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Improvement of the Heart Rate Measurement During Sleep Periods

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DEDICATIONS

I dedicate this research work to my parents, especially my mother for her great support, encouragement and constant prayers. To my little brother and my beloved grandparents.

I also dedicate it to my friends for their encouragements in moments of difficulty and stress. And to all who will read this work.

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ABSTRACT

Technology has helped men in various domains, especially in the medical field, many devices were made to prevent, diagnose or treat diseases. This research endeavors to ameliorate the method of resting heart rate measurement ECG-TMEA. The experiment aims at reaching accurate results on heart rate during sleep. The elements used are: the Shimmer3 Unit device and an algorithm. The Shimmer3 placed on the trunk muscles is utilized to measure the ECG and thediscrete wavelet decomposition algorithm is used to separate the ECG-Trunk muscle signal from the ECG. The sample used in the experiment is a healthy subject (body mass=90 kg, height=1.88m, age=34 years old). The experiment aims to study the three parameters (Heart rate, Acceleration and the ECG-TMS) in different sleep periods (stability periods and body movement periods). The results obtained from the data collected from the experiment showed that the use of ECG-TMS is a more accurate method to determine the reason behind the change in the heart rate.

Key words: Heart rate, Sleeping heart rate, ECG, ECG-TMS, measurement

La technologie a aidé l'humanité homme dans divers domaines, en particulier dans le domaine médical. De nombreux dispositifs ont été conçus pour prévenir, diagnostiquer ou traiter des maladies. Ce travaille vise à améliorer la méthode de mesure de rythme cardiaque au repos. L'expérience vise à obtenir des résultats précis sur le rythme cardiaque pendant le sommeil. Les éléments utilisés sont: le dispositif Shimmer3 Unit et un algorithme. Le Shimmer3 placé sur les muscles du tronc et est utilisé pour mesurer l'ECG et l'algorithmeest basé sur décomposition discrète en ondelettes et est utilisé pour séparer le signal musculaire ECG-Tronc de l'ECG. En raison de la situation pandémique du COVID19, un seul sujet sain (masse corporelle = 90 kg, taille = 1,88 m, âge = 34 ans) a participé à l'expérience. L'expérience vise à étudier les trois paramètres (rythme cardiaque, accélération et ECG-TMS) dans différentes périodes de sommeil (périodes de stabilité et périodes de mouvement corporel). Les résultats obtenus à partir des données recueillies lors de l'expérience ont montré que l'utilisation de l'ECG-TMS est une méthode plus précise pour déterminer la raison du changement due le rythme cardiaque pendant le sommeil.

Mots clés : Rythme cardiaque, rythme cardiaque pendant le sommeil, ECG, ECG-TMS, mesure.

قدمت التكنولوجيا للإنسان خدمات في مختلف المجالات وخاصة في المجال الطبي. العديد من الأجهزة اخترعت لتشخيص وعلاج الأمراض. يسعى هذا البحث إلى تحسين طريقة قياس معدل نبضات القلب. تهدف التجربة إلى الوصول إلى نتائج دقيقة عن معدل ضربات القلب أثناء النوم. العناصر المستخدمة هي: جهاز شيمر3 وخوارزمية. يتم استخدام جهاز شيمر3 الموضوع على عضلات الجذع لقياس تخطيط القلب ويتم استخدام خوارزمية تحلل الموجات لفصل إشارة (تخطيط القلب- عضلة الجذع). بسبب جائحة فيروس كورونا التي أصابت العالم ، شارك في التجربة شخص واحد فقط سليم (كتلة الجسم = 90 كجم ، الارتفاع = 1.88 متر ، العمر = 34 سنة). تهدف التجربة إلى دراسة المؤشرات ثلاث التاليات (معدل ضربات القلب، والتسارع، تخطيط القلب - عضلة الجذع) في فترات النوم المختلفة (فترات الثبات وفترات حركة الجسم). أظهرت النتائج التي تم الحصول عليها من البيانات التي تم جمعها من التجربة أن استخدام تخطيط القلب - عضلة الجذع هو طريقة أكثر دقة لتحديد السبب وراء التغيير في معدل ضربات القلب عند النوم.

الكلمات المفتاحية: معدل نبضات القلب، معدل نبضات القلب أثناء النوم، تخطيط القلب، تخطيط القلب - عضلة الجذع، القياس.

LIST OF ACRONYMS

ANS : Autonomic Nervous System.

AV : AtrioVentricular.

BP : Blood Pressure.

Bpm: Beat per minute.

CO_2: Carbonic acid gas

COPD: Chronic Obstructive Pulmonary Disease.

COVID19: CoronaVirus Disease 2019.

CPU: Core Processing Unit.

CSA: Computer Science Application.

CVDs: CardioVascular Diseases.

D:Detail.

DWT: Discrete Wavelet Transform.

ECG: ElectroCardioGram.

ECG-TMEA: ElectroCardioGram- Trunk Muscle Electrical Activity.

ECG-TMA: Electrocardiogram- Trunk Muscle Activity.

ECG-TMS: ElectroCardioGram- Trunk Muscle Signal.

EMG: ElectroMyoGram.

HR: Heart Rate.

HRM: Heart Rate Monitor.

HRV: Heart Rate Variability.

MHz: Mega Hertz.

MSP430: Mixed-Signal Processor 430.

mV: mili Volt.

NREM: Non-Rapid Eye Movement.

PA: Physical Activity.

REM: Rapid Eye Movement.

RMS: Root Mean Square.

SA: SinoAtrial.

SD : Standard.

VO_2: Volume Dioxygen gas.

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Chapter II

Summary

General Introduction

General Introduction

From the beginning of creation, the heart was regarded as the brain; it was thought to be the center of emotions and personality. It was the only organ ancient Egyptians preserved during mummification. With the advancement in the medical field, this concept has changed.However, its significant role in the body remained.

The heart is an incredible organ, it pumps blood throughout vessels branching, delivering nutrients andoxygen, disposes of wastes and CO_2. It permits the indication of the person's physical and mental health and even the environment. This non-stop organ keeps the basic body functions running, thus, tracking the pulse and trace its alteration is of a paramount importance. The number of heart beats per minute is called Heart Rate;it differs from a person to another; a normal healthy adult human resting heart rate is 60-100 bpm.

There are several methods used to measure the heart rate such as the heart rate monitor and/orthe accelerometer. On the one hand, the heart rate monitor is used to detect the changes in the cardiac rhythm.On the other hand, the accelerometer which is a motion sensor is used for the estimation of the energy expenditure as well as the physical activity. These two devices, however, have been more useful when combined together, as the two devices have certain limitations in the accuracy of the data provided. The former cannot detect the reason behind the shift in the cardiac rhythm,if it is a physical movement or an emotional state;the latter limitation is its inability to detect the intensity of the physical activity when performed by a standing person such as weight lifting etc., which could interpret the shifts of the heart rate as a health issue.The use of both apparatuses still was not providing reliable and accurate results.

The purpose of the study is to improve the accuracy of the measurement of the heart rate while asleep, using an algorithm that separates the ECG-TMS (ECG-Trunk Muscle Signal) from the ECG signal that is detected by the Shimmer3 Unit device placed on the trunk muscles to determine the reason behind the changes in the ECG while asleep.

This research work is organized into three chapters. The first chapter is an overview that includes definitions and explanations that paves the way for a better comprehension of the work. These definitions include: Heart and heart rate, factors that affect the heart rate, resting heart while asleep, etc. The second chapter is concerned with introducing the methods and the devices to measure the heart rate such as: the heart rate monitor and the motion sensor as well as the limitations of these methods. Finally, the third chapter tackles the experiment, results and discussion.

Chapter I

Heart Rate and Sleeping Heart Rate

I.1. INTRODUCTION

The first chapter is an overview that includes definitions that could help in the understanding of this research work. Some concepts related to heart rate, the factors that affect it such as: the diseases, the physiological factors and the mental ones are provided and explained. These data are provided for a better comprehension of the practical work and serves as an introduction that explains the existing data associated with this work.

I.2. HEART AND HEART RATE

The heart is a muscular organ also called myocardium, responsible for pumping blood into blood vessels branching throughout the body. Located under the ribcage in between the lungs slightly to the left of sternum, surrounded by the pericardium which is a double-layered fibrous sac that encloses the heart and defines the mediastinum. It weighs about 250-300g, approximately about the size of a clinched fist. It is divided into a left side and a right side, each side has two chambers, the upper ones are called atria and the lower chambers are called ventricles. They contract in a steady rhythm known as heartbeat.

Sinoatrial node also called SA node is a cluster of cells in the upper part of the wall of the right atrium, it is considered as the heart's natural pacemaker as it automatically generates an electrical signal that causes the atrium to contract. The signal passes through the Atrioventricular node (AV node)-located in between the atria and ventricle-to Purkinje fibres that extend from the AV node and spread through the ventricles, causing the contract or the pump of the heart. [2]

While heart rhythm is regulated entirely by the SA node under normal conditions, heart rate (HR) is modulated by innervation from both sympathetic and parasympathetic of the autonomic nervous system (ANS). [4][6] The sympathetic activity leads to an increase in HR (e.g. during sports exerciseor stressful period), while parasympathetic activity induces a lower HR (e.g. during sleep). [9]

Heart rate is the speed of the heartbeat measured by the number of contractions of the Cardiac muscle per a unit of time -typically per minute (heart rate unit is beat per minute (bpm)). A normal healthy adult human heartbeat is 60-100 bpm. [2]

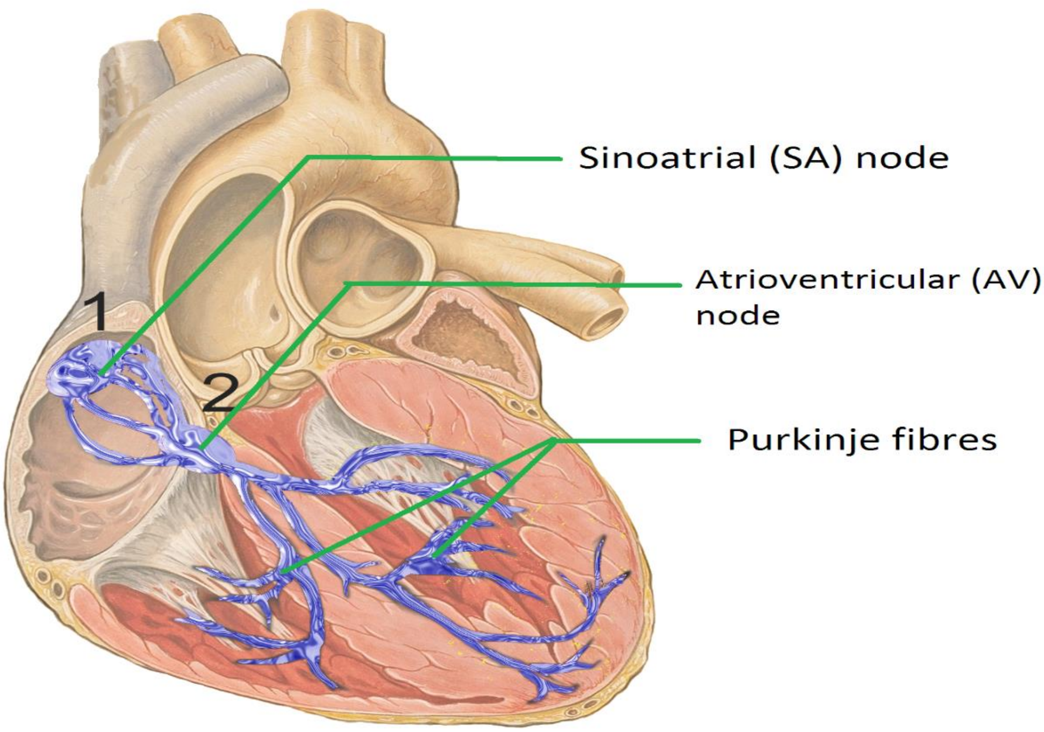


Figure I.1- Presentation of heart anatomy[31]

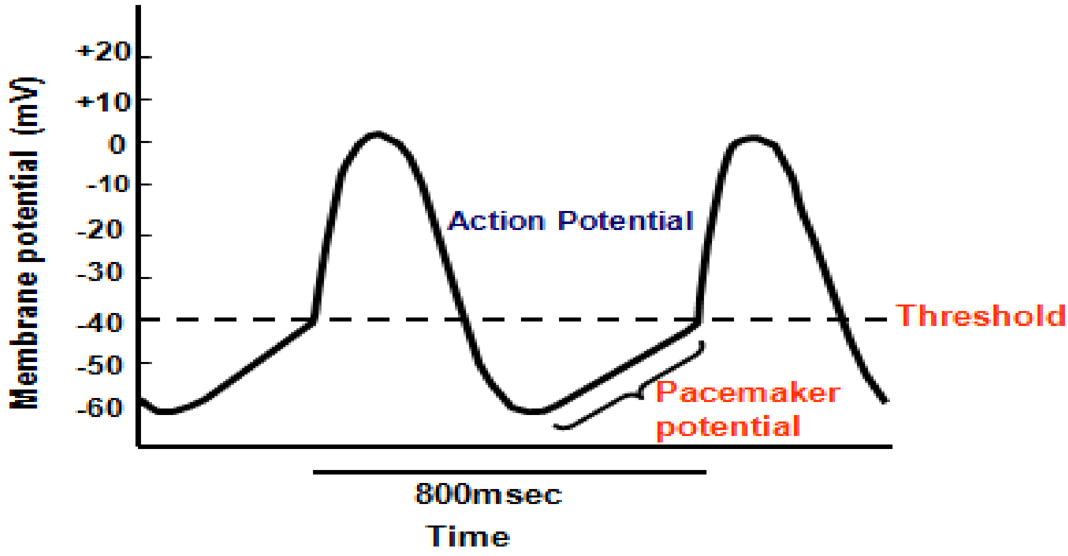


Figure I.2- Diagram of the pacemaker potential [32]

I.3. FACTORS THAT AFFECT HEART RATE

Heart rate variability (HRV) figureI.3 is a physiological phenomenon, defined as the variations in the time intervals between consecutive heartbeats called interbeat intervals.[7] HRV reflects the changes that occur in the blood pressure, gas exchange and regulation of autonomic balance. [8]

HRV is affected by various physiological factors and mental factors.[5] The heart rate can vary according to the body's physical needs. Physical activity, anxiety, diseases, stressand drugs, all these can also provoke changes in the HRV.[3]

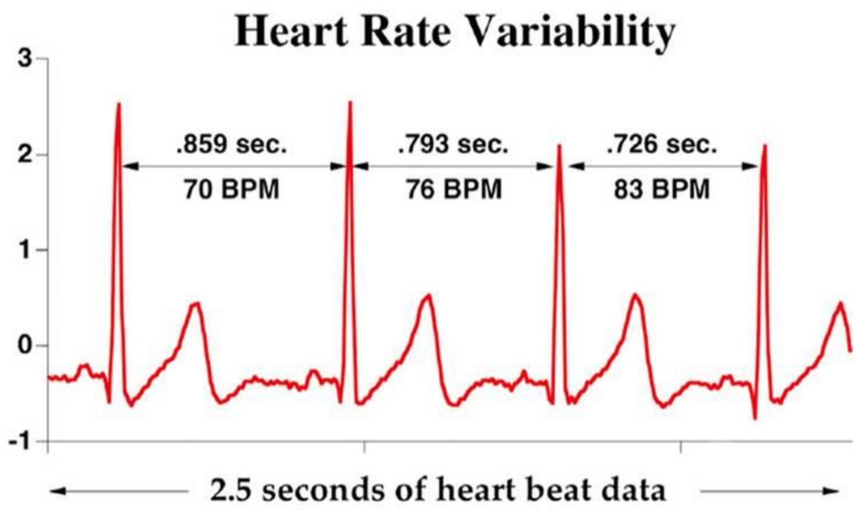


Figure I.3-ECGwith HRV [33]

I.3.1. PHYSIOLOGICAL FACTORS

Life style: the individual's life style highly affects the HRV, the habits he performs on a daily basis determines the variability of his heart rate. These habits include; physical activity, food, weight, smoking habits, alcohol, etc., which will either have a negative or a positive effect. Physical activity is defined as various aspects of an individual's daily behaviours (sports, occupation), activities (jogging, household, dancing, drawing) or any bodily movement that requires energy.[16][24]

The term "exercise" is defined as a planned, structured and repetitive movement in order to enhance or maintain physical fitness; it is usually confused with the term "physical activity". Exercise is a subcategory of physical activity. Physical activity varies in its intensity levels which are:

- Low intensity of physical activity.
- Moderate intensity of physical activity.
- Vigorous intensity of physical activity.

According to Kirsten L. Rennie, both moderate and vigorous-intensity of physical activity were related with higher HRV regardless of age.[12]

Age and gender: The effect of both of age and gender on HRV have been proven scientifically, according to a study done on 470 subjects without cardiovascular conditions, elders have a significantly lower HRV than younger people.[10] Another study done on 56 healthy subjects maintains that females have higher heart rate in comparison to males and the risk of developing cardiovascular diseases is lower.[11]

Genetics: ethnic origin has been proven to have an effect on the HRV. A meta-analysis established on a systematic reference survey comprising 17 studies, Hill et al., [20] showed a relatively lower short-term resting HRV in American subjects of European origin than Afro-American subjects.[5]

Diseases:

- *Sepsis:* it has been found that HRV is reduced among individuals with severe acute diseases, such as multiple organ failure, and this decrease is associated with an increase in mortality.
- *Heart diseases:* A decrease in HRV has been found among people with heart disease and cardiac insufficiency or who have suffered a heart attack. It has been known since the mid-1980s and was confirmed in a meta-analysis that a decrease in HRV correlates with an increase in mortality. Also, hypertension reduced HRV.
- *Lung diseases:* People with a chronic obstructive pulmonary disease (COPD) also seem to have lower HRV and the degree to which the HRV is lower correlates with the severity of the COPD.
- *Renal diseases:* HRV is also shown to be lower in patients with chronic kidney insufficiency than in healthy controls. [5]

I.3.2. Mental Factors:

Psychosocial factors play a clinically important role in the heart rate variability; one's own mental state highly affects his physical health. Studies have shown that people with cardiovascular diseases often have psychological issues such as excessive stress, tension, etc. [14]

Depression is one of the leading factors for the development of cardiovascular diseases and abrupt cardiac death after a heart attack. [14]

The data obtained from various studies maintains that patients with mood and anxiety disorders, as well as individuals, who experience distressed emotional states, are more susceptible in increasing the risk of developing cardiovascular disease due to decreased heart rate variability. [13][15]

There are numerous psychiatric cases in which heart rate variability turns significantly low. For example, men who are aggressive tend to have lowered heart rate variability.[14]

Despite the fact that stress is a psychological state, it has a strong influence on the physiological level of the individual. When someone is having a stressful situation or tension, the autonomic nervous system (ANS) is alarmed: where the sympathetic nervous system which prepares the body for fight takes over and the parasympathetic system which works on calming down is suppressed [38]. When the sympathetic nervous system is activated the release of epinephrine and norepinephrine into the blood stream causing several physiological changes such as high blood pressure, muscle tension, vasoconstriction of blood vessels and of course in HR and HRV. [9]

I.3.3. OTHER FACTORS:

There are other factors that could affect the HRV such as the climate. The human body system works according to the environment he lives in, this can be seen in how people living in different climates, immune system differs. The same happens in the HVR, climate factors affect it because of the physiological reactions of the nervous system. The heat stimulates sympathetic nervous system activity, lessening the HRV. [5]

Figure I.4- ExamplesofHeart Rhythmfrom Cardiogram of Apple Watch /34/

I.4. HEART RATE AND CARDIOVASCULAR DISEASES

Cardiovascular diseases (CVDs) are the conditions that affect the heart and the blood vessels, they include : Coronary artery disease, Heart failure,cerebrovascular disease, rheumatic heart disease and many other conditions. CVDs are the primary cause of death globally, taking an estimated 17.9 million lives each year, an estimated 31% of all deaths worldwide. [17]

Accelerated heart rate raises the risk of death: one of the first conducted studies to test this question was in 1980, the Chicago People Gas Company Study, which demonstrated that there is a relation between the levels of a heart in a resting state and coronary mortality. Many other findings maintain that there is a strong connection between resting heart rate and cardiovascular disease mortality. Despite the adjustment for various risk causes and other dangerous factors. [18]

The autonomic nervous system can be investigated through examining the HRV. It evaluates the variations in intervals between the sinus heart beats as the heart rate shifts around a mean value. These shifts are adjusted by the autonomic nervous system and can be examined using different measures. Mostly time and frequency domains are used in researches.[19] The central nervous signals regulate the heart rate variability, which are transmitted through sympathetic and parasympathetic nerves.[19]

I.5. RESTING HEART WHEN SLEEPING

Sleep is a natural and physiological condition where the mind and the body are in a state of rest. The ANS has a prominent role in this process as it arranges and regulates cardiovascular functions while asleep as well as the alteration to the different stages of sleep.[21]

It is commonly recognized that sleep is a complex condition in which autonomic cardiac control shifts between sympathetic and parasympathetic dominance. Specifically, in the alteration to the different sleeping stages (wakefulness, NREM and REM).[21]

Rapid eye movement (REM) sleep is featured by an unexpected behavior where the cardiovascular system is activated and elevates higher than the state of wakefulness. As a result, the non-rapid eye movement (NREM) to REM cause a massive increase of HR and blood pressure (BP). [21]

Many investigations regarding change of autonomic cardiovascular control by means of HRV while awake and in the various sleep stages established significant information of the relation between the change that occur in different sleep stages and autonomic fluctuations. [37]

What happens to the person’s heart rate after he goes to bed is somehow related to his state or condition during the day. The sleeping timing, the physical state, even the food consumed in the afternoon affects the heart rate. There are three patterns that may occur in a person’s own nocturnal heart rate curve which are the following:

- **The Hammock:**

The Hammock-shaped curve is the ideal HR curve. In the first sleep stage, the HR and the blood pressure gradually decreases till it reaches its lowest point, at that level, the secretion of melatonin is in its highest. [35]

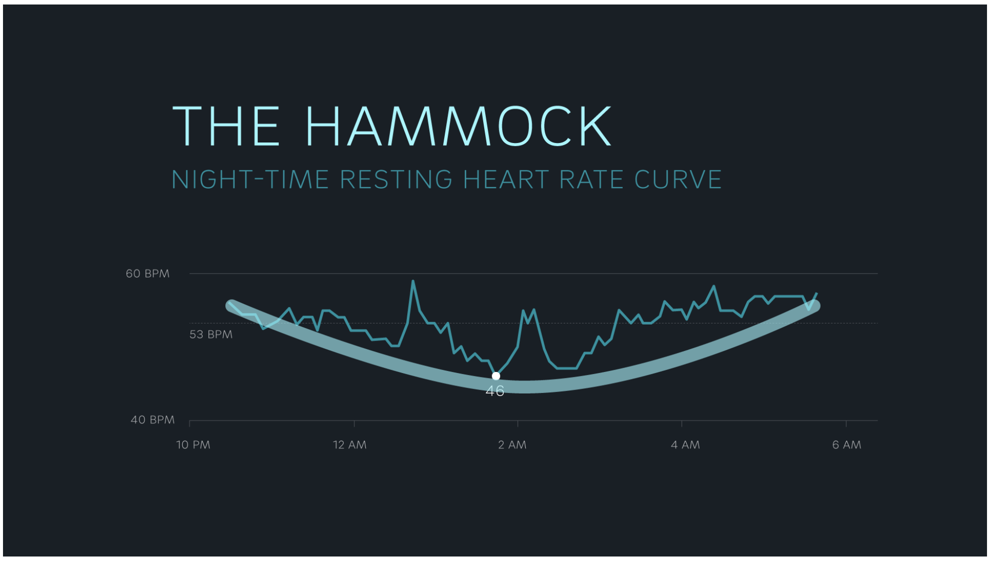


Figure I.5- The Hammock-shaped curve from OURA ring /35/

- **The Downward Slope :**

The Downward Slope indicates the extra work of metabolic system. In this case, the resting HR reaches its lowest point the moment the person wakes up. This usually happens when having a late meal, a late workout or consuming alcohol. [35]

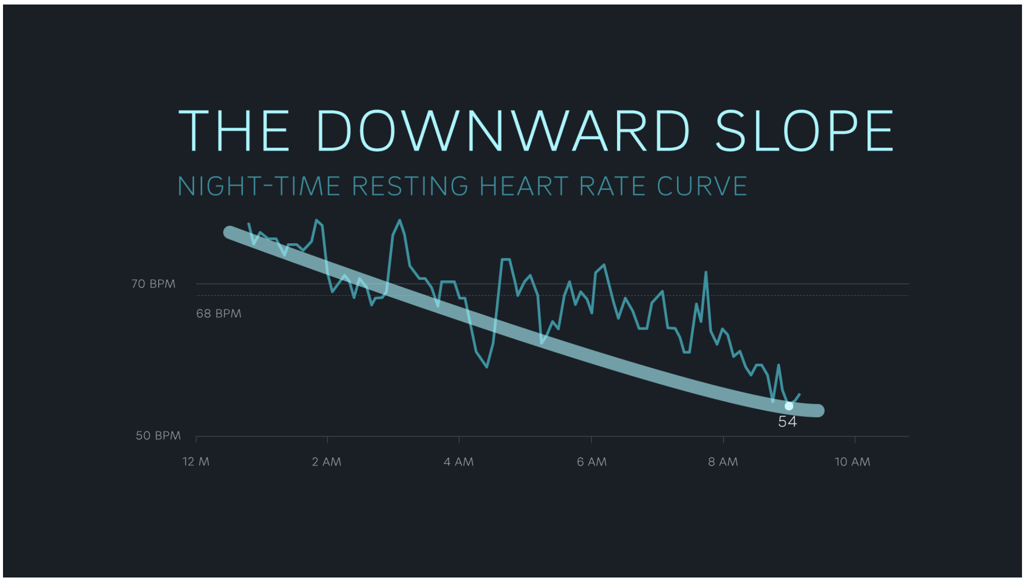


Figure I.6- The Downware Slope curve from OURA ring /35/

- **The Dune:**

The Dune-shaped curve is a sign of exhaustion or skipping bed time. [35]

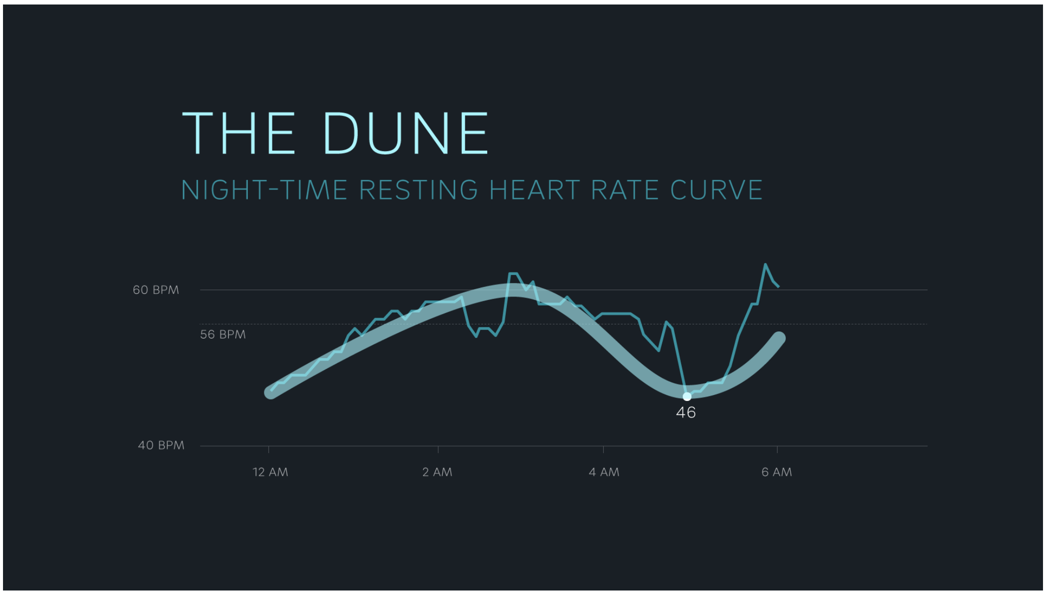


Figure I.7- The Dune-shaped curve from OURA ring /35/

I.6. CONCLUSION

The heart as a muscular organ reveals so much about the person's physical state, it provides significant data of his health and life style. Through the interpretation of the heart beats, one can come up with the reasons behind the occurrence of certain health issues for example : Coronary artery disease, Heart failure, cerebrovascular disease, ect. The HRV is affected by various factors such as: the environment (humidity, temperature…), age and gender, genetics and mental factors (depression, stress, etc.,). Sleep is a condition where the cardiac control shifts between sympathetic and parasympathetic dominance, these alterations demonstrate the activities the individual performed during the day. The coming chapter, methods of the measurements of heart rate will be provided and explained.

Chapter

II

Methods to Measure Heart Rate

II.1. INTRODUCTION

Physical activity is defined as any bodily movement produced by skeletal muscles that requires energy expenditure in a period of time (Caspersen, 1989). PA has been related to a healthy life style and decreased risk of many diseases such as noninsulin dependent diabetes mellitus, cardiovascular diseases and even certain types of cancer (Haskell, 1994). The assessment of the PA is important yet difficult as it can be affected by many factors.

This chapter is concerned with providing the methods or the devices to measure the heart rate, it also provides the different types of devices that exist. The heart rate monitor is introduced alone and when combined with a motion sensor knowing that the two devices combined give more accurate results. Finally, limitations of both devices are mentioned to identify the reason behind the combination of the two apparatuses. Finally, limitations of both methods combined are shown to explain the added value of our method of measure.

II.2. THE IMPORTANCE OF THE PHYSICAL ACTIVITY

Before technology has invaded the world and the occurrence of machines, man was obliged to depend on his force to build houses, find food and be safe, so him being physically active was a must for his survival. Consequently, the intensity level of his physical activity was the highest. Since the industrial revolution, the advancement of technology has permitted people to reduce the amount of intensity of physical activity required to accomplish tasks. The effects of some of these technologies on the physical activity are obvious as there is an inverse relationship between the availability of new devices and physical labor and human energy expenditure. Increase the individual worker productivity and reduce physical hardships were the main objective of the development of technology. However, this change has backfired. The lack of physical activity effected the human body system and its optimum function.[39] According to the World Health Organization in studying the physical activity levels of adults by country, the results show that 45.3% of Korean adults never worked out, in Europe (34.0%), the United States (32.5%), and Australia (18%) [40]. The physical inactivity become a problem around the world, and the risks followed are increasing.

II.2.1. For children

The physical inactivity effected children and adolescent as it did to adults. According to a study done on 24 children aged 6-12 years, indicate the strong association between the intensity of physical activity and the lower levels in obese children, and insure the importance of the practice of physical activity during childhood and adolescence. [41]. According to another study Out of 200 school students, results show a strong connection between physical inactivity and obesity. [42].

A study done on 1001 adolescents, physical activity was measured objectively using accelerometers, variables on mental health were assessed through an online questionnaire and academic achievement was assessed using grade point average collected through school records. This study shows the relationship between physical activity and various dimensions of mental health

, especially among children and young people, and the role of physical activity in mental health promotion, prevention of mental health problems. [43]

To reduce the danger, in 2008, Physical Activity Guidelines for Americans recommended that children and adolescents, 6 to 18 years old, accumulate at least 60 minutes of moderate- to vigorous-intensity physical activity each day, with muscle strengthening physical activity included on at least 3 days per week. The 2018 update of the study added the preschool-aged children (3 to 5 years).[44] The U.S. Centers for Disease Control and the Institute of Medicine recommend also that children and adolescents accumulate at least 225 minutes of physical activity per week, with 50% of that time spent in moderate- to vigorous-intensity physical activity.

The increasing number of risks that are caused by physical inactivity for children and adolescent emphasize the important role of physical education and health-related behaviors.

II.2.2. For patients

Cancer survivals always suffer after finishing their cancer treatment of fatigue, decreased physical activity, depression, anxiety, reduced overall quality of life, and weight gain. According to a study done on patients who completed their cancer treatment, results show that physical activity has positive effects on physiology, body composition, physical functions, psychological outcomes, and quality of life in patients after treatment for breast cancer or other kind of cancer. Recent systematic reviews and meta-analyses have reported clear benefits of physical activity among cancer survivors. [45] More than 25 studies over the last 20 years have indicated that women who are physically active have a 30% to 40% lower risk of developing breast cancer compared with physically inactive women. [46]

Physical inactivity is a certain risk factor for cardiovascular diseases. Moderate or high levels of physical activity were associated with a significantly reduced risk of total and cardiovascular mortality among patients with type 2 diabetes. [47]

Type 2 diabetes is one of the fastest expanding and largest global health concerns. In 2015, 415 million people were diagnosed with diabetes worldwide (91 % of which were type 2 diabetes) [48]. Studies have shown that Physical activity can benefits people with diabetes achieve goals, including increased cardiorespiratory fitness and strength, improved glycemic control, decreased insulin resistance, improved lipid profile, blood pressure reduction and maintenance of weight loss, increased mitochondrial density, insulin sensitivity, oxidative enzymes, compliance and reactivity of blood vessels, lung function, immune function, and cardiac output [24]

II.2.3. For adults

Mental illness is a leading cause of the global burden of disease. The physical activity positive effect on human including quality of life or physical health metrics, symptoms of mental illness specifically depression and anxiety according to results from 32 separate systematic reviews. [49] The relationships between physical activity undertaken in different life domains, mental health and mental ill-health have been indicated in many outcomes of meta-analysis.

According to a study based on the 2018 Physical Activity Guidelines Advisory Committee Scientific Report resulted about a 76 systematic reviews and meta-analysis. It has been proved that moderate-intensity physical activity reduced the risk of excessive gestational weight gain, gestational diabetes, and symptoms of postpartum depression. Limited evidence suggested an inverse relationship between physical activity and risk of preeclampsia, gestational hypertension, antenatal anxiety and depressive symptomology. [50]

From the previous studies, it has been approved that participating in recommended amounts of physical activity promotes health.

II.3. HEART RATE MONITOR ALONE

The heart rate monitor (HRM) is a device that enables the measurement of the heart rate. There are different types of heart monitoring devices, the most common are the ones found in hospitals which are wired and used with multiple sensors and the other type is portable devices which are designed for everyday use, they are known as “Holter Monitors”. The linear relationship between the physical activity (or the VO2) and the heart rate is used to estimate the energy expenditure and the intensity of PA. It is friendly-user and popular in gyms as it can determine the fitness level and other exercise parameters of the user.

The HRM displays the number of beats per minutes. The electrode sensors spot each heart beat and pass on the data to a receiver display such as a watch, a phone app, etc. This light weight device is used for tracking down the person’s heart rate as well as the oxygen consumption (or VO2) in order to measure the quality and the intensity of physical activity, or it is utilised to detect any potential cardiovascular problem. [51]

The modern heart rate monitor utilises two various methods to track heart signals, electrical and optical. The HRM based on Electrocardiography (ECG) assess a voltage time-series signal using electrodes on the skin’s surface, which results a full ECG waveform signal. [28]

II.3.1. Portable Heart Rate Monitors:

Figure II.1 – The different types of portable heart rate monitors. [57][58][59]

II.3.2. Wired Heart Rate Monitors:

Figure II.2 – A wired heart rate monitor used in hospital. [60]

II.4. MOTION SENSOR ALONE

Accelerometer, that is essentially a motion sensor, refers to a lightweight device that converts a physical measure into a signal that is read by an observer or by an equipment, commonly using components which are piezoresistive, capacitive and piezoelectric. This sensing device intended for the monitoring of proper acceleration has been used in various fields including biology, navigation, transport, gravimetry and in the medical field. The small packaging, relative stability over time, minimum user interface, good dynamic ranges, long monitoring times, and independence of motion parameters from other physiological changes are all strengths of movement sensors. [52]

The motion sensors are effective devices for the measurement of the energy expenditure and the physical activity, they are characterized by their small size and unobtrusive shape, and vary in cost and complexity. The commonly used motion sensor and the cheapest one is the pedometer, which is a portable recorder that counts the number of steps taken in a distance walked on foot. it could be utilized in other studies as well. There is also the uniaxial accelerometer which is also very practical and useful in various activities. Moreover, the CSA and Actillume accelerometers present temporal data (frequency and duration) regarding the activity performed. The triaxial accelerometer as well gives temporal data, however, it could record more movement in comparison to the uniaxial accelerometer. regardless of type, complexity or cost the data obtained by the motion sensor are best evaluated as counts, for the reason that the data provided are not accurate enough to determine the approximations of energy expenditure. [22]

II.5. HEART RATE MONITOR COMBINED WITH MOTION SENSOR

Both motion sensors and HR monitor are not perfect indicators of physical activity.[22] The two devices combined compliments the deficiencies that occur in both and may improve precision of the intensity of physical activity assessment. Nowadays, many companies are promoting to what is known as *Fitness Tracker,* which a device that combine both HRM and motion sensor (Pedometer)

According to a study done on children with an Acquired Brain Injury, the use of both accelerometer and HR monitor have better outcomes that can be applied to evaluate physical activity performance. [25]

it has also been approved that “In general, the combined accelerometer and HR monitor method has better accuracy and precision than either method alone.” [53] Moreover, the obtained results from a study showed that the combination of the HR monitor and motion sensor is a practicable and useful method, which is implemented in various studies to provide an exact assessment of free-living physical activity. [23]

II.6. LIMITATIONS OF EACHMETHOD

II.6.1. Heart rate monitor alone

Physical activity is often assessed by the heart rate monitor which is a device attached to a person performing bodily movement and provides the number of his heart beats, it is often used to identify the intensity of the workout. The heart rate monitor tracks the number of heart beats and relates the changes that occur due to physical activity but there are many other factors that could affect the heart rate. These factors include the environment for example a high temperature, high humidity, etc. the emotional state of the person also affects is heart rate for example stressful situations, extreme excitement, anger, etc. [55] The size of the muscle mass also affects the heart rate of VO2 (Rowlands et al., 1997). For instance, an arm workout drowns out a higher heart rate in comparison to a leg workout at the same VO2 and this is because of the relatively smaller size of the arm musculature. the kind of the muscular contraction happen to affect the relationship with the isometric contractions evoking a significantly higher heart rate at a similar VO2 than dynamic contractions. [56]

In addition to the many factors that affect the heart rate the person's daily physical states like fatigue, hydration, sleep, diet, fitness level, etc. have an impact on his heart. age and gender also affect the heart rate that is why it is difficult to compare the heart rate of individuals especially when they have different fitness levels and a completely different life style. As a result, measurement of the intensity of physical activity using HRM is least accurate at low intensity levels including sleep and better at moderate and vigorous ones. Overall, there are numerous factors that could have a direct effect on the heart rate rather than the exercise or a health issue and which could not be determined by HRM.

II.6.2 Motion sensor alone

One of the major limitations of accelerometers to estimate energy expenditure is the inability to identify the energy expenditure of various activities such as walking, carrying weights or walking uphill, for the reason that acceleration does not alter under such circumstances. Where to exactly put the device for the obtainment of a more accurate results of the activity level of the body is still undetermined. Physical activity could be underrated in case where the accelerometer is placed on the hip waist or lower back in elders. When it is placed on the wrist the identification of the kind of activity that is common in late life is possible, precisely in the upper body movements concerning everyday activities that happen while both sitting (e.g. drawing, playing chess) or standing (e.g., cooking).Some researches have tested whether wearing additional accelerometers on the wrist or the ankle can promote the accuracy of energy expenditure predicted with a single accelerometer on the hip or lower back.[26]

In a study by Swartz and colleagues [27] in a sample population of 70 participants between 19 and 74. The findings based on the experiment where the accelerometer was placed on the hip only 32% of the variance, meanwhile the combination of the output from the hip and wrist showed a small increase in explanatory power (about 2.6% plus of the variance). other limitations involve the prices of monitors and staff time-consuming to process and analyze data.

The accelerometer assesses the amount and the level of the physical activity. However, it would falsely elevate the participant’s energy expenditure during load carriage or on a grade. [56]

II.6.3. Heart Rate Monitor Combined with Motion Sensor

Despite the fact that the two apparatuses combined together ameliorate the accuracy of the results obtained.Still deficiencies are presented, knowing that the motion sensor is unable to detect a movement of certain activities such as weight lifting, any task performed in a standing position or the different positions a sleeping person does. the placement of the device plays a decisive role in the measurement of the heart rate especially when sleeping because any movement that happens when the heart is in a state of rest occurs in the ECG.

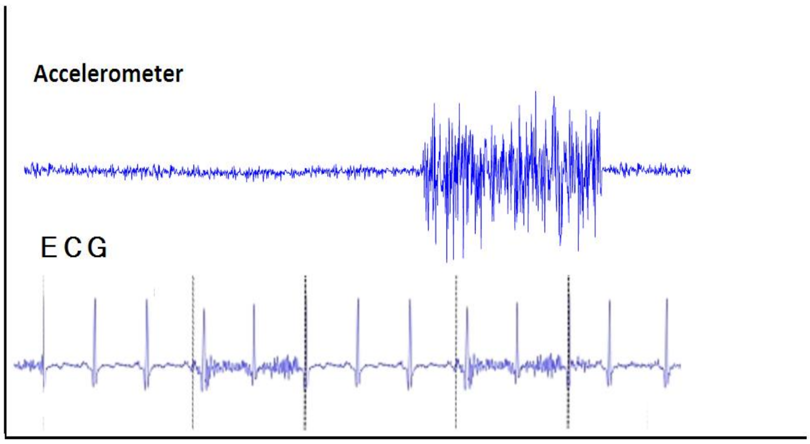


Figure II.3 –Presentation of ECG and Accelerometer signals from

a fitness tracker of a sleeping subject

II.7. OUR METHOD

In the present work we have endeavored to ameliorate the quality of the measurement of the resting heart rate. Our method is based on the measure of ECG signal in a special position which is trunk muscles. After we acquire the ECG signal, we use a frequency time decomposition to extract ECG noises such as ECG-TMS and use it to estimate physical activity. With the comparison of the tree parameters (HR, ECG-TMS and Acceleration) the determination of the reason behind the changes of the heart rate could be possible, if it is due a physical movement performed while asleep or a cardiac health issue.

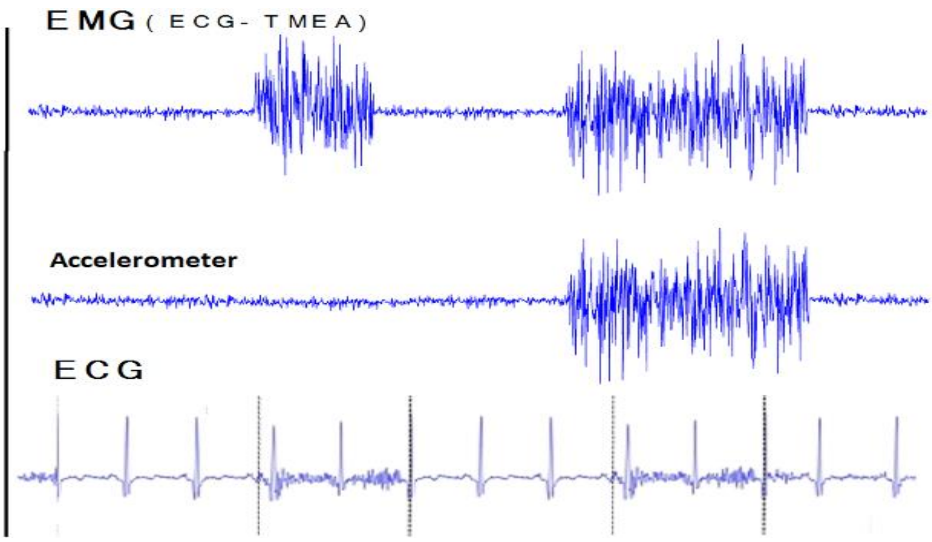


Figure II.4 – ECG, Accelerometer and ECG-TMS Signals

II.8. CONCLUSION

The combination of both heart rate monitor and motion sensor, provided a better measurement result; yet, the identification of the real reason behind the cardiac rhythm shifts was still inaccurate. The elements added in our method endeavors to fill those gaps and improve the quality and accuracy of the results. The coming chapter will tackle the practical part of the research which is the experiment, the elements used and the discussion of the main results.

Chapter III

Experiment and the Main Results

III.1. INTRODUCTION

Tracking the heart rate helps measure multiple systems simultaneously, it indicates the physical adaptation, the intensity of the effort and also one's health. Improving the devices in the medical field is crucial as it can spare lives and avoids serious problems. In this experiment we have tried to ameliorate the accuracy of the measurement of the sleeping heart rate. Based on the method explained in the previous chapter an experiment will be conducted and an analysis of the main findings will be provided.

III.2. EXPERIMENT

In the experiment, the electrodes of the Shimmer3 Unit device were placed on the trunk musclesunder the pectorals of the subject to measure the HR (see figure III.1)The area of measurement was chosen because of its proximity to the heart, this position permits to have high ECG signal amplitude.Also, with this position we can have access to the electrical activity of trunk muscles.

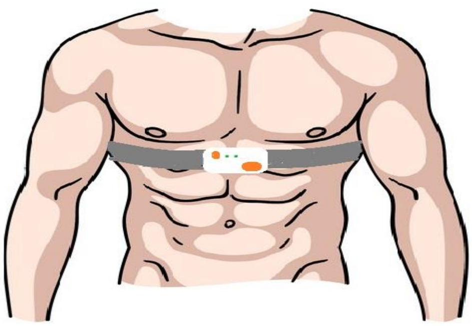


Figure III.1-ECG electrodes of Shimmer3 Unit device position[61]

The subject was asked to lay on the bed.After a period of time without any movement (period 1), the subject changed his body position (period2) (see figure III.2).

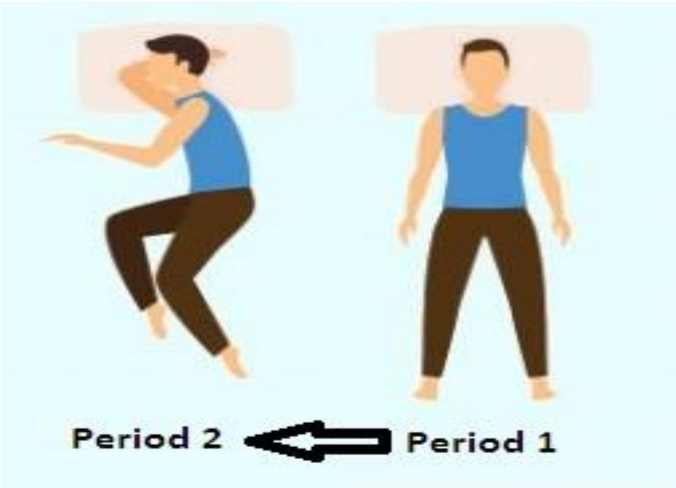


Figure III.2.1 – Changing position of the subject (period 1 and 2) [62]

After another period of stability (period 3), the subject did a light body movement (period 4) (see figure III.3).

Figure III.2.2 – Changing position of the subject (period 3 and 4)[62]

III.3. SUBJECT

Dueto the COVID19pandemic, the experiment could not be doneon a laboratory and only one male volunteer subject, at the department of Electrical Engineering, (body mass=90 kg, height=1.88m, age=34 years old), participated and gave informed consent. The subject washealthy, with no evidence of past or present disorders. No intake of drugs known to affect energy metabolism, having a balanced diet, and non-smoking. The subject was encouraged to maintain his normal daily physical activity and food intake.During the experiment, the subject was asked to refrain from exercise and caffeine intake less than 5h before the test.

III.4. DEVICE

III.4.1. SHIMMER3 ECG UNIT

The Shimmer3 ECG unit presents a configurable digital front-end, developed for the assessment of physiological signals for ECG. The Shimmer3 ECG (Electrocardiogram) sensor records the pathway of electrical impulses through the heart muscle, and can be measured on resting and moving subjects, or while working out to display information on the heart's response to energy expenditure.

• Five-wire, four-lead ECG solution, measuring bipolar limb leads and user's choice.
• Digital interface includes test signal generation for validation purposes
• 10 DoF Inertial Motion Sensing capability
• Respiration demodulation from ECG data and lead-off detection

With the ConsnesysPRO platform all signals can be recorded simultaneously and in real-time. Information can be provided for live visualization, while raw data can also be recorded on an SD card and accessed for further post processing. ConsensysPRO has an ECG to Heart Rate algorithm that can be applied to live or logged data. [36]

Figure III.3 –ECG Shimmer3 device [36]

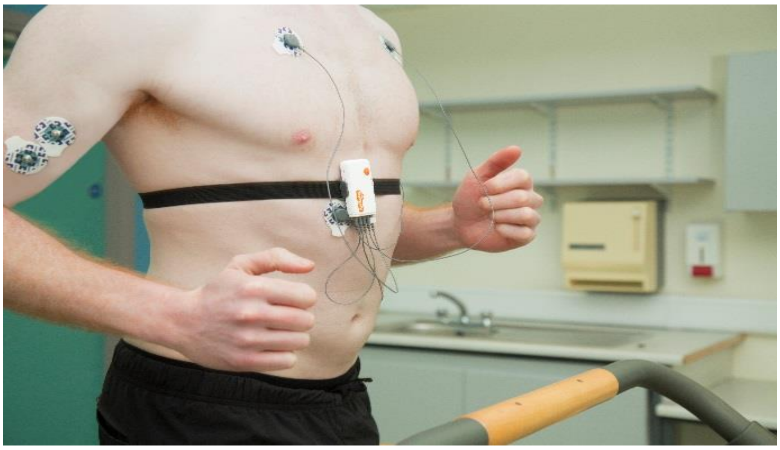


Figure III.4 - A subject wears Shimmer3 [36]

III.4.2. Features and benefits:

Specific Features: [36]

- Measures physiological data, EMC and ECG
- 5 Wire, 4 lead ECG Solution
- Measures 2 channel EMG with a common reference electrode
- Software configurable for amplifier gain and data rate
- Software configurable right-leg driver for common-mode interference rejection
- EEPROM storage devise enables expansion board detection and identification

Leverages Shimmer3 Functionality: [36]

- MSP430 microcontroller (24MHz, MSP430 CPU)
- Bluetooth Radio – RN-42
- Integrated 8GB micro SD card
- 450mAh rechargeable Li-ion battery
- Low profile & stylish wearable enclosure
- Highly configurable to user/developer's specific needs

III.5. SOFTWARE

MATLAB, an abbreviation of MATrix LABoratory is a multi-paradigm numerical computing proprietary and a programming environment for algorithm development, image processing, plotting signals and functions, data analysis and creation or interfacing programs even with other languages.

Simulink which is part of MATLAB, is a block diagram environment that allows Model-Based Design and graphic simulations for dynamic and embedded engineering systems.

Both MATLAB and Simulink are used for technical fields, such as the automotive, aerospace, communications, electronics, and industrial automation industries. Also, for modeling and simulation in increasingly financial services and computational biology.

More than 4 million use MATLAB in 2020. MATLAB is used in various fields such as engineering, science, and economics. [29]

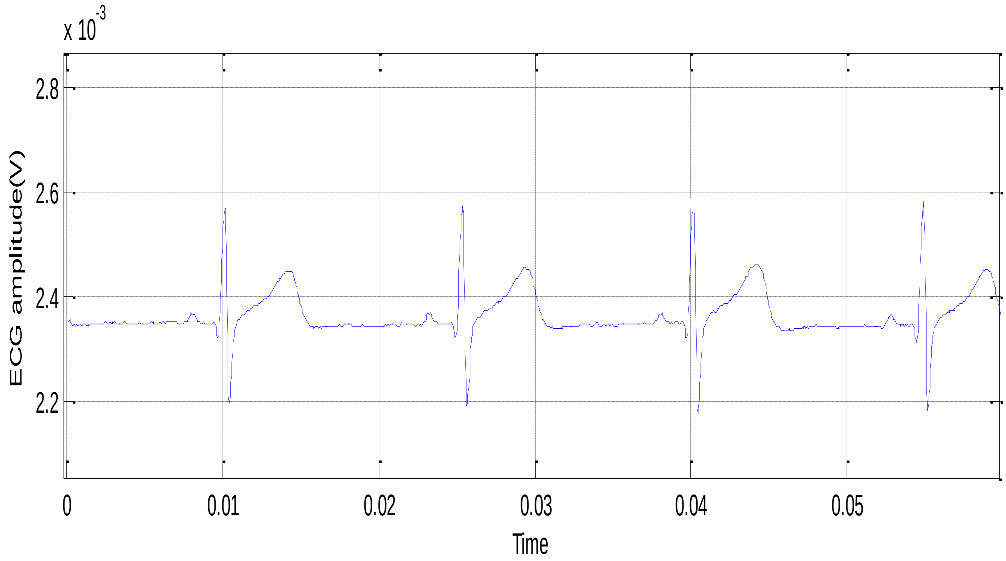
III.6. ALGORITHM

III.6.1. HEART RATE DETECTION

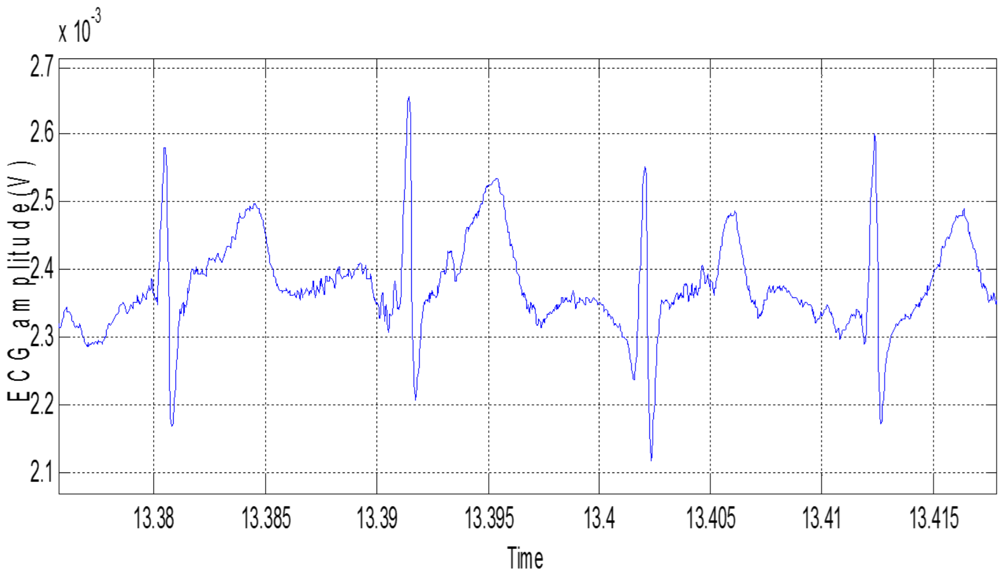
The algorithm used to detect the RR intervals from R waves and compute HR is extracted from a previous work [63]. This algorithm gives an accurate result even when the presence of a high noise.

III.6.2. ECG-TRUNK MUSCLE NOISES IDENTIFICATION

The ECG is contaminated by noise and artefacts such as: power line interference, electrode contact noise, patient–electrode motion artefacts and EMG noise. The EMG noise is originated from muscles contractions, in our case from trunk muscles contractions. In this study, thisnoise is considered as a signal of interest. Consequently, ECG waves are considered as non-desired signals and must be separated from ECG-Trunk Muscles Signals. ECG-TMS appear as large fluctuations and vary faster than the other ECG waves, however, it has a smaller amplitudes(see figure III.5)



a



b

Figure III.5 -a: clear ECG signal, b: noised ECG signal with superimposed

The simplest method to separate ECG-TMS and ECG waves is to use the gating method which eliminates periods that contain the ECG waves. This method is potentially efficient and simple to apply as a method for ECG waves removal. However, this method suffers from losing the portions of the ECG-TMS which overlap with the ECG waves, especiallyfor non-stationary signals, which makes it inaccurate.

Several other methods are proposed to separate EMG signals from ECG. In this study, the signals are separated using Discrete Wavelet Transform (DWT).

III.6.2.1. Wavelet Transform

ECG-TMS could be studied in time domain, frequency domain or time-frequency domain.Fourier analysis, using the Fourier transform, though it is less accurate in analyzing the elements of a non-stationary signals, it is very useful tool in stationary data.

The wavelet transform is one of most accurate methods for multiresolution analysisand separating signals from noises, especially non-stationary components. The wavelettransform is capable of providing the time and frequency information simultaneously. HenceIt is utilized to tackle the problem of frequency and time domain resolution. It is of a paramount importance to use time-frequency units with different time supports in orderto analyze signal structures ofvarious sizes.The wavelet transform decomposes signals over dilated and translated wavelets. Mathematically speaking, the wavelet transform of at time u and scale s is aconvolution of the mother wavelet function with the signal.

A wavelet tool is considered a high-pass filter, which approximates a data set (a signal or time series).There are many sets of wavelets such as: Haar wavelets, Meyer, Symlet, Daubechies, Morlet, etc. The selection of the wavelet's typevaries according to the application used.

Multi-resolution analysis

DWT is used to break down hierarchically discrete time signals into a series of successively lower frequency component of the signal called approximation coefficients and an associated detail signal. At each level, the approximation and the detail signals that contain the information are needed to be reconstructed back to the next higher resolution level. The DWT has two parameters: the wavelet mother ψ and the number of iterations. Discrete wavelets can be scaled and translated in discrete steps wavelet representation as the following:

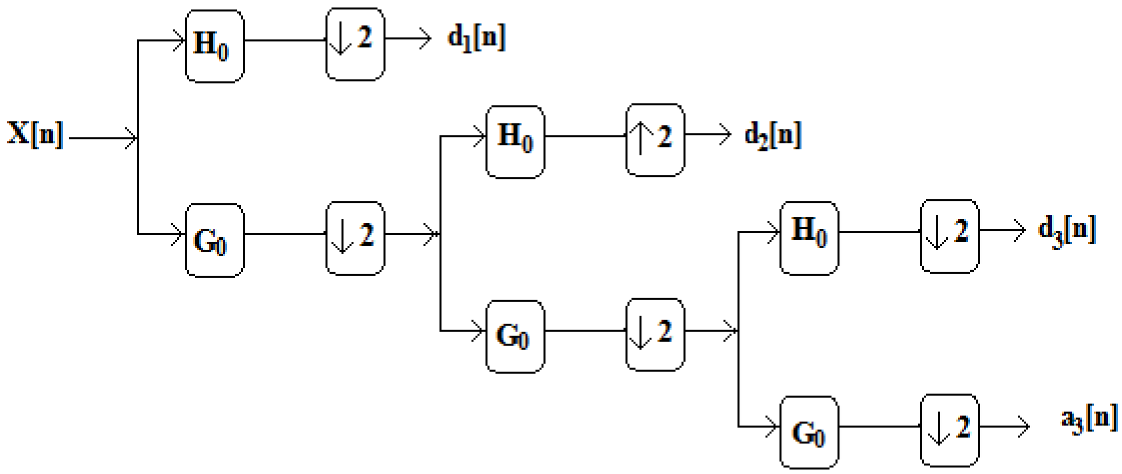


Figure III.6 - Three-level wavelet decomposition tree.

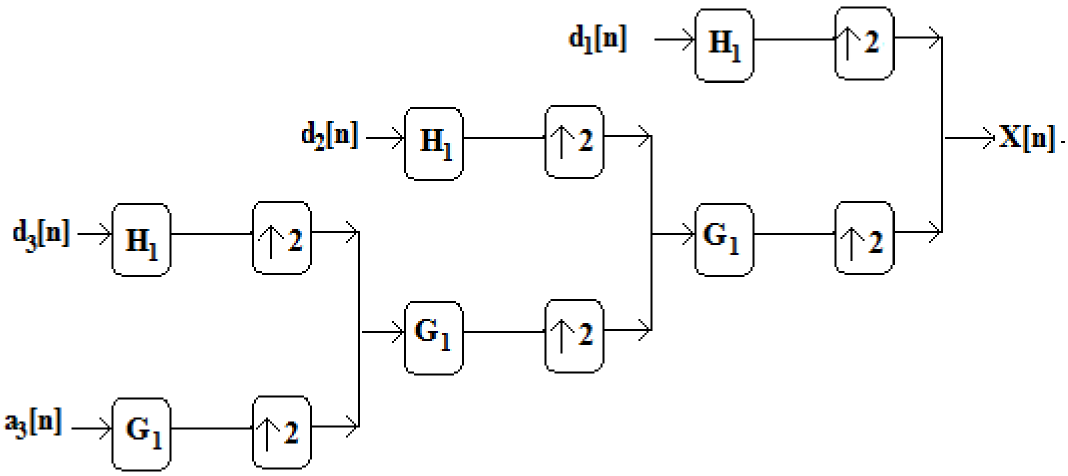


Figure III.7 -ResultsThree-level wavelet reconstruction tree.

The application of this wavelet transform requires the use of various cut-off frequencies filters to analyze the signal at different scales. The signal is passed through a series of high pass filters (denoted by H_0) and low pass filters (denoted by G_0). The high pass filters analyze the high frequency components of the signal and the low pass filters analyze the low frequency components of it. At each level, the low-pass filter associated with scaling function produces coarse approximations a[n], while the higher pass potions are the detailed coefficients d[n].

The filtering operations determine the signal's resolution, meaning the quantity of detail information in the signal, while the scale is determined by up-sampling and sub-sampling operations. The Mallan-tree decomposition algorithm showed in figure

III.6. Also, the details of eleven wavelet scales of an ECG signal are presented in figure III.8. The DWT of the original signal could be produced by concatenating all the coefficients a[n]and d[n], starting from the last level of decomposition. Due to successive sub-sampling by 2, the signal length must be a power of 2, or at least a multiple of power of 2 and it determines the number of levels that the signal can be decomposed to. Figure III.7 shows the three-level wavelet reconstruction tree.

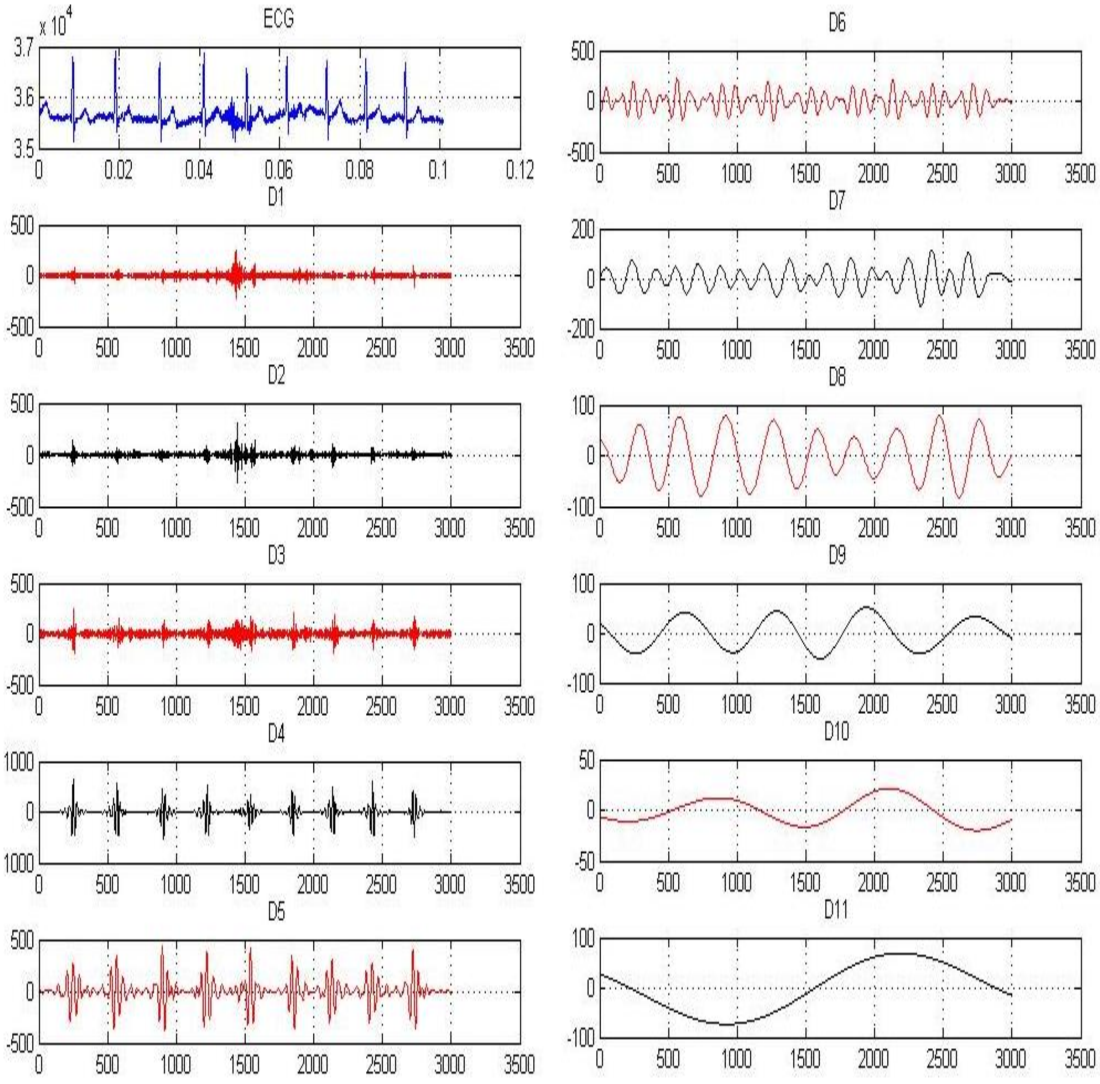


Figure III.8 -Multi-resolution decomposition of ECG signal

DWT is used to decompose hierarchically the ECG signal into a series of successively low approximation coefficients and high pass portions (detailed coefficients). There various wavelet types to separate ECG from any sort of noise, such as: Daubechies (db4, db8), Coiflets (coif5), discrete Meyer (dmey), and Biorthogonal (bior4.4).In this study, both of Mallar-tree decomposition algorithm and the discrete Meyer (dmey) wavelet transform were used. The noises originated from the trunk muscles do not have a characteristic shape, however, the enhancement would be significant if the dilated version of the wavelet (or the scaling function) at some scale matches the shape of the signal or noise components. It is based on passing the signals through a series of high pass filters and low pass filters depending on the level of decomposition chosen. the low-pass filter associated with scaling function produces coarse approximationsa[n], while the higher pass potions are the detailed coefficients d[n]. After the decomposition, the level of the electrical activity inthe muscle could be represented by the process of details signals by integration, root mean square or low-pass filtering. The sampling frequency of the ECG signal is 500 Hz, the TMS are predominantly represented in the initial four details but particularly in detail2 (D2) and detail1 (D1) since the Root Mean Square (RMS) of D1 and D2 have the highest amplitudes when segments of the ECG signals are affected by TMS; see figure 5.10. Even if the D2 is more sensitive than D1 to trunk muscle activities it is however more sensitive to the R peaks. Therefore, D1 is chosen as the signal which represents the ECG-TMEA.

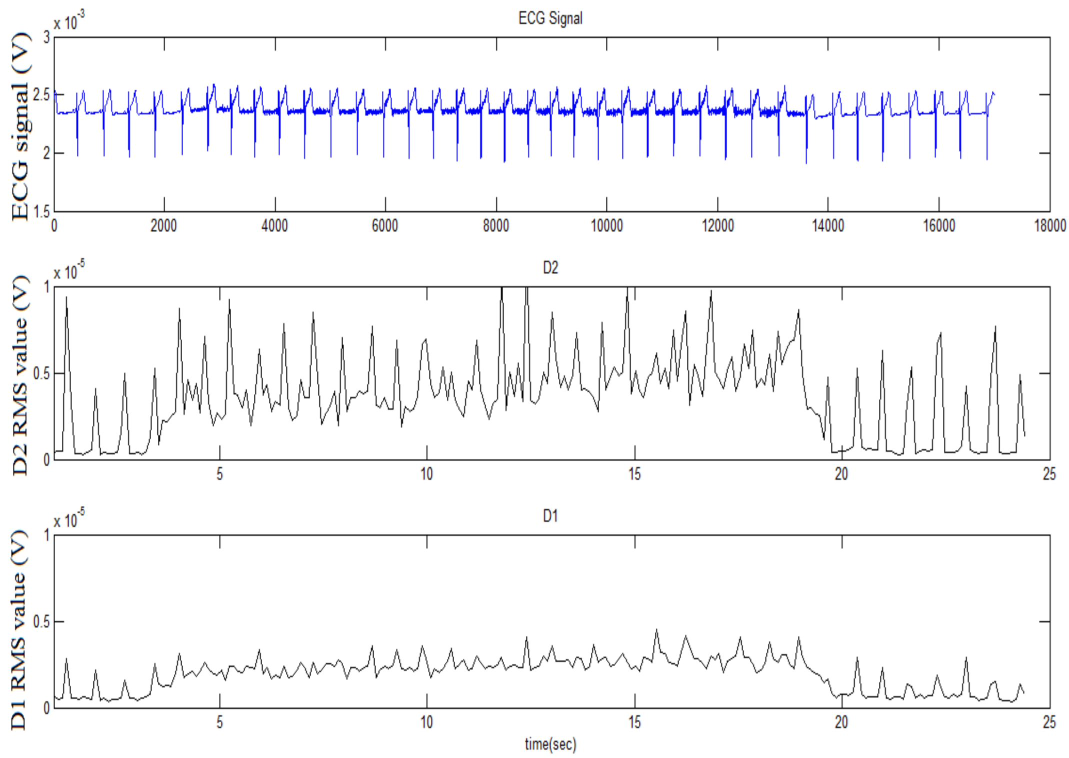


Figure III.9 - ECG-signal with an ECG-TMSA signal noise

b: RMS value of D2, c: RMS value of D1.

III.7. Summary of the Main Results

The following result is obtained from the last experiment from a MATLAB plotting program:

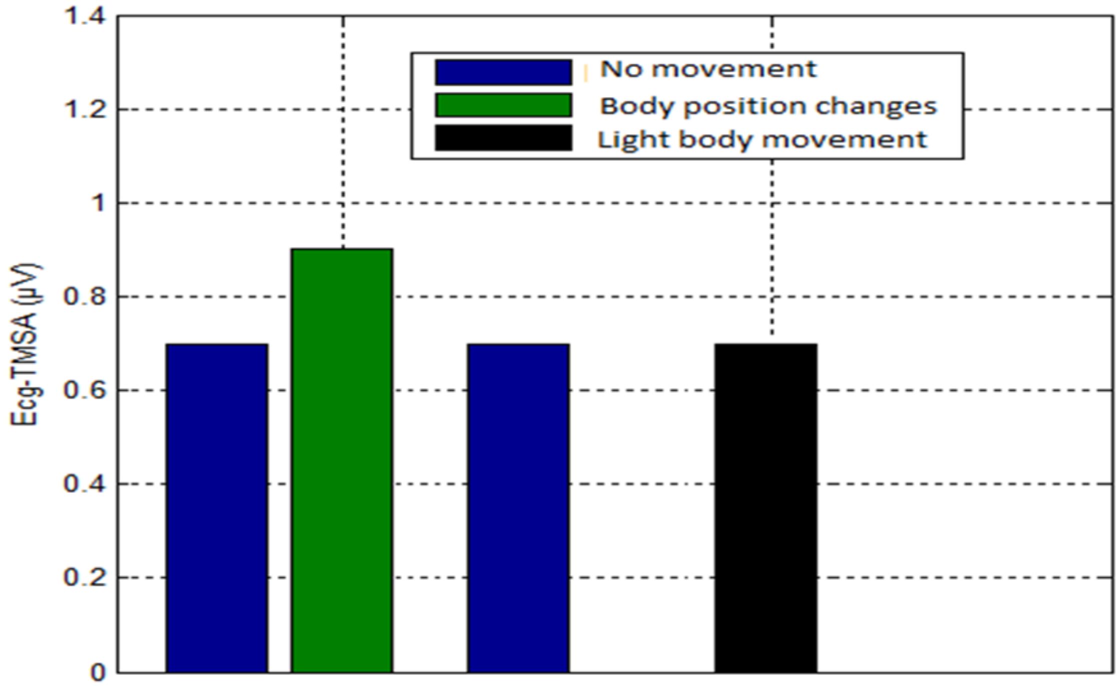


Figure III.10-ECG-TMSA when body movement, resting periods and light body movement

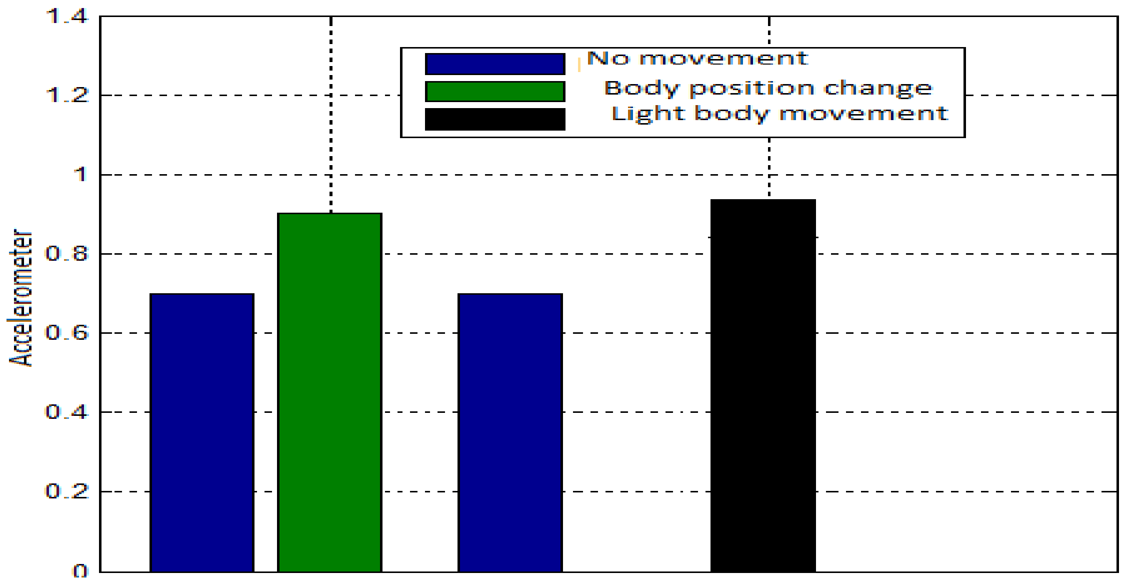


Figure III.11 - Accelerometer signal when body movement, resting periodsand light body movement

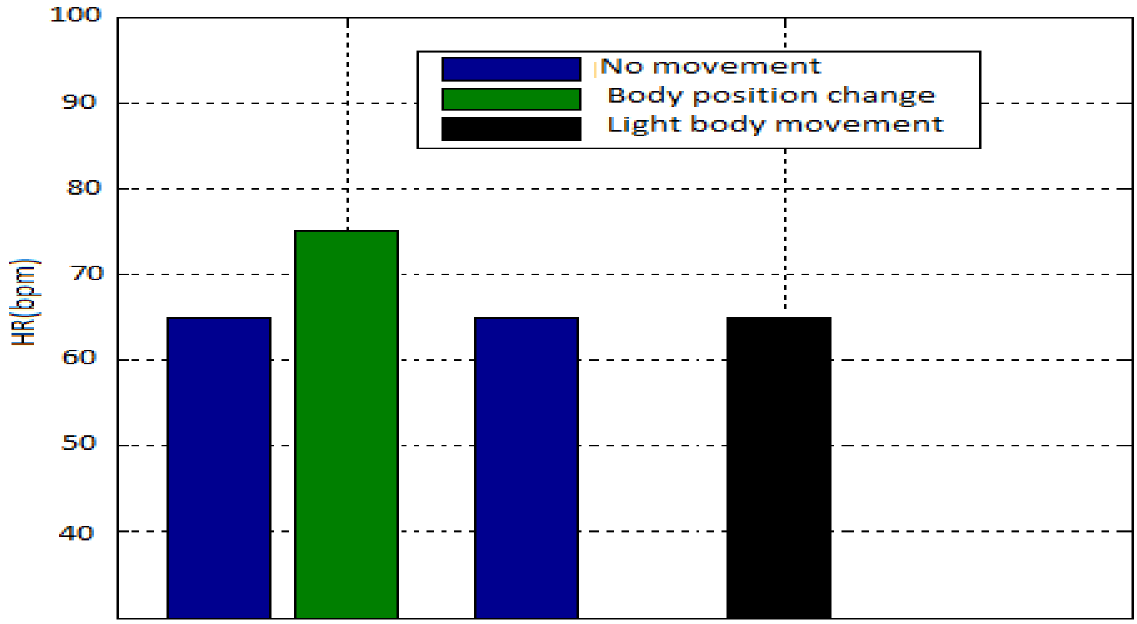


Figure III.12 -HR when body movement, resting periods and light bodymovement

III.8. Discussion

During the myocardium activity, an ECG signal is generated, which is a recording of small surface potentials (mV). Both cardiac muscleselectrical potentials and other electrical potentials are detected and recorded by the ECG electrodes, however,differences in amplitude and frequency range occur.

This present work, our main concerned is to figure out if an increase in HR is due to PA or due to a health conditionuse ECG-TMEA. We deduced that the use of both ECG-TMS and HR derived from the ECG signal is very effective; however, related studies have not been found; therefore, a comparison analysis cannot be done.

During the first resting period all the three graphs (HR, Accelerometer and ECG-TMS) show no changes. At that level the body is stable, it doesn't require more oxygen, because there is no muscles contractions.

During the second period (the body position is changed) the heart rate automatically increases, to determine the real cause behind the shift in the heart rate whether it is due to a body movement or a health condition, the observation of the two other parameters is necessary. We could notice that there is an increase in both acceleration and our parameter ECG-TMS, which led us to know that a body movement results an increase in the HR.

During the third period (resting period), the body was stable, which means there was no increase in the heart rate, until now the accelerometer is an effective way to determine the reason behind the increase in the heart rate.

However, during the fourth period, the accelerometer showed a change without any increase in the heart rate. The motion sensor detected a strong body movement yet the heart rate remained stable, for this reason, our parameter ECG-TMS was added to confirm that there are no body muscle contractions.

The results obtained confirmed that the accelerometer is not a reliable device to determine the reason behind the increase in the heart rate. That is why we have added the ECG-TMS which is a more accurate tool to identify the reason of the increase of the heart rate during sleep, if it is due to a body movement or a health condition.

III.9. CONCLUSION

This chapter is concerned with providing the experiment as well as the main results. Deficiencies of the accelerometer and the heart rate monitor were presented, and the effectiveness of the elements used was tested. The reason behind the increase of the heart rate could be determined using the ECG-TMS which was proven to be more accurate tool.

GeneralConclusion

GENERAL CONCLUSION

The heart is the power generator of the body, a network of blood vessels that transfers blood to every part of the body. It gives us a clear report of the condition of the whole system. Tacking the heart rate is crucial for identifying one's health. The heart rate is the speed of the heartbeats. It is affected by various factors such as: physical, mental, environmental, etc. Sleep which is also one of the factors that have an impact on the heart rate is a physiological process where the human body is in a state of rest. A resting heart rate reveals a lot about the activities, the food consumed and the emotional state of the individual during the day.

There are many devices used to measure the heart rate, the commonly used ones are the heart rate monitor and the accelerometer. The two devices combined gave better results as each has limitations. Despite the fact that combining the two apparatuses provided better results, some gaps were still present such as providing accurate feedback on the reasons behind the change in the ECG during sleep.

This research is concerned with ameliorating the heart rate measurement mainly during sleep. The elements used in the experiment are the Shimmer3 Unit device and the discrete wavelet decomposition algorithm. The shimmer3 Unit device is used to detect the ECG during sleep and the algorithm is used to separate the ECG-TMS from the ECG signals.

This research is organized into three chapters. The first chapter is an introduction to the study, various concepts were introduced such as the heart and heart rate, factors that affect the heart rate, resting heart while asleep, etc. These definitions were given to help in the understanding of the work. The second chapter tackles the devices used to measure the heart rate which are the heart rate monitor and the accelerometer, limitations of these devices were introduced. The third chapter includes the experiment as well as the main results obtained.

The purpose of this experiment was to ameliorate the accuracy of the heart rate measurement during sleep, the implementation of the ECG-TMS made this possible, because it is more accurate tool in determining the real reason behind the heart rate changes while asleep. The identification of whether a shift in the heart beats occurred because of a body movement or a health condition was attainable.

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