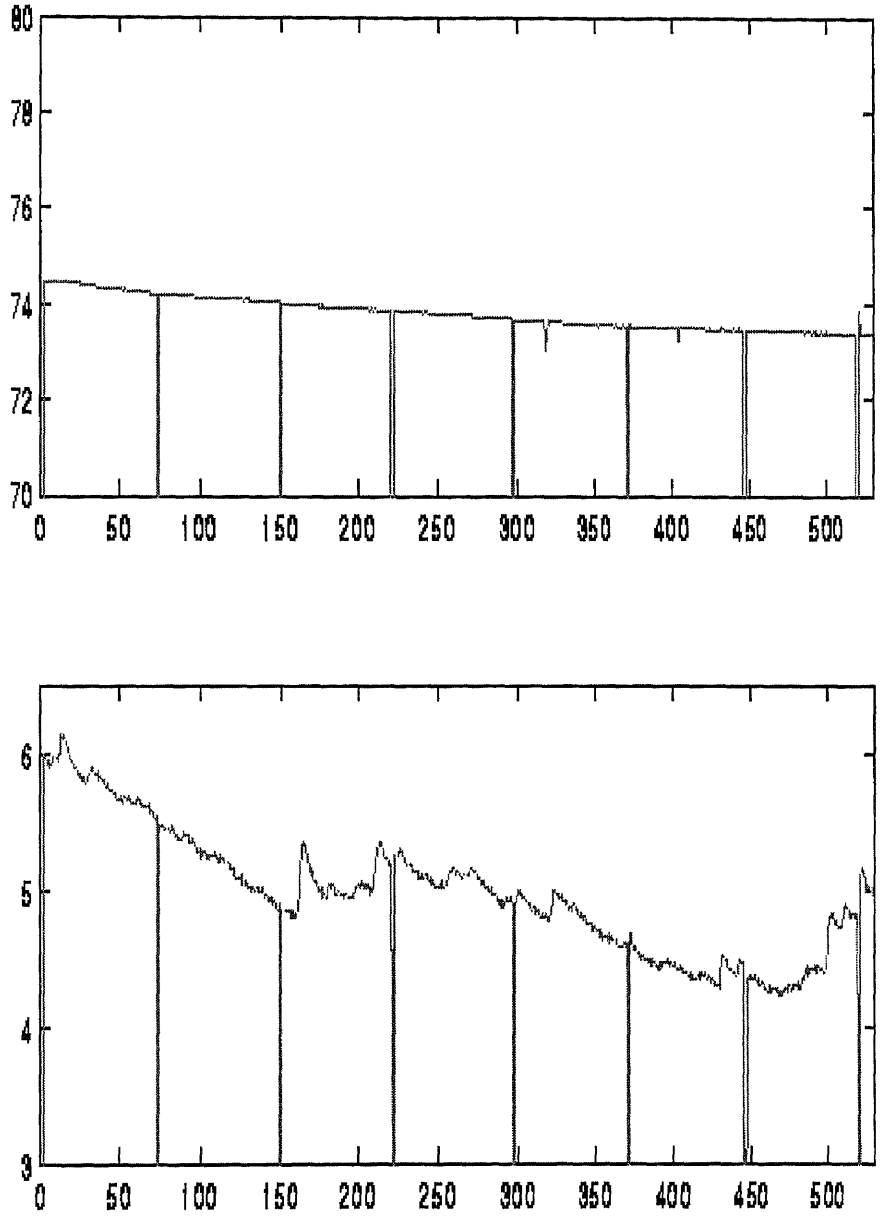


Figure 5.74: Temperature and conductivity plots respectively. Each section represents a different color.

APPENDIX E

<<<TEMPERATURE AND CONDUCTANCE ACQUISITION >>>

<<< PROTOOL4.BAS >>>

```
stepone:
        clear
        dim option$(64)
        dim cv(15)
        dim hue(7)
        dim hexconvert(2,7)
        dim restart$(11)
        dim boxrefct$(2,4)
        dim chan$(4)
dim color$(9)
nc=1
color$(2)="red"
color$(3)="orange"
color$(6)="yellow"
color$(5)="green"
color$(7)="blue"
color$(8)="violet"
color$(9)="gray"
color$(1)="white"
color$(4)="brown"
dim mod$(8)
mod$(1)="A"
mod$(2)="1"
mod$(3)="B"
mod$(4)="1"
mod$(5)="C"
mod$(6)="1"
mod$(7)="D"
mod$(8)="1"
steptwo:
        gosub prevopt
        gosub setcolour
        gosub opstrings
mnprogbod:
gosub signonscrn
input filename$
open filename$ for output as #5
open "junk1.prn" for output as #6
fil:
mac=0
newstart%=0
cls
locate 20,10
if nc=10 goto endprog
if nc=1 goto bbb
print "enter diagnosis for previous color followed by return"
print "Enter 1 for uncomfortable, 2 for neutral, 3 for comfortable"
input fill$
bbb:print "The next color is  " color$(nc)
print "Press any key when ready."
```

```
input fil$

nc=nc+1
gosub refcount
expectresponse=0
gosub channelsel
      keyboard:
      alfnum$ = inkey$
            if len(alfnum$) = 0 then
                  locate 25,70
                  print time$;
                  expectresponse = 1
                  nnn = 1
                  send$ = "SS"
                  gosub communicate
                  gosub decodechan
                  expectresponse = 0
                  nnn = 2
                  color hue(2)
            else
                  gosub detree
            end if
goto keyboard
endprog:
     print "enter diagnosis for previous color followed by return"
     print "enter 1 for uncomfortable, 2 for neutral, 3 for uncomfortable"
     input fill$
     close #5
      close #6
      end
communicate:
      for complace = 1 to len(send$)
            if complace <= len(send$) then
                  cmd$ = mid$(send$,complace,1)
                  print#2, cmd$;
                  echo$ = input$(1, #2)
            end if
      next complace
      print#2, cmd2$;
      echo$ = input$(len(send$)+nnn, #2)
      if expectresponse = 1 then
      line input #2, respond$
            color hue(4)
      end if
return
decodechan:
for n=1 to 15
gosub delay
next n
newline%=0
      newstart%=newstart%+1
      for n = 1 to picks
            readmod = (4*(n-1))+1
            hexnum$ = mid$(respond$,readmod,4)
            gosub hexconvert
            chancount = decimal
```

```
                locate echoy + 6 + n,25
                chancount$ = str$(chancount) + "      "
                print chancount$
                chanval = chancount * .0063
                locate echoy + 6 + n,35
                chanval$ = str$(chanval) + "      "
        if newstart%=3 then
        if newline% = 3 then
         newline% = 0
         newstart%=0
         if mac=0 then
         nc1=nc-1
         print #5, chanval$;" ";
         print #6, chanval$;" ";
         print #5, color$(nc1);" ";
         print #6, color$(nc1);" ";
         if nc=1 then goto AA
         print #5, fill$
         print #6, fill$
         AA: mac=1
        else
         print #5,chanval$;" "
         print #6,chanval$;" "
end if
         else
         newline%=newline%+1
         print #5, chanval$;" ";
         print #6, chanval$;" ";
         end if
        else
        end if
        next n
return
refcount:
        expectresponse = 1
        locate echoy - 1, 35:print "Reference Counts"
        locate echoy,echox:print, " Box 1","    Box 2",
        print "        Box 3          Box 4"
        for n = 1 to 10
                locate echoy + 1,echox:print n
                send$ = "RF"
                gosub communicate
                for hexref = 1 to 24 step 6
                        boxnum = int((hexref/6)+.84)
                        boxrefct$(1,boxnum) = mid$(respond$,hexref,5)
                        locate echoy+1,3*hexref+13
                        print boxrefct$(1,boxnum)
                        hexnum$ = boxrefct$(1,boxnum)
                        gosub hexconvert
                        boxrefct$(2,boxnum) = str$(decimal)
                        color hue(6)
                        locate echoy+3,3*hexref+13:print "          "
                        locate echoy+3,3*hexref+13:print decimal
                        color hue(4)
                next hexref
                color hue(2)
```

```
        next n
        expectreponse = 0
return
detree:
if alfnum$="n" then goto fil
if alfnum$ = "x" or alfnum$ = "X" then
        out 763,64:gosub delay:garbage% = inp(760)
        send$ = "*"
        gosub communicate
        close #2
        close #5
        close #6
        end
else
        'signal manipulation keys
end if
return
signonscrn:
        color hue(2),hue(3)
        cls
        locate 25,70
        print time$
        locate 2,20:
        print line1$;:color hue(5):print comm$:color hue(2)
        locate 3,17:print line4$
signon:
        cmd2$ = chr$(&H0D)
        out 763,64:gosub delay:gosub delay:garbage% = inp(760)
        close #2:open comm$ as #2
        garbage% = inp(760):garbage% = inp(765)
        print#2, cmd2$;
        gosub delay
        echo$ = input$(17, #2)
        echo$ = left$(echo$,15)
        locate 3,39:color hue(4):print echo$;:locate 25,70:print time$;
        color hue(2):gosub shortdelay
sethex:
        locate 25,70:print time$;
        cmd$ = "S"
        print#2, cmd$;
        echo$ = input$(1, #2)
        cmd$ = "H"
        print#2, cmd$;
        echo$ = input$(1, #2)
        print#2, cmd2$;
        echo$ = input$(2, #2)
        color hue(4):locate 25,70:print time$;
        color hue(2):gosub shortdelay
vernum:
        locate 25,70:print time$;
        cmd$ = "V"
        print#2, cmd$;
        echo$ = input$(1, #2)
        cmd$ = "E":print#2, cmd$;:echo$ = input$(1, #2)
        print#2, cmd2$;:echo$ = input$(3, #2)
        hexvernum$ = input$(7, #2):hexnum$ = mid$(hexvernum$,3,2)
```

```
        gosub hexconvert
        decimal = decimal * .1
        locate 4,20:print line6$:locate 4,46:color hue(4)
        print decimal;:color hue(2):print line5$
return
prevopt:
        opt = 1
        open "preopt.doc" for input as 1
        while not eof(1)
                input #1, option$(opt)
                opt = opt + 1
        wend
        opt = 1
        close #1
return
setcolour:
        for sc = 0 to 15
                cv(sc) = sc
                color ,cv(sc)
                cls
                gosub shortdelay
        next sc
        for sc = 1 to 7
                hue(sc) = val(option$(sc + 4))
                color ,hue(sc)
                cls
                gosub shortdelay
        next sc
        color hue(2),hue(1)
        cls
return
delay:
        for delay = 1 to 50
                locate 25,70
                print time$;
        next delay
return
shortdelay:
        for shortdelay = 1 to 5
                locate 25,70
                print time$;
        next shortdelay
return
opstrings:
        screen val(option$(1)),val(option$(2)):'EGA, 320 x 200, mid-res
        width 80
        color hue(2),hue(3)
        cls
        scp$ = option$(64)
        br$ = ":" + option$(62)
        comm$ = "COM" + scp$ + br$ + ",n,8,1"
        line1$ = "Attempting to sign-on at COM PORT "
        line2$ = "Looking for and stablizing boxes."
        line3$ = "The present referance counts are:"
        line4$ = "I-330 responds with.."
        line5$ = ", has signed on."
```

```
        line6$ = "The I-330; version number"
        echoy = 7:echox = 5
        expectresponse = 0:nnn = 2
        fivey = 5:fivex = 5
setmultiplier:
        for placevalue = 1 to 7
                hexconvert(0,placevalue) = 16^(placevalue-1)
                next placevalue
cleanout:
        for layer = 1 to 2
                for placevalue = 1 to 7
                        hexconvert(layer,placevalue) = 0
                next placevalue
        next layer
return:
hexconvert:
        gosub cleanout:decimal = 0
        for x = 1 to len(hexnum$)
                if len(hexnum$) - x > -1 then
                        hexplace$ = mid$(hexnum$,x,1)
                        hexplace = asc(hexplace$)
                        xx = (len(hexnum$)+1) - x
                        if hexplace > 47 and hexplace < 58 then
                                hexconvert(1,xx) = hexplace - 48
                        end if
                        if hexplace > 64 and hexplace < 71 then
                                hexconvert(1,xx) = hexplace - 55
                        end if
                        hexconvert(2,xx) = hexconvert(0,xx) *
hexconvert(1,xx)
                        if hexconvert(1,xx) = 0 then hexconvert(2,xx) = 0
                        decimal = decimal + hexconvert(2,xx)
                end if
        next x
return
channelsel:locate echoy+16,echox+10
print "Press 'n' for next color"
locate echoy+17,echox+10
        print "Press 'x' to exit"
        locate echoy+fivey,echox+fivex
        print "Enter Module Letter (A - P), then Channel Number (1 - 4)."
        send$ = "CC"
        gosub communicate
        number = 0:picks = 1:nnn = -3
        locate echoy + 6,echox + 2
        mn=0
        print "Mod/Ch  Send$    Counts    Value"
channelkey:
        if picks = 5 then
                picks = 4
                nnn = 2
                color hue(2)
                return
        end if
        mn=mn+1
        gosub delay
```

```
alfnum$ = mod$(mn)
if len(alfnum$) = 0 then
        locate 25,70
        print time$;
goto channelkey
else
        if alfnum$ = "x" or alfnum$ = "X" then
                nnn = 2
                color hue(2)
                return
        end if
        color hue(6)
        if fivey < 9 and number = 0 then fivey = fivey+1
        locate echoy+fivey + 1,echox+fivex+number
        alfnum = asc(alfnum$)
        if asc(alfnum$) > 96 and asc(alfnum$) < 113 then
                alfnum = asc(alfnum$) - 32
        end if
        if alfnum > 64 and alfnum < 81 and number = 0 then
                alfnum$ = chr$(alfnum)
                print alfnum$
                alf$ = alfnum$
                modnum = (4*(alfnum-65))
                number = 1
        end if
        if asc(alfnum$)>48 and asc(alfnum$)<53 and number=1 then
                print alfnum$,
                chan$(picks) = alf$ + alfnum$
                chnlnum = asc(alfnum$)-49
                chan$ = hex$(modnum+chnlnum)
                send$ = "AC" + chan$:print send$
                gosub communicate
                picks = picks + 1
                number = 0
        end if
    end if
goto channelkey
```

<<<FILE SEPARATION>>>

<<< LHSPLIT >>>

```
FILE="$1"
NAME=`echo $FILE|cut -d "." -f1`
#echo working on file: $NAME
#awk '{print $1}' $FILE>col1
#echo col1
#awk '{print $2}' $FILE>col2
#echo col2
#awk '{print $3}' $FILE>col3
#echo col3
#awk '{print $4}' $FILE>col4
#echo col4

NUM=1
#for file in col1 col2 col3
#do
```

```
echo working on $file column $NUM
tail +96000 $file > cojunk
mv cojunk $file
head -48000 $file>"b"$NUM$NAME
tail +48000 $file|head -96000 >"r"$NUM$NAME
#tail +78000 $file|head -60000 >"s"$NUM$NAME
NUM=`expr $NUM + 1`
done
```

<<< DRFSPLIT >>>

```
unzip -a $1.zip
tail +96001 $1.txt > tmp.$$
mv tmp.$$ $1"2"
rm $1.txt
zip -k $1"2".zip $1"2"
```

<<<EKG>>>

<<< PS1>>>

PS1

```
clear

clc


global signal peaks k


 FirstStep=250 ;

[ECGs] = getdata ;       % get ECG signal

[signal,peaks] = getpeaks(ECGs,FirstStep) ;


clear ECGs

control ;

display ;
```

<<< GETDATA >>>

```
function [ECGsig] =  getdata


% GETDATA reads an ascii file with three columns with the ECG signal in
the
%       third column and the respiration in the first one. It returns
```

```
%      these two signals in ECGsig and RESPsig variables respectively


[fname,pname]=uigetfile('*.*','Open Data File "ASCII" ');

if isstr(fname) == 0
      disp(' Cannot find file')
      dbquit
 end

Filename = [pname fname];

load(Filename) ;                % load file
fname = strtok(fname,'.');      % drop extension
m=eval(fname);                          % evaluate fname
k=m;

ECGsig=k(:,1);                  % ECG signal
%RESPsig=k(:,3);                % Respiration sugnal

clear fname pname Filename
```

<<< GETPEAKS >>>

```
signal=signal(:);               % vertical column
V = mean(signal(2:length(signal)));
sig=rot90(signal);                      % horizental row

sig(1) = V ;        % modify first point


    %%%%%%%%%%%%%% high-pass filter  %%%%%%%%%%%%%


    A=[V V sig V V];
    B=[V V V V sig];            % shift right by 2
    C=[sig V V V V];            % shift left by 2
    m= 2*A - B - C;
    m=m(3:length(m)-2);         % remove added 4 points

    clear A B C V

    %%%%%%%%%%%%%%  low-pass filter
    %%%%%%%%%%%%%%%%%%%%

    V = mean(m);
    A = [V m V];
    B = [V V m];
    C = [m V V];
    s = A + B + C ;
    s=s(2:length(s) - 1)/4;
    clear A B C V
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%
FirstStep=250;
LENGTH=length(s);
TOP=max(s);
[MAX,k]=max(s(1:FirstStep));
peaks=zeros(1,LENGTH);
peaks(k)=TOP;


%%%%%%%        testing for the peaks        %%%%%%%%%

N1 = 200 ;                      % to be used for interval threshold
n=fix(0.2*(k + N1));            % initial count of points per cycle
 i=k+n ;

THERMOMETER = bar(0,' Detecting the Peaks ');

 while i < LENGTH
      i=i+1;            % increment count
      n=n+1;
      if s(i) >= 0.25*MAX + 0.2*TOP             % check for threshold
              [MAX,T] = max(s(i:min(i+10,LENGTH)));
              N=n+T-1;                          % update current interval
              peaks(i+T-1)=TOP;                 % a peak
              n=fix(0.2 *(N + N1));
              i=i+T+n-1;                        % Jump foreward
              N1 = N ;                  % previous interval
              bar(i/LENGTH)                     % update
THERMOMETER

      end

end
close(THERMOMETER) ;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

signal=sig - min(sig)+TOP;

clear m s MAX TOP k n N LENGTH
```

<<< PSLWSU >>>

```
% This function gets the file to be analyzed from the users and

% Processes the data by calling several functions and terminates

% by plotting 3 plots required for our study. The variables

% available for use and for further processing are IBI, IIBI,
% respiration, and frequency and spectrum of both IIBI
% and respiration.
% pi and fi are the power and the frequency of iibi respectively.
% pr and fr are the power and the frequency of respiration respectively.
```

```
global peaks RESPs

clear g ibi rsp rpd iibi
close(gcf)      % close current figure

tit_le = ' ' ;

peaks=peaks(:) ;
peaks=rot90(peaks) ;   % row matrix


[g,ibi,rpd]=grep(peaks,RESPs);

clear peaks

x=iibi(g,ibi);

clear g

[iibi,rsp]=seq(x,rpd);

clear x rpd

[d_iibi,d_rsp]=sqdt(iibi,rsp);

[pi,pr,fi,fr] =graph(iibi,rsp,ibi,d_iibi,d_rsp,tit_le);

%[AL,AH]=peakpow(pi,pr,fi,fr);

clear d_iibi d_rsp

stdgraff(pi,fi,pr,fr,tit_le);

toc
```

<<<EEG>>>

<<< TF.M >>>

```
function [FOUT,tindx,findx]=tf(data,WL,SWL);


% initial parameters

% data loading

      KK=512;

      N=WL;

      K=SWL;
```

```
C=floor(length(data)/N);
L=1;
i=1;

% main loop
    while ((L+N)<=min([length(data)]))


% mean extraction
    [o]=data(L:L+N-1)'-mean(data(L:L+N-1)');

% output data matrix
    D_OUT(i,:)=o;

% normalized data
    o_n=o/sqrt(o*o');
    DNOUT(i,:)=o_n;

% output frequency response
    FO=fresp(o);
    FOUT(i,:)=FO(1:KK);

% loop variables
    tindx(i)=(L-1)+N/2;
    L=L+K;
    i=i+1;
    end

    fi=[0:pi/1024:pi];
    findx=(fi(1:KK)*100)/pi;
    tindx=tindx/(200*60);
    FOUT/max(min(FOUT));
    L1=round(3/(50/512)); L2=round(24/(50/512));
    meshz(findx(L1:L2),tindx,FOUT(:,L1:L2));
    %AXIS([0 25 0 4 0 10])
    xlabel('Frequency (Hz)')
    ylabel('Time(min)')
    zlabel('Magnitude')
    view(-37.5,75)
    colorbar
    brighten(0.5)
    %print -dpcx256 s1basr;
```

<<<BLOOD FLOW>>>

<<< ABF.M >>>

```
function [amp]=abf(x,p)


    q=length(x);
    m=q/p;
    val1=0;
    for n=0:m-1
        k=x((n*p)+1:(n+1)*p);
        s(n+1)=min(k);
```

```
        b(n+1)=max(k);
        c(n+1)=b(n+1)-s(n+1);
        val=c(n+1);
        val1=(val1+val);
        j(n+1)=n+1;

end

amp=val1/j(n+1)
plot(x);
```

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