

# **Fast Stress Detection via ECG**

by

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## **Author's Declaration**

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## Abstract

Nowadays stress has become a regular part of life. Stress is difficult to measure because there has been no definition of stress that everyone accepts. Furthermore, if we do not get a handle on our stress and it becomes long term, it can seriously interfere with our health. Therefore, finding the method for stress detection could be beneficial for taking control of stress.

Electrocardiogram (ECG) is the measurement of the electrical activity of the heart and represents an established standard in determining the health condition of the heart. The PQRST<sup>1</sup> [55] complex of ECG conveys information about each cardiac-cycle, where the R-peak is placed in the middle of the PQRST complex and represents the maximum value of the PQRST. Since the PQRST depicts the entire cardio-cycle, the R-peak determines half of the cardio-cycle. The distance between two adjacent R-peaks is defined as a heart rate (HR). The variation of the HR in the specific time frame, defined as heart rate variability (HRV), can reflect the state of the autonomic nervous system (ANS). The ANS has two main divisions, the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS occurs in response to stress while the PNS results from the function of internal organs. The activity of ANS can cause an acceleration (SNS) or deceleration (PNS) of the HR. The SNS activity is associated with the low-frequency range ( $L_F$ ) while, the PNS activity is associated with the high frequency ( $H_F$ ) component of the HRV. Therefore, the power ratio of the low and high-frequency components ( $L_F/H_F$ ) of the spectrum of HRV can potentially show whether the subject is exposed to stress or not [48] [50].

In this research, we introduced three new indices, with one of them proposed as a proxy to provide equivalent results in the detection of stress or no-stress states while avoiding complex measurement devices as well as complex calculations. The goal was to find a more time efficient method for fast stress detection which could potentially be used in the applications that run on devices such as a wearable smartwatch in tandem with a smartphone or tablet.

The experiment was established to measure the literature proposed index for stress measurement [48][50] as well as our introduced indices. In the experiment, we induced stress to the participants by using mental arithmetic as a stressor [51][53]. The experiment contained two kinds of trials. In the first one, the participant was exposed to different amounts of cognitive load induced by doing mental-arithmetic while, in the second one, the participant was placed in a relaxed environment. Each participant in the experiment gave feedback in which period of the experiment he/she felt stress. During the entire experiment, we recorded the participant's ECG. The ECG was used to calculate HRV which consequently was used for the calculation of the values of the  $L_F / H_F$  index as proposed from the literature for calculating the level of the stress. The same data was used for the calculation of our introduced indices. The values of our proposed index was compared with the  $L_F / H_F$  index and the participant's feedback. Finally, the data analyses showed that our proposed index is suitable to determine whether a participant is exposed to stress.

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<sup>1</sup> The PQRST complex is a systematic method of interpreting rhythm on an ECG. It does consist of the P wave, PR interval, QRS complex, and T wave.

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## List of Abbreviations

<b>AVNN</b>	Average of all NN intervals
<b>ANS</b>	The autonomic nervous system
<b>AV node</b>	Atrioventricular node
<b>aVR, aVL, aVF</b>	The unipolar limb leads
<b>ECG</b>	Electrocardiogram
<b><math>H_F</math></b>	Total spectral power of all NN intervals between 0.15 and 0.4 Hz
<b>HM-R1</b>	The values of the index during the first mental math run for the high motivated participants
<b>HM-R2</b>	The values of the index during the second mental math run for the high motivated participants
<b>HM-REF</b>	The threshold for the high motivated participants
<b>HR</b>	Heart rate
<b>HRV</b>	Heart rate variability
<b>LA</b>	Left arm electrode
<b><math>L_F</math></b>	Total spectral power of all NN intervals between 0.04 and 0.15 Hz.
<b><math>L_F / H_F</math></b>	Ratio of low to high frequency power
<b>LL</b>	Left Leg Electrode
<b>LM-R1</b>	The values of the index during the first mental math run for the low motivated participants
<b>LM-R2</b>	The values of the index during the second mental math run for the low motivated participants
<b>LM-REF</b>	The threshold for the low motivated participants
<b>M-R1</b>	The values of the index during the first mental math run for the motivated participants
<b>M-R2</b>	The values of the index during the second mental math run for the motivated participants

<b>M-REF</b>	The threshold for the motivated participants
<b>pNN50*</b>	Percentage of differences between adjacent NN intervals that are greater than 50 ms; a member of the larger pNNx family
<b>PNS</b>	Parasympathetic nervous system
<b>PPG</b>	Photoplethysmography,
<b>PQRSR</b>	PQRST complex of the ECG signal
<b>RA</b>	Right Arm Electrode
<b>RL</b>	Right Leg electrode
<b>rMSSD</b>	Square root of the mean of the squares of differences between adjacent NN intervals
<b>SA Node</b>	Sinus-atrium node
<b>SDANN</b>	Standard deviation of the averages of NN intervals in all 5-minute segments of a 24-hour recording
<b>SDNN</b>	Standard deviation of all NN intervals
<b>SDNNIDX</b>	Mean of the standard deviations of NN intervals in all 5-minute segments of a 24-hour recording
<b>SNS</b>	Sympathetic nervous system
<b>TOTPWR</b>	Total spectral power of all NN intervals up to 0.04 Hz
<b>ULF</b>	Total spectral power of all NN intervals up to 0.003 Hz
<b>UM-R1</b>	The values of the index during the first mental math run for the unmotivated participants
<b>UM-R2</b>	The values of the index during the second mental math run for the unmotivated participants
<b>UM-REF</b>	The threshold for the unmotivated participants
<b>V1, V2, V3, V4, V5, V6</b>	The Precordial leads
<b>VLF</b>	Total spectral power of all NN intervals between 0.003 and 0.04 Hz

# 1 Introduction and Background

## 1.1 Introduction

Nowadays, stress has become an unavoidable part of life, and it is usually a product of changes in life. Although we are prone to experience stress as a result of adverse changes, the stress can also be caused by positive changes. According to [44], there are four primary sources of stress: environmental, social, physiological, and thoughts. Firstly, our body is continuously exposed to a diverse array of environmental stressors such as allergens, toxins, pollution, noise or traffic. Many of those environmental stressors cannot be personally controlled, and our bodies are constantly adapting to whatever our current environment is throwing at us [44][45]. Secondly, we are exposed to social challenges such as work demands, financial obligations, family life, and loved ones. Sometimes we are abusing our body with the lack of sleep, a sedentary lifestyle, and a poor diet. Finally, our internal cognitive processes are an incredible source of stress for many people. On a daily basis, we are faced with challenging cognitive tasks. The way that we interpret and handle a cognitive task has a great deal to do with the individual levels of stress that we experience.

There is acute and chronic stress. Acute stress is the most common form of stress, and it is thrilling and exciting in small doses, but too much is exhausting. The symptoms caused by acute stress are easily identified but difficult to define, its nature varying by circumstance and individual [45][57]. On the other hand, chronic stress is the grinding stress that wears people away day after day, year after year, and it may lead to diseases such as hypertension, insomnia, diabetes, asthma and depression [58]. In addition, chronic stress “may also contribute to social problems such as marriage breakups, family fights, road rage, suicide and violence” [58]. Therefore, the ability to monitor and report the patient’s personal state for long periods of time to find stress-related symptoms would be highly beneficial. In our research, we proposed the method for fast stress detection, which could be used in the wearable devices for monitoring personal state for stress-related symptoms over a short or potentially long period of time. Much of the existing studies have been dealing with effects of stress over the short period of time. For example, mental stress during daily life has been reported to double the cardiovascular risk of myocardial ischemia in the subsequent hour []. That was true even in the case self-reported feelings of tension, frustration, and sadness. Possibility of ECG based stress measures could come very handy here, therefore there is a relevant research which proposes using ECG in an application for short term stress detection [60]. However, in order to correlate ECG based measures with health outcomes over longer periods of time does require studies, which span potentially over several years. There are studies, like Seven Countries Study, which tried to correlate diet with health outcomes. Therefore, there is uncertainty to which extent ECG based stress measures over longer period of times correlates with health outcomes.

One of the most common ways for detecting the level of stress is through heart rate variability [25][31][34][12]. The heart rate variability, conventionally abbreviated as HRV, represents the variation over time of the period between consecutive heartbeats. The HRV is a non-invasive method which has been becoming an essential tool in cardiology for assessing the activities of the autonomic nervous system, acronym ANS [34]. The ANS has two components: the sympathetic (SNS) and the parasympathetic (PNS) nervous system. The SNS is stimulated in response to stress, heart disease, and physical activity such as exercise [45]. Therefore, the SNS increases heart rate (HR). At the same time,

PNS primarily resulting from the function of internal organs, trauma, allergic reactions and the inhalation of irritants, decreases the firing rate of pacemaker cells and the HR, providing a regulatory balance in physiological autonomic function. Studies related to subjective self-reported stress have been published. However, findings regarding its correlation with objective HRV-based stress were not conclusive. Tiina Föhr1\* et al. [59], in their study, suggested that subjective self-reported stress is associated with objective HRV-based stress. Furthermore, there are a number of other studies that have reported the potential inaccuracy of self-reporting measures such as failure to recall the exact details, and social desirability effects [58]. Self-reporting stress measuring can be biased due to the varying subjective assessments performed by the subjects [59]. On the other hand, measuring stress via HRV is more accurate since HRV is sensitive to changes in the SNS and PNS. [60]. Although analysis of subjective self-reported stress was not the subject of our research, as it did serve the sole purpose of measurement validation, we can suggest that subjective self-reported stress did correlate well with objective HRV-based stress measurements. In any case, more research is required to validate the correlation between subjective self-reported stress with objective HRV-based stress.

The most common ways to measure heart rate variability are the electrocardiogram (ECG) [12] and the photoplethysmography (PPG) [22][31][38]. The ECG measures the electrical activity of the heart through electrodes attached to the human body. In this case, the HRV is a measure of the variation in

$R-R^2$  intervals of a heartbeat [12]. More about ECG and HRV will be presented in Section 1.4.3. On the other hand, the PPG measurement is based on the fact that each contraction of the heart results in a blood volume pulse which propagates through more prominent arteries towards comparatively smaller capillaries. This blood volume pulse signal can be tracked optically and therefore in case of PPG we do not need electrodes with wires, but just a device that has a LED and a photoreceiver [22][38][47]. In this case, the HRV is measured through variation of the interbeat intervals (IBI), the interval between two pulses. The challenge with PPG is to find a measuring spot that provides an accurate and reliable result.

When a person is exposed to stress, the SNS part of the autonomic nervous system (ANS) is more active than its PNS part [43][22]. The level of the activity of the ANS can be determined via HRV which can be calculated through ECG or PPG. The PNS is associated with the high-frequency component, from 0.15 to 0.4Hz ( $H_F$ ), and AS is associated with the low-frequency component, from 0.04 to 0.15Hz ( $L_F$ ) [43]. Therefore, the ratio between high and low components can show whether a person is exposed to stress or not [21][48][49][50].

McDuff et al [22] presented the study in which they tried to measure cognitive stress using a digital camera (PPG). They used the fact that a cognitive task has an impact on heart and breathing rate. The study presented classifiers which had the following input parameters mean heart rate, mean breathing rate, normalised  $L_F$  and  $H_F$  component power of the HRV, and the ratio of  $L_F / H_F$  of the HRV power spectrum [47]. The first classifier is based on a linear supported vector machine (SVM) and the other one was based on Naive Bayes. When making a prediction of cognitive stress, the preliminary results showed that SVM classifier achieved an accuracy of 85% and Naive Bayes classifier achieved the accuracy of 80%. Also, the study [38] presented a framework on detecting cognitive loads using video frames obtained from a web camera. The paper used wave transformation to precisely calculate the instantaneous HRV. The results of the proposed method showed that HRV can be properly estimated even in the

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<sup>2</sup>R-R is the interval between successive heartbeats

presence of strong motion artifact giving the opportunity for remote stress assessment induced by cognitive load. Jeong et al.[28] presented the method for calculating the level of the stress which was calculated from ECG measurement via contact sensors. The ECG data was used for calculation of the HRV. The study presented the index to calculate the level of the stress determined from HRV.

In our research, we introduced three new indices, with one of them proposed as a proxy to provide equivalent results in the detection of stress/no stress comparable to literature proposed index  $L_F / H_F$  [48][49][50]. Two indices were calculated via l1 and l2 norms of the HRV vector [36] calculated from ECG. The ratio between those indices is our proposed index. The goal was to find a more time efficient method for stress detection which can be run on less powerful devices such as wearable watches in combination with as smartphone or tablet. We designed an experiment in which participants did mental math calculations. The participants in these experiments were undergraduate and graduate students from the engineering faculty and from the faculties of social science. The assumption was that mental math calculation should produce enough cognitive loads to induce mental stress for the participants. In the end, the participants were divided into four groups based on the results achieved in the experiment. The first group represents the participants who successfully managed mental math calculation tasks (got most answers correct and before the time given for resolving the math question) throughout the entire experiment session. The other three groups of participants did not succeed as they were not able to manage the mental math calculation tasks during the whole experiment session. For example, the second group of participants successfully managed three quarters of the all mental math tasks, the third group succeeded to manage half of all the mental math tasks, and finally, the fourth group managed only a quarter of the mental math tasks. Our proposed index representatively showed the periods where the participant was exposed to the cognitive load. The stress was mainly induced by cognitive load even though we tried to increase the level of the stress by distracting the participants in doing mental arithmetic calculations; this will be described in detail in the method and materials chapter.

### 1.1.1 Contributions

The overall aim of this thesis is to propose and demonstrate a method for stress assessment using heart rate variability (HRV) which can be run on less powerful devices such as a wearable watch in combination with a smartphone or tablet.

1. We reviewed and analysed the existing method for detecting stress known as the  $L_F / H_F$  index [25] (Chapter 2).
2. We introduced three indices with one of them proposed for stress detection. The first two indices were based on a calculation of the l1 and l2 norms from the HRV power spectrum segment  $L_F$ . The third index is the ratio between those two indices. The calculation of those indices is described in Chapter 2.
3. We compared and discussed the results calculated via  $L_F / H_F$  and our proposed index (Chapter 3) The index provided equivalent results in detection of stress/no stress comparable to the one from the literature( $L_F / H_F$  ).

### **1.1.2 Thesis outlines**

In Section 1.2 we will present background information such as the anatomy of the heart and ANS (Section 1.2.1), electrical activity of the heart (Section 1.2.2), electrocardiogram (ECG) (Section 1.2.3), and the Measurement of the HRV through ECG (Section 1.2.4). Afterwards, in Section 2 we will describe the experimental protocol and data processing. Finally in Sections 3 and 4, we will present the results, conclusions, and discussions.

## 1.2 Background

### 1.2.1 The anatomy of the heart and ANS

The heart is a muscular pump, which with its rhythmic contractions, allows a constant flow of blood through all tissues ensuring regular exchange of gasses nutrients and waste products. The heart is wrapped with a thin membrane called pericardium. It is located in the central part of the chest, above the diaphragm (muscle barrier which divides the abdomen from the chest). The size of the heart is that of a closed fist; the weight varies from 300-350 grams for men and 250-300 grams for women. The heart consists of two atria and two ventricles. The atria, (atrium dextrum et atrium sinistrum), takes up blood, that returns after circulating into the heart. Afterwards, it transmits that blood into the two lower chambers that are called ventricles (ventriculus dexter et ventriculus sinister) (see Figure 1.1).

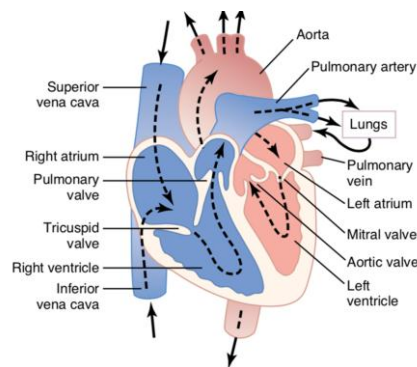
The atria and ventricles on either side of the heart are separated by the wall called the septum, which prevents the mixing of the blood of the left and right side of the heart. The part of the wall dividing the right and left atrium them is called the inter-atrial septum, while the part dividing right and left ventricular is called the inter-ventricular septum. The right atrium delivers the deoxygenated blood to the right ventricle which then pushes the deoxygenated blood to the lungs. After releasing the carbon-dioxide and taking on oxygen, the oxygenated blood comes to the left atrium. The left ventricle takes the oxygenated blood from the left atrium and pushes that blood to the rest of the body.

The pulsation of the heart is a product of rhythmic contractions and relaxations of the heart muscle, which is called the myocardium. During the contraction phase, the wall of the atrium or ventricle contract increasing the pressure within the heart thus ejecting blood out of the closed chamber. Subsequently, the atrial or ventricular wall relaxes and is ready to receive a new amount of blood.

The ANS controls the heart contractions. As previously mentioned, the ANS has two main branches, SNS and PNS, which work antagonistically. The SNS prepares the human body to respond to stressful situations. That response is known as the “fight or flight” mechanism. At the same time, the PNS controls the free functions of the human body in a normal basal condition, popularly called the “rest and digest” mechanism. The SNS part of the ANS is activated in response to a stressful situation, during hard physical activity, or when we feel angry or are frightened. The following are the most common facts related to the SNS:

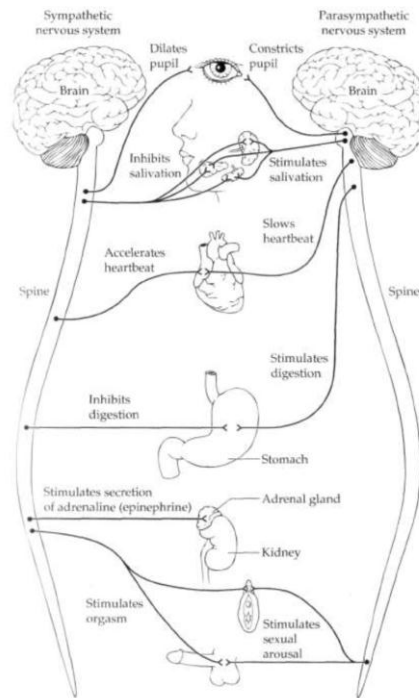
1. HR can increase from 70 to 150 in 3 seconds.
2. The blood pressure can double in 10 seconds.

The PS part of the ANS is activated when the influence of stress mitigates. It helps in returning the human body to the normal state. Figure 1.2 outlines some of the effects of the sympathetic and parasympathetic nervous systems on various organs and glands.



*Figure 1.1 presents the anatomy of the heart. Taken from Textbook of medical physiology / Arthur C. Guyton, John E. Hall.—11th ed.*

The heart can contract without outside innervation. However, the power of the heart contraction is controlled by the ANS. Under the influence of the SN part of the ANS, the HR and the power of the heart contraction are increased, while under the influence of the PS part of the ANS, HR and cardiac contractions are decreased.



*Figure 1.2 outlines some of the effects of the sympathetic and parasympathetic nervous systems on various organs and glands. Taken from Why Zebras don't get ulcers by Robert M. Sapolsky (2009) Third Edition,*

### 1.2.2 The electrical activity of the heart

The heart activity would not be possible without electrical impulses. The electrical impulses cause contractions of the heart's muscle. The formation and transmission of the electrical impulses depend on the properties of the heart's cells such as:

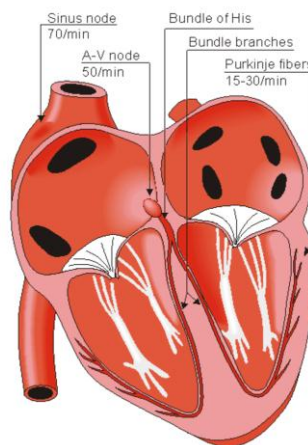
- The spontaneous generation of the electrical impulses;
- The stimulation of the cell's membranes, caused by ionic activity;  
This property shows how cells respond when stimulated by an electrical impulse;
- The cell's ability to convey the electrical impulse to an adjacent cell;
- The contraction of the cell as a reaction upon receiving the electrical impulse;

The specialised tissues in the myocardium have the ability of high conductivity of the electrical impulses through the heart. The conductive system of the heart has two parts: a sino-atrial system and an atrioventricular system. The sinus system runs from the from sinus-atrium node (SA node). The atrioventricular system originates from the atrioventricular node (AV node), Purkinje fibres, and the His



bundle. The atria and ventricles are entirely independent of each other, and they communicate through impulses produced by the SA node.

The electrical impulse produced by the SA node passes through the right atrium of the heart (Figure 1.3) to the AV node, along with the Bundle of His and through bundle branches, ends up in the Purkinje fibres. The electrical impulses stimulate the contractions of the atria first and then of the ventricles.



*Figure 1.3. The conductive system of the heart. Taken from Bioelectromagnetism Principles and Applications of Bioelectric and Biomagnetic Fields by Jakko Malmivuo and Robert Plonsey*

Bioelectricity represents the ability of biological tissues to generate electricity without external excitation. The first research about bioelectricity was published by Luigi Galvani, in 1791. He discovered that the muscles of dead frogs' legs twitched when struck by an electrical spark and it was the first study regarding bioelectricity.

The electrical charges, in the tissue, originate from the ions. Therefore, in cells, there are two kinds of electrical potentials: static potential and action potential. When the excitation is higher than the threshold it opens the ionic channel, the positive sodium's ( $\text{Na}^+$ ) ions come into the heart cell causing the changing of the electrical potential. This process is called depolarisation.

The process of the repolarisation represents the change of the difference of the electrical potential inside the cell. The process of the repolarisation is caused by the flow of the potassium's ( $\text{K}^+$ ) ions through the heart cells as well as the closing of  $\text{Na}^+$  and  $\text{Ca}^{2+}$  channels. In general, the repolarisation and depolarisation represent the foundation of the electrical activity of the heart, which allows the heart to work. The process depolarisation and repolarisation are passing through five phases which are presented in figure 1.4.

Phase 0: Rapid depolarisation – the cell receives impulses from a neighbouring cell and depolarizes (contraction occurs);

Phase 1: Early repolarisation - there is rapid repolarisation of the cells;

Phase 2: Characteristic plateau - there is slow repolarisation of the cell;

Phase 3: Rapid repolarisation (Hyperpolarization) - The cell returns to its normal state;

Phase 4 Resting phase – the cell waits for an excitation pulse (subtraction);

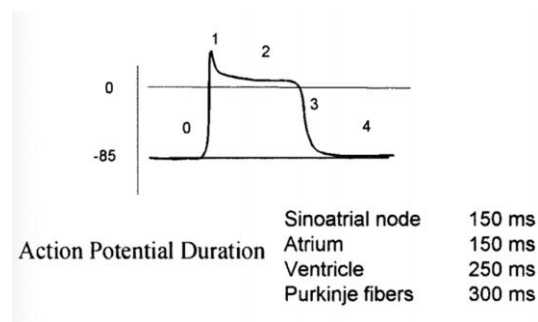
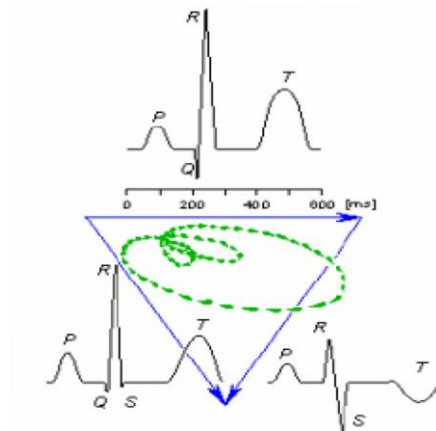


Figure 1.4. The action potential of the heart cell. Taken from textbook *Handbook of cardiac Anatomy* by P.A. Iaizzo

### 1.2.3 Electrocardiogram-ECG

The electrical activity of the heart produces the electrical current flowing through the tissues of the heart. This current produces the differences in the electrical potential on some parts of the surface of the human body. The signal, the electrical current flowing through the heart, is caused by depolarisation and repolarisation processes, described in the previous section. The electric current flow produces the scalar potential field which is approximated with the electrical field vector. During the cardio cycle, the vector electrical field changes the magnitude and direction.

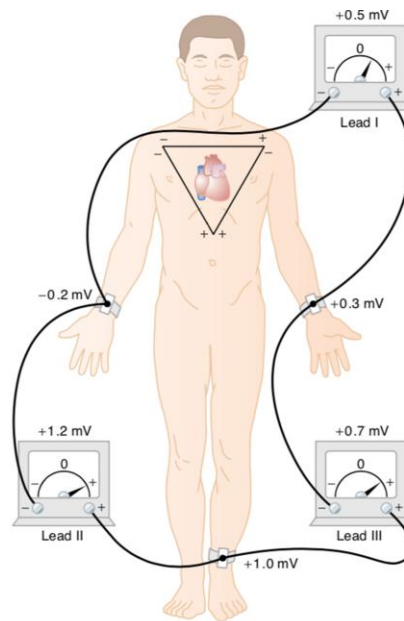
Throughout depolarisation and repolarisation, the top of the vector of the electrical field draws an ellipse, and it is called a *vector-cardiogram* (Figure 1.5). The curve depicted by the vector of the electrical field during the process of depolarisation is called a *depolarisation vector loop*. The curve itself, described by the vector of the electrical field during the process of repolarisation, is called a *repolarisation vector loop*. The electrocardiogram oscillation is defined as a projection of both vector loops, to the line of the lead [20].



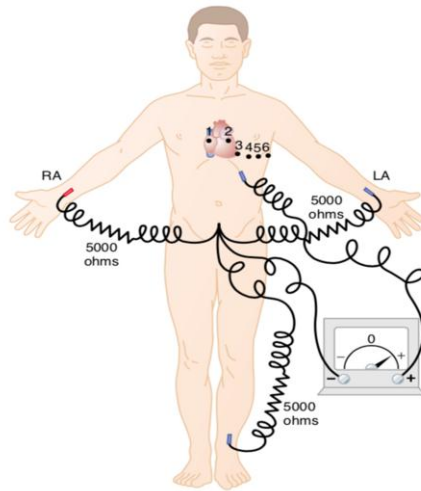
*Figure 1.5. The vector loops and their projection on the lead. Taken from Textbook of medical physiology / Arthur C. Guyton, John E. Hall.—11th ed.*

The lead provides tracking of the electrical activity of the heart between the positive and negative terminal. In the case of weak electrical activity of the heart, in which the electrical potential is below the threshold value ( $-60\text{mV}$ ), the ECG signal has the shape of a flat line.

The ECG signal depends on the position of the lead's point used for measuring the ECG. There are 12 lead points that can be divided into three groups: three standard leads (I, II, III) which consists of Einthoven's triangle (Figure 1.7), three unipolar limb leads ( $aVR$ ,  $aVL$ ,  $aVF$ ) (Figure 1.8), and chest (Precordial) leads ( $V1$ ,  $V2$ ,  $V3$ ,  $V4$ ,  $V5$ ,  $V6$ ) (Figure 1.9). Additionally, the figure 1.10 shows the electrodes placement of the 12-lead ECG.

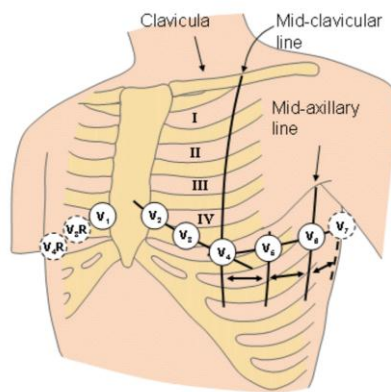


*Figure 1.7 Einthoven's triangle. Taken from Textbook of medical physiology / Arthur C. Guyton, John E. Hall.—11th ed.*



*Figure 1.8. The unipolar limb leads. Taken from Textbook of medical physiology / Arthur C. Guyton, John E. Hall.—11th ed.*

The ECG is presented on the grid where the x-axis represents time, and the y-axis represents voltage. The horizontal square corresponds to a time interval of 0.04 s, while the vertical square represents a change of 0.1 mV (Figure 1.11)



*Figure 1.9 The Precordial leads (V1, V2, V3, V4, V5, V6). Taken from Bioelectromagnetism Principles and Applications of Bioelectric and Biomagnetic Fields by Jakko Malmivuo and Robert Plonsey*

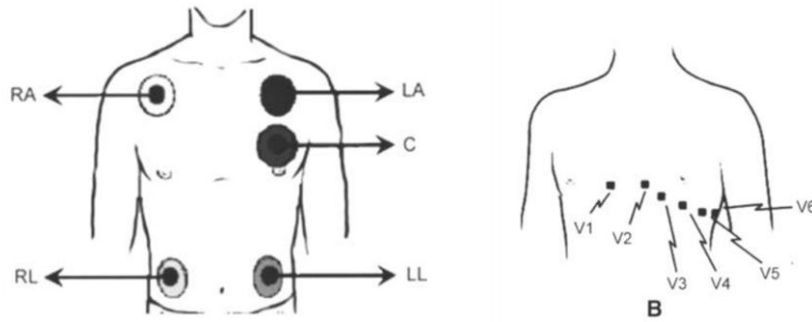


Figure 1.10. The electrode placement of 12 lead-ECG, Taken from textbook *Handbook of cardiac Anatomy* by P.A. Iaizzo

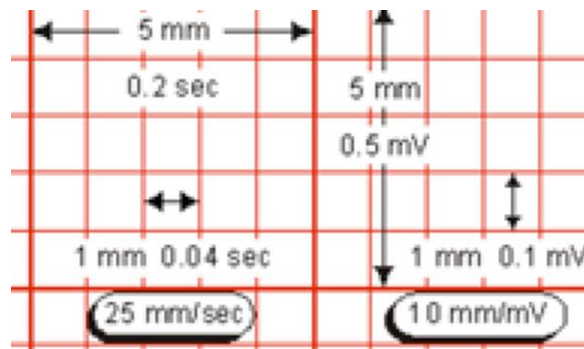
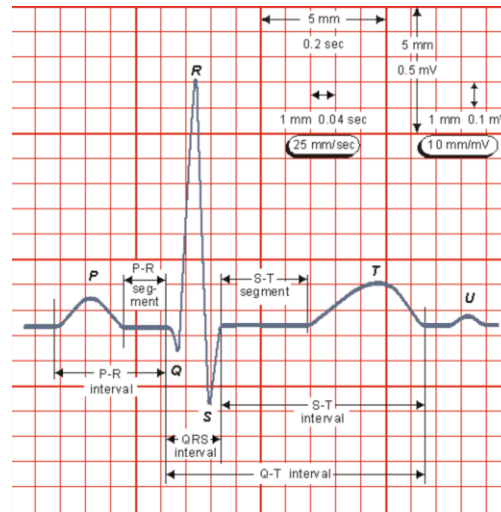


Figure 1.11. The ECG grid. Taken from *Bioelectromagnetism Principles and Applications of Bioelectric and Biomagnetic Fields* by Jakko Malmivuo and Robert Plonsey

During the cardio cycle, the ECG depicts a PQRST complex. The PQRST complex consists of five parts, which are represented by the alphabetic values of P, Q, R, S, and T (see Figure 1.12). Each part of the PQRST complex has its characteristic shape. The duration, amplitude, and shape of each part in the PQRST complex can show whether the heart works regularly or not [55].

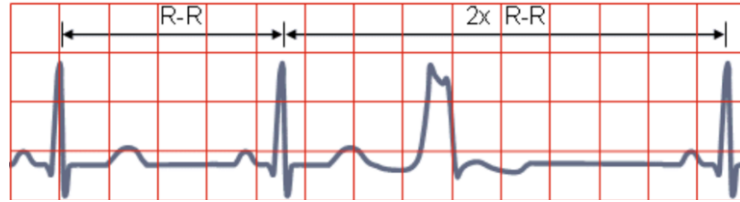


*Figure 1.12. The shape of the PQRST complex. Taken from Bioelectromagnetism Principles and Applications of Bioelectric and Biomagnetic Fields by Jakko Malmivuo and Robert Plonsey*

The ECG intervals and segments are:

- The P wave represents atrial depolarisation and precedes the QRS complex. It looks like a small bump upwards from the baseline. The amplitude is normally 0.05 to 0.25mV (0.5 to 2.5 small boxes). Normal duration is 0.06-0.11 seconds (1.5 to 2.75 small boxes). The shape of a P-wave is usually smooth and rounded.
- The PR interval is the period, which starts from the beginning of the P wave (the beginning of atrial depolarisation) until the beginning of the QRS complex (the end of atrial depolarisation and the beginning of ventricular depolarisation). The duration of the PR-interval of the average heart rate is 0.12-0.20 seconds. The shorter duration of the PR-interval is associated with arrhythmias nodes, while the longer one is associated with heart failure.
- The QRS complex indicates ventricular depolarisation which triggers the contraction of the ventricles. The normal QRS complex amplitude is 0.5-3 mV (5-30 mm), and the duration is 0.06-0.1 seconds or half the duration of the PR interval. It consists from the Q part (the first negative angle after the P wave), the R part (the first positive angle after the P and Q parts), and the S part (the first negative angle after the R part). Depending on the drain on to which the electrodes are placed, the QRS complex may look different (the angle is negative on drains VR, V1, V2 and V3).
- The ST interval represents the early part of ventricular repolarisation. The ST segment is the line from the end of the QRS complex to beginning of the T wave. Usually, the ST segment is flat relative to the baseline.

- The T-part of the signal monitors the repolarisation of the chamber. The typical shape of the T-section is a rounded amplitude shape at the interval of 0.05-1 mV. The amplitude, orientation and angle depend on the drain at the location of their associated electrode.



*Figure 1.13 Definition of the R-R intervals in ECG. Taken from Bioelectromagnetism Principles and Applications of Bioelectric and Biomagnetic Fields by Jakko Malmivuo and Robert Plonsey*

#### 1.2.4 The Measurement of the HRV

The calculation of HR depends on the methodology, ECG or PPG [22][28][31][38][48]. In our research, we used the ECG where HR is defined as the intervals between heartbeats, called the R-R intervals (Figure 1.13). The heartbeat is defined as the R peak in the QRS complex. The Heart Rate Variability (HRV) is a measure which indicates how much variation there is in the heartbeats (R-R intervals) within a specific timeframe.

The HRV measures are usually divided into two broad categories: time domain measures and frequency domain measures. Commonly used time domain and frequency domain measures are presented in Table 1.1 and Table 1.2 respectively. The values of the HRV measurements are usually dependent on age, physical conditioning, activity, sleep/wake cycle, disease, drug effects, and gender. In the case of time domain measures, the NN<sup>3</sup> [56] interval sequence is treated as an unordered set of intervals or pairs of intervals that employ different techniques to express the variance of such data. On the other hand, the frequency domain measures are calculated by resampling the original NN interval series and then applying a discrete Fourier transform or autoregressive spectral estimation. [30] The instantaneous heart rate (HR) requires resampling at uniform intervals and replacement of unusable samples due to the presence of abnormal beats or because of gaps or extreme noise in the original ECG recording. The Lomb periodogram is usually used instead of Fast Fourier transformation, to avoid these requirements [1]. The Lomb periodogram estimates power spectrum density directly from irregularly sampled signals.

Most of the HRV measures, presented in Table 1.1 and Table 1.2, are highly correlated with each other. These include SDNN, SDANN, total power and ULF power; SDNNIDX, VLF power and  $L_F$  power; and rMSSD, pNN50 and  $H_F$  power [48][49][50]. At the same time the  $L_F/H_F$  the ratio does not correlate strongly with any other HRV measures. For short-term data (less than 15 minutes in length), only the time domain measures of AVNN, SDNN, rMSSD and pNN50 and the frequency domain measures of total power, VLF power,  $H_F$  power and  $L_F/H_F$  the ratio should be used. The SDANN,

<sup>3</sup> NN-intervals refer to the intervals between normal R-peaks. During a measurement, artifacts may arise due to arrhythmic events or faulty sensors. This may lead to abnormal R-peaks, which may, in turn, distort the statistical calculations. To ensure reliable and valid data, only normal R-peaks are selected.

SDNNIDX and ULF power should be used only for long term (24-hour) data [48][49]. Figure 1.14 presents the 24-hour power spectrum of RR-intervals in a double logarithmic scale, and it can be seen that almost 90% of the spectrum was distributed within ULH and VLH. Most time and frequency domain measures are sensitive to outliers requiring visually inspected data and eventually filter outliers.

In our research, we measured the HRV in the frequency domain, since we tried to measure  $L_F$ , (0.04 - 0.15 Hz), and HF (0.15 - 0.4 Hz). We also used Lomb periodogram to calculate the power spectrum because it does not require regular sampled HRs from the ECG signal. We compared all of our results with the  $L_F/H_F$  index. As it was mentioned, the  $L_F/H_F$  does not correlate with other HRV measurements so it can be used for both long term and short term data. Therefore one of the main goals in our research was to propose a new index which behaves similarly to  $L_F/H_F$ .

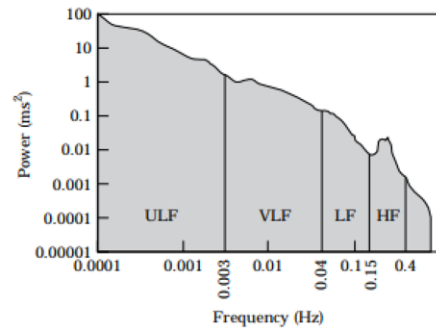
**Table1.1 Commonly used time-domain measures**

Measure	Description
AVNN	Average of all NN intervals
SDNN	The standard deviation of all NN intervals
SDANN	The standard deviation of the averages of NN intervals in all 5-minute segments of a 24-hour recording
SDNNIDX	Mean of the standard deviations of NN intervals in all 5-minute segments of a 24-hour recording
rMSSD	The square root of the mean of the squares of differences between adjacent NN intervals
pNN50*	Percentage of differences between adjacent NN intervals that are greater than 50 ms; a member of the larger pNNx family



**Table1.2: Commonly used frequency-domain measures**

Measure	Description
TOTPWR	Total spectral power of all NN intervals up to 0.04 Hz
ULF	Total spectral power of all NN intervals up to 0.003 Hz
VLF	Total spectral power of all NN intervals between 0.003 and 0.04 Hz
$L_F$	Total spectral power of all NN intervals between 0.04 and 0.15 Hz.
$H_F$	Total spectral power of all NN intervals between 0.15 and 0.4 Hz
$L_F / H_F$	The ratio of low to the high-frequency power



*Figure 1.14 The 24-hour power spectrum of RR-intervals in a double logarithmic scale. Taken from European Heart Journal (1996) 17, 354–381*

### 1.3. Summary

In this chapter, we provided introductory and background information about our research. The Introduction provided information about motivation, literature review, and the contribution of our study. On the other hand, the background section provided information about research areas such as anatomy of the heart, ANS, electrical activity of the heart, methodology of the ECG, and the measurement of the HRV. In the next chapter, we will fully explain all the steps of the experimental protocol and data processing. Also, we will introduce our indices and the process of the calculation.

## 2 Method and Material

This chapter provides information about the acquisition, processing, and classification of the experimental data, which have been collected at the Engineering Bionic Lab, Department of Systems Design Engineering, University of Waterloo. A total of 20 healthy adults, aged between 19 and 32 years old, were recruited as study participants. The experiment protocol has been approved by the ethics committee of the University of Waterloo (ORE#: 22188). Also, each participant had signed an informed consent form before the experiment took place.

### 2.1 Experiment Design

The experiment was designed to induce the participant through a series of cognitive loads followed by a rest period. The cognitive load was induced via mental arithmetic tasks with levels increasing in difficulty. During the rest period, the participant was placed in a relaxed environment where he/she listened to music while watching a peaceful landscape picture. All together there were five periods; two mental arithmetic tasks and three rest periods. The second arithmetic task had an increased difficulty level. The first period is the rest period and further on called baseline.

During the entire time of the experiment, the ECG was recorded using a device developed by the Waterloo Engineering Bionic Laboratory (Figure 2.1). The device was developed to collect 12-lead ECG signals from the participant and send out the digitalized signal in a format as eight-row matrix (eight channels signal). The ECG data was then processed using scripts written in MATLAB; this procedure will be explained in the Data Processing section. In the experiment, we only used three out of twelve electrodes to record the lead II of the ECG signal.

The experiment was conducted in a lab environment. The equipment used in the experiment was a headset, the ECG device with electrodes, and a computer. During the experiment session, the participant was in a sitting position, and the computer screen was placed one meter away from his/her eyes. The headset was placed on the participant's head, and the ECG electrodes were connected to the RA (right arm), RL (right leg), and LL (left leg) positions of standard ECG electrode positions, which allowed the recording of the Lead-II of the standard ECG recording (Figure 2.2). The headset is used to produce noise, distracting the subjects from performing the mental calculation. In order to avoid motion artefacts, the participant only used the left hand when interacting with the computer. Additionally, due to the limited wire length, the participant was asked to keep his/her legs closed, and the ECG device was placed on the right thigh. Finally, all the equipment had to be set up and fixed in the way so that the participant felt comfortable.

The experiment had five periods with the following order:

1. The first rest period(120 seconds), also named baseline period;
2. The first mental math period (length varies up to the maximum of 150 seconds);
3. The second rest period (60 seconds);
4. The second mental math period ( up to 750 seconds);
5. The third rest trial (120 seconds);

The duration of the rest periods were fixed, 120 seconds for the first and third rest period while the second rest period lasted 60 seconds.

On the other hand, the duration of the mental math period depended on the participants. The first mental math period had ten questions. For each question, a maximum of 10 seconds was provided for mental calculation, and five seconds for presenting feedback to the participants. Therefore, the maximum duration of the first mental math period was 150 seconds. The second one contained 30 questions. For each question in this period, a maximum of 20 seconds was provided for mental calculation and 5 seconds for presenting feedback to the participants. Hence, the maximum duration of the second period of mental math was 750 seconds. The entire experiment session lasted no more than 21 minutes. Figure 2.3 presents the experiment timeline.

The goal of the rest trials was to reduce the cognitive load and place the participant into a relaxing environment. In order to achieve that, on the computer screen the participant was presented with a peaceful landscape picture (Figure 2.4) along with some relaxing instrumental music, which he/she could hear via headset.

On the other hand, the goal of the mental math trial was to induce cognitive load. Here the participant used only his/her left hand and a numeric keyboard to submit their answers. The level of difficulty of the questions in the second math session was significantly higher compared to the first math session. In order to control the level of the mental load, some of the questions were set up to be even more difficult than others during the same trial. They were used as control points in the phase of data processing, where it was expected that the participant had been exposed to elevated cognitive loads.

A mathematical question was presented to the participant on a computer screen, placed one meter away from the participant's eyes. The form of the question was the same in both mental math trials, and it was:

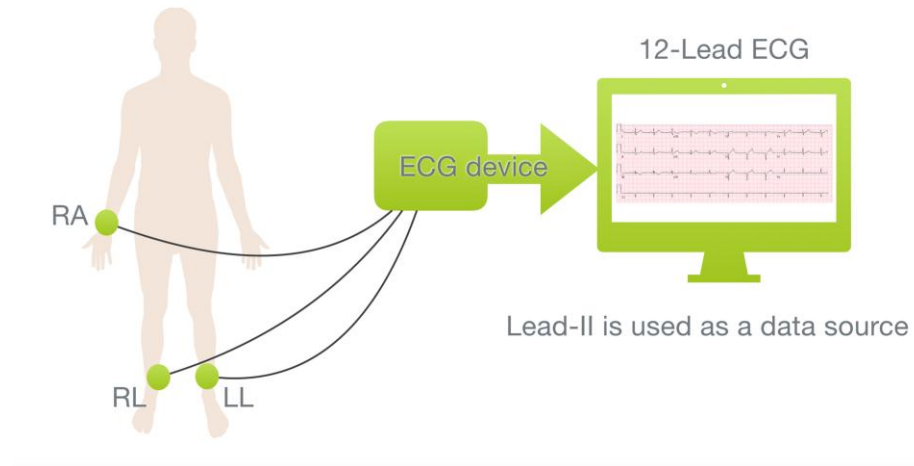
$$A*B+C \text{ or } A*B-C,$$

Where A, B, and C represent positive integer numbers, and the symbols '\*', '+', and '-' represent the mathematical operations of multiplication, addition, and subtraction, respectively. For the first mental math trial the ranges of the integer numbers were:

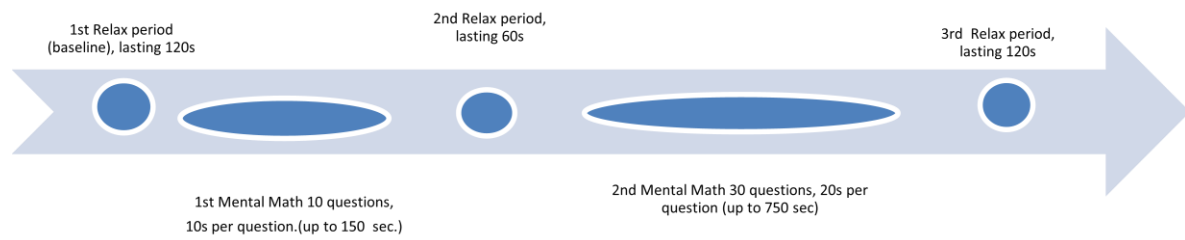
$$A \in \{2, \dots, 9\}, B \in \{11, \dots, 39\}, \text{ and } C \in \{4, \dots, 9\}$$



*Figure 2.1 the ECG device developed by Waterloo Engineering Bionic Laboratory*



*Figure 2.2 The electrodes position in the experiment*



*Figure 2.3 The experiment session time line. The circles represent the rest periods, while the ellipses represent the mental arithmetic trials.*



*Figure 2.4 The landscape picture presented to the participants during the relax periods.*

Some examples of the questions from the first mental math trial are:

$$3*15+8, 8*23-6, \text{ and } 9*32+9$$

The ranges of the number for the questions in the second mental math trial were:  $A \in \{2, \dots, 9\}$ ,  $B \in \{21, \dots, 69\}$ , and  $C \in \{21, \dots, 49\}$

The examples of the questions from the second mental math trial were:

$$4*28-34, 6*22+56, \text{ and } 8*67+43$$

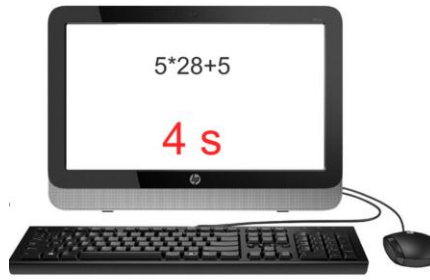
Consequently, the questions from the second mental math trial were more difficult than the question in the first mental math trial; since the numbers in the math expression were larger [53]. Moreover, in both trials, there were questions that were significantly more difficult than the rest of the questions during the same trial. The A and B of those most difficult questions were much larger. Some examples of these most difficult questions were:

$$99*87-11 \text{ or } 87*78+32$$

Solving those questions in a short period such as 10 or 20 seconds is almost impossible for the majority of people. However, we set all the answers on these types of difficult questions to return false in order to increase the stress level of the participant.

In addition to the above, there were five distracting factors implemented to enhance the level of cognitive loads further. Firstly, during the two stress trials, the participants were disturbed by noise through the headset. The noise was that of a crowded street during rush hours, with noises from motor vehicle traffic as well as several pedestrians walking by. Secondly, below the displayed question, on the computer screen, there was a stopwatch representing the remaining time allowed for solving each question, along with a beeping sound, which accentuated the count-down. The pitch of the beeping sound increased as the count-down continue. After the submission of the answer or the time-out, feedback was provided as to whether the answer was correct or incorrect. The acoustic feedback was five-seconds long depending on the accuracy of the answer: in the case of an incorrect answer, the sound was high of frequency and unpleasant to hear, wherein the case of a correct answer the sound was not high and pleasant to hear.

Furthermore, there was always at least one person, in addition to the experimenter, who was invited to come to the lab and stay next to the participant during the mental math trials. Finally, Figure 2.5 shows a sample of a question along with the stopwatch representing the remaining time on the mental math trial presented on the computer screen. During the experiment each participant's action was logged to a file with the format: described in Table 2.1



*Figure 2.5 The example of the question in the mental math trial, The read number with suffix 's' represents the number of the second left for solving the question.*

**Table2.1: The format of the log file**

<i>Id</i>	Id of the participant
<i>Event</i>	Event of the quiz (submit Answer, Rest, or Quiz Complete)
<i>Question #</i>	Cardinal number of the question
<i>Answer</i>	Submitted answer
<i>Is Correct</i>	Whether the answer is correct or not
<i>Time Left</i>	The number of the seconds left for submitting the answer
<i>Current Time</i>	The event time

## 2.2 Processing the data

The data processing has two steps. The preprocessing of the raw data (filtering) and post-processing which incorporates the calculation of the heart rate variability (HRV).

The device is designed initially to process ECG signals collected through ten electrodes from the participant and sends it out as an eight-channel signal. In our research we used only ECG signal from lead-II. Therefore we used only three out of ten electrodes for collecting ECG signals from lead-II. The other electrodes were not connected to the participant. A MATLAB script with two functions processed the output signal. The first function was for real-time visualisation of the lead-II of the ECG signal during the experiment. The resulting plot provided visual feedback information about the ECG of the participant and indicated the quality of the input signal. The second function records the signal in the same format as it is delivered from the device, eight channel ECG signals, into a binary file. The data from the binary file was used in preprocessing data.

During the preprocessing, the raw data was filtered. In order to eliminate the noise from the power source, the second order bandstop Butterworth filter was used. The band stop frequencies were from 58 to 62Hz. Afterwards, a sixth-order Butterworth high pass filter with the cut-off frequency of 0.1Hz was used to eliminate the noise from the motion artefacts.

The final phase of the raw data preprocessing consisted of labelling the data. The data was tagged with two types of labels. The first label assigns the trial of the experiment. The trials were represented by positive integers where the label assigns a cardinal number to the trial (Figure 2.6). This kind of labelling was used to determine to which trial the current data point of the ECG belongs. The second label was given only to the data belonging to the mental math trials. In this step, we used a log file with the participant's action to determine when the participant was resolving the question or submitted the answer. The data belonging to the period when the participant tried to resolve the question was assigned with the cardinal number of the question, and the data belonging to the period when the answer has been submitted was assigned with -1 or -2. The value -1 represents a correct answer and -2 represents an incorrect one. The rest sessions were labelled with 0 (zero) (Figure 2.7)

The second step of data post-processing used labelled data. Opposite to the previous preprocessing step, data post-processing was done in the frequency domain. The post-processing incorporated the following steps:

1. Detect the peaks;
2. Remove artefacts;
3. Calculate the power spectrum using the Lomb-Scargle method [1][15];
4. Calculate literature proposed stress index  $L_F H_F$  ;
  - 4.1. Identify the threshold as the mean value of the above index from baseline data
5. Calculate the proposed index.
  - 5.1 Identify the threshold as the mean value of the proposed index from baseline data

In order to calculate the HRV, we first had to capture all R-peaks of the ECG signal. The R-peak represents the maximum value during the cardio-cycle. In our study, as we expected noise in the ECG which was caused by the motion artefact and weak electrode contact, we used amplitude and derivate (slope) based algorithm to detect the peaks of the QRS complex. The R-peaks have been located using the algorithm developed by Moriet-Mahoudeaux [53][63]. We passed through all lead-II ECG data and appended each maximum value to the array devoted to keeping maximum values. In each iteration step, we compared the current value of the ECG with the last member of the array of maximum values.

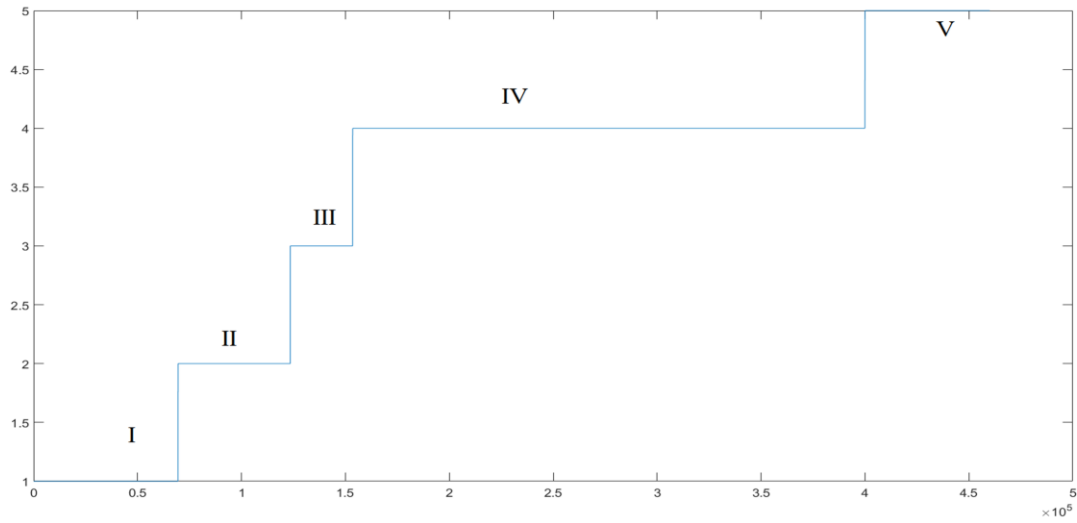


Figure 2.6. Session labels. X-axis represents time and Y-axis the cardinal number of the period. In this version of the experiment protocol sessions I,III, and V were the rest period while II and IV were mental arithmetics trials.

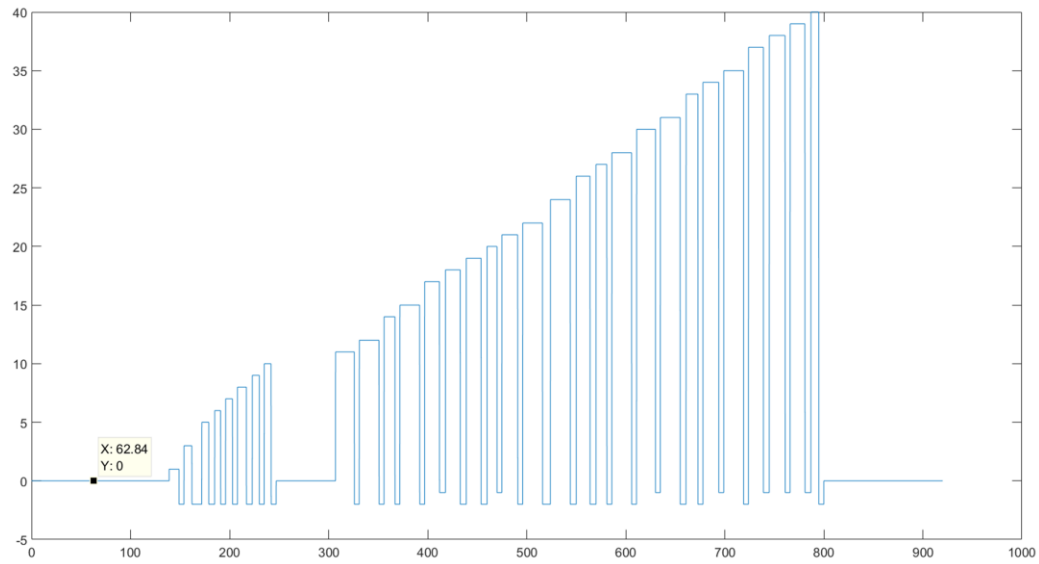
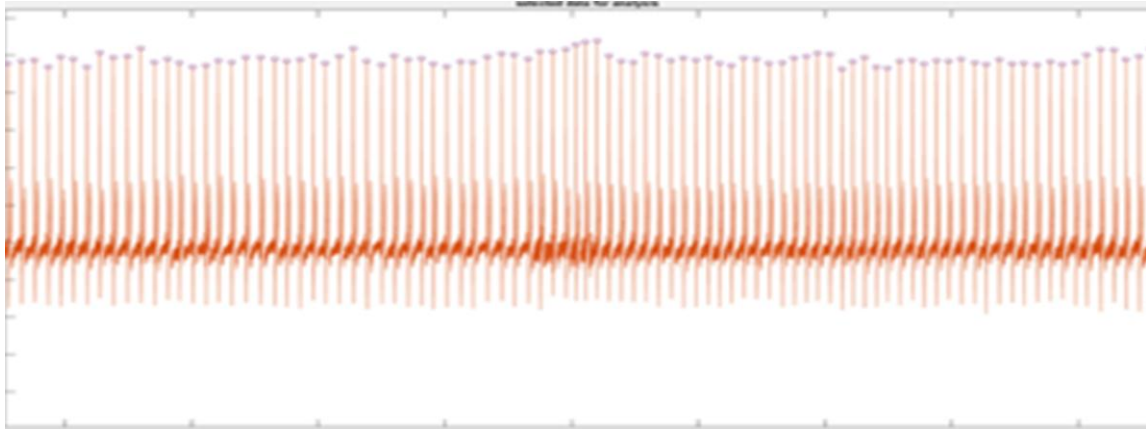


Figure 2.7 Labels of the mental arithmetic trials. X-axis represents time Y-axis positive values represent cardinal number of the question, negative values submitted answer and finally zero value represents the rest period.



As the cardio-cycle repeats from 40 to 100 times per minute [48][50], the distance between two adjacent peaks should be less than 0.6 seconds. In our calculation, we used 0.4 seconds. In the post-processing step of removing artefacts, any peak with a distance of fewer than 0.4 seconds from the previous one was removed. In Figure 2.8, we present selected data for analysis after artefacts were removed.



*Figure 2.8 The ECG data with selected R-peaks for data processing, Each R-peak is assigned with purple circle. X-axis represents time while Y-axis represents voltage.*

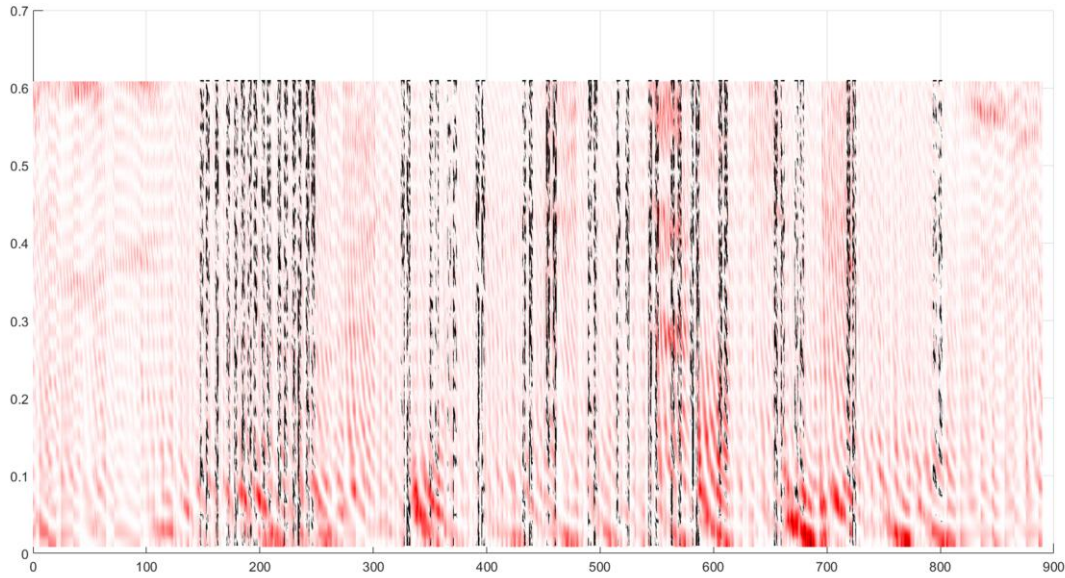
In the third post processing step, the Lomb-Scargle period-gram [1][15] was used to calculate the power spectrum of HRV. A time window of 30 seconds and a time step of 1 second were selected. At each step, we selected the ECG data frame for 30 seconds and calculated the Lomb-Scargle periodogram. The data frame was shifted for 1 second, and the process was repeated until the end of the data had been reached. The Lomb-Scale method returned the power spectrum of the HRV. We were only interested in the power spectrum in the frequency ranges 0.04-0.14Hz (low frequency) and 0.14-0.4Hz (high frequency) [48][49][50]. McDuff et al. [22] showed that for 80% of the participants the HRV  $L_F$  components were higher during the cognitive stress session. According to that, we expected the low-frequency spectrum to be higher during the question trials. In Figure 2.9, we present the power spectrum during the experiment. The X-axis represents time in seconds, Y-axis frequency, and the intensity of the red colour represent the magnitude of the spectrum. Therefore, it can be seen that during the rest sessions (120 seconds in the beginning and the end of the experiment) low spectrum components were insignificant. On the other hand, the low spectrum components had significantly higher values during the question sessions. The black colour is assigned to the periods when incorrect answers were submitted.

In the fourth post-processing step, we calculated the value from the literature proposed index  $L_F / H_F$  . [48][50]. This index, namely  $(L_F / H_F)$  , is defined as a ratio of the sum of the power spectrum in the low frequency range (0.04Hz-0.15Hz) over the sum of the power spectrum in the high frequency range (0.15Hz-0.4Hz). The power spectrum was calculated via Lomb Spectrogram explained in the previous chapter [1][15]. Equation 1 shows the calculation of this index.

$$L_F / H_F = \frac{\sum_{k=0}^n PS(Low\ Frequencies)}{\sum_{k=0}^n PS(HighFrequencies)} \quad (1)$$

The threshold for the above index was calculated as a mean value of the index in the baseline period. In the baseline period, we assume that the participant was relaxed and therefore data from the baseline was used for the threshold calculation.

Finally the fifth step, we proposed a new method, which could faster determine whether the participant was on stress not. In particular, in this study, we investigate a new index. For this purpose, in each step (1 second) for a given window (5 seconds size), we calculated the power spectrum and average value. The threshold for the proposed index was calculated during from data of the first rest period (baseline) when it was assumed that the participant is completely relaxed. The threshold represents the average index values during the first rest session.



*Figure 2.9. the power spectrum calculated with time window of 30 seconds using Lomb-Scargle method. The x-axis represents time in the experiment while y-axis represent power spectrum. Question trials present more dominant low frequency spectrum. The black colored power spectrum is assign to the questions on which participant gave wrong answer.*

The steps for calculation proposed index are:

1. Calculation the Euclidian (l2) norm of the power spectrum:

$$L2 = \sqrt{\sum_{i=0}^k x(i)^2} \quad (2)$$

2. Calculation mean of the power spectrum. The power spectrum is calculated via l1 norm: 
$$L1 = \frac{\sum_{i=0}^k x(i)}{k} \quad (3)$$

3. The proposed index 
$$L_{21} = \frac{L2}{L1} \quad (4)$$

where  $x(i) \in \{x(1), x(2), \dots, x(k)\}$  the values of the power spectrum of the HRV form the range from 0.04 to 0.15 Hz.

Finally, at the end of the processing, we calculated the ratio for each index, which is defined as the sum of the power spectrum of the index's values greater than threshold over the sum of the all values index's values. This ratio was calculated only for the first and second mental math trial separately.

Ratio equation: 
$$R(\text{index\_name}) = \frac{\sum_{p=0}^k x(p)}{\sum_{i=0}^k x(i)} \quad (5)$$

Where  $x(p)$  represents the indexes which values were higher than the threshold (mean value of the power spectrum of HRV at the first relax trial), during the mental math trial and  $x(i)$ , represent the index values during the mental math trial. The way it is defined, the ratio should always have a value of 1.

### 2.3 Classification of the participants

The dataset used in this research was achieved through the experiments explained before, where the participants were healthy adults between 19 and 32 years of age. All subjects were students from the University of Waterloo. Hence, the question was whether the mental arithmetic was equally challenging for all the participants. For example, for the students from the engineering faculty, the mental math should not have been as challenging as it would be for the students from social science. Therefore, we had to find a way to measure how challenging the mental arithmetic trials were to a participant. The primary goal of this task was to classify the participants according to the level of cognitive load they experienced through the experiments.

The parameters used in the classification of the participants were:

1. Total score of the quiz (TS)
2. Total score of the first mental math trial (TSCorrect1)
3. Total score of the second mental math trial (TSCorrect2)
4. Total per cent of the time spent on resolving the mathematical question during the first mental math trial (PST1)
5. Total per cent of the time spent on resolving the mathematical question during the second mental math trial (PST2)
6. The duration of the experiment. (TAll)

These six parameters were used as features for classification of the participants. The total score of the quiz was calculated as a ratio of the number of correct answers over the total number of the questions. The same approach was used for calculating the total score of the first mental math trial as well as on the second mental math trial. On the other hand, the total per cent of the time spent on resolving the question

during the mental math trials, was defined as a ratio of the total time spent in resolving the questions over the total duration of the trial. The total time spent on resolving the questions was defined as a difference of total duration of the mental math trial minus the time devoting to present feedback to the participant whether the answer was correct or not. The input data for calculation above mentioned parameters were obtained from the log file previously described in Table 2.1. The equations 6 and 7 show the calculation of the Total scores (1, 2 and 3) and the Average time (4 and 5)

$$\text{Total scores :} \quad TS = \frac{TSCorrect}{TSAll} \quad (6)$$

where TS is the total score, correct is the number of the correct answers, and TSAll is the total number of the questions.

$$\text{Total per cent of the time :} \quad PST = \frac{TDAll - TQAll * 5}{TQAll} \quad (7)$$

where PST is the total per cent of the time spent per question during the mental math trial, *TDAll* is the total duration of the mental math trial, and *tall* is the total number of the questions in the mental math trial.

The average values of these above parameters from all experiment sessions and were used as the threshold, by which four classes of the participants are classified: highly motivated (HM), motivated (M), low motivated (LM), and unmotivated (UM), as detailed below. The motivation was defined as a period where participant achieved a good score in the quiz and reported stress at the same time. Moreover we analyzed the score in the quiz only in the periods where stress was self-reported by the participant. With this criterion, we excluded the periods in the quiz with the questions which were not challenging for the participant or the answer was submitted with guessing.

The total number of classes could be more than four. However, we reached the final number of the classes (four) based on the results of the experiments such as the score in the quiz combined with the time spent for resolving the questions in both mental math trials, the total duration of the experiment, and the participants' feedback after the experiment sessions. The feedback contained the impressions of the participants about the experiment and their answers on the questions: was the quiz hard for him/her and when did he/she feel the stress during the session. These four classes gave only a starting point in the data analyses in order to compare the stress reported by participants with values of the indices calculated from the data. Later we will calculate statistics which will compare the results of the indices between the group of the participants with low performance on the quiz and low self-reported stress; and the group of the participants which achieved a good score on the quiz and had self-reported stress. The results from those two data analysis that approaches should provide sufficient material to derive the conclusion and make discussion on the thesis.

The highly motivated participants, namely HM participants, had total scores of the quiz and total scores in the first and second mental math trial above the value of the threshold. Additionally, HM participants achieved high scores in the quiz and had less present of the time spent for resolving the questions than average. Their motivation during the quiz did not vary too much, and therefore it was assumed that they were constantly exposed to the cognitive load.

In the case of motivated participants, namely M participants, the level of cognitive load varied during the quiz. This class of participants had the total scores of the quiz and the total scores in the first

and second mental math trials above the threshold. Likewise, for the total per cent of the time spent for resolving the questions and total duration of the quiz, the values were above the thresholds. This class of participants had high motivation during the first mental math trials and at least during the first half of the second mental math trials, but after that period their motivation decreased.

Table 2.2 represents the threshold values for the selected features and table 2.3 classes of the participants with classification rules

**Table 2.2. The features and threshold**

Feature	Threshold (Average value)
Duration of the experiment (TAll)	933 seconds
The total score (TS)	53%
The total score at the first run (TSCorrect1)	40%
The total score at the second run (TSCorrect2)	56%
Total per cent of the time spent on resolving the mathematical question during the first mental math run (PST1)	7 seconds
Total per cent of the time spent on resolving the mathematical question during the second mental math run (PST2)	12 seconds

**Table 2.3. The classes with classification rules regards with the features listed in the table 2.2**

class	TAll	TSCorrect1	TSCorrect2	PST1L	PST2
The highly motivated participants (HM)	Lower than threshold	Greater than threshold	Greater than threshold	Lower than threshold	Lower than threshold
The motivated participants (M)	Greater than threshold	Greater than threshold	Greater than threshold	Greater than threshold	Greater than threshold
The low motivated participants (LM)	Greater than threshold	Lower than threshold	Lower than threshold	Greater than threshold	Greater than threshold
The unmotivated participants (UM)	Lower than threshold	Lower than threshold	Lower than threshold	Lower than threshold	Lower than threshold

### 3 Results

In this chapter, we will present the results of the experiments followed by the discussion of the results and statistical analyses. At first, the participants were classified according to their achievements in the experiments such as results in the mental arithmetic trials, duration of the entire experiment, and average time spent in solving mathematical questions in both mental arithmetic trials. The classification rules were explained in the previous chapter in the subsection classification of the participants. Secondly, the values of the proposed indices and the index proposed from the literature  $L_F / H_F$  will be calculated for each participant for each class, and summarise the results. Finally, in the statistical analysis section we will present the comparative analyses between our proposed indices and the index proposed from the literature,  $L_F / H_F$  taking all participants as a sample.

In this study, we used indices derived from Heart Rate Variability (HRV) for stress detection. For all indices, the thresholds between stress and no-stress states were defined as an average value of the index calculated from baseline. Additionally, we calculated the average value of the indices during the mental arithmetic trials and second and third relaxed periods. Moreover, the average index values were also explicitly calculated during the question period where the participant answered incorrectly. It should provide the trend of the index during the current mental arithmetic trial.

#### 3.1 The highly motivated participants

The highly motivated participants achieved the best results in the quiz regarding the scores in both mental arithmetic trials and time spent on resolving mathematical questions. Their efficiency was high, and therefore it was expected that their level of stress did not vary too much during the experiment session. In order to prove this hypothesis, we will at first present the results of the experiments using the index  $L_F / H_F$  from the literature [25], as well as the index proposed in this study.

Figure 3.1 presents an example of the  $L_F / H_F$  index for a highly motivated participant. The red, green, blue, yellow, blue, and purple lines represented the average value of  $(L_F / H_F)$  index during the first relax period, the first mental arithmetic trial, the second relax period, the second mental arithmetic trial, and the third relax period, respectively. The short black lines were the average  $(L_F / H_F)$  values during the questions with incorrect answers.

The  $L_F / H_F$  index shows that the participants had experienced stress during all periods of the experiment after the initial relax period (baseline), from which the threshold (reference) level was obtained. The average values of the index during the questions which participant answered incorrectly varied during the mental arithmetic trials. The average values for some incorrect answers were below the average values of the index of the corresponding mental arithmetic trials.

On the other hand, Figure 3.2 and 3.3 represent the proposed indices for the same participant. Figure 3.2 represents the L1 and L2 index and 3.3 represents L2/L1. The equations for calculating the proposed indices were explained in the previous chapter. Figure 3.3 shows that our proposed index L2/L1 clearly differentiates the relax periods from mental arithmetic trials.



The average values of the L1 index were increased during the experiment session. The high level of the average values during the rest runs depicts that the participant was under higher levels of cognitive load. Additionally, the L2 index presents clearly the difference between stress and relax period since the

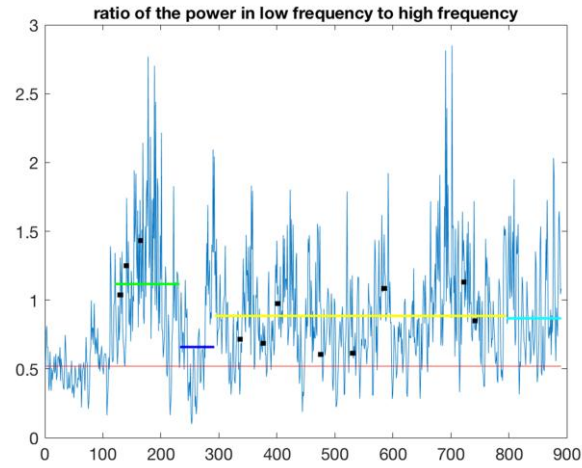


Figure 3.1 The  $L_F / H_F$  index for the highly motivated participants. The green and yellow lines represent the average value of the index during the first and second mental arithmetic trials. The red line represents the threshold while the blue and the cyan are the average values of the index during the second and the third rest periods.

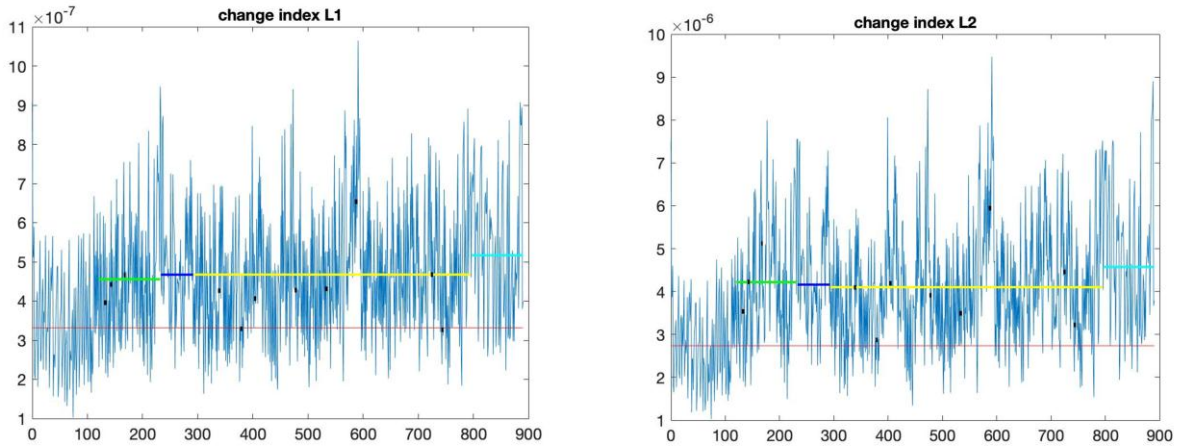


Figure 3.2 The L1 and L2 indices of the highly motivated participant shows that the level of stress experienced did not vary too much during the experiment session.

level of the average values did not vary too much. Lastly, our proposed index  $L2/L1$  presents similar trends during mental arithmetic trials as  $L_F / H_F$ . In the relax period the difference between  $L2/L1$  and  $L_F / H_F$  was significant. That difference during the relax period was expected since that  $L2/L1$  was calculated via  $L_F$  component only which reflects activity of the PNS branch of ANS.

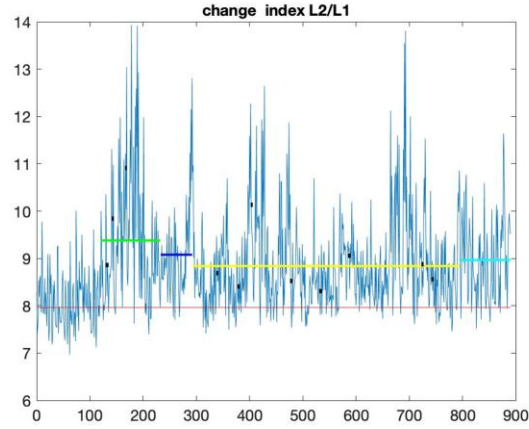


Figure 3.3 The L2/L1 index of the highly motivated participants represents the ration of the L2 over L1. The index shows slight difference in the level of stress experienced between the first (green line) and the second (yellow line) mental math run.

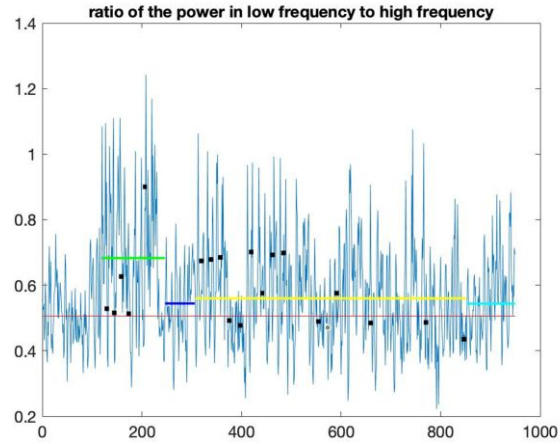


Figure 3.4 the  $L_F / H_F$  index for motivated participants shows that the stress was permanent during the experiment.

Table 3.1 Ratio equation of Indices for the highly motivated participants (defined in the chapter 2 (equation 5))

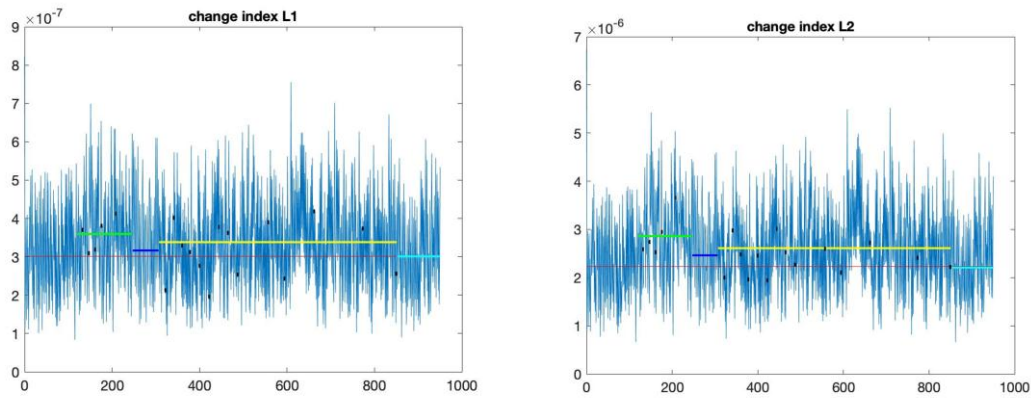
Ratio equation of Index	The first mental arithmetic trial	The second mental arithmetic trial
$R(L_F / H_F)$	0.885	0.753
$R(L2/L1)$	0.929	0.902
$R(L1)$	0.672	0.747
$R(L2)$	0.769	0.779



Finally, Table 3.1 presents the values from the ratio equation defined in the chapter 2 (equation 5) for all indices for highly motivated participants. Consequently, the differences between the values in the first and the second mental arithmetic trials are insignificant. This was expected since for the highly motivated participants the cognitive load did not vary too much between the first and second mental run.

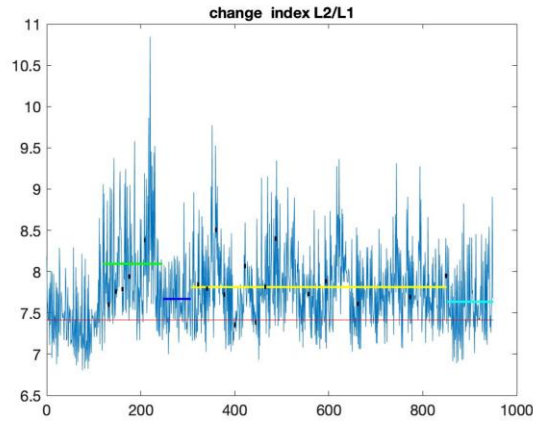
### 3.2 The motivated participants

The main characteristic of the motivated participants was that they did not have high motivation during the entire experiment session. Their motivation decreased after the 10<sup>th</sup> or 15<sup>th</sup> question in the second mental arithmetic trial. Therefore, they were motivated during the first mental arithmetic trial and, at least, during the first half of the second mental arithmetic trial. Figures 3.4, 3.5, and 3.6 show the index values for the motivated participants. It can be seen that the indices L1, L2, and L2/L1 accurately present



*Figure 3.5 The L1 and L2 indices for the motivated participants show that the level of the stress experienced is less in the second mental arithmetic trial (yellow line) than in the first mental arithmetic trial (green line).*

the difference between the stress and relax periods. The  $L_F / H_F$  index presented whether the participant experienced stress or not. Since the second mental arithmetic trial was significantly longer than the first mental arithmetic trial and the participant lost motivation in the second half of the second mental arithmetic trial, the average values of the  $L_F / H_F$  index were almost the same on both mental arithmetic trials. On the other hand, the average values of the indices L1, L2, and L2/L1 were not the same. Therefore, those indices depicted accurately the difference between stress and no-stress periods during the mental arithmetic trials since for the calculation of the L1, L2, and L2/L1 indices used the power spectrum only from the low-frequency range (0.04Hz-0.15Hz). This corresponds with the fact that the activity of the sympathetic nervous system (SNS) directly reflects the changing in the ECG power spectrum in the low-frequency range [25][44]. Finally, Table 3.2 presents the values from the ratio equation for the motivated participants. The difference of the values in the first and second mental arithmetic trials are from between 6% to 8% for proposed indices. On the other hand, for the  $L_F / H_F$  index both values are almost equal which supports the fact that L1, L2, and L2/L1 more accurately present the difference between stress and no-stress states during the mental arithmetic trials.



*Figure 3.6 The L2/L1 index of the motivated participants shows that the difference in the level of stress experienced between the first and second mental arithmetic trials was significant.*

**Table 3.2. Ratio equation of Indices for the motivated participants (defined in the chapter 2 (equation 5))**

Ratio equation of Indices	The first mental arithmetic trial	The second mental arithmetic trial
$R(L_F / H_F)$	0.613	0.619
$R(L2/L1)$	0.677	0.596
$R(L1)$	0.596	0.536
$R(L2)$	0.556	0.479

### 3.3 The low motivated participants

The low motivated participants did not do right in math. Therefore their results in the quiz were below the average. In general, the low motivated participants had motivation during the first half, or, at least, the third quarter of the first mental arithmetic trial. Later, their motivation decreased rapidly. Figures 3.7, 3.8, and 3.9 present the values of the  $L_F / H_F$ , L1, L2, and L2/L1 indices for the low motivated participants. The  $L_F / H_F$  index shows that there was a significant difference between average index values in the first and the second mental arithmetic trial. The L1, L2, and L2/L1 also accurately present the experienced stress, since the average index values had been decreasing through the experiment session. Table 3.3 presents the values from the ratio equation for low motivated participants. Consequently, the values on the second mental arithmetic trial are significantly less than the values in the first mental arithmetic trial.

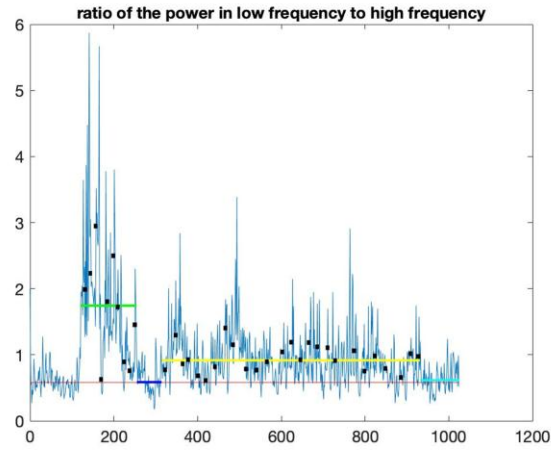


Figure 3.7 The  $L_F / H_F$  index for the low motivated participants shows that there is a significant difference in the level of stress experienced in the first (green line) and the second (yellow line) mental arithmetic trial.

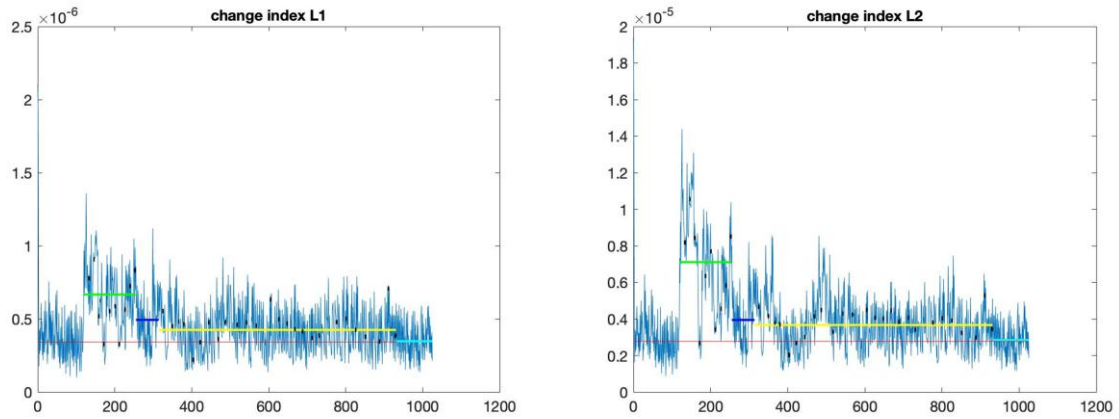


Figure 3.8 The L1 and L2 indices for the low motivated participants show that the level of stress experienced is higher in the first mental arithmetic trial (green line) than in the second mental arithmetic trial (yellow line).

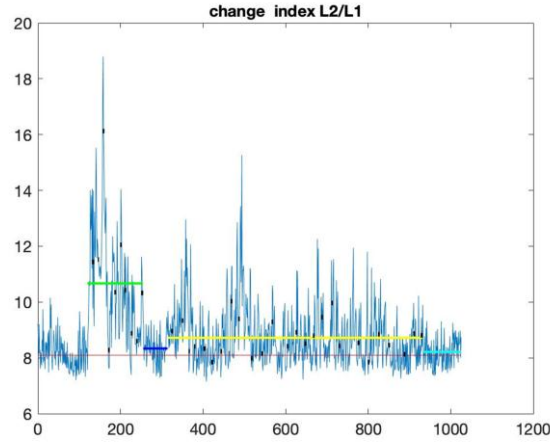


Figure 3.9 L2/L1 index for the low motivated participants shows a significant difference in the level of stress experienced in the entire experiment session.

Table 3.3 Ratio equation of Indices for the low motivated participants (defined in the chapter 2 (equation 5))

Ratio equation of Indices	The first mental arithmetic trial	The second mental arithmetic trial
$R(L_F / H_F)$	0.941	0.805
$R(L2/L1)$	0.97	0.774
$R(L1)$	0.874	0.539
$R(L2)$	0.859	0.390

### 3.4 The unmotivated participants

The unmotivated participants lost their motivation at the very beginning or, at least, during the first quarter of the first mental arithmetic trial. They were passive during the entire experiment session. Therefore it was expected that they barely experienced or did not experience any stress at all. The  $L_F / H_F$  index shows that stress was experienced during the first mental arithmetic trial, but later it went down (the values of the index were below the threshold). However, the proposed indices demonstrate that their values were below the threshold during the experiment session. Furthermore, the average values of the L1, L2, and L2/L1 show that the participants did not try to resolve the challenging questions and he/she only tried to answer on the questions with low a number such as  $10 \times 2 + 2$  or  $7 \times 5 + 3$  and therefore the level of experienced stress was insignificant. Additionally, Table 4.4 presents the values from the ratio equation for unmotivated participants. Figure 3.10, 3.11, and 3.12 presents  $L_F / H_F$ , L1, L2, and L2/L1 indices for the unmotivated participants.

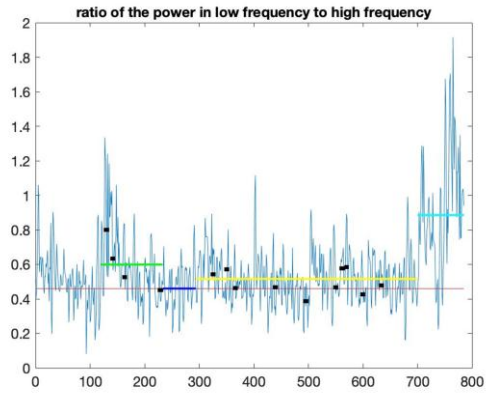


Figure 3.10 The  $L_F H_F$  index for the unmotivated participants presents very low experienced stress during the entire experiment session.

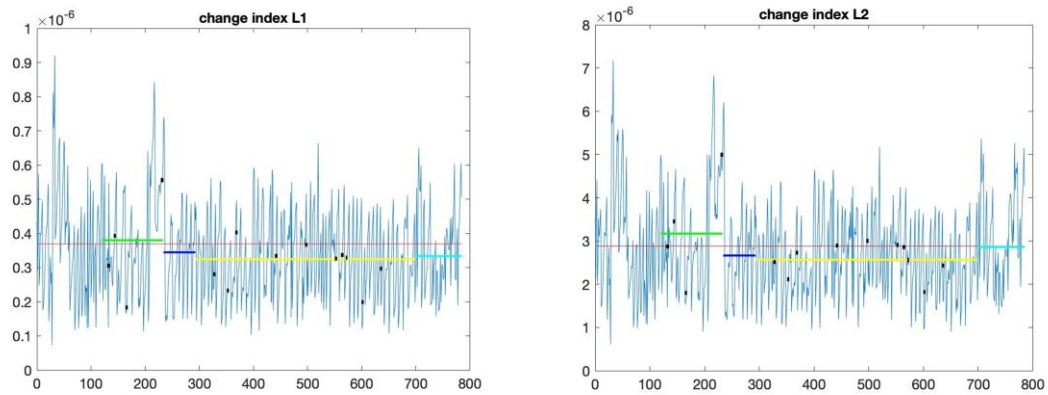


Figure 3.11 The L1 and L2 indices for the unmotivated participants show that there was no stress experienced during the entire experiment session.

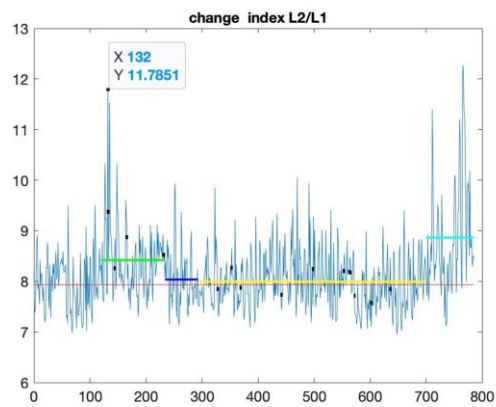


Figure 3.12 The L2/L1 index for the unmotivated participants shows that there was no stress experienced during the entire experiment session.

**Table 3.4 Ratio equation of Indices for the unmotivated participants (defined in the chapter 2 (equation 5))**

Ratio equation of Indices	The first mental arithmetic trial	The second mental arithmetic trial
$R(L_F / H_F)$	0.543	0.369
$R(L2/L1)$	0.605	0.374
$R(L1)$	0.403	0.288
$R(L2)$	0.350	0.145

### 3.5 Summary of data analysis

In this chapter, we presented the results of the experiments. Throughout all the experiment sessions, we tried to induce cognitive load via mental arithmetic tasks. Since mental arithmetic was not challenging enough for all participants, we had to classify the participants according to their results in the quiz and their feedback from the experiment. At first, we presented the results of the experiment session through the  $L_F / H_F$  index which was used in the literature [25]. Secondly, the results of the sessions were presented via L1, L2 indices and proposed L2/L1 index which should have similar behavior as  $L_F / H_F$ . Although the L2/L1 was calculated through  $L_F$  only, it showed similar results in detecting stress during the first and the second mental arithmetic trials such as  $L_F / H_F$ . The  $L_F / H_F$  index showed the period where the participants experienced stress, the L2/L1 showed also reliably differentiates stress and no-stress periods. Furthermore, it showed how experienced stress changed throughout the experiment session. Finally, Figures 3.13, 3.14, 3.15 and 3.16 present the boxplot diagrams of the results of all indices for all classes of the participants. The Y-axis represents the values of the relevant index while the X-axis represents the class of the participants and the values referenced. Therefore, for example, UM-REF represents the threshold values for the unmotivated participants. Table 3.5 presents a detail description of each value on the X-axis. In the next session, we will present a statistical analysis for all participants together.

**Table 3.4 The description of the X-axis values of Figures 3.13, 3.14, 3.15, and 3.16**

The name of the value	Description
HM-REF	The threshold for the high motivated participants
M-REF	The threshold for the motivated participants
LM-REF	The threshold for the low motivated participants
UM-REF	The threshold for the unmotivated participants
HM-R1	The values of the index during the first mental math run for the high motivated participants
M-R1	The values of the index during the first mental math run for the motivated participants
LM-R1	The values of the index during the first mental math run for the low motivated participants
UM-R1	The values of the index during the first mental math run for the unmotivated participants
HM-R2	The values of the index during the second mental math run for the high motivated participants
M-R2	The values of the index during the second mental math run for the motivated participants
LM-R2	The values of the index during the second mental math run for the low motivated participants
UM-R2	The values of the index during the second mental math run for the unmotivated participants

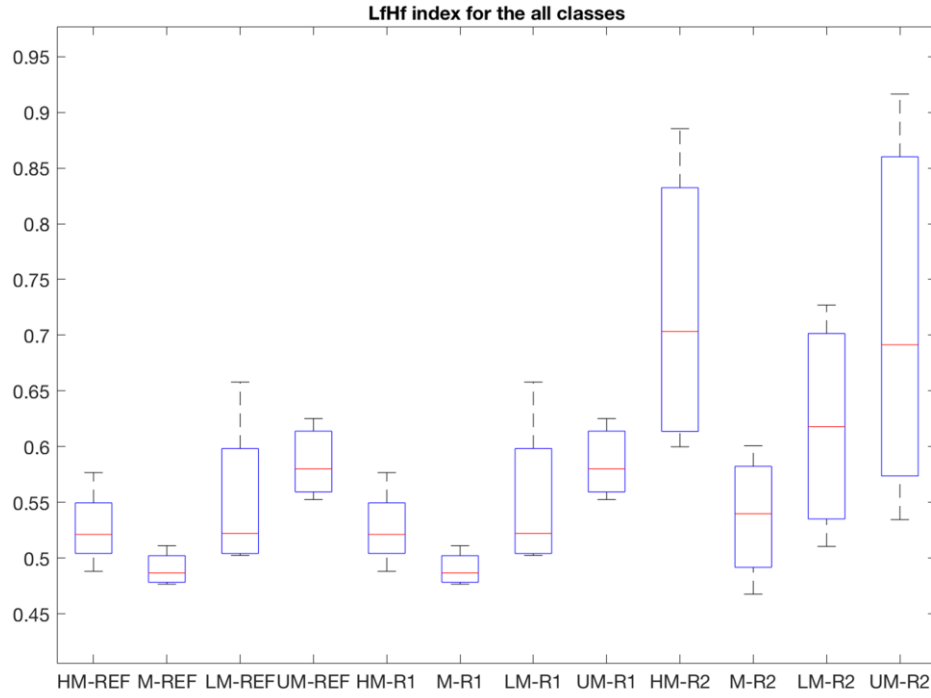


Figure 3.13 The boxplot diagram for  $L_F H_F$  index for all classes of the participants. See Table 3.5 for the description of the acronyms on the X-axis.

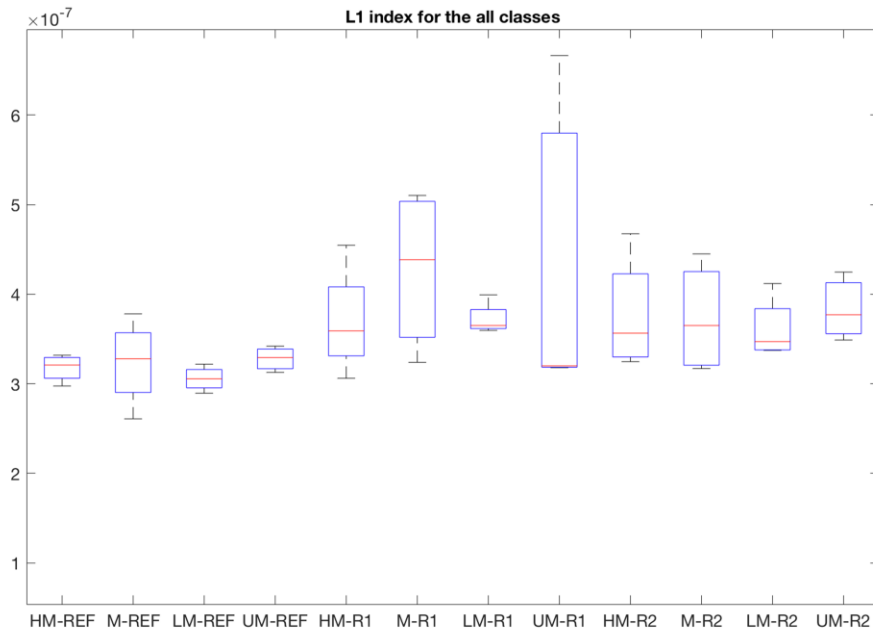


Figure 3.14 The boxplot diagram for  $L1$  index for all classes of the participants. See Table 3.5 for the description of the acronyms on the X-axis.

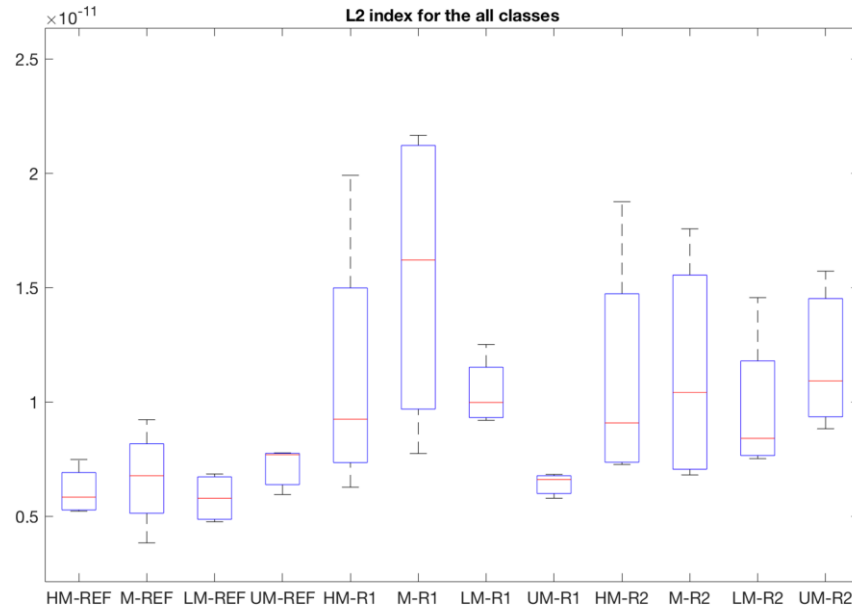


Figure 3.15 The L2 index for all classes of the participants. See Table 3.5 for the description of the acronyms on the X-axis.



### 3.6 Statistical analyses

In this section, we will present the comparative analyses between our proposed index and the index proposed by the literature,  $L_F / H_F$ . At first, we will present statistical analyses of the index  $L_F / H_F$ . Afterwards, we will analyze the power spectrum of  $L_F$  and  $H_F$  individually. The values of the L1, L2, and L2/L1 were analyzed as well. The goal was to determine if the  $L_F$  component of the HRV power spectrum can be used as a feature in the classifier between the stress and no-stress state. The goal was to determine similarity between L2/L1 index and  $L_F / H_F$  index.

At first, we calculated correlations between  $L_F / H_F$  and  $L_F$ , as well as  $L_F / H_F$  and  $H_F$ . Table

**Table 3.5 Correlation values between  $L_F / H_F$  and  $L_F$**

1 <sup>st</sup> Rest Period (Baseline)	1 <sup>st</sup> Mental Arithmetic Trial	2 <sup>nd</sup> Rest Period	2 <sup>nd</sup> Mental Arithmetic Trial	3 <sup>rd</sup> Rest Period
0.0247	0.264	0.635	0.346	0.121
0.0247	0.264	0.635	0.346	0.121
0.06	-0.71	0.720	0.688	0.575
0.07	0.081	0.652	0.411	0.277
-0.104	0.71	0.69	0.901	0.564
0.02	0.183	0.418	0.382	0.837

**Table 3.6 Correlation values between  $L_F / H_F$  and  $H_F$**

1 <sup>st</sup> Rest Period (Baseline)	1 <sup>st</sup> Mental Arithmetic Trial	2 <sup>nd</sup> Rest Period	2 <sup>nd</sup> Mental Arithmetic Trial	3 <sup>rd</sup> Rest Period
-0.307	0.192	0.149	-0.17	0.101
-0.307	0.192	0.149	-0.17	0.101
0.013	0.202	0.747	-0.267	0.57
-0.281	0.295	0.033	-0.138	0.228
-0.273	0.075	0.517	0.024	0.415
0.032	0.060	0.292	0.013	0.272

3.5 and Table 3.6 present the matrix correlation coefficients for both mentioned correlations. It can be seen that correlation coefficients between  $L_F / H_F$  and  $L_F$  for both rest periods and mental arithmetic trials correlates better then  $L_F / H_F$  and  $H_F$ .

Secondly, we compared distribution of the power spectrum of  $L_F / H_F$  with distributions of the power spectrum of  $L_F$  and  $H_F$ . Figure 3.16 presents the boxplot diagrams of the power spectrum of  $L_F / H_F$ ,  $L_F$ , and  $H_F$ . From those boxplot diagrams, it can be seen that the trend which shows  $L_F$  power spectrum between the rest periods and mental arithmetic trials is similar to the trend as  $L_F / H_F$  power spectrum shows.

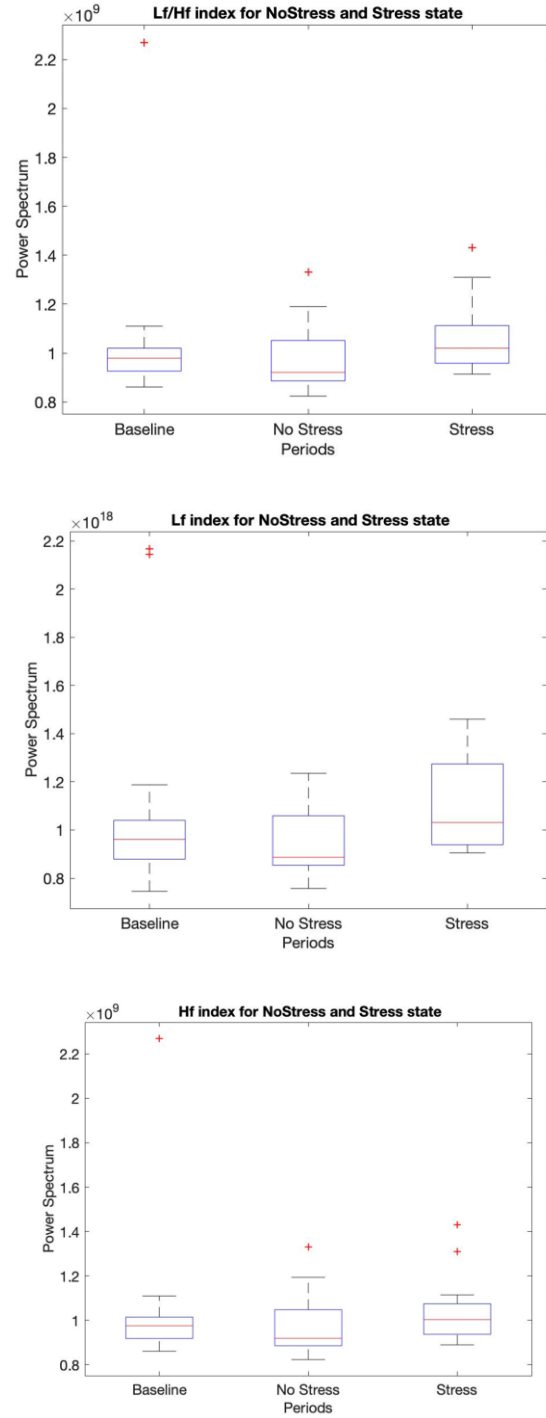


Figure 3.16. Distribution of the power spectrum for  $L_F / H_F$ ,  $L_F$ , and  $H_F$ . It can be seen that  $L_F$  has a similar trend between stress and no stress state such as  $L_F H_F$ .

In addition, Figure 3.17 presents boxplot diagrams for our indices calculated via l1 norm (L1 index) and l2 norm (L2 index) such as our proposed index (L2/L1). As it was mentioned before, all proposed indices used  $L_F$  power spectrum only. It can be seen that index L2/L1 behaves similarly as  $L_F / H_F$  index proposed from literature.

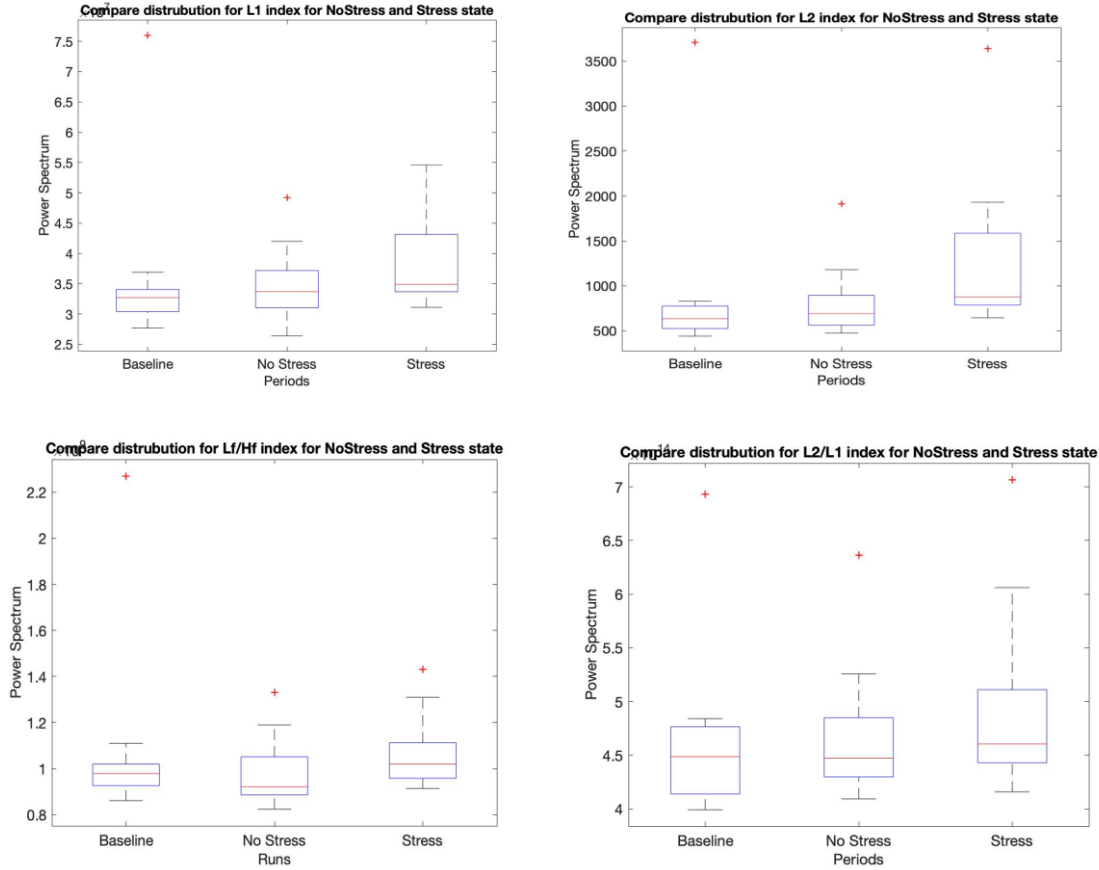


Figure 3.17 Distribution for L1, L2,  $L_F / H_F$  and L2/L1 indices.

Figure 3.18 represents bar diagrams for  $L_F / H_F$ ,  $L_F$  and  $H_F$  power spectrum such as for L1, L2, and L2/L1 indices for 15 out of 20 participants. We present only 15 participants to make diagrams more readable. The results from the participant with Id 11 are quite impressive. That participant came to the experiment under stress since the participant's wallet was stolen half an hour before arriving to the lab. For this participant, the values for baseline are significantly higher than the values for rest and stress periods. Finally, the ratio between baselines between no- stress states for is 0.81 while in the case of L2/L1 index the ratio between no- stress and stress baseline is 0.9. On the other hand the ratio between min values for no-stress periods is 0.89 for and 0.98 for L2/L1. The same ratio, but for max values are 0.85 for and 0.94 for L2/L1. The difference is up to 10%, which was expected since we calculated L2/L1 using only  $L_F$ . In addition, Table 3.7 presents t and p values of T-test, paired by subject, which compares no-stress periods with stress periods. The results of the T-test show that there is no significant difference between samples for no-stress and stress periods when it was measured with  $L_F / H_F$  or L2/L1 index.

**Table 3.7. Presents value of the T-test for  $L_F / H_F$ , and L2/L1 index for no-stress and stress period. The result of the T-test show that there is not significant difference between samples in the both no-stress and stress periods. The p values represent the probability that observed differences are due to chance between stress and no-stress cases.**

T-Test values	$L_F / H_F$	L2/L1
t	-1.48672	0.24523
p	0.0785	0.388

Here we divided participants into two classes. The first one represented the participants who achieved a good score in the mental arithmetic trials and self-reported stress (the participants with id: 1,3,4, 5, 6, 9,11, 12,13, 14, and 15). For this class of the participants, the values in the stress period (mental arithmetic trials) were higher than the values in the rest periods. The second class of the participants represents the participants who did not achieve good results in the mental arithmetic trials and did not self-report stress (the participants with id: 2,4,7,8, and 10). For this class of participants, the values in the stress period (mental arithmetic trials) were slightly higher than the values in the rest periods. The number of the participants in the first class was 14, while in the second class the total number of participants was 6. Conclusions drawn from those figures are similar to those already previously discussed.

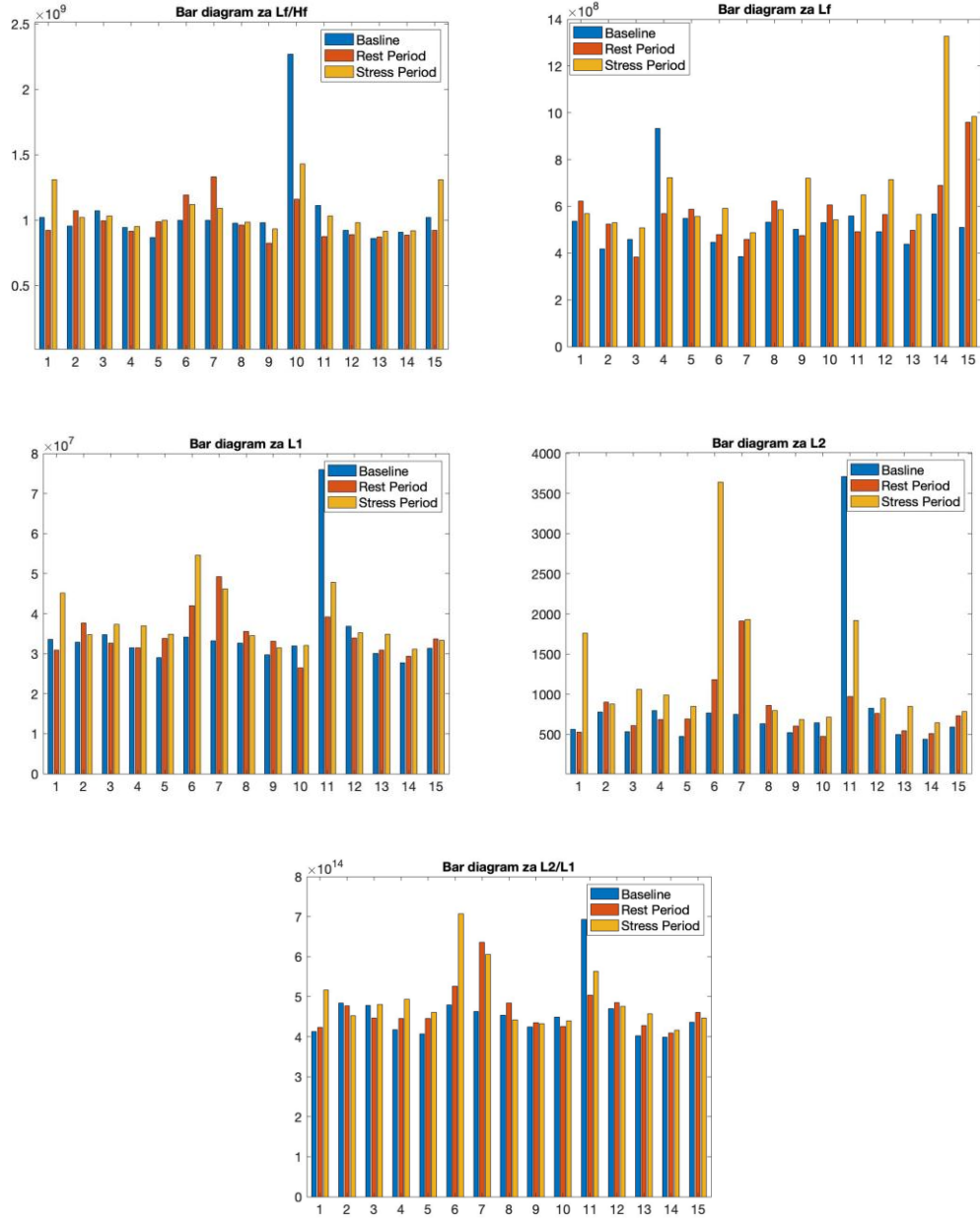


Figure 3.18. Bar diagrams for indices  $L_F / H_F$ ,  $L1$ ,  $L2$ , and  $L2/L1$  for 15 participants. The  $L2/L1$  shows similar behaviour as  $L_F / H_F$ .

## 4 Conclusions and Discussion

There are many factors inducing stress. When the person is exposed on the stress the sympathetic (SNS) part of the autonomic nervous system (ANS) is more active than parasympathetic (PNS). Moreover, the level of the activity of the ANS can be determined through ECG where PNS is associated in the high-frequency component, from 0.15 to 0.4Hz, and SNS is associated in the low-frequency component, from 0.04 to 0.15Hz. Therefore the ratio between the high and low components of the ECG can show whether a person is exposed to the stress or not.

According to the research [44], there are four primary sources of the stress: environment, social, physiological, and thoughts. In addition to, the stress can be acute or chronic. Acute stress is the most common and its symptoms can be easily identified. On the other hand, chronic stress is the grinding stress that wears people away day after day, year after year. Chronic stress destroys bodies, minds and lives and it wreaks havoc through long-term attrition. The adverse consequences of chronic stress can trigger many diseases such as diabetes, strokes, heart attacks, and cancers [45][57]. Therefore, the ability to detect stress and stressors gives us the opportunity to take control over it.

In our research, we proposed an index for stress detection which behaves similarly as the index  $L_F / H_F$  well known from the literature [26]. We tried to induce stress to the participant using cognitive load as a stressor. In order to do that, we designed an experiment where participants did a mental arithmetic calculation. The experiment session had five periods wherein the first, third, and fifth period the participant was placed in a relaxed environment while during the second and the fourth periods the participants did the mental arithmetic calculation. During the entire experiment session, the ECG of the participant was recorded. The hypothesis was that in the mental arithmetic trials (the second and the fourth period of the experiment) the participant should be exposed on the stress due to cognitive load. Therefore in order to confirm the hypothesis the participant was exposed on alternating relax (the first, the third, and the fifth) periods and mental arithmetic (the second and the fourth) period, where the result of the measurement should show the discrepancy between relax and stress periods.

The mental arithmetic trials were established in the form of the quiz with mathematical questions which the participant had to resolve in the short period of the time using only mental calculation. The first mental arithmetic trial (the second period) contained ten questions where the participant had ten seconds for resolving each question. Likewise, in the second mental arithmetic trial (the fourth period), the participant had to resolve 30 questions, where the time for answering each question was 20 seconds. During the entire experiment session, the participant was in a sitting position with a headset on the head. The questions were presented on the computer screen, and the participant used the keyboard and left hand to submit the answer. Through the headset, we tried to distract the participant during the mental arithmetic trials playing the sound recorded from a street during the rush hours. On the other hand, in the relax periods (the first, second, and fifth periods) we tried to relax the participant as much as possible, presented to him/her peaceful landscape picture and played relaxed instrumental music through the headset. Finally, during the mental arithmetic trials, we logged all activities of the participants such as whether they submitted a correct answer on the question and how long time was needed to answer each question. Moreover, at the end of the experiment session the participant was asked did he/she feel the stress and when.

According to the result of the quiz ( the number of the correct answers, time average time spent in resolving questions, and duration of the entire experiment session, such as the feedback of the participants after the experiment session), we divided all participants into two classes. The first one represented the participants who achieved a good score in the mental arithmetic trials and reported stress which lasted more than half of the total duration of the mental arithmetic trials. The second one represented the participants who did not achieve good results in the mental arithmetic trials and reported stress which lasted less than half of the total duration of the mental arithmetic trials.

During the data analyses process, we divided those classes of the participants into two subclasses based on the level self-reported stress and the results achieved in the quiz. Therefore, the first class of the participants was divided into the high motivated participants (HM) and motivated participants (M). The HM participants reported the stress and achieved good results in the quiz through all experiment session, while motivated participants (M) reported the stress and achieved good results in the quiz until the middle of the second mental arithmetic trial. On the other hand, the second category of the participants was divided on low motivated (LM) and unmotivated (UM) participants. The LM participants reported the stress and achieved good results in the quiz by the first quarter of the second mental arithmetic trial. The UM participants reported stress and achieved good results in the quiz during the first half of the first mental arithmetic trial. Finally, at least all participants reported stress and achieved a good score in the quiz during the first half of the first mental arithmetic trial.

In the data analyses process, we presented results calculated from our proposed index as well as the index well known from the literature  $L_F / H_F$  [26]. The goal of the data analyses process was to verify the results in stress detection of our proposed index and  $L_F / H_F$  in the periods where the participant reported stress and achieved good results in the quiz. The indices showed that at the first part of the first mental arithmetic trial the participants were experienced stress. This was expected since that it was the beginning of the quiz and the participant still has been trying to be familiarized with the rules and environment of the quiz. Later the values of the proposed index as well as the  $L_F / H_F$  index were changed according to the level of the reported stress by the participants. The proposed index showed similar behavior in the stress detection as  $L_F / H_F$  index. In the statistical analyses, we compared the results in stress detection of our proposed index with the results of the  $L_F / H_F$  index. Here we divided all participants into two classes in the same way as it was done in the data analyses process but without subclasses. We compared the results in the stress detection between our proposed index and  $L_F / H_F$  index for each class separately such as for all participants together. The conclusions were similar like from data analyses process.

Finally, we presented the result of the stress detection of our proposed index. However, we did all our measurement in the lab environment with a small sample of 20 participants. Furthermore, we tried to induce stress to the participants via cognitive load using mental arithmetic as a stressor, which has been using as a stressor for assessment of the impact of acute stress on HRV [64]. Even though there are studies which indicate that acute and chronic stresses are both associated with decreases in HRV and increases in LF/HF, there is still need to research in which extent LF/HF behave similarly for acute and chronic stress.

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