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WEARABLE AND MOBILE APPROACH TO STRESS AND FATIGUE MONITORING

GONÇALO DE OLIVEIRA PIMENTEL
DISSERTAÇÃO DE MESTRADO APRESENTADA
À FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO EM
ENGENHARIA BIOMÉDICA

U.PORTO

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

MEB - MESTRADO EM ENGENHARIA BIOMÉDICA **2014/2015**

A Dissertação intitulada

"Wearable and mobile approach to stress and fatigue monitoring"

foi aprovada em provas realizadas em 16-10-2015

o júri

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Wearable and Mobile Approach to Stress and Fatigue Monitoring

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Resumo

Há hoje uma preocupação crescente com os problemas de saúde que ocorrem devido a stress e fadiga no trabalho. Em todo o mundo, trabalhadores sofrem destes distúrbios e isso afeta, sem dúvida, o seu desempenho e a sua saúde. O stress, por exemplo, está na origem de diversas doenças cardiovasculares e neurológicas. Por outro lado, a fadiga tem sido amplamente relatada como causa de vários acidentes de trabalho e de viação.

Com isto em mente, este trabalho tem o visa usar o estado da arte da tecnologia vestível e móvel para monitorar parâmetros de stress e fadiga durante as rotinas normais de diferentes profissionais. Questionários já validados na literatura também foram utilizados para avaliar a função cognitiva do participante que também é importante em estudos nesta área.

Para estudar melhor os eventos que podem induzir stress e fadiga, uma aplicação Android (chamada VJ E-Diary) foi desenvolvida que permite o registo de eventos no smartphone para que depois sejam sincronizados com outros dados. Além disso, uma pequena aplicação informática (chamada VJ Assembly) foi desenvolvida para sincronizar os dados de diferentes sensores e apresentá-los para o usuário de forma eficiente. Esta ferramenta também foi projetada para aceitar os dados gerados pela aplicaçao Android para que os eventos registados possam ser automaticamente sincronizados com outros dados.

Estudos com 3 tipos diferentes de profissionais (6 polícias, 3 Neurocirurgiões e 4 Bombeiros) foram desenvolvidos com o objetivo de monitorizar tanto stress como fadiga.

Diferentes Polícias foram monitorizados durante rotinas de trabalho e dias de folga. Dois eventos foram detectados como sendo stressantes, mas apenas um destes foi relatado pelo profissional. Foram observadas mudanças significativas nos valores de racio entre baixas frequências e altas frequências (LF/HF) entre os dias de trabalho e de folga. A monitorização dos neurocirurgiões foi feita durante cirurgias de aneurisma intracraniano e diferentes eventos foram identificados como stressantes. Os resultados também apoiam o facto de uma cirurgia mais stressante induzir uma maior fadiga mental. Quatro Bombeiros foram submetidos a um protocolo no qual eles tinham de completar diferentes tarefas que eram mentalmente e fisicamente exigentes, de modo que suas respostas psicológicas e fisiológicas podessem ser estudadas. O *Trial Social Stress Test* (TSST) e a tarefa de fitness parecem cumprir os seus papéis como indutures de stress e fadiga física, respectivamente. No entanto, é necessário realizar algumas mudanças no protocolo para obter de forma fiável dados de basais fidedignos.

Foi possível retirar importantes conclusões destes e que podem ser de enorme importância para a concepção de intervenções eficazes que possam reduzir os níveis de stress e fadiga em diferentes profissionais. As ferramentas desenvolvidas também mostraram grande potencial na melhoria deste tipo de estudos e vários objetivos foram propostos como trabalho futuro para atingir isso. São também apresentadas diferentes sugestões para melhorar os estudos desenvolvidos.

Keywords: Stress. Fadiga. Variabilidade Cardíaca. ECG Vestível. Profissionais.

Abstract

There is a growing concern about the health problems that occur due to stress and fatigue at work. Around the world, workers suffer from this disorders and this undoubtedly affects their performance and health. Stress, for example, is the cause of various cardiovascular and neurological diseases. Furthermore, fatigue has been widely reported to cause several work and car accidents.

With this in mind, this work aims to use state of the art wearable and mobile technology to monitor parameters of stress and fatigue during normal routines of different professionals. Surveys already validated in the literature were also used to assess the subject's cognitive function which is also important in studies in this area.

To better study events that can induce stress and fatigue, an Android app (called VJ E-Diary) to enable the registration of events in the phone so that later they can be synchronized with other data was developed. Furthermore, a small computer application (VJ Assembly) was developed to synchronize data from different sensors and present it to the user efficiently. This tool was also designed to accept the files generated by the VJ E-Diary so that the registered events can be automatically synchronized with the other data.

Studies with 3 different types of professionals (6 Police Officers, 3 Neurosurgeons and 4 Firefighters) were developed with the goal of monitoring both Stress and Fatigue.

Police Officers were monitored during their work routines and days off. Two events were detected as being stressful, but only one was reported by the officer. Significant changes in the ratios between Low Frequencies and High Frequencies (LF/HF) values were observed between work days and day offs. Neurosurgeons were monitored during intracranial aneurysm procedures and different stressful events were identified. Results also support the fact that a more stressful procedure induces higher mental fatigue in the surgeon. Four Firefighters underwent a protocol where they had to complete different tasks which were mentally and physically demanding, so that their psychological and physiological responses could be studied. The Trial Social Stress Test (TSST) and Fitness tasks seem to fulfill their roles as stress and physical fatigue inducers. However, some changes need to be done to the protocol to reliably obtain unbiased baseline data.

It was possible to draw important conclusions which may be of enormous importance for the design of effective interventions in order to reduce stress and fatigue levels in different professionals. The tools developed also shown great potential in improving this type of studies and several goals were proposed as future work to achieve this. Furthermore, various suggestions are also presented with the aim of improving the developed studies.

Keywords: Stress. Fatigue. Heart Rate Variability. Wearable ECG. Professionals.

Acknowledgments

Primeiro, gostaria de começar por deixar os meus mais sinceros agradecimentos ao Professor João Paulo Cunha pela enorme oportunidade que me deu ao me acolher no seu grupo de investigação e confiar em mim para levar este trabalho até ao fim. A sua confiança em mim e no meu trabalho foi uma constante e foi sem dúvida essencial para conseguir chegar até aqui. Quero também agradecer ao serviço de Neurocirurgia do Hospital de São João, em especial ao Dr. Vilarinho e ao Dr. Pedro Silva, pela enorme disponibilidade e paciência mostradas, assim como pela oportunidade de presenciar algumas das suas ínumeras cirurgias.

A todos os elementos do BRAIN que me foram apoiando e acompanhando durante este último ano deixo também o meu mais sincero obrigado. Ao Hugo Choupina quero deixar um especial agradecimento não só pelas contagiante alegria, mas também pelo exemplo de vida e força que sempre mostrou. Um grande Obrigado ao grande ano de 2013 do MEB que muitos sorrisos e aventuras me proporcionaram. Em especial, quero agradecer à Joana, à Inês e aos meus eternos colegas do edifício I - Luís, Hélder e Diogo -pela enorme amizade. Sem eles nunca teria conseguido chegar a este momento.

Sendo este o culminar de um longo período académico não posso deixar de agradecer às pessoas que, durante a minha licenciatura, e mesmo agora, contribuíram para a conclusão desta tese. Primeiro, quero agradecer ao Professor João Ventura por tudo aquilo que me ensinou e que, ainda agora, aplico constantemente em todo o trabalho que realizo. Se hoje estou a apresentar uma tese de Mestrado, muito devo a ele. Também quero agradecer à Catarina Dias por ter sido a melhor parceira que poderia ter tido para iniciar a minha carreira na investigação. A sua curiosidade e empenho sem dúvida me contagiaram e me marcaram. Quero também deixar um sincero agradecimento à minha família do 5ºA - Gui, Élia e Ana Luísa - por todos os sorrisos e apoio dados.

A todos os meus colegas de Vagos, Ílhavo, Aveiro e Porto, muito obrigado por sempre se preocuparem comigo e mostrarem interesse naquilo que faço. Em especial, quero deixar um sincero Obrigado àqueles que sempre fizeram questão de nunca se esquecer de mim, quer fosse na praia, ou quando se juntavam. Obrigado por tudo malta !

Aos Vagueirudos, uma palavra de agradecimento pela contagiante vontade de viver que sempre me transmitiram e por me acolherem como um de vós.

À Maria Pedro, ao Tochá e à Júlia, quero agradecer por todo o amor e disponibilidade que sempre ofereceram. Não há como descrever a gratidão e adoração que sinto para com vocês. Muito vos devo. Obrigado.

Às minhas tias, primas e Avó quero agradecer pelo apoio e amor que sempre me deram e que tanto me motivou. Nunca saí sem um sorriso (ou fome) de vossas casas.

Ao meu Pai e Irmão, tenho a agradecer por serem os meus grandes pilares desta vida e nunca me deixarem ir abaixo. Pela sua força e vida que me trazem esperança e alegria. Pelo apoio e amor incondicional e por serem o meu porto seguro e a minha luz - Obrigado.

À minha Mãe, por tudo, Obrigado.

"If opportunity doesn't knock, build a door."

Milton Berle

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List of Abbreviations

ACC	Accelerometer
ANS	Autonomic Nervous System
API	Application Program Interface
AV	Atrioventricular
BVP	Blood Volume Pressure
CI	Cardiac Intensity
ECG	Electrocardiogram
EDA	Electrodermal Activity
EEG	Electroencephalogram
EU-OSHA	European Agency for Safety and Health at Work
GPS	Global Positioning System
HR	Heart Rate
HRV	Heart Rate Variability
IDC	International Data Corporation
IR	Infrared
LF/HF	Ratio between Low Frequency (LF) and High Frequency (HF)
NASA-TLX	National Aeronautics and Space Administration - Task Load Index
PC	Portable Computer
PPG	Photoplethysmogram
PSNS	Parasympathetic Nervous System
PSS	Perceived Stress Scale
RSA	Respiratory Sinus Arrhythmia
RT	Reaction Time
SA	Sinoatrial
SCL	Skin Conductance Level
SD	Standard Deviation
SDK	Software Development Kit
SNS	Sympathetic Nervous System
SPSS	Statistical Package for the Social Sciences
STAI	State-Trait Anxiety Inventory
Stressor	Stress Factor
SURG TLX	Surgery - Task Load Index
UI	User Interface
UML	Unified Modeling Language
VAS	Visual Analog Scale
VJ	Vital Jacket®

List of Symbols

°C	Celsius
%	Percentage
μS	microSiemens
bpm	Beats per Minute
g	Gram
Hz	Hertz
mm	milliMeter
ms	milliSecond
s	Second
V	Volt

Chapter 1

Introduction

1.1 Context and Motivation

Every day millions of people struggle with the demanding roles their jobs require, either is because of the extremely high performance they have to give every day (e.g. surgeons), or the dangerous environments that they are exposed to (e.g. firefighters, police officers), or even just to make sure their job is done correctly and on time. Many situations, like conflicting demands or excessive workload, may exceed the workers' coping ability, leading them to feel stressed and worried with the outcome. This "job stress" is undoubtedly a source of health problems, being already associated with a range of mental and psychological health outcomes like including anxiety, depression and chronic fatigue [1]. Therefore, it has already been identified by the European Agency for Safety and Health at Work (EU-OSHA) as a major issue to be addressed [2]. According to the 2013 EU-OSHA pan-European opinion pool, which covered different professionals over 30 countries, about 51% of them find work-related stress to be common in their workplace and 40% think that this stress is not handled well in their organization [3]. This factor is crucial, as in the health of the professionals, as for the health of the organization. According to a 2013 European Union funded project, the cost to Europe of work related depression, which can be due to prolonged exposures to stress, was estimated to be of approximately 800 billion dollars annually [1]. All this lead to the launch of the two year (2014-2015) Europe-Wide Campaign "*Healthy Workplaces Manage Stress*" [2].

Also, due to really highly demanding, repetitive tasks experienced during work, fatigue may also be experienced in different professions. This factor has been reported to be associated with health problems, and is a constant between the working population [4] [5]. In the United States, a study involving around 29,000 employees concluded that 65.7% of the workers with fatigue reported health-related lost productive time, while only 26.4% of the ones without reported the same. This translated into a cost to fatigued worker's employers of about 136.4 billion dollars annually – 101.1 billion dollars more when compared with workers without fatigue [6].

Besides this financial impact, fatigue and stress have shown to be crucial factors in the performance of healthcare professionals, like surgeons, which interfere with the success of surgical operations, putting the patient's life at risk [7] [8].

These facts support the development of continuous studies of stress and fatigue during work routines in order to identify the main causes for these problems and correct them.

However, the monitoring of a professional's health during their daily routine is not a simple task. Besides the various sensors that devices should have in order to collect information, one also needs to know which measures are significant for detecting stress and fatigue. Furthermore, if these typical available devices interfere too much with the person's movements, it will affect the way they perform and, therefore, influence the results. Thus, non-intrusive, comfortable technology is very relevant for a study of these disorders. With the mobile technology industry experiencing an amazing growth, smartphones and wearable devices are gaining market and worldwide interest. This has led to the development of better non-intrusive ways to study the human body and its behavior.

Therefore, using state-of-the-art mobile and wearable technology, one can study how stress and fatigue relate to various events in different professions. With this kind of information, it will be possible to identify the "*stressors*" (stress factors) that lead to associated disorders during the daily routine of different professionals and increase their performance while providing a better quality of life for them as well.

1.2 Objectives

Given the subjective and objective nature of stress and fatigue, this thesis will include many concepts from Psychology and Medicine, that will be studied recurring to engineering, in order to:

- Identify events that induce stress and fatigue in professionals through assessment of different physiological variables, namely Heart Rate Variability (HRV), as well as the subjective appraisal of the subjects;
- Develop tools that enable the monitoring of stress and fatigue events in uncontrolled environments during the professional's daily routines;
- Study the relationships between physiological and psychological variables related to stress and fatigue.

1.3 Publications

The present thesis resulted in the following publications in conferences:

- R.Tuna, G.Pimentel, A.Vilarinho, R.Vaz and J.P. Cunha, "Monitorização do Stress Cardiovascular em Cirurgias de Clipagem de Aneurismas" In *30º Congresso Nacional da Sociedade Portuguesa de Neurocirurgia*, 2015. (see Appendix A) ;

- G.Pimentel, A.Vilarinho, R.Vaz and J.P. Cunha, “Cardiovascular Strain and Autonomic Imbalance in Neurosurgeons” In *37th Annual International IEEE EMBS Conference* , 2015. (see Appendix B).

Furthermore, one publication was submitted to a conference but was rejected :

- G.Pimentel, A.Vilarinho, R.Vaz and J.P. Cunha, “Cardiovascular Strain and Autonomic Imbalance in Neurosurgeons during Intracranial Aneurysm Procedures” In *37th Annual International IEEE EMBS Conference* , 2015. - **Rejected** (see Appendix C).

Finally, two articles are being finished in order to be submitted to 2 different indexed journals, which present some of the results shown in this thesis. However, up until the submission of this thesis, these articles were still being reviewed by other authors. Therefore, they are not available in this document.

1.4 Structure

This thesis is divided in two major parts. The first, composed by chapters 2 and 3, introduces essential concepts of physiology for stress and fatigue assessment as well as a literature review of relevant parameters, systems and studies which successfully monitor different professionals to interesting results.

The second part of this thesis includes chapter 4 and 5. The first focuses on the tools that were developed in order to better assess stress and fatigue while the latter addresses the results obtained through the monitoring of different professionals recurring to these same tools, as well as others.

Finally, in chapter 6 the overall results from this work are discussed and conclusions are taken from these. Furthermore, several goals are proposed as future work and follow-up to this thesis.

Part I

State of the Art

Chapter 2

Background

Psychology and medicine have different views over the concepts of stress and fatigue. Since one of the purposes of this work is to support the physiological behavior analysis with subjective appraisal of this events, it becomes important to define and explain their basis. Furthermore, cardiac behavior will be an important part of this work as well. Therefore, basic physiology concepts about it and how it can be monitored are also presented.

2.1 Stress

2.1.1 Physiology

Hans Selye first defined stress, in a biological context, as being "*the non-specific response of the body to any demand placed upon it*" [9]. This definition was recently complemented by Koolhaas *et al.* who suggested that it "*should be restricted to conditions where an environmental demand exceeds the natural regulatory capacity of an organism*" [10]. Independently of the way we look at it, stress seems to be a response of our body to external *stimuli* that disrupt the human homeostasis, or, in other words, the equilibrium that exists in the human organism.

2.1.1.1 Autonomic Nervous System

Internally, responses to stressful situations are regulated by the brain. When we are exposed to a stressor, it will release specific chemicals (Noradrenaline, Adrenaline, Cortisol) into our body to alter the activity of some organs, enabling appropriate responses to the event [11].

The Autonomic Nervous System (ANS), a part of the Peripheral Nervous System, which belongs to the organism's nervous system, responsible for regulation of the body's major physiological unconscious activities (like blood pressure, respiration, gland secretion, heart's electrical activity, etc.) [12], has a very important role in this behavior, by making sure that vital body processes are adjusted accordingly with changing conditions imposed by the stressor [11]. This system is divided in three major components, which can operate independently or co-operatively [13]:

- **Enteric Nervous System** — responsible for the gastrointestinal system [14].
- **Parasympathetic Nervous System (PSNS)** — regulates body functions related to "rest-and-digest" events, or in other words, basic bodily functions while one is at rest. This includes salivation, urination, digestion, lacrimation and sexual arousal [13]. The PSNS has ramifications in the heart that come from the Vagus nerve [12]. The influence of the PSNS in the cardiac activity is mediated via the release of acetylcholine by the parasympathetic nerve fibers, which act on the sinoatrial (SA) and atrioventricular (AV) nodes [12], modulating heart rate.
- **Sympathetic Nervous System (SNS)** — regulates many of the homeostasis mechanisms, controlling the response of the organism to a perceived attack, dangerous event or survival threat, preparing the body to "*fight*" or "*flight*" ("*fight-or-flight*" response) [15]. Because of this, the SNS is also known as the "*fight-or-flight*" system. Specifically, the SNS supplies nerves to the adrenal medulla and controls the release of both adrenaline and noradrenaline. It is the mixture of this chemicals that prepares the body to respond accordingly [11]. This changes in organ and tissue function throughout the body are coordinated so that there is an increase in the delivery of well oxygenated and nutrient rich blood to the working skeletal muscles. Example of this is the increase of the heart rate and myocardial contractility, so that the heart pumps more blood per minute and the release and creation of glucose in the liver to increase the concentration of glucose molecules in the blood, thus providing the organism of extra energy to respond [13].

2.1.1.2 General Adaptation Syndrome

The "*fight-or-flight*" response is recognized as being the first stage of the General Adaptation Syndrome, which regulates the responses of vertebrates and other organisms to stress [9][16]. This specific behavior, discovered by Hans Selye, and illustrated in Figure 2.1, is characterized by three distinct stages [16][17][18]:

1. **Alarm** — This stage is divided in two phases. The first, known as the *Shock* phase, is characterized by the initial endurance of the body to changes. Afterwards the organism response to the stressor drops temporarily and some level of shock may be experienced. The second phase, the *Antishock* phase, begins when the threat is identified by the organism and it starts to develop methods to respond to the event. It is when the mechanisms of the "*fight-or-flight*" response, mentioned earlier, are activated.
2. **Resistance** — In this stage, the body begins to try to adapt to the strains of the environment, by increasing the secretion of certain chemicals, which end increasing glucose, fat and protein concentration in the blood. Even using the extra resources available due to the aforementioned mechanism, the organism cannot keep up indefinitely, leading to a third and final stage in this process.

3. **Exhaustion** — This stage can be defined as *Recovery* as well, depending on the success of the body to overcome the stressor effect. If the system successfully overcomes it, then will enter a recovery stage. When in it, the organism will use the high amounts of amino acids, fat and glucose in blood, which are available due to the mechanisms activated in the resistance stage, for anabolic reactions, regeneration of cells and restoration of the homeostasis. Otherwise, it will enter the *Exhaustion* stage. This happens when the body is unable to overcome the adverse situation, and eventually depletes all its physiological resources trying to fight the stressor. Due to this, it will be unable to maintain normal function, possibly leading to serious health problems. A prolongation of this stage may result in the exhaustion of the organism's immune system and impairment of bodily functions, decompensating [17].

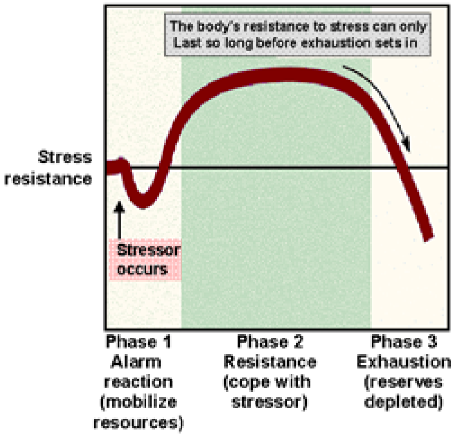


Figure 2.1: Illustration of the General Adaptation Syndrome process. Source: [18]

2.1.1.3 Respiratory Sinys Arrythmia

Under resting conditions, the variation between consecutive human heart beats varies periodically with the phase of respiration - it increases during inspiration and decreases during expiration. This mechanism, known as Respiratory Sinys Arrythmia (RSA) is predominantly mediated by the PSNS, whose activity is absent during the inspiration (leading to decreases in the interval between beats) and present during expiration, increasing that same interval.

Furthermore, during the "*fight-or-flight*" response, the sympathetic branch of the ANS is much more active than the PSNS, even existing an inhibition of parasympathetic activity during this period [19]. Without the interference of the PSNS, the RSA mechanism will not be present and therefore, Heart Rate Variability (HRV) will decrease, which can therefore be defined as a symptom of stress as mentioned in Table 2.1.

Resuming, during the response to adverse external *stimuli*, the activity of the SNS is increased while vagal activity is inhibited. After the stress has passed, the PSNS is responsible for reversing the processes stimulated by the SNS, in order to reset the body to its natural equilibrium [20]. It can be then concluded that the PSNS and SNS complement each other. Table 2.1 summarizes the symptoms that characterize the described response of the human body to stress.

Table 2.1: Common symptoms and signs of stress. Adapted from [21].

Organ System	**Symptom**	**Sign**
Cardiovascular	Increased Blood Pressure Increased HR Reduced HRV	Flushed appearance Racing heart rate Palpitations
Muscular	Increased tension	Stiff neck Grinding teeth Headaches
Digestive	Increased motility	Gas/burping Diarrhea
	Increased acid secretion	Indigestion/Heartburn Nausea
	Reduced salivary secretion	Dry mouth
Integument	Increased glandular secretion	Perspiration Oily skin Body odor

2.1.2 Psychological Interpretation

Stress is also a major subject of study in the area of psychology. In this approach, stress is defined as a feeling of pressure and strain, being experienced when the expected demands exceed the person's ability to overcome the task successfully. It takes in consideration the way a person evaluates the event and weights it against their ability to handle the situations [22]. In other words, their mental response becomes the main subject of study. This is also important in order to understand how people react to stressful events. Their response can vary, depending on diverse factors like their own coping strategies, social support networks, perception of the situation they are in and their ability for adaptation [23].

Selye also contributed to the development of the stress concept in the area of psychology by distinguishing two types of stress – "*eustress*", which is considered to have a positive contribution to the individual, and "*distress*", the most common and unwanted kind, which can be harmful to an organism [24]. However, distress has been the topic of focus in diverse studies due to the extremely bad outcomes that a prolonged exposure to this kind of strain has in health [25]. Besides, recently it has been reported a relation between distress and loss of productivity as well [26]. This kind of responses are not measurable physically. Instead, the study of psychological processes must be done taking into account the environment the person is in, since various perceptions can exist. The most common approaches are interviewing the person or ask them to fill a questionnaire created specifically for the study.

2.1.3 Clinical Relevance

It has been proven that chronic stress, derived from long exposures to stress, can lead to serious health problems. Some of them are presented in Table 2.2. Since it has been reported that workers experience stress during their daily tasks, there should be a concern with preventing this kind of health problems from affecting the working population.

Table 2.2: Examples of disorders related to chronic stress.

Stress Related Disorders		
Coronary Artery Disease [27]	Epilepsy [28]	Gastrointestinal Disorders [29]
Hypertension [30]	Multiple Sclerosis [31]	Generalized Anxiety Disorder [29]
Rheumatoid Arthritis [32]	Schizophrenia [33]	Fibromyalgia [34]

2.2 Fatigue

2.2.1 Definition

Fatigue is considered a non-specific symptom, due to its relationship to various causes or conditions. It is defined as a feeling of wariness, tiredness or lack of energy [35]. It has also been linked to decrements in performance during work [36]. Sleep deprivation, intense physical exercise, depression, anxiety and mental stress are some of the disorders to which fatigue can be an indicator of [37]. With this in mind, fatigue has been classified into two different types:

- **Physical fatigue**, also known as peripheral fatigue, is defined as being the temporary physical inability of a muscle to perform optimally.

- People often experience, during or after prolonged periods of cognitive activity, a feeling which involves tiredness or even exhaustion. This is known as **Mental Fatigue** [38]. It has also been associated with impaired cognitive control [39] as well as with behavioral performance [40]. Mental Fatigue can manifest itself in different forms like somnolence, "lack of energy", difficulty in sustaining attention and ignoring relevant information [38].

2.2.2 Clinical relevance of mental fatigue

In terms of duration, mental fatigue can have two different denominations. Prolonged mental fatigue is diagnosed to a patient who, during at least one month, self-reported the symptom, while chronic fatigue corresponds to at least six consecutive months of self-reporting. This kind of time-measurement is important to identify the reason why an individual is experiencing this symptom.

Several heart diseases [41] and neurological disorders [42] are just some of the reported complications which have fatigue as a symptom. Some examples are presented in Table 2.3.

Table 2.3: Some of the diseases to have fatigue reported as symptom.

Cardiovascular Disorders	Neurological Disorders	Others
Cardiomyopathy [43]	Multiple Sclerosis [44]	Acquired Immunodeficiency Syndrome [45]
Myocarditis [46]	Narcolepsy [47]	Lyme Disease [48]
Angina [49]	Parkinson's Disease [50]	Anemia [51]
Coronary Artery Disease [52]	Postpoliomyelitis [53]	Hodgkin Lymphoma [54]

2.2.3 Causes of mental fatigue

High mental workload, mental stress, jet lag, depression, sleep deprivation and even boredom are some of the possible causes of mental fatigue. However, none of these explain this symptom physiologically.

Several studies where physiological changes are analyzed have been carried out in subjects with chronic fatigue and other disorders. Yet, very few physiological relationships have been found for healthy people. Only recently a study has provided evidence that mental fatigue induced by prolonged cognitive load in healthy adults is associated with changes in the activity of the parasympathetic and sympathetic branches of the ANS [55].

Concluding, being a consequence of subjective behaviors and conditions, Mental Fatigue should be defined psychologically. Nonetheless, it can be related with the different physiological parameters that make the user experience the "feeling" of fatigue and help identify it.

2.3 Cardiac Monitoring

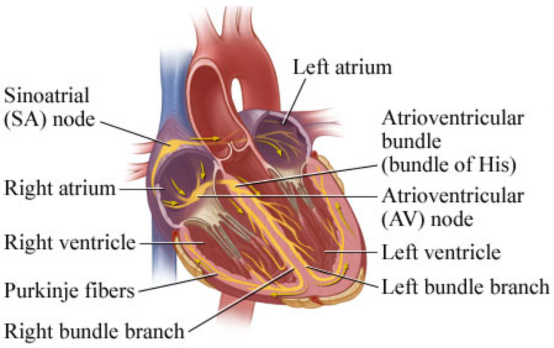
2.3.1 Physiology

As it is known, the heart is the organ responsible for pumping blood to every part of the body. Normally, this action is done in a constant cycle, composed by contraction and relaxation of different parts of the organ, at different times. This are coordinated by a series of electric charges, from specific localized nodes within the myocardium [12].

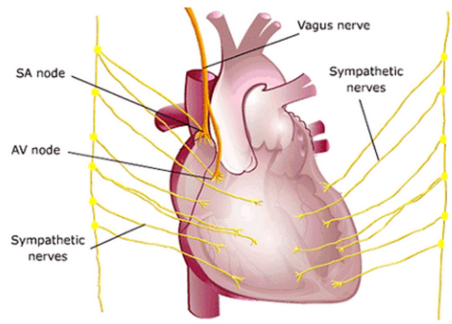
The cardiac cycle starts with the stimulation of the SA node, located in the right atrium, as presented in Figure 2.2a, which leads to the depolarization of the cardiac muscle in that area (i.e. they are electrically stimulated), changing their resting potential from negative to positive thus contracting. This process occurs regularly and spontaneously, at an intrinsic frequency, which is generally defined as the human heart rate. The average resting HR is 60 to 80 beats per minute (bpm) [56]. Afterwards, the impulse spreads to the upper two cavities of the heart known as the atria, reaching the AV node, located in the right atrium, causing contraction of the mentioned area. Then it passes the bundle of His, spreading out into the inter-ventricular septum and dividing itself into the left and right bundle branches. As it moves through this region it stimulates the depolarization of both ventricles. After this, a transient period is followed, which lasts, at least, 200 milliseconds (ms). There is a repolarization of the ventricular myocardium afterwards (i.e.

they relax), returning it to its resting electrical potential. The heart is then ready to repeat the described cycle of contraction and relaxation [12].

The ANS has ramifications in the heart that enables it to control cardiac activity during different events (e.g. stress responses). More specifically, ramifications of the Vagus nerve, which belongs to the PSNS, and sympathetic nerves innervate the heart and enable autonomic modulation. Moreover, due to the nature of the parasympathetic innervation, activity associated with the PSNS is often regarded as vagal activity. This is presented in Figure 2.2b.



(a) Source: [57]



(b) Source: [58]

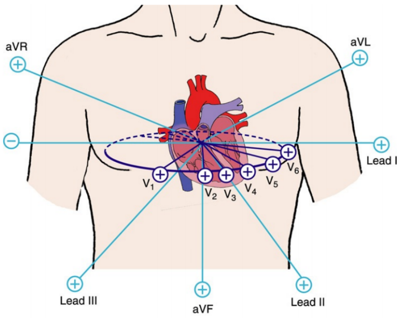
Figure 2.2: (a) Physiology of the Heart. (b) Autonomic innervation of the Heart.

2.3.2 Electrocardiogram

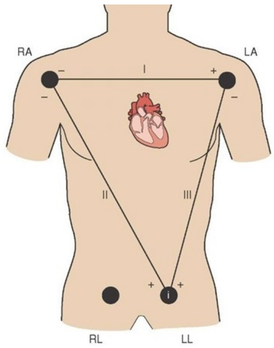
Using an Electrocardiogram (ECG) device, one can detect, record and analyze the electrical activity of the heart that is generated during the cycle described previously. Changes in polarization of the heart muscle lead to electrical changes in the skin thus enabling the monitoring of the heart activity with appropriate technique and equipment.

Basically, the ECG is a measurement of a *vector* corresponding to the electrical potential difference between combinations of two points. Each of these *vectors* is referred to as a lead. Different combinations of leads can be used to extract the cardiac waveform. The standard clinical ECG consists of 12 leads - 6 frontal leads, that are in a plane parallel to the body (coronal plane), and 6 pre cordial leads which are in a plane perpendicular to the body (transverse plane). These are represented in figure 2.3a. Ten electrodes are needed to obtain all 12 *vectors*. Usually, these electrodes consist of a conducting gel embedded in a self adhesive pad [59].

Three different electrodes are used to form the frontal ECG leads. These are usually placed on the right arm, left arm and left leg or right leg as illustrated in Figure 2.3b, and form what is known as the Einthoven's triangle [59]. Leads I, II and II are formed from the triangle itself. With only these it is possible to obtain enough information for cardiac rhythm-monitoring. However, for determination of the elevation of the ST segment (see section 2.3.3), more leads are necessary, being the full 12 needed for an optimal setup for this [60].



(a) Source: [61]



(b) Source: [62]

Figure 2.3: (a) Vector view of the available 12 leads. Frontal leads are light blue while pre cordials leads are dark blue. (b) Identification of the placement of electrodes to form the frontal ECG leads and the Einthoven's triangle. RA stands for Right Arm, LA for Left Arm, RL for Right Leg and LL for Left Leg.

2.3.3 Cardiac Wave

In Figure 2.4 we can see an ECG sample, where the different components that compose the signal are identified, as well as the RR interval. The **RR interval** is defined as the time interval between two R peaks and it is used to calculate HR. Sometimes, the term **NN interval** is used instead, in order to emphasize that the interval considered is between two normal beats.

Each wave represents a different step of the cardiac cycle previously described [63]:

- **P Wave** — Produced by the atrial depolarization;
- **QRS Complex** — Composed by waves Q,R and S, it represents ventricular depolarization;
- **ST Segment** — Corresponds to the period when the ventricles are depolarized;
- **T Wave** — Produced by the repolarization of the ventricles.

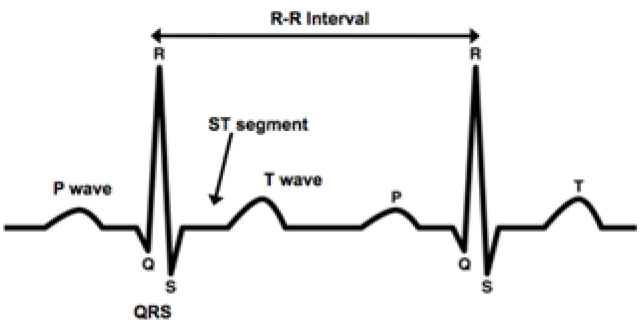


Figure 2.4: ECG Sample, with the different wave components identified. Source: [64]

2.4 Conclusions

To fully understand stress and fatigue, different concepts from distinct areas must be taken into consideration. A physiological approach should be performed together with a psychological one in order to take into consideration the individual's perception of the events. The autonomic behavior seems to be physiologically correlated with both these disorders. Furthermore, several body mechanisms occur as a consequence of the imposing demands by the environment therefore opening an window to study the ANS during the exposure to this disorders. According to the literature, the heart is one of the most interesting organs to study stress due to the strong, noticeable changes imposed by the ANS during stressful events. Fatigue has also been correlated with cardiac changes. Consequently, the study of the cardiac behavior appears as one of the main windows to study both stress and fatigue.

Chapter 3

Relevant Studies and Tools

As explained in chapter 2, stress and fatigue are associated with different changes in the human system that are controlled by the brain. Knowing this, different studies have been made to understand the behavior of different physiological parameters during exposure of an individual to stress and fatigue. Therefore, it becomes essential to know how this information can be collected, through assessment of the current monitoring systems available, and how the literature is designing their studies to identify these disorders.

3.1 Monitoring Parameters

3.1.1 Heart Rate Variability

With the information present in an ECG, one can obtain the beat-to-beat variation, or in other words, the HRV. Different time-domain and spectral-domain parameters can be extracted from this to better understand the cardiac behavior.

However, in order to study the spectral domain features of the signal, some processing has to be done. The most common methods to do this are the Fast Fourier Transform [65], the Lomb Periodogram [66] and the Auto Regressive spectral estimation [67].

The following presented measures were considered relevant by the task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology for the purposes of HRV analysis [19].

3.1.1.1 Time-Domain Parameters

Simple time domain variables that can be calculated with only the NN intervals (see section 2.3.3) are:

- **Mean NN** (ms) – Mean Heart beat interval
- **Mean HR** (bpm) – Mean Heart Rate.

Some statistical measures can be obtained as well. Normally these are obtained from a predefined time window (e.g. 5 minutes). This include:

- **SDNN** (ms) – Standard Deviation of all NN intervals. Reflects all the cyclic components responsible for variability in the analyzed period of recording.
- **RMSSD** (ms) – Root Mean Square of Successive Differences between adjacent NN intervals.
- **SDSD** (ms) – Standard Deviation of Successive Differences between adjacent NN intervals.
- **NNx** – number of pairs of successive NN intervals that differ by more than x ms (for example 50 ms (NN50)).
- **pNNx** (%) – percentage of NNx compared to the total number of NN intervals (for example 50 ms (pNN50)).

3.1.1.2 Spectral-Domain Parameters

As mentioned in 2.3.1, it is in the SA node that the cardiac cycle begins. In this region, there is a periodical generation of action potentials at an almost constant frequency (which are propagated to the other areas of the heart) due to the unstable membrane potential of the myocytes (muscle cells) that exist there [68]. This apparent constant frequency is modulated by diverse factors that add variability, at different frequencies, to the signal. As discussed earlier in section 2.3.1, the ANS can influence the cardiac behavior. Therefore, the study of the mentioned frequency modulation can be very interesting to understand the autonomic activity that is related to the heart beat.

Of the possible frequency related features, the most relevant are:

- **ULF** (ms^2) – Spectral Power in the Ultra Low Frequency (ULF) range (0.003 Hz). It is related to the circadian rhythm [69].
- **VLF** (ms^2) – Spectral Power in the Very Low Frequency (VLF) range (0.003 Hz - 0.04 Hz), which is supposedly associated with regulation of temperature and humoral systems [70].
- **LF** (ms^2) - Spectral Power in the Low Frequency (LF) range (0.04 Hz - 0.15 Hz). There are studies that relate LF to changes in cardiac sympathetic and parasympathetic nerve activity [71]. This is due to the fact that the SNS has a longer response time when compared to the PSNS, which is also capable of very short responses. Because of this, low frequency fluctuations in heart rate can be mediated both by the PSNS and SNS [72].
- **HF** (ms^2) - Spectral Power in the High Frequency (HF) range (0.15 Hz - 0.4 Hz). The PSNS has a lower response time compared to the SNS [73], which enables it to react rapidly enough to mediate high frequency fluctuations in heart rate. Besides, it has been reported that high frequencies are synchronized with the respiratory rhythm [74], which is expected since vagal activity is also related to RSA (as verified in section 2.1.1.3).

- **LF/HF** – Ratio of LF for HF. Considering that the SNS activity is reflected in the LF power of the spectrum while the PSNS exert their influence more quickly on the heart and principally affect the HF power, the LF/HF ratio can be taken as a measurement of sympathovagal balance [15][75][76]. Therefore, increases in sympathetic activity (e.g. during the *fight-or-flight* response) translate in the increase of the LF/HF values.

- **Total Power** ((ms^2) – Variance of all NN intervals (frequency range 0.4 Hz).

- **LF norm** – LF power in normalized units (obtained by dividing the LF power by the difference between the Total Power and VLF power).

- **HF norm** - HF power in normalized units (obtained by dividing the HF power by the difference between the Total Power and VLF power).

It is also important to distinguish between short term recording (2 to 5 minutes) and long term recordings (usually 24 hours long) [19].

If considering the first one, three main spectral components may be distinguished: The VLF, LF and HF. The normalized measures presented (normalized LF and HF power) are used to emphasize the mentioned behavior of two of the branches of the ANS during short term recordings. Besides, this normalization tends to minimize the effect that changes in total power have in the values of the LF and HF components (since it does not take in consideration the VLF component). The reason why the VLF power is discarded is because its non-harmonic component, one of the VLF major constituents, does not have coherent properties and is affected by algorithms of baseline or trend removal [19].

Otherwise, when analyzing day-long (24 hour) recordings, besides the three major components mentioned, one should also take in consideration the ULF component of the signal, which is related to the circadian rhythm, as stated, which cannot be seen, obviously, when considering recordings of just a few minutes.

In Figure 3.1 it is illustrated this division of the HRV spectrum during a long-term recording, where all components are visible.

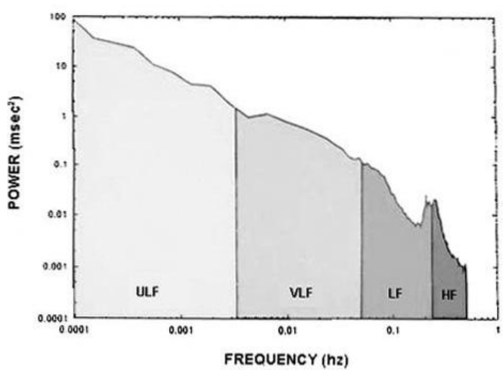


Figure 3.1: Log Plot of the HRV spectrum over 24 hours. Source: [77].

3.1.1.3 Cardiovascular Intensity

Another interesting value that can be extracted from the HR is the Cardiovascular Intensity (CI), which takes in consideration the maximum HR recommended for a person and is an indicator of the challenge to the cardiovascular system that a certain event or exercise represents. According to Tanaka *et al.*, the maximum HR is given by [78]:

$$HR_{max} = 208 - 0.7 \times age \tag{3.1}$$

With this, and having the baseline value during rest (HR_{rest}) to compare to, it is possible to obtain the CI by applying the following equation:

$$CI_i = \frac{HR_i - HR_{rest}}{HR_{max} - HR_{rest}} \times 100\% \tag{3.2}$$

3.1.1.4 Relevant Factors

Besides the mentioned autonomic influence on HRV, other factors may, as well, affect the cardiac output. The subject's details like age [78], exercise routines [79], and caffeine consumption [80] are very important to have when assessing stress and fatigue through cardiac parameters. Their history of hearth-related disorders is, obviously, also important.

3.1.1.5 Application

Due to the high correlation with ANS, HRV has been widely used in the literature to assess stress.

However, fatigue can also be identified using it. A study developed by Yvonne Tran *et al.* suggest fatigue is associated with psychological factors and increased sympathetic activity in healthy populations [81]. Furthermore, it has been reported that HRV is also correlated with the psychological cognitive performance of an individual [82]. These findings suggest that the study of the heart behavior can be used as a physiological factor for the study of fatigue.

3.1.1.6 SenseMyHeart

Taking into account all the available variables that can be extracted from HRV, it becomes viable to develop tools that can allow researchers to easily access feasible information concerning the cardiac wave's time and spectral components. Physionet developed a software library for process and analyze physiological signals, including ECG [83]. However, this software requires an Unix environment (e.g. Linux), as well as computation skills in that operating system, which can make difficult its usage by researchers. With this in mind, Pinto Silva and Silva Cunha developed a cloud service that, ultimately, provides an Application Programming Interface (API) for a Physionet-based pipeline for ECG processing and HRV measurement [84]. By creating a WaveFrom Database record from the raw ECG signal input, this tool recurs to PhysionetToolkit to extract different HRV measurements through a simple user-friendly interface. QRS detection can be done recurring to three different detectors (labelled *sqrs*, *swqrs* and *sgqrs*). It also accepts already filtered RR interval files as input, therefore skipping the R peak identification part. The Lomb periodogram is used to obtain the power spectrum. Furthermore, this tool is available for use and development in Windows and Android environments. An illustration of this tool's pipeline can be seen in Figure 3.2.

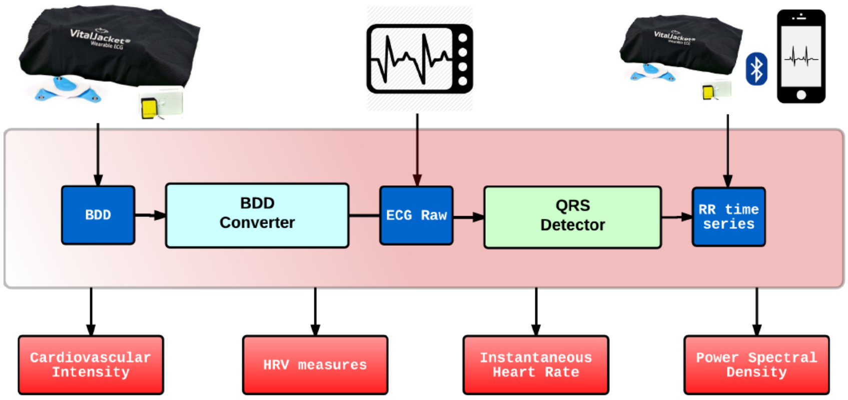


Figure 3.2: SMH's pipeline block diagram. Source: [84]

3.1.2 Blood Volume Pressure

Blood pressure is defined as being the force the heart exerts against the walls of arteries as it pumps the blood out to the body [85]. Its study is divided in two measurements:

- **Systolic Pressure** - corresponds to the pressure as the heart beats and forces blood into the arteries.
- **Diastolic Pressure** – corresponds to pressure as the heart relaxes between beats.

Blood Volume changes can be used to obtain interesting details of the cardiovascular system such as HR, arterial blood oxygen saturation and cardiac output. Blood Volume Pressure (BVP) can be measured through a Photoplethysmogram (PPG), which contains information regarding changes in light absorption by the blood. However, the PPG sensors are typically placed in fingers or ears, which might not be very comfortable for the user and restrain movements.

As explained earlier, the cardiac parameters are very relevant for the measurement of autonomic activity. Therefore, this method has also been widely used in the field of stress and fatigue monitoring [86][87].

3.1.3 Electrodermal Activity

Sweat secretion leads to an increase in the electrical conductance of the skin. With Electrodermal Activity (EDA), one is able to identify electric resistance of the skin. The EDA analysis has two components – Skin Conductance Level (SCL) and Skin Conductance Response (SCR). The first corresponds to a slow changing part of the EDA signal and can be obtained as the mean value of skin conductance over a defined data window. SCR is associated with the fast changing part of the signal and occurs in relation to a single stimulus [88]. Latency and magnitude of SCR and average SCL are the most used values to analyze in EDA studies.

Since, when experiencing stress, one of the reactions of the ANS, as depicted in Table 2.1, is to increase the glandular secretion through the SNS (which results in oily skin, for example), EDA can be used to assess sympathetic activity.

During stressful situations, the skin conductance level increases due to secretion by the SNS, resulting in a peak, as we can see in Figure 3.3.

Besides, as stated in 2.2.3, fatigue is also related with autonomic activity, which makes EDA a viable study for it as well [89]. The sensors for this parameter are typically placed in peripheral areas like the hand's fingers, due to the high density of sweat glands present in that area [64].

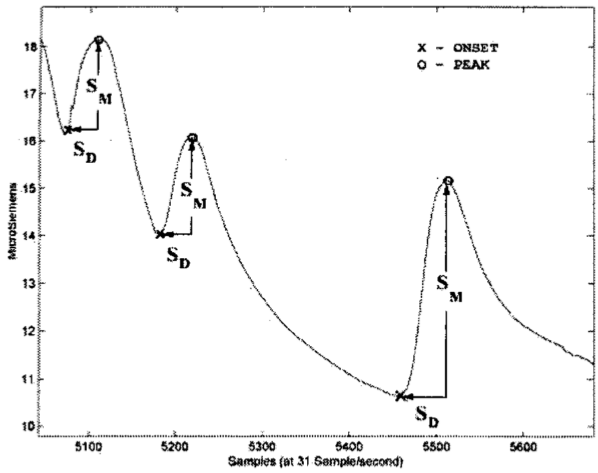


Figure 3.3: Example of a EDA graph where the three peaks identified are associated with stressful events. SM and SD are features of the signal (Signal Magnitude and Signal Duration, respectively) that are also relevant for its study. Source : [90]

3.1.4 Skin Temperature

Stress is also related with temperature changes in the human body. Skin temperature varies directly with the blood flow in blood vessels. However, some conditions may alter as well, like the environment, evaporation, core temperature and muscle tone. Since, during the stress response, the ANS activates different mechanisms that influence the blood flow to the organism, the measurement of skin temperature can provide some information about this behavior [91].

A recent study concludes that the exposure to stressful events resulted in consistent changes in skin temperature that followed a gradient type pattern with temperature decreases in specific locations like the fingers (fingertip and finger base). Gender proved also important due to the decrease in nasal skin temperature in females and an increase cheek temperature in males due to stress. However, some precautions should be taken to attain for external influences. The room temperature should stay the same throughout the whole experiment (approximately 24 °C), and a clear distinction between male and female subject should be done as well [91][92].

3.1.5 Salivary Cortisol

During the stress response, the ANS change the secretion of some hormones in our body, as described earlier in 2.1.1. Changes in Salivary Cortisol may occur possibly due to this mechanism. Therefore, it has been used for several studies of stress. This parameter is known to increase with psychological stress differently in males and females as well [93]. However, even being a non-intrusive parameter, the study of Salivary Cortisol implies following a protocol to guarantee reliable results. In [94], for example, it starts by collecting saliva from the surgeon into a cotton swab or *salivette*, immediately before and after each procedure, with the correspondent times of collection recorded as well. Samples were then stored at -20°C prior to the analysis, which is then performed in different steps:

- First, the saliva is removed from the swab by centrifuging the samples at 1000x during 5 minutes;
- Afterwards they are stored at 4 °C;
- Cortisol concentrations are then determined by luminescence assay.

Furthermore, subjects were instructed to report activities that may influence the final outcome (e.g. recent food, caffeine intake, tooth brushing, exercise, etc.) A total of 54 procedures were observed with 11 surgeons, where 23 of those procedures were self reported as stressful. Results show that salivary cortisol had an specificity of 91% and sensitivity of 70% for detecting stress during surgery [94].

3.1.6 Oculomotor Measurements

Ocular muscles are highly innervated by the ANS, therefore it is natural that the analysis of the eye can provide information of autonomic activity. There are different parameters that are controlled unconsciously, and have been reported to be related with fatigue in humans:

- **Pupil size** has been successfully used as measure of cognitive workload [95];
- Recently, in 2011, a study developed by the United States Air Force Research Laboratory concluded that the **pupil position** can be used to detect fatigue in relevant military aviation tasks [96];
- **Blink frequency** has been reportedly associated with both fatigue (where it becomes slower (i.e. frequency decreases)) [97] and stress (where it increases) [98]. Blink duration has also been used to assess fatigue [99];
- Schmidt *et al.* reported an overall slowing of **saccadic velocities** due to mental fatigue [100];

- **Eyelid closure** has been also used, together with HRV, to estimate the driver's drowsiness level [101] with high accuracy.

3.1.7 Electroencephalography

Electroencephalography (EEG) is a common method to assess brain activity. More specifically, to assess voltage fluctuations resulting from ionic current flows within the neurons of the brain [102]. The different recorded signals can be categorized into 4 frequency bands [103]:

- Delta band (0.5 – 3 Hz);
- Theta band (4 - 7 Hz);
- Alpha band (8– 13 Hz);
- Beta band (13 – 30 Hz).

The amplitude of the signals ranges from 2 to 100 V. Data above this superior limit can be due to the addition of noises or artifacts (e.g. eye movement, electrode noise). Therefore, a filtering (e.g. threshold) of the signal must be done previously to obtain reliable data [103]. Fast Fourier Transform can be used, as with ECG, to obtain the signals' spectrum.

By comparing the amplitudes of EEG alpha and beta bands, one is able to monitor the subject's emotion state [104]. An increase in the Alpha band power has been reported to be related with relax and conscious conditions [105] while stress due to anxiety, excitement and tension lead to a higher Beta band power [106]. A decrease of power of both bands seems to be related with intense mental activity [105]. Other important parameters include *Arousal*, which is defined as the ratio between the Beta and Alpha bands and *Valence* which is the ratio of alpha power between the F3 and F4 areas [107] illustrated in Figure 3.4. More specifically, Arousal defines the intensity of the emotion and Valence how negative or positive it is. This two values are often used in a two dimensional emotional representation [108].

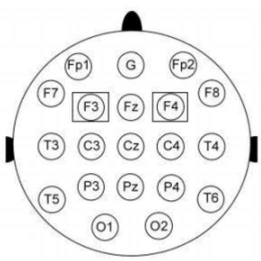
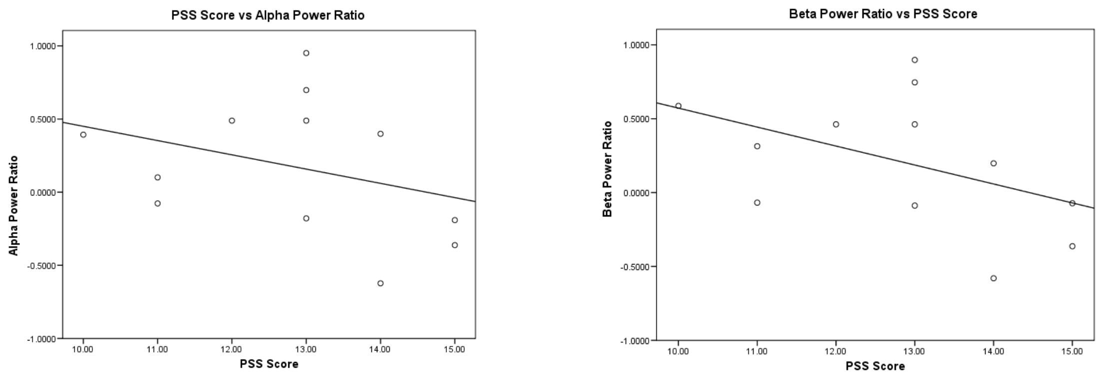


Figure 3.4: Standard Electrode Placing for EEG. Source:[108]

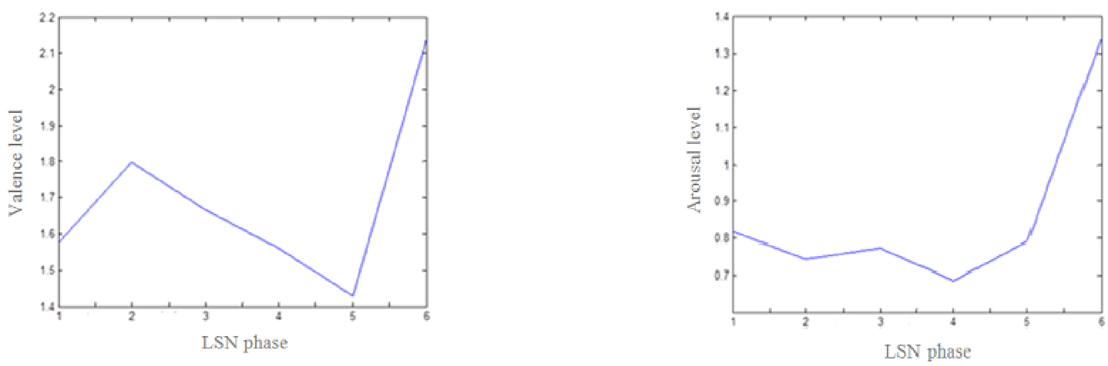
Having this in mind, Hamid *et al.*. reported a negative correlation between Cohen's Perceived Stress Scale (PSS) stress scores and EEG power spectrum of both alpha and beta components [109]. Figure 3.5 shows these results. In the other hand, Duru *et al.* reported the application of EEG for stress measurement during Laparoscopic Simple Nephrectomy using the two dimensional

Arousal-Valence model. They divided the surgery in 6 different phases and calculated the Arousal and Valence values for each one. They concluded that phase 4 was the more problematic due to it being the one with the overall lowest Arousal and Valence values [107]. The results are shown below in Figure 3.6. In order to perform an EEG, the usage of a headset to extract this kind of signal is needed. With the recent advances in technology, comfortable systems have been developed that enable the extraction of this type of information (see 3.2.4).



(a) (b)

Figure 3.5: Correlation results between PSS score and Alpha Power Ratio (a) and Beta Power Ratio (b). Source: [109]



(a) (b)

Figure 3.6: Mean Valence (a) and Arousal (b) levels in one of the LSN surgeries. Source: [107]

3.1.8 Subjective Measurements

As described earlier, a subjective appraisal of an individual is also important to understand exactly the levels of stress and fatigue experienced. Besides, this kind of approach helps complement the physiological results obtained. With this in mind, there are questionnaires developed solely for stress and fatigue studies. In terms of stress, the most widely used and accepted surveys are the State-Trait Anxiety Inventory (STAI) and PSS.

Several Subjective rating scales have been developed to measure fatigue. Some of the available methods are the Fatigue Severity Scale [110], Fatigue Assessment Inventory [111], Fatigue Impact

Scale [112], FACES (Fatigue, Energy, Consciousness, Energized and Sleepiness) [113], Visual Analog Scale for Fatigue [114] as well as the National Aeronautics and Space Administration Task Load Index (NASA-TLX) [115].

3.2 Monitoring Systems

Modern technology has enabled the creation of devices that can be worn by its users as simple accessories and even cloths, while providing reliable quality information about their vital signs and movements. This has enabled the quantification and tracking of one's behavior in a non-intrusive way and thus permitting to study several disorders and behaviors in an everyday life environment that cannot be reproduced in a laboratory. Furthermore, the market of wearable devices has grown tremendously in 2015. According to a study performed by the International Data Corporation (IDC), shipment volumes will reach 72.1 million units during 2015 alone, which represents a growth of 173.3% over the previous year. In addition, according to the IDC's forecast, this market is predicted to grow up to 155.7 million units in 2019 . One of the reasons for this incredible growth is the possibility of this wearables running third party apps, raising the expectations of what this kind of devices can do [116].

3.2.1 Smartphones and Wristbands

Today, everyone has access to their mail, social media and even news just with a simple touch in their smartphone. But not only that, today's smart mobile devices have imbued in them many sensors that years ago would be impossible to have in a pocket. High processing power, sensors like the Global Positioning System (GPS), Accelerometer (ACC) and the wide access to the internet are now available everywhere, and at very low prices. Furthermore, with the growing interest of the public in quantifying their own vital signs, there has been a high concern of the mobile industry in embedding their products with physiological monitors.

The latest releases by Samsung, the Samsung Galaxy S5 and S6, both come with an HR sensor. This sensor is actually a pulse oximeter [117]. The device works by shining red and infrared (IR) light on the finger and measuring the amount of light that is absorbed by the blood, which is correlated with the blood volume in the skin, resulting in an PPG. Afterwards, with the correct approach, one is able to extract the HRV information [118]. However it requires a person to leave its finger still upon the sensor, which is not very practical for a continuous monitoring. This is just one of the examples already available.

But besides this imbued capabilities, the mobile industry is now expanding to other hardware devices that can be worn by the users and complement the already long list of smartphone sensors that exist. Smart watches and wristbands are now entering the market and, with them, the possibility to better monitor vital signs while complementing that information with the processing and storage power of modern smartphones. One of the recent examples is the Samsung Gear 2, which also possesses a pulse oximeter which works like a HR Sensor, just as in the Galaxy S6 [119]. However, one just need to wear the watch in order for the device to gather the wearer's vital signs, enabling a continuous monitoring during everyday events and complement that information with the localization and movement sensors. Apple (through Apple Watch), has also been investing in this market. Other companies have been focusing only in development of the smartwatches. Fitbit's Surge [120] and Basis' Peak [121] are examples of this.

Therefore, considering all these products from influential companies in mobile and sports technology, it is clear that there is a commitment of the industry to include physiological sensors in every day, comfortable devices in order to improve the quantification of one's vital signs and increase health awareness.

(a) Source: [117][119] (b) Source: [121]

Figure 3.7: In (a) Samsung Galaxy S6 (left) and Gear 2 (right) and in (b) the Basis Peak.

3.2.2 Wearable Biometrical Shirts

A new generation of technology imbued cloth is revolutionizing the way we monitor our activities. An example of this is Vital Jacket®.

Developed in the Institute of Electronics and Telematics Engineering of Aveiro of *Universidade de Aveiro*, Portugal, and later licensed to a biomedical engineering spin-off company called Biodevices, S.A., Vital Jacket® (VJ) is, basically, a t-shirt composed by textiles and microelectronics that makes it an wearable vital signs monitoring system capable of obtaining clinical quality signal [122].

A certified medical device, and in the market since 2010, VJ includes a small (66x38x16 mm) and lightweight box (50g), that sits in a pocket inside the t-shirt, and stores the recordings from the sensors on the fabric in an SD card. Furthermore, it has a Push Button system that registers the action in the recording. Besides this, VJ also has a Bluetooth transmitter which enables the coupling of this device with smartphones or a Portable Computer (PC), for example, enabling the real time view and analysis of the signal. A 3 axis accelerometer can also be found embedded in this device, which enables matching of the vital signals with the users' movement intensity [123]. This t-shirt is capable of continuously recording ECG information as well as some other vital signals during several hours or even days, depending of the version used, and thus enabling non-intrusive studies of physiological behavior in an everyday life environment. Furthermore, efforts have been made by Biodevices to provide support to the development of software based in Matlab® or Android, making this product also attractive to developers. In Figure 3.8, an exemplar of this product is shown.

OMsignal's Biometrical Smartwear® [124] and Carré Technologies' Hexoskin® [125] are other examples of wearable biometrical shirts which are available in the market, very similar to VJ. In Table 3.1, a comparison between each device is presented.

Still not fully developed, but worth mentioning, is another Carré Technologies' product – the Astroskin, in which the Canadian Space Agency is also working on, with the purpose of monitoring the astronauts' health on board the International Space Station. This device is reported to have a more sophisticated ECG sensor and an optical sensor for blood oxygenation quantification. In addition, using data from other sensors, this features will enable the calculation of blood pressure as well [126].

HealthWatch's Smart Garment® [127] and nuubo's nECG Textile® [128][129] are other monitoring devices worth mentioning. However, this smart clothes are, presently, solely directed for Holter monitor replacement, containing only the ECG sensors, and not for an everyday study and correlation between cardiac behavior and other parameters like motion.

Figure 3.8: Biodevice's Vital Jacket®. Source: [123]

Table 3.1: Specifications of some biometrical shirts available in the market for continuous monitoring.

Characteristic	Biodevices, Vital Jacket®	OMSignal, Biometrical Smartwear®	Carré Technologies, Exoskin®
Device Weight/Measures	50g/ 66x38x16mm	Information Not Available	40g/ 41x73x13 mm
Features	ECG, ACC	ECG, ACC, Straps	ECG, ACC, Straps
Connectivity	Bluetooth	Bluetooth	Bluetooth
ECG leads	1 and 5	3	1
Sampling Rate	500 Hz /channel	256 Hz	256 Hz
Recording Time	Up to 168 hours (7 days).	30h active use	Up to 150 hours of standalone recording
API/SDK	Yes/Yes	No/No	Yes/No
SD Card	Yes	No	Yes
Starting Price	$600	$109	$399
Certification	CE, Brazil (ANATEL)	None	CE,CFF
Available since	2010	2014	2013
Other	Washable Clinical Quality signal, Push Button	Washable, App available for iOS, Clothing line	Washable, App available for iOS and Android

3.2.3 Others

Holter-like remote ECG monitoring systems with smartphone connection have appeared in the market recently, which also provide a reliable solution for a continuous monitoring of the heart behavior. Example of this are the Mega Electronics' eMotion® ECG [130] and SHL's SmartHeart® Pro [131]. However, they are much less comfortable that wristwatches or t-shirts, due to the way the sensor must be placed in the chest, as we can see in Figure 3.9a, for example.

Another example is the Vital Connect's HealthPatch® [132], which is a disposable biosensor. Just like the name suggests, this monitoring device is a technology imbued adhesive which tracks vital signs and sends them to a phone. However, it is very limited in terms of longevity since it is generally discarded after one use, just like a regular adhesive.

3.2.4 Fatigue Monitoring oriented devices

Optalert™ has developed drowsiness detection glasses which incorporate a system of IR reflectance oculography to measure and characterize the physiology of alertness and drowsiness in real time. With a sampling rate of 500 Hz, this device records and analyses the eye and eyelid movements, which are key to identify fatigue. This device is normally licensed for companies which aim to ensure safe, high-performing, 24-hour operations. The system has been scientific validated through studies which were successfully publish in journals [133] and conferences [134] of the area of sleep and fatigue monitoring. Another unique device which is available in the market is the SmartCap®, by EdanSafe. This system is composed by sensors which are capable of reading EEG through hair, without the need for any scalp preparation [135]. With this kind of information, and the help of a Bluetooth enabled device (i.e. a smartphone) , it is possible to determine the user's level of fatigue and display it on the device.

(a) Source: [131]

(b) Source: [135]

Figure 3.9: In (a) SHL's SmartHeart® Pro and in (b) the Edansafe's SmartCap®.

3.3 Studies

With the measurement methods already described, in conjunction with state-of-the-art mobile technology, several studies of stress and fatigue in professionals have been reported. This have spread in a number of different areas due to the different environments and factors that the workers are exposed to.

3.3.1 Police Officers

The job strain that Police Officers experience is quite unusual and unique, due to the dangerous nature that it is related with. Furthermore, it is an occupation frequently reported in the literature for being particularly stressful [21].

In 2011, a study was published where an officer of the Seattle Police Department was monitored through the use of a GPS enabled wrist watch monitor equipped with a wireless HR monitor chest strap during his regular shift. The study concluded that the methodology applied (using physiological sensors complemented with geographical information) is both feasible and suitable for systematic studies of police stress. This information can be used as a base for redistricting, instead of volume alone, possibly improving the performance of the police team in their zone [136].

3.3.2 Nurses

As is well known, nurses are exposed to a lot of stressful situations during their work hours, being constantly called for urgencies and continuous patient treatments. Therefore, the study of their vital signs during their daily routines can also contribute for better performances by this type of professionals. Jovanov *et al.* presented a monitoring architecture to study the stress of nurses using an approach very similar to others described previously. The nurses wore a standard monitoring belt (for HR data) and a foot pod sensor (for step count), which communicated with a personal server (i.e. smartphone). This device would then transfer the information to a server where it would be available through a web interface (like a PC) [137]. Results show that HR and HRV can be reliably measured using wearable sensors to assess allostatic load [138].

3.3.3 Surgeons

It has been reported that excessive levels of intra-operative stress can compromise both technical and nontechnical skills [8]. This leads to a degradation of the overall surgical performance of the professional and, therefore, of patient outcome. As in previous studies, monitoring of surgeons can be very helpful for the surgery team management in order to minimize possible mistakes.

A large portion of the recent studies made so far have analyzed surgeon's vital signs during Laparoscopic surgery (a type of general procedure), also called Minimal Invasion Surgery. Cardiac surgery professionals are also being the target of some research as well. The increased likelihood of exposure to stress due to the nature of the workload of this type of procedures seems to be the main reason why there is a larger amount of studies in these areas [139]. Some systematic reviews of stress and fatigue effects on surgeon performance have been developed as well, which support a more detailed research in this field [7][140][141].

As stated previously, the psychological approach is important to complement the physiological evidence of stress and fatigue. With this in mind, researchers have developed a modified NASA-TLX questionnaire for application in surgery, called Surgeon Task Load Index (SURG-TLX) [142]. Developed by Wilson *et al.*, this tool aims at measuring surgery-specific multidimensional workload, which increases with the obtained score, and has been reported to be associated with poorer performances in surgery [115] and is sensitive enough to evidence differences in the roles of the surgical team members and the different stressors that the procedure induces on them [143].

Others rely in the NASA-TLX for workload measurement [115]. To assess stress, the STAI form has been the standard subjective measurement method. However, a six item version [144] of this tool seems more appropriate for surgery assessment due to the amount of time needed to fill this, compared to the 40 item version [94].

Arora *et al.* have been conducting studies in this field and developing a tool for stress appraisal during surgeries called Imperial Stress Assessment Tool, which is composed by three different tests (salivary cortisol, HRV and the 6-item STAI), as we can see in Figure 3.10 [94]. Since the publishing of this tool, Arora has been using it to interesting results in stress appraisal during laparoscopic surgeries [145][146]. Furthermore, a study made in 2013 used EEG as a parameter to detect stress in surgeons during an Laparoscopic Simple Nephrectomy [107].

Stress has also been reported to be related to the role of the surgeon (main or assistant) during a procedure as well as to the experience of the professional. A study published in 2009 assessed the relationship of the role with mental strain during 50 coronary artery bypass graftings (a cardiac procedure). The subject was an attending-consultant surgeon who was the main surgeon in 30 procedures and supervised another 20 performed by two resident surgeons. To assess stress, the ECG was recorded with a Holter device and HRV parameters were extracted. The study identified different reactions during the roles, being the surgeon more anxious during the procedure while supervising [147].

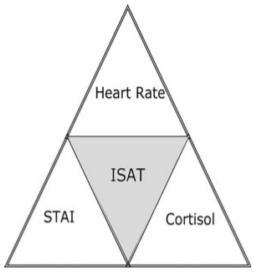


Figure 3.10: Imperial Stress Assessment Tool structure illustration. Source: [94]

3.3.4 Firefighters

A firefighter is trained to perform under high pressure and dangerous situations that are simultaneously physically and psychologically demanding, exposing the professionals to different stressors in a very aggressive environment. According to the U.S. Fire Administration, 34.9% of firefighter fatalities in the U.S., from 2013, were as a result of cardiac or cerebrovascular complications (e.g. heart attack, strokes) [148]. This presses the development of a monitoring system to alert this professionals of their vital signs during field operations to prevent this kind of losses.

An interdisciplinary project called Vital Responder formed by teams of the Institute of Electronics and Telematics Engineering of Aveiro, Carnegie Mellon University, *Instituto de Telecomunicações* of Porto and Aveiro and Biodevices, S.A. have used the aforementioned Vitaljacket®, together with other sensors, to study physiological signals of firefighters during their daily routines to identify stressors. Analyzed signals include HRV and BVP [86]. To complement this study, a psychological approach with questionnaires to the first responders was also done in another work. These questionnaires were developed specifically for the purposes of this project [149] [150]. In one of the studies, morphological wave alterations were seen to significantly differentiate the most stressful tasks from the others [151]. In conjunction with smartphones, both physiological and psychological approaches were continuously studied. Overall, this project was able to analyze how firefighters cope with stress and fatigue during their daily tasks, resulting in a system that measures the professional's vital signs during uncontrolled environments with the help of wearable technologies .

3.3.5 Car Drivers

Fatigue in drivers has been a subject of great interest due to the high life risks related to it. A recent study used eyelid movement, mouth movement and HR as the parameters to successfully detect stress in drivers. However some modifications on the system's hardware are needed to be able to cover all possible cases of use [87]. Recently, EEG has also being used to assess fatigue in drivers [152][153].

Another recent study used the Optalert™ system to assess the relationship between sleepiness and the incidence of adverse driving events in nurses commuting to and from night and rotating shifts during 2 weeks. The maximum total blink duration was associated with greater incidence of sleep-related events. This study concluded that, under real-world driving conditions, shift working nurses experience high levels of drowsiness as indicated by ocular measures [133].

A study in the city of Porto, Portugal, has been conducted to detect bus driver stress during daily routines. The study used VitalJjacket® for physiological signal (HR) gathering, a GPS to obtain geographical data and an On Board Diagnostics unit. In one specific exit of a bridge called "Ponte do Freixo", high levels of stress were identified. The existance of high traffic in the area may be the reason for this finding. This type of information can be used to improve road signals, to increase drivers' awareness of dangerous places or to detect and prevent imminent accidents [154]. A different approach to driver monitoring is being developed by Plessey Semiconductors. Instead of using an wearable monitor device, they are embedding the car seat with their EPIC ™ sensors which are capable of extracting the driver's EEG, ECG, and other physiological parameters [155].

3.3.6 Crowd Sensing

As we have seen, the monitoring of different professionals is possible and wearable technology is of great importance for this. Two recent projects have taken the concept of continuous monitoring to another level, by increasing the area of study from a few individuals and buildings to a whole city. Crowd sensing is a concept that very well describes the aim of these studies.

In Rome, a real time urban monitoring system was implemented using the *Telecom Italia LocHNESs* platform. This system was able to obtain a set of maps describing the vehicular traffic status and the movements of pedestrians and foreigners, as well as the instantaneous location of buses and taxis and the voice and data traffic served by all the base transceiver stations of the network. All the data collected was anonymous. However no vital signs were extracted in this project [156].

A more complex infrastructure was built in Porto. The project, called FutureCities, implemented a network of sensors through the city, which include:

- 802.11p technology, WiFi or 3G in taxis, buses and harbor trucks for vehicle traffic, intercommunication and provide WIFI access,

- Vital Jackets, Smartphones and On Board Diagnostics units for vital sign monitoring of different individuals and professionals;
- A large scale infrastructure for local monitoring of a dedicated environment using heterogeneous sensors to cover a fixed area.

All this information and monitoring has turned the city into an urban-scale living lab, enabling a true sensing of their citizens or, in other words, crowd sensing. With this project, researchers and companies can develop and test technologies, products and services, exploring such subjects as sustainable mobility, urban-scale sensing, safety and privacy, as well as the quality of life for citizens and their families [157].

3.4 Conclusions

Besides cardiac behavior, several other parameters have been used, with success, in the literature to identify stress and fatigue. Some even reported these results backed up with the subjects' perception of the events as well, making a complete and rigorous assessment of these disorders, as advised in Chapter 2. The great growth that mobile and wearable technology have been suffering has also helped the improvement of studies in this area, enabling non-intrusive monitoring of professionals and different parameters in ways never possible before. This concept of physiological monitoring is also being spread to accommodate physiological data of entire cities, instead of one or two individuals, further enabling the study of human habits and improve the overall quality of life of the citizens.

Part II

Monitoring Stress and Fatigue

Chapter 4

Developed Tools

4.1 VJ E-Diary

One of the problems that arises with real-time monitoring is the correct registering of relevant events. One of the great features of the aforementioned VJ (see Section 3.2.2) is the possibility of registering events through the Push Button. Furthermore, the Android library released by Biodevices enables the developer to trigger the event associated to the button programmatically, therefore enabling the customization of highly precise event registration.

Therefore, a VJ electronic diary (VJ E-Diary) was developed in Android, in order to help researchers register events throughout their monitoring sessions in a feasible and practical way.

4.1.1 Structure

As a first step towards the conception of the application, requirements were collected from researchers who work in the area of physiological monitoring and recur to VJ during their sessions. The possibility to add details to certain session events as well as to save other types of information besides text (i.e. photos, video and audio) have been shown to be of interest to them. Furthermore, the synchronization with the information that VJ saves in the SD card through push button events was requested.

Besides the aforementioned feature, it seemed relevant to save the data following a certain structure. Therefore, in order to establish this, a Database also needed to be implemented. Finally, the possibility to send the content through the internet so that the data is not lost, and further enabling the researcher to access the data as soon as the session ends, without needing to recur to external tools, showed to be an relevant addition to the application. Finally, implementation of an User *Login* and *Password* framework was also considered.

Figure 4.1 shows the final Use Case Diagram (developed with Visual Paradigm for Unified Modeling Language (UML) 11.0) for the application resultant of the requirements gathering process.

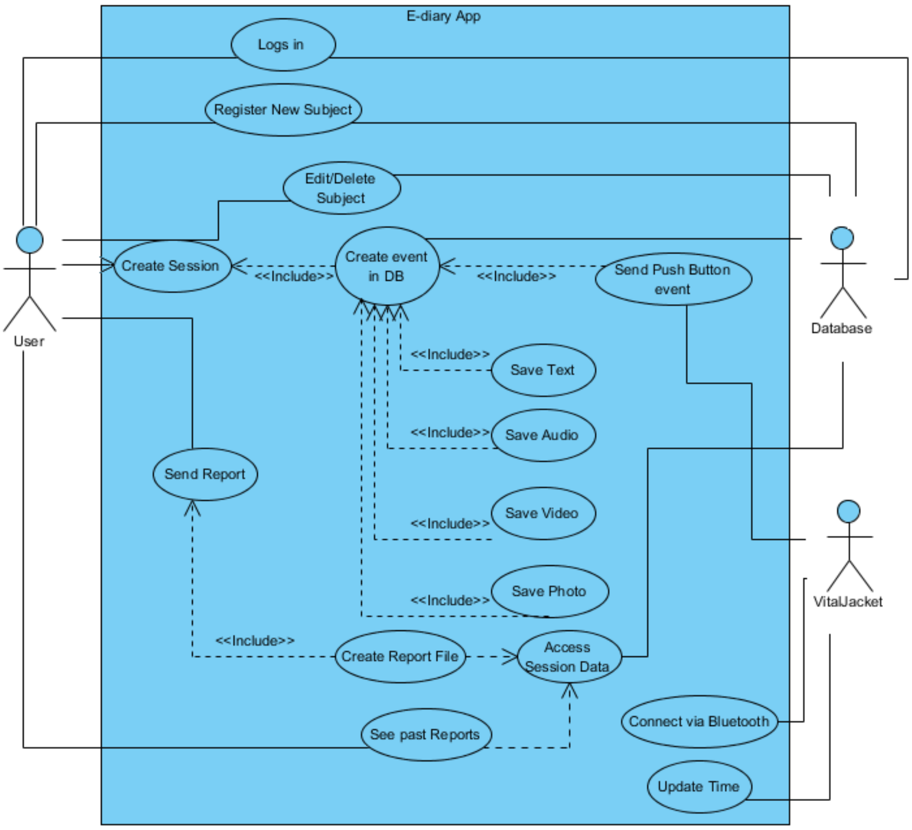


Figure 4.1: Use Case Diagram for VJ E-Diary

4.1.2 Database

A database was developed in SQL Light for Android and its structure is presented in Figure 4.2. This is formed by three main entities:

- **Login**

  Associated with this entity there are 4 entries. The *Username* is unique to each account and, together with the *Password*, constitutes the information that the user must input to access the application. For better differentiation, a *Name* was also associated to each account. Finally, an *Email Address* was also added in order to simplify the upload process that will be described later in Section 4.1.3.

- **Subject**

  Before registering events, *Subjects* must be available in the database. For each entry, an *Name* and a Device are needed, as well as the subject's current *occupation* (ie. Surgeon, Firefighter, etc.). An *ID* was given to each of the subjects in order to enable the association of one with different devices.

- **Event**

Events are the most complex entry in this database, requiring many details to be inserted correctly.

Each entry has its own, unique *ID* that is used to differentiate all the events. A *Session ID* is used to identify ensembles of events, and is later used to filter them. An *Event ID*, within the *Session*, is given for each event for better organization, later, with the User Interface (UI). *Main* and *Assistant* subject entries consist of the *ID* of the correspondent subjects. Every other entry is self explanatory.

With this structure, the application can access all information easily, and even add more if needed (for example, an physiological parameter file path), just by introducing a new variable in the *Event* structure.

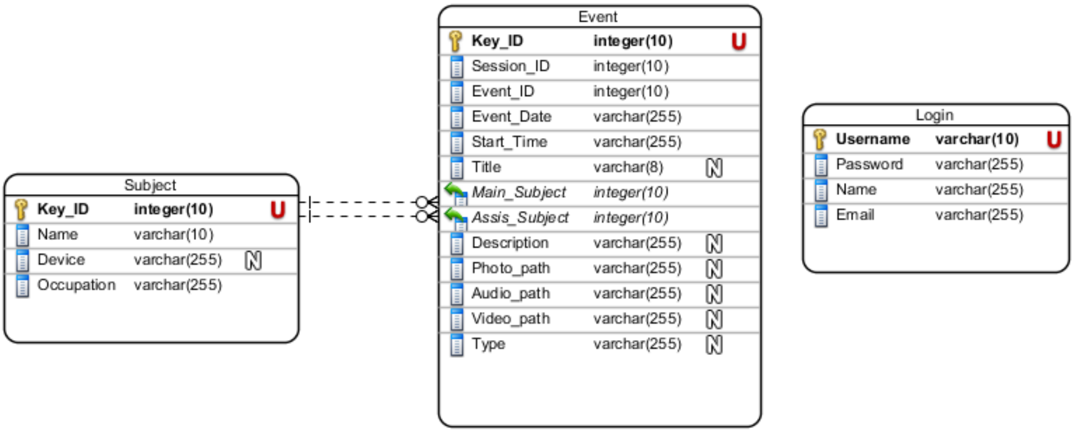


Figure 4.2: Database structure.

4.1.3 Workflow

In order to better illustrate the features and design of the developed application, an workflow will now be presented.

The application starts by asking for an *Username* and *Password* to login (Figure 4.3a). When entered correctly, the user is sent to the *Main Menu* (Figure 4.3b) where it is possible to access three different areas.

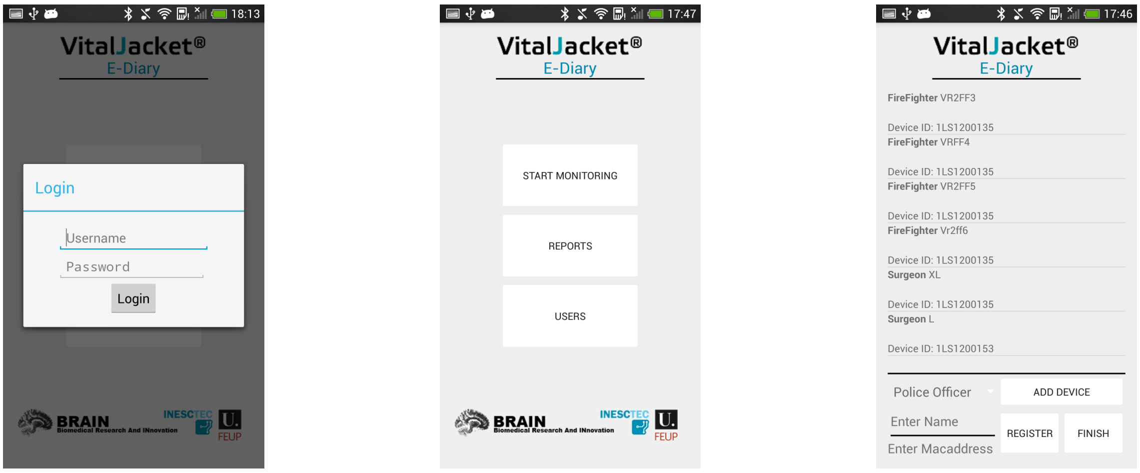
- **Subjects**

  Clicking *Subjects* redirects the user to an activity where all available subjects are presented (Figure 4.3c). In the bottom of the window there are different fields for the user to fill in order to register a new *Subject*. Clicking on *Add Device* will open an activity with the list of available devices from which the user can choose from. After selecting one (or even none) of the devices, the user is again sent to the *Subjects* area, but now with the field *Address* updated. After clicking Register, if all the fields are filled correctly, the list will add the newly registered *Subject* to the database.

By long clicking one of the entries in the list 3 options will be presented in a context menu:

- *Edit* - will open an activity with the devices available. After selecting one of them (or none), the subject's device address will be updated;
- *Delete* - Removes the subject from the database. Whoever, if the subject is associated with any event in the database this operation will not be performed and a warning will pop up;
- *End* - withdraw the context menu.

By clicking *Finish* the user is sent to the *Main Menu* again.



(a) Login (b) Main Menu (c) Subjects

Figure 4.3: Different activities of the VJ E-Diary app.

- **Start Monitoring**

  When the user selects this option, a new activity is presented where the target subjects to be monitored can be chosen. Clicking the *Add* button will connect the smartphone to the selected subject's VJ (Figure 4.4a). This is possible because of the associated VJ Bluetooth address in the *Subject* entity in the database (see Figure 4.2). If the connection fails the user is prompted to retry again the connection or cancel it. If the latter is chosen, the user will not be registered for monitoring.

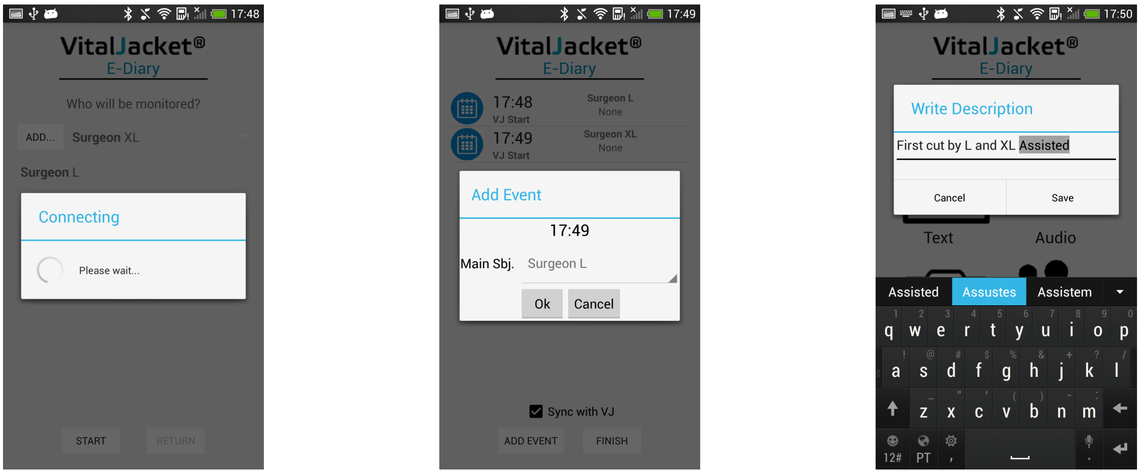
  However, if the opposite occurs and he is successfully registered for monitoring, his name will disappear from the available subjects list.

  After registration of the target subjects, the user is then sent to the *Report* menu where he has access to all the events registered so far in the session. The events associated with the start of the monitoring are automatically added (they correspond to the time when the user registered them for monitoring). Clicking the *Add Event* button will show a dialog box asking for the user to select who will be the *Main Subject* and *Assistant Subject* (Figure 4.4b). The app will connect to each VJ in order to send the push button event, but will disconnect right afterwards. By unchecking the box near *Synch with VJ*, this last step will be disabled. This was implemented in order to provide a safe solution to event registration when the VJ connection is, for some reason, not possible. This way, even though the events are not registered in the SD Card, they can still be found in the file produced by the app.

After this, the app will switch to the *Report Event* menu, where different types of reporting (text, video, audio and photo) are possible (Figure 4.4c). There can only be one file of each type of recording. Each file's path is associated to the current event in the database (see Figure 4.2) and enables its access easily afterwards. After clicking the *Finish* button the user will be prompted to associate a title to the event. It is this title that will appear in the event entry in the *Report* menu. Then the app will redirect the user again to the previous menu.

Finally, each event can be edited during the monitoring session by long clicking an entry. The user will be reconducted to the *Report Event* menu and any file there will overwrite the previous one for that event. Text is easily edited as well.

By clicking the *Finish* button the session will be closed and the user will be sent again to the main menu. The user can the access the recorded session data through the reports sessions, as described earlier.



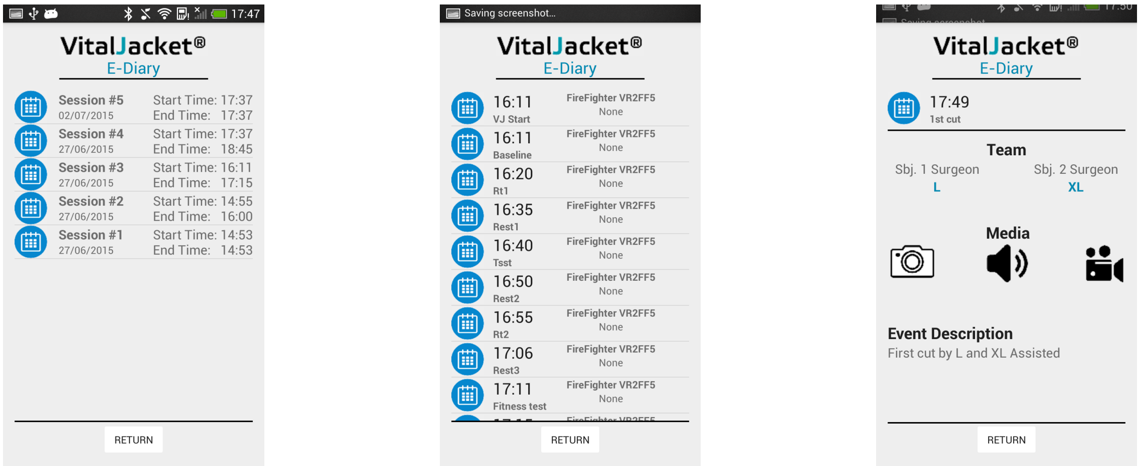
(a) Connecting to an VJ. (b) Selecting Main. (c) Writing Description.

Figure 4.4: Different activities of the VJ E-Diary app.

- **Reports**

  In this section it is possible to access saved *Sessions* (Figure 4.5a and their *Events* (Figure 4.5b). A long click on an session list item will pop up a menu that enables the user to send the selected *Session* information to their personal email (previously registered with their *Login* account) or upload the data to a *Dropbox* account. The file created is in *.xls*. All associated files to the *Session* (i.e. all event's audio,video,etc) will be sent/uploaded as well. The same is true for *Events*. It is also possible to delete *Sessions*.

Detailed *Event* information include all the media associated as well as text, as presented in Figure 4.5c.



(a) List of sessions (b) Sesssion's events. (c) Event Description

Figure 4.5: Different activities of the VJ E-Diary app.

All this processes are summarized (from the user's point of view) in a simplified Activity Diagram (also developed with Visual Paradigm for UML 11.0) shown in Figure 4.6. To clarify the processes behind the application's functioning, an detailed activity diagram was also created and is presented in Appendix D.

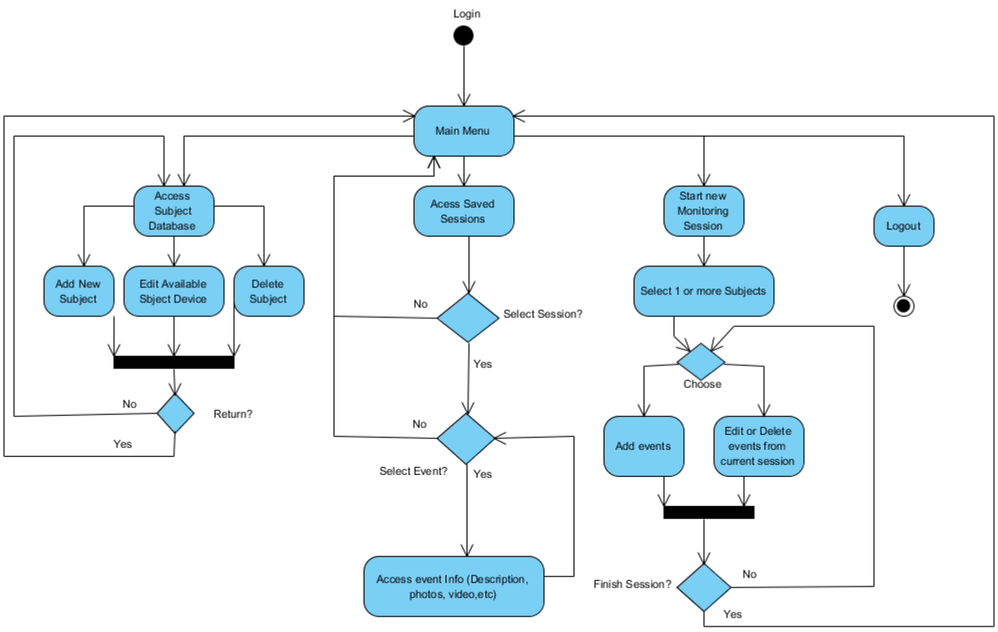


Figure 4.6: Simplified Activity Diagram for the VJ E-Diary App.

4.2 VJ Assembly

As seen in chapter 3, different parameters, either combined or alone, can be used to assess stress and fatigue. However, different hardware and other tools, like the reports, might be needed to collect all the data, leading to problems in its synchronization for a reliable analysis.

Therefore, a tool that can assemble and synchronize the data from different sources and present it to the users in a simple and reliable way can be useful to study stress and fatigue more efficiently.

4.2.1 Structure

VJ Assembly is a MatLab® program to extract the parameters from data files that are obtained from different sources in order to synchronize, organize and present the results to the user efficiently, providing the researchers a better overview of the acquired data effortlessly. An example of the use cases of this tool is presented in Figure 4.7.

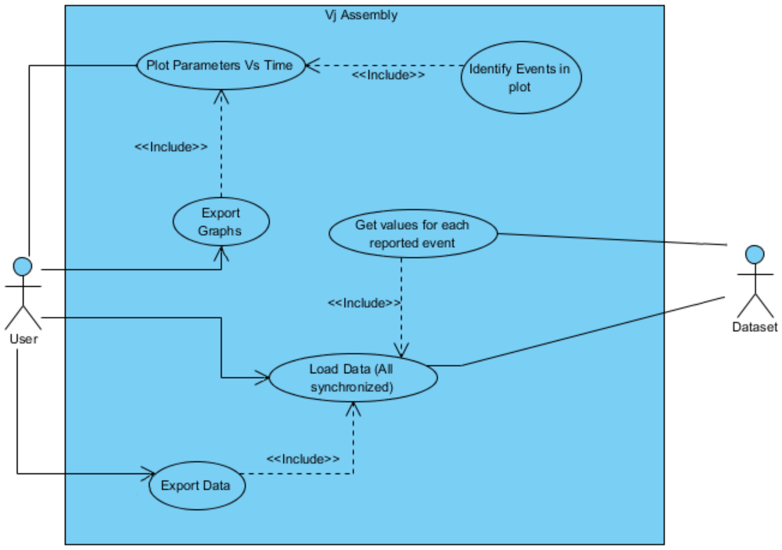


Figure 4.7: VJ Assembly's Use Case Diagram.

Considering the previously mentioned tools, as well as the studies developed in chapter 5, the types of data which are included in VJ Assembly are:

- EDA from Bitalino Board;
- ACC from VitalJacket®;
- HR from Biodevices' QRS detector;
- HRV data from files generated by SenseMyHeart (see section 3.1.1.6);
- Report files created by the VJ E-Diary app (see section 4.1).

However, HRV data can only be acquired after the original ECG file has been processed by different tools.

First, the RR peaks needs to be extracted from the signal into a format compatible with SenseMyHeart, so that it can perform the analysis in 5 minute windows.

To do this we recurred to the Biodevices' QRS detector, which relies in an improved version of the Pan and Thompkins Algorithm [158] by P. Hamilton [159]. Afterwards, several bins will be generated by the SenseMyHeart service, containing the HRV data for each 5 minute bin. This are the files that will be read by VJ Assembly.

A summary of the mentioned process is presented in Figure 4.8.

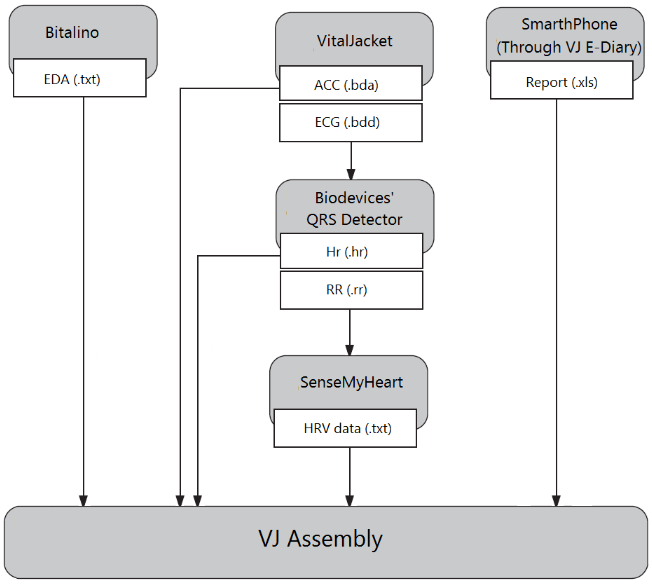


Figure 4.8: Simplified Diagram for VJ Assembly.

However, all this is only possible if a certain folder structure is followed rigorously. First, each project is composed by *Sessions* that are identified by *Date* and *Location*. Each session can have different *Subjects* and, for each *Subject* within that session, several *Runs* can exist. Finally, it is in the *run* folder that all the accessed files, mentioned in Figure 4.6, are placed.

4.2.2 Motionless Segments

Analysis of times when the subject is not in motion can also be important for study of stress due to the autonomic cardiac modulation associated to the subject's movement. Therefore, using the ACC data, a method was developed to generate 5 minute RR files where no considerable motion was detected.

The variation in the x,y and z axis values between each consecutive ACC entry was computed and then a sum of the absolute value of the variation in each component was added and compared to a threshold value for each entry (see eq. 4.1). This threshold was previously obtained from studying the average standard deviation (SD) of the three ACC components of participants while seated and using the VJ.

$$\Delta_{xyz} = \sum (\|\Delta x\| + \|\Delta y\| + \|\Delta z\|) \tag{4.1}$$

This threshold was previously obtained from studying the average SD of the three ACC components of participants while seated and using the VJ. During the generation of the RR segment, if the total time associated to values higher than the threshold, was greater than 15 seconds (i.e. 5 % of the total time window), then the segment up until that point is discarded and a new one is started again. Otherwise, if no considerable motion occurred during a total of 300 seconds (5 minutes), the RR values obtained for that time period were saved in a format equal to the one generated by Biodevices' QRS detector that can later be analyzed using SenseMyHeart.

An image illustrating this process is shown in Figure 4.9.

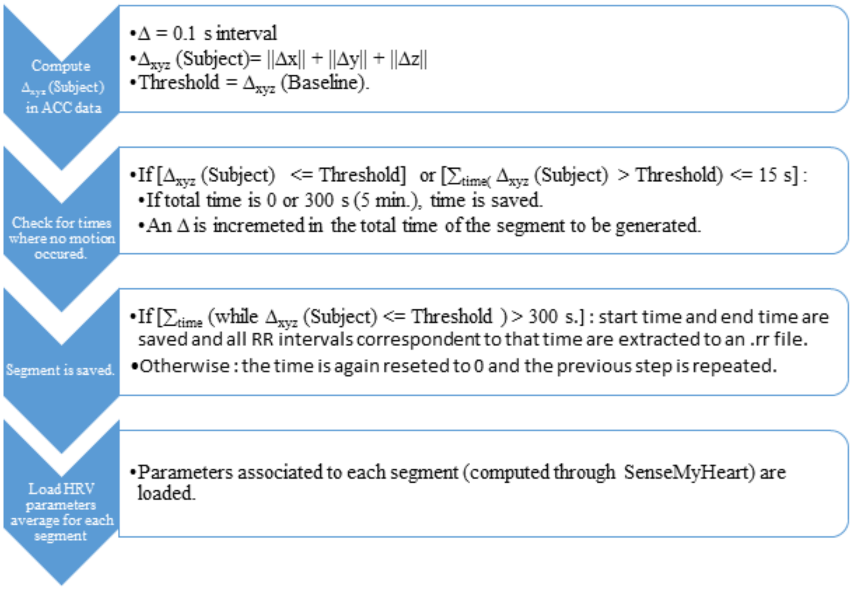


Figure 4.9: Algorithm for generating RR interval files correspondent to times where no considerable motion was detected.

4.2.3 Workflow

In Figure 4.10, an example of the program's interface is shown.

The user starts by selecting one of the available *Projects*, followed by the *Session* and *Subject* and then the desired *Run*. By clicking *Load Data*, an window will pop up and the user interface will be disabled until all the data is presented.

Each radio button in the *Parameter* section loads the corresponding data into the chart. If that parameter is not available for that specific run, then its button will be disabled.

In the *Event Analysis* section, different data can be observed :

- ***Full Data*** - All 5 minute segments generated by SenseMyHeart are shown. Furthermore, HR and EDA data corresponding to that period of time are also presented.

- ***Single*** - For each event reported, an 5 minute window was selected and resulting parameters are shown.
- ***Interval*** - This section shows the average of the parameters between each occurrence of events. All 5 minute intervals that occurred between two consecutive events are gathered and the average, for each parameter, is shown. Again, HR and EDA were also computed for the same interval.
- ***Motionless*** - If no motionless segments were generated, the button Generate Motionless Segments will appear below this option. After clicking it, an waintig window will appear and the routine described in section 4.2.2 will be performed. After all the data is placed in the correct folder, and the window has been cleared, this option will be enabled and the results regarding moments of time were no motion was detected will be shown.

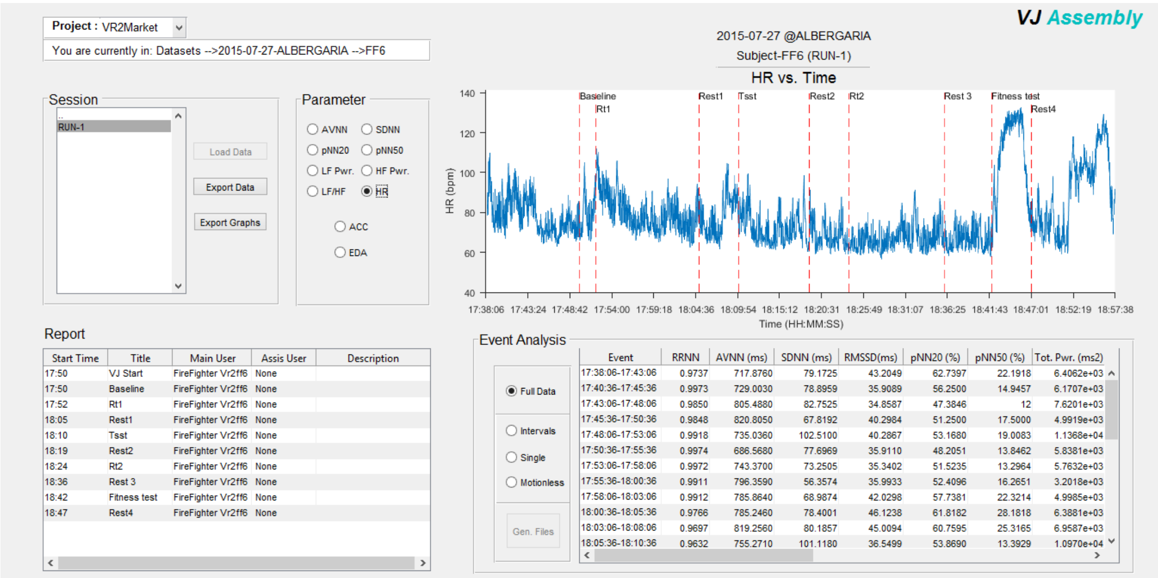


Figure 4.10: VJ Assembly's interface.

Finally, the *Export Data* button saves all the loaded data into an Excel and .mat file in the chosen destination. *Export Graphs* saves all the plots for that session, exactly as they appeared in the interface.

4.3 Conclusions

With the tools mentioned in this chapter, it becomes easier to both identify and analyze events in professionals during their daily routines without any need to interfere in their activities. Furthermore, the analysis is more accurate and reliable due to the fact these events can be annotated with some of the data (in this case, ECG through VJ) and that all data is correctly synchronized. Finally, this tools were developed to work with one another, and can be easily scalable to include other parameters from different sources as well as different methods of analysis, therefore showing great potential in the development of studies regarding physiological monitoring.

Chapter 5

Developed Studies

Since the purpose of this work is to identify events that induce stress and fatigue in professionals through assessment of physiological variables, different subjects (with different occupations) were monitored during daily activities. Also, an in-lab test was performed with the purpose of obtaining reactions in an controlled environment and find more about the physiological behavior of the individuals before going to the working field.

Two of the datasets (police officers and the pilot study in neurosurgeons) were obtained prior to this thesis. However, their analysis was part of the developed work and therefore was included in this section as well.

5.1 Police Officers

As mentioned earlier in section 3.3.1, police officers are exposed to stressful events regularly and is reported in the literature as a stressful occupation. Therefore, it becomes interesting to understand how these professionals react to stressors. One of the purposes of the SCOPE project is to study police officers' physiological variables during their work routines. Using their acquired dataset we performed an analysis in the ECG and ACC signals to assess which events can induce stress in this occupation.

5.1.1 Dataset

The available dataset is composed by 6 male police officers, aged between 31 and 44 years, and was gathered in the framework of the SCOPE project from July, 2013 to May, 2014.

5.1.2 Protocol and Tools

To obtain this dataset a specific protocol was followed:

- Data was collected during one shift and one day off, using the full "kit" (SCOPE app + VJ) only during the working shift. On the day off the participants were required to only use the VJ, in order to collect baseline physiological data.

- At the beginning of each shift the participants dressed up the VJ and the ECG electrodes were placed following given instructions. Then, they switched the smartphone, launched the SCOPE App and filled in an initial stress questionnaire. Following this procedure, the officer was ready to carry the equipment for the full working day period.

- Following the experience of a stressful situation, participants were required to fill in the event questionnaire on the smartphone, including a description of the event (e.g., checklist of possible options was provided) and ratings of stress appraisal. These events were saved in the system and could also be available for police officer description later at the end of the work shift.

- At the end of the shift, a researcher met the participant at the police station, and checked if all the data in the VJ was synchronized with selfreported information. Afterwards, the user exported all the data collected during the shift to a web-server by clicking on a single button of the smartphone. The processed ECG data, together with the GPS information and the Google Earth platform, as well as the ACC data, was used to identify events of interest in the map, labeled as events, displaying the information for the full workday of that participant. For each of the displayed events, police officers visualized the exact location, thus, facilitating memory retrieval of the experienced situations. In the event any selfreported data was missing, (e.g. situations when the participant could not remember the event) a brief interview was conducted to facilitate the officer's memory recall and complete missing information. Therefore, the participant was asked to recall the situation identified by the events, and to provide a brief description of it. This process was simultaneously completed in the computer and stored and synchronized with the physiologic data on the cloud server. All the protocol is resumed in Figure 5.1.

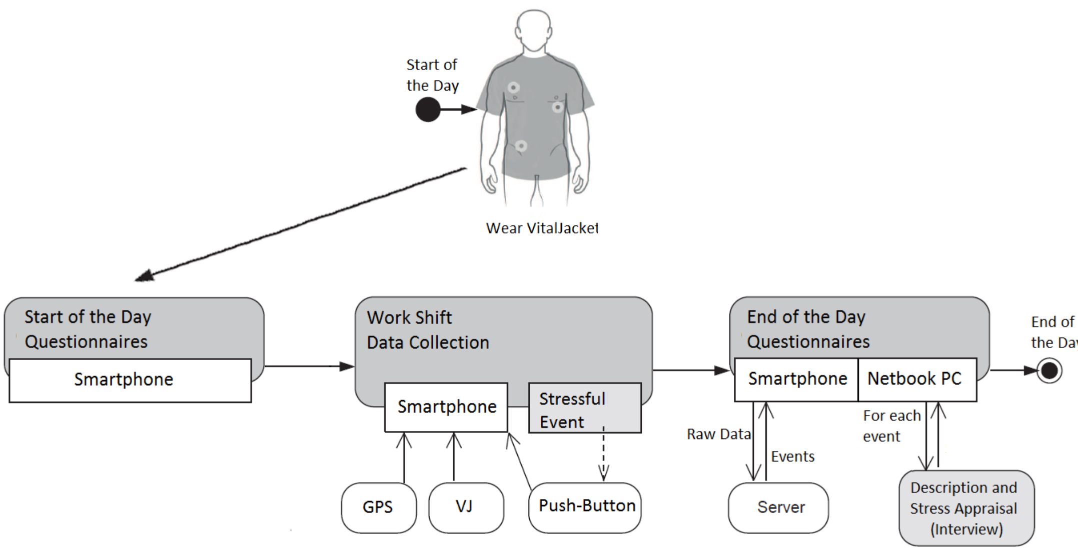


Figure 5.1: Diagram of the followed protocol during monitoring sessions.

From this protocol, we recurred to the ECG and ACC data, obtained from VJ, as well as the self reports gathered, to obtain the results that will be presented. ECG signal was obtained through the use of the already mentioned VJ. With this in mind, we used the SenseMyHeart service, described in section 3.1.1.6, and VJ Assembly (section 4.2) to extract parameters from the recorded signals and analyze them.

Specifically, a comparison of stress during work days and days off was conducted as well. In order to better differentiate stress activity from physical activity, the ACC data provided by VJ was considered for the analysis. In order to see how physiological behavior changes in work days and non-workdays several 5 minute segments were extracted for each participant. These segments correspond to times when the participant was not in motion in order to exclude autonomic cardiac modulation due to movement. The extraction method followed was the one described in section 4.2.2. The same number of segments was computed for the shift day and day off of each participant and an average of the LF/HF ratio for each selected time period (segment) of each day was obtained. Only ECG recordings from six participants were considered for analysis, due to the high noise present in one of the participant's cardiac signal (probably, the electrodes were misplaced).

5.1.3 Results

Based on self-report data when synchronizing with ECG information results show that only two events of intense stress were detected (driving fast; gun situation) based on the analysis of pNN20 and associated LF/HF (see Figure 5.2 and Figure 5.3).

Additionally, a high LF/HF average, when compared to standard values in the literature [160], was detected for all the subjects, (except for Participant 2 and 3) during their work shifts and the days off (see Table 5.1), suggesting the exposure to high levels of stress during their work routines.

Table 5.1: Average LF/HF during the motionless moments during shift and days off. The same number of 5 minute segments (N) was extracted for each subject. Corresponding total minutes are also presented.

Participant	N (min.)	LF/HF (shift)	LF/HF (day off)
P1	2 (10)	4.8 ±0.2	3.5 ±0.6
P2	39 (195)	2.1 ±1.2	2.2 ±1.7
P3	26 (130)	3.0 ±0.9	2.3 ±0.7
P4	29 (145)	6.6 ±2.7	5.8 ±2.3
P5	33 (165)	6.3 ±2.5	3.6 ±1.0
P6	45 (225)	4.9 ±1.6	4.7 ±1.9

The results shown in Table 5.1 are collected from several 5 minutes segments where the participant is always relatively still (e.g. seated), which was possible to obtain by analyzing the ACC data (through the Motionless method described in section 4.2.2).

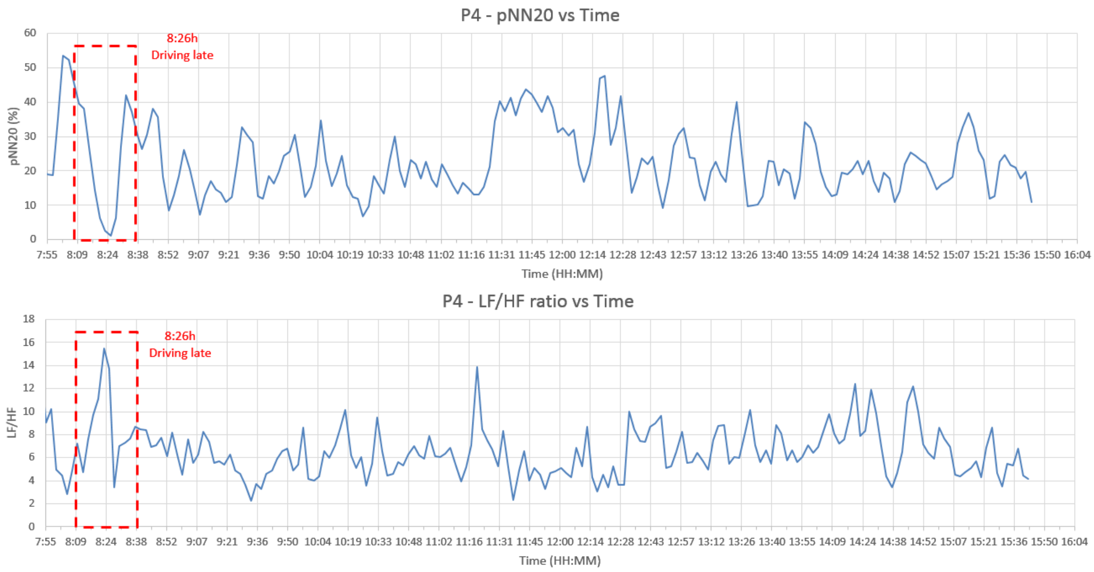


Figure 5.2: ECG signal analysis for Participant 4 (P4), reporting one stressful event (driving late). On top, results regarding pNN20 over time. Below results regarding LF/HF.

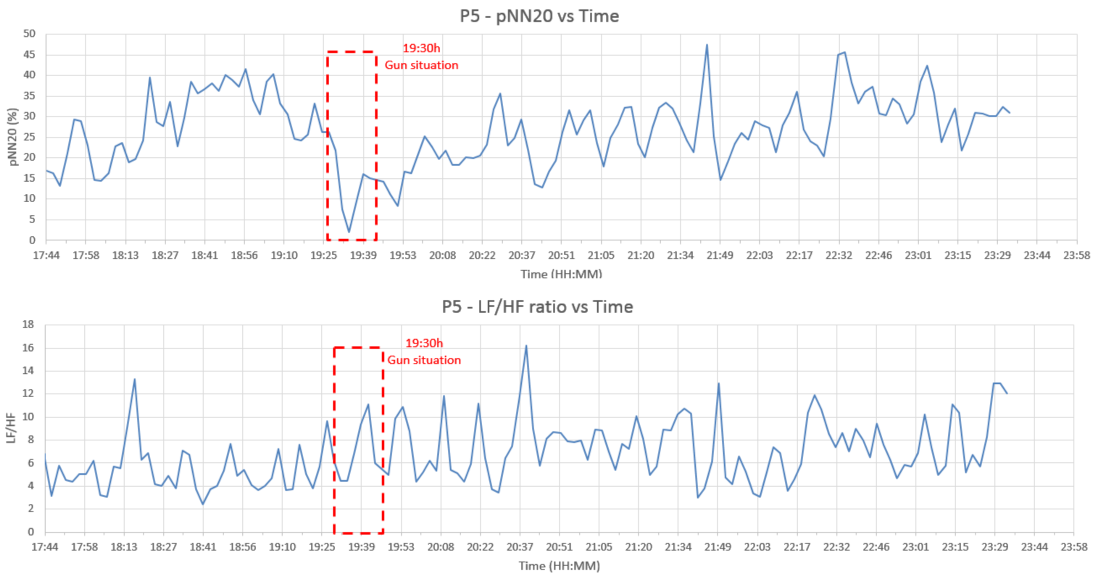


Figure 5.3: ECG signal analysis for Participant 5 (P5), reporting one stressful event (driving fast). On top, results regarding pNN20 over time. Below results regarding LF/HF.

5.1.4 Discussion

Only one event (Suspect escape) was voluntarily reported by one police officer as being a stressful event. Furthermore, the stress intensity self-reported during their daily events was very low. Results from Table 5.1 show a high LF/HF ratio for all the subjects studied, either on duty and on the day off, when compared to healthy subjects [160], suggesting the constant presence of stress.

Considering the LF/HF and pNN20 parameters, only two situations were detected as being stressful events: a “*driving fast*” situation and a “*gun*” situation. The first was not self-reported as being particularly stressful, probably due to car driving being a frequent activity in the officer’s routine, and therefore situations like this one occur frequently. However the gun situation was rated accordingly. This finding is in agreement with the literature, suggesting that shooting episodes have been considered as being very stressful events for police officers due to the psychological negative impact of these events [161]. Additionally, the current study suggests that this event is stressful not only from a psychological perspective but has also an impact on the biological functioning, by increasing physiological stress reactivity.

The current findings suggest a possible mismatch between police officers self-report measures of stress and their physiological responses, considering that participants show high physiological reactivity without being aware of it. One possible explanation for these results could be related with the presence of confounders between self-reports and exhibited physiological measures. An alternative explanation for these findings could be related with “*superhuman coping skills*” image associated with police officers, as well as with the stereotype that when a police officer expresses psychosocial stress, this could be viewed as weakness because police are individuals who are viewed as independent, competent, and trained to take care of dangerous situations, and to protect the population [162] [163]. Therefore, the presence of the researcher, that was a graduate in Psychology, could also have biased officer’s responses. In agreement with this, [164] have previously call the attention for the existent lack of confidence between officers and clinicians, because looking for mental health professionals could be viewed as a weakness.

5.1.5 Conclusion

Based on the ambulatory cardiovascular analysis, this study suggests that police officers experience high levels of physiological stress that can suggest the presence of chronic stress. However, when questioned about the presence of stressors during their shifts, police officers did not report any significant stress events. Moreover, as referenced in chapter 1, stress in the workplace has been identified as a health problem by the European Union that must be tackled. Therefore, by collecting not only information about what causes stress, but also concerning its real impact on psychological and physical health, this study reinforces the importance of ambulatory assessment research for the design of prevention and intervention plans and programs adapted to this population real needs. Thus, monitoring stress during real events might be the key for controlling stress related problems.

5.2 Surgeons

Everyday surgeons are put under tremendous mental pressure in order to perform skillful surgeries where the patient's life is almost always at risk. Amongst these professionals are neurosurgeons which carry some of the most critical and demanding procedures.

5.2.1 Intracranial Aneurysm Clipping Procedure

By definition, an aneurysm is a weak area in a blood vessel wall that causes it to balloon out, while being filled with blood. As it grows, it may rupture, leading to bleeding, which can result in life threatening complications [165]. In case an aneurysm occurs in the brain, the risk of the procedure becomes even higher, due to the difficult access to the affected area and the sensitivity of it. To correct this, surgeons can recur to different approaches. One of them, known as clipping, consists in the placement of a clip in the aneurysm's neck (see Figure 5.4) in order to stop blood from flowing in. Besides, this type of aneurysms are very hard to detect, and often the person that arrives at the operating room already suffered from a subarachnoid hemorrhage caused by the ruptured aneurysm, aggravating the conditions in which the surgeons will perform. Furthermore, this type of surgeries is expected to last several hours. In order to tackle the exhaustion that comes from such a long procedure, normally two surgeons are present during the surgery and they exchange role (between main and assistant) according to the skill and experience they have to assess the problem.

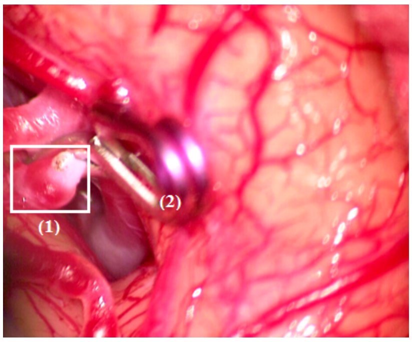


Figure 5.4: Picture taken from one of the microscope's recordings of an aneurysm surgery, after an aneurysm (1) was successfully corrected with the placement of a clip (2) in its neck.

In order to reach the affected area, the surgeons first need to cut through several layers of the head in order to expose the brain. This includes a craniotomy, which consists in the removal of part of the bone from the skull. After the last layer, the *Dura Mater*, is cut through, the surgeons will then start opening the path, through the brain, to the aneurysm. Before clipping, control of the blood flow in the area around the aneurysm is needed in order to control its rupture, if needed. Therefore, one or more provisory clippings are placed across the affected blood vessel until an optimal environment is reached.

Afterwards, the placement of the definitive clip can be done. It is during this moment that an aneurysm rupture can occur, due to the pressure that this clip will exert in the area. Sometimes, more than one clipping is needed due to the physiology of the aneurysm.

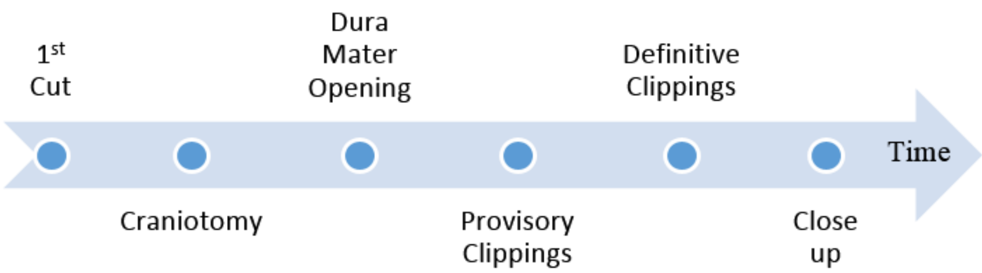


Figure 5.5: Workflow of an intracranial aneurysm procedure recurring to the clipping technique.

5.2.2 Study 1 (Pilot)

5.2.2.1 Dataset

The Dataset analyzed in this section is composed by 4 Surgeries, obtained from Hospital de São João (HSJ) from November 2013 to May 2014. Two healthy neurosurgeons - one male (L, 49 years), and one female (M, 38 years) - were monitored during 4 intracranial aneurysm procedures. They always performed the clipping technique to correct the detected aneurysm.

5.2.2.2 Protocol and Tools

Surgeons wore the VJ moments prior to the surgery and stayed with them until the last suture point was done. Together with the ECG data recorded by the VJ, surgeries were reported by a nurse, which wrote the main events - craniotomy, clipping, rupture (if occurred), etc. - with the corresponding time of occurrence, in Greenwich Mean Time.

Once again, we recurred to SenseMyHeart to extract the different parameters and VJ Assembly to gather this data.

5.2.2.3 Results

Average results for surgeon L's CI and HRV parameters (AVNN, SDNN, pNN20, pNN50, LF/HF) for the four surgeries are presented in Table 5.2. Aneurysm rupture only occurred in one of the cases. During the first clipping, HRV was considerably lower than during the first cut (SDNN – avg. 33.4 ms vs. 57.2 ms; pNN20 - avg. 4.4 ms vs. 32.1 ms). CI increased as well during this event (avg. 38.5% vs. 7.6%). When the rupture of the aneurysm occurred, CI reached the maximum value of any moment in any of the surgeries (64.9%), while HRV decreased to a minimum. Furthermore, the LF/HF parameter, regarded as one of the best indicator of physiological stress, reached the highest value (4.5) during this time, when compared to the other events.

Table 5.2: Average CI and HRV parameters from surgeon L

Event	N	CI (%)	AVNN (ms)	SDNN (ms)	pNN20 (%)	pNN50 (%)	LF/HF
1st cut	4	7.6	723	57.2	32.1	4.1	3.1
Def. clipp.	4	38.5 ↑	519 ↓	33.4 ↓	4.4 ↓	0.2 ↓	3.6 ↑
Aneur. rupt.	1	64.9 ↑↑	446 ↓↓	21.6 ↓↓	0.17 ↓↓	0.0 ↓↓	4.5 ↑↑

In Figure 5.6, a plot of the temporal behavior of pNN20 during one of the surgeries is presented. When placing provisory clips the pNN20 values decreased to global minima, in this case. Furthermore, the same behavior can be seen during the placement of the definitive clip. These changes, during definitive clipping, were found in every procedure for the main surgeon (L).

M was the surgeon in charge of removing the different layers that protect the brain. After cutting through the *Dura Mater*, she switched roles with surgeon L, and this can be seen Figure 5.6 as well (M's HRV started to increase when this occurred, while L's decreased). Furthermore, there were no relevant changes in the pNN20 values during the provisory and definitive clipping for surgeon M.

Differences can also be seen in the spectral distribution of each surgeon. For a better visualization of the spectral components, we calculated the percentage of HF (HFp) and LF (LFp) compared to the sum of LF with HF. The following charts, presented in Figure 5.7, were obtained by computing the mean spectral values for each 5 minute segment analyzed during an entire surgery (the same procedure as in Figure 5.6) for surgeon L and M respectively.

Figure 5.7a shows a predominance of the LF component over the HF component for the main surgeon, while there is a much more balanced distribution associated to M (Figure 5.7b).

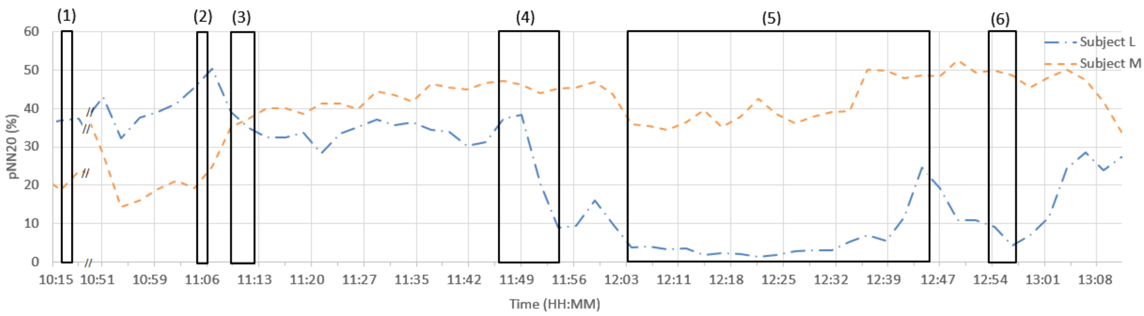
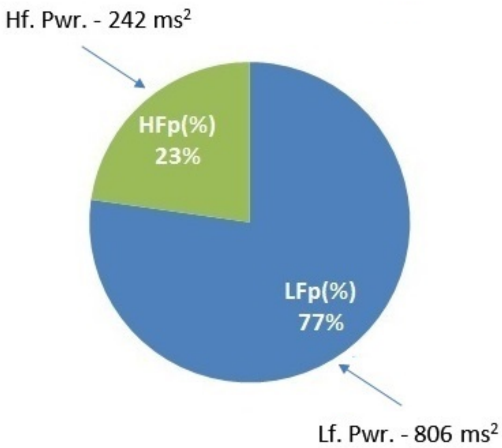
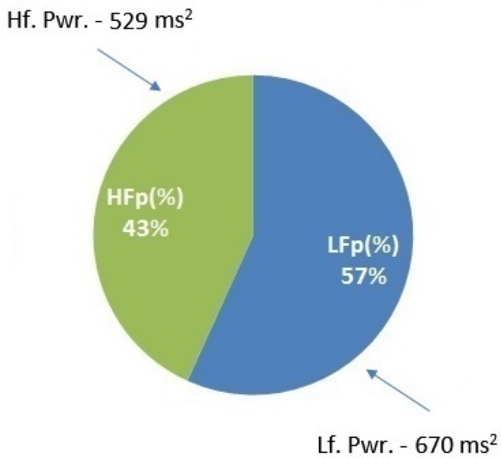


Figure 5.6: Surgeons' pNN20 changes registered over one of the surgeries. First incision and the opening of the *Dura Mater* occurred in (1) and (2), respectively, and performed by surgeon M. Afterwards, surgeon L stepped in as the main surgeon (3). Aneurysm was reached in (4), and dissection near that area was perfomed as well to expose the aneurysm. Several provisory clippings (5) were placed by surgeon L in order to obtain an optimal environment for the final clipping. Definitive clip was placed in (6).



(a) Surgeon L (Main)



(b) Surgeon M (Assistant)

Figure 5.7: HF and LF distribution for the Main Surgeon (A), as well as for the assistant surgeon (B), during one of the procedures.

5.2.2.4 Discussion

Analyzing Table 5.2, it can be verified that the 20 ms threshold value used for HRV evaluation (pNN20) presented good results, taking into consideration the SDNN for each action. This is also the reason that the change in the pNN50 values between the events is so small compared to pNN20.

L's CI increased during the definitive clipping, when compared to the first cut, while HRV (SDNN, pNN20) decreased. In other words, it seems that surgeon L is exposed to high cardiovascular strain during the clipping event. This is probably due to the self-reported perception of being a risky maneuver that increases the possibility of rupture, inducing high levels of mental pressure to the surgeon. The rupture of the aneurysm induces the highest cardiovascular strain in surgeon L, as it was expected, since it is the worst outcome that can occur during this type of procedures. HRV decreases with this changes (SDNN, pNN20, pNN50) to minimum values. Finally, supporting all this findings, an increase in LF/HF ratio is observed, which shows, a dominance of the SNS over the PSNS – a typical indicator of a stressful situation, according to the literature [19].

There is also clear difference in the cardiac behavior of each surgeon in Figure 5.6. When surgeon L stepped in to take the lead in the surgery, his HRV started to decrease, achieving minimum values when he started to analyze the area where the aneurysm is and performed several provisory clippings. A similar behavior was also registered when he placed the definitive clip. During these events, surgeon M's HRV did not change considerably, and stayed at higher values than the ones she had before the exchange. This findings allow us believe that L's heart was exposed to a higher strain than M's, probably due to the responsibility that his actions would have in the patient's life. This interpretation also matches the self-report of surgeon L. Furthermore, when comparing the HF and LF distribution of both surgeons, differences were also found. There is a clear predominance of the LF component when compared to the HF one in Figure 5.7a (LF/HF >3), which is relative to surgeon L's ECG. However, the same is not true for subject M (Figure 5.7b), who has a more balanced LF and HF distribution

5.2.3 Study 2

5.2.3.1 Dataset

Considering the results from the Pilot study, we decided to take on two male neurosurgeons to perform this second study (L, 50 years and XL, 32 years), both again from HSJ. A total of 10 intracranial aneurysm procedures were monitored from January 2015 to July 2015. Surgeon L was in all of the surgeries while surgeon XL was only on 8. They always performed the clipping technique to correct the detected aneurysm.

5.2.3.2 Protocol and Tools

As before, surgeons wore the VJ moments prior to the surgery and stayed with them until the last suture point was done.

In order to assess the surgeon's subjective behavior different surveys were provided for the surgeons to complete regarding their mental state before and after the surgery:

- For stress analysis we recurred to the 6-item Strait Trait Anxiety Inventory (STAI) questionnaire [144] to understand about their anxiety state prior (pre) and after (pos) the surgery. This tool has been used with success by different authors to assess stress during surgeries (higher scores are associated with higher stress), as already mentioned in section 3.1.8.

- We also recurred to the SURG-TLX survey [142], in order to assess the cognitive workload associated with the procedure, as already mentioned in section 3.3.3. This tool assesses different dimensions of cognitive function, including mental fatigue ("*How mentally fatiguing was the procedure?*") and situational stress ("*How anxious did you feel while performing the procedure?* "), which are relevant for stress and fatigue appraisal.

These surveys are presented in Appendix E.

Together with the ECG data recorded by the VJ, surgeries were reported by a researcher, who registered the main events, as before, with the corresponding time of occurrence, in Greenwich Mean Time.

As in the pilot study, we recurred to SenseMyHeart to extract the different parameters and VJ Assembly to gather this data.

To perform the statistical analysis (e.g.correlations between variables) we recurred to the IBM Statistical Package for the Social Sciences (SPSS) for Windows, version 22.0 .

5.2.3.3 Results

In Figure 5.8, a plot of the temporal behavior of both surgeon's pNN20 during one of the surgeries is presented.

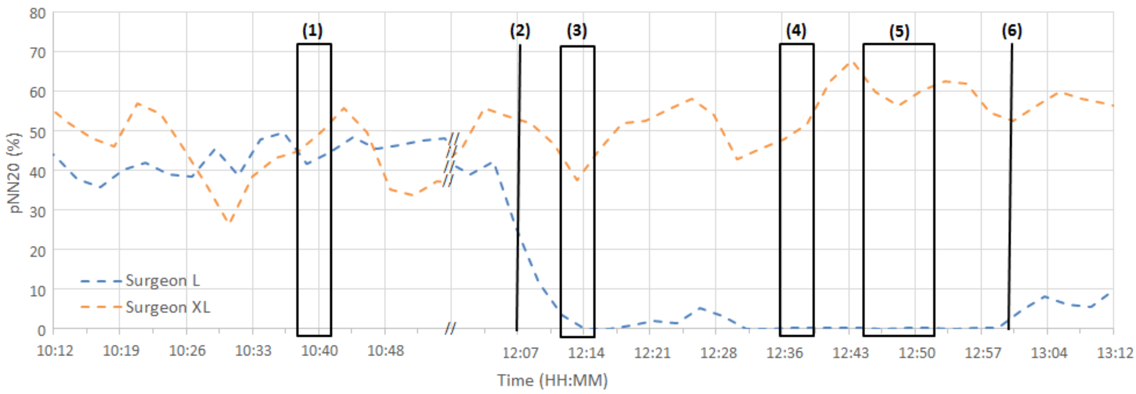


Figure 5.8: Surgeons' pNN20 changes registered over one of the surgeries. Time starts at first incision and the opening of the *Dura Mater* occurred in (1), both performed by surgeon XL. Afterwards, surgeon L stepped in as the main surgeon (2). Aneurysm was definitively clipped in (3). However the clip needed to be repositioned due to bad placement (4). When finally L was able to place the clip correctly, the aneurysm ruptured (5). During this time, L had to correctly place the definitive clip to stop the bleeding as soon as possible. Finally, with the problem corrected, close up began at (6).

XL was the surgeon in charge of removing the different layers that protect the brain (i.e. from the first cuts to the removing of the *Dura Mater*). During this time, their pNN20 values remained above 25%. However, when L exchanged roles with XL, his physiological behavior changed. L's HRV decreased considerably, achieving pNN20 values near 0% when placing the definitive clip. Furthermore, during the aneurysm's rupture, L's HRV remained low for a long time window (approx. 20min), while XL's pNN20 was always above 25%, following the same behavior as before the exchange occurred. An average of the physiological behavior of the surgeons before and after this trade, across a total of 6 surgeries (N=6) is presented in table 5.3. In all of these cases, surgeon XL always started the surgery and later traded with L, who was assisting him at the time. Overall, L's HRV seem to decrease considerably (AVNN, pNN20 and pNN50, SDNN) while CI increases. XL's physiological parameters follow an inverse but less accentuate pattern.

Table 5.3: Average CI and HRV parameters from Surgeon L (Assistant to Main) and XL (Main to Assistant) Before and After Trading (N=6).

Event	CI (%)	AVNN (ms)	SDNN (ms)	pNN20 (%)	pNN50 (%)	LF/HF
L Before	16%	719	61.9	34.0	5.1	3.5
L After	40% ↑	567 ↓	38.1 ↓	14.0 ↓	1.5 ↓	3.6 ↑
XL Before	9%	766	58.6	43.7	8.9	2.4
XL After	6%	785	58.3	45.3	10.1	2.7

L's pNN20 behavior (seen in Figure 5.8) was present in all of the surgeries where he performed the clipping as main surgeon. Average results for his CI, LF/HF and HRV parameters (AVNN, SDNN, pNN20, pNN50) for different surgery events are presented in Table 5.4. Surgeon L assisted one definitive clipping by surgeon XL. During these events, his CI and LF/HF increased while HRV parameters decreased (compared to the first moments of the surgery (first cut)). This changes are aggravated when L performs the clippings by himself, achieving CI values of 55%. The rupture of the aneurysm is associated with the very high CI and the highest LF/HF values (49% and 4.6 respectively) when compared to the other events, while SDNN and pNN20 decreases to a minimum (17.4ms and 0.6% respectively), similar to the case shown in Figure 5.8.

Table 5.4: Average CI, HRV and LF/HF parameters from Surgeon L

Event	**N***	**CI (%)**	**AVNN (ms)**	**SDNN (ms)**	**pNN20 (%)**	**pNN50 (%)**	**LF/HF**
1st Cut	10	11%	749	61.1	36.6	6.6	3.2
Def. Clipp. (Assis)	1	11% ↑	754 ↓	49.7 ↓	38.0 ↓	6.5 ↓	4.4 ↑
Def Clipp. (Main)	9	55% ↑↑	486 ↓↓	26.9 ↓↓	2.2 ↓↓	0.1 ↓↓	3.2 ↑
Aneu. Rupt (Main)	3	49% ↑↑	503 ↓↓	17.4 ↓↓	0.6 ↓↓	0.0 ↓↓	4.6 ↑↑

* N - number of occurrences of the event.

However, physiological changes regarding surgeon XL's values, presented in Table 5.5, are not as consistent as the ones seen for L. During the assistance in clipping his CI is lower than during the first cuts. When rupture occurs XL's physiological behavior did not change considerably. While performing as main surgeon, surgeon XL's LF/HF value is lower than during the first cuts, while HRV increased, going against the pattern seen for L.

Table 5.5: Average CI, HRV and LF/HF parameters from Surgeon XL

Event	**N***	**CI (%)**	**AVNN (ms)**	**SDNN (ms)**	**pNN20 (%)**	**pNN50 (%)**	**LF/HF**
1st Cut	8	8%	760	57.2	47.8	10.6	3.0
Def. Clipp. (Assis)	7	5%	797	56.6	47.5	9.4	2.9
Aneu. Rupt (Assis)	3	4%	806	65.9	47.4	11.7	2.9
Def Clipp. (Main)	1	7%	788	71.9	56.7	15.9	1.9

* N - number of occurrences of the event.

STAI-pre and STAI-pos scores showed how different surgeon L's and XL's stress appraisal before and after the different procedures was. For example, in the procedure P5, where an aneurysm rupture occurred, L was the Main surgeon while that event occurred, and therefore he was more exposed to the stressor than XL. This is supported by the results in Table 5.6, where his scores were higher than XL's prior and after to that surgery in most cases. Furthermore, XL's scores did not differ as much as L's throughout all the surgeries, showing that he did appraise all these similarly.

Table 5.6: STAI scores for surgeon L and surgeon XL.

Procedure	**L**		**XL**	
	STAI-Per	**STAI-Pos**	**STAI-Per**	**STAI-Pos**
P3	15	10	14	10
P4	9	7	10	11
P5 *	**18**	**17**	**10**	**14**
P6	11	7	9	9
P7 *	**15**	**11**	**14**	**14**
P8 *	**12**	**14**	**9**	**11**
P9	18	12	10	10
P10	11	10	11	12

* Aneurysm Rupture Occurred.

Regarding cognitive workload associated with each surgery, the occurrence of aneurysm ruptures was associated with a higher SURG-TLX scores, as seen in both Figure 5.9 and Figure 5.10. The complexity score was highest in these cases for L. However, since L was the main surgeon while the ruptures occurred, he reported higher levels of cognitive workload during these events. Also worth noting is the low scores registered by L in surgeries P4 and P6 for both stress appraisal and Cognitive Workload (Figure 5.9 and Table 5.6 respectively). In P4, XL performed as main surgeon the entire procedure, while L was assistant. P6 was an incidental case, which means that the person arrived in the operating room without any previous aneurysm rupture, presenting no subarachnoid bleeding, and therefore there was a much more stable environment for clipping.

Correlations were performed between the survey's results and physiological data obtained from surgeon L during the time the *Dura Mater* was removed onwards (i.e. since the brain was exposed). The reason for this was to assess only the changes resulting from the brain surgery itself. Results are show in Table 5.7. Cognitive Workload during the procedures was correlated with changes in his physiological behavior. Three of the SURG TLX's sub scales (Mental Demand Task Complexity and Situation Stress) were also correlated.

Relationships were found between the STAI-pos with different physiological parameters. SURG-TLX confirmed an increase in CI and decrease in HRV with the increase of overall score (i.e. cognitive workload). Furthermore, L's reported stress associated to each surgery (assessed through the SURG-TLX's Situational Stress subscale) was highly correlated with different physiological parameters. The stress felt prior to the surgery (assessed through the STAI-pre score) does not seem to be related to any physiological parameter during surgery.

As for relationships between the surveys, STAI-pre was only related to the STAI-pos score ($p<0.05$). As for STAI pos and SURG-TLX and its subscales, a very strong positive correlation was found between SURG-TLX and the Situational Stress subscale scores with the STAI-Pos ($p<0.01$). The Mental Demand subscale was also correlated positively with the STAI-pos score ($p<0.05$) and strongly correlated with the SURG-TLX and Situtation Stress subscale scores ($p<0.01$). As for surgeon XL, no psychophysiological correlations were found. Furthermore, no correlations between the STAI-pre, STAI-pos and SURG-TLX scores were identified as well.

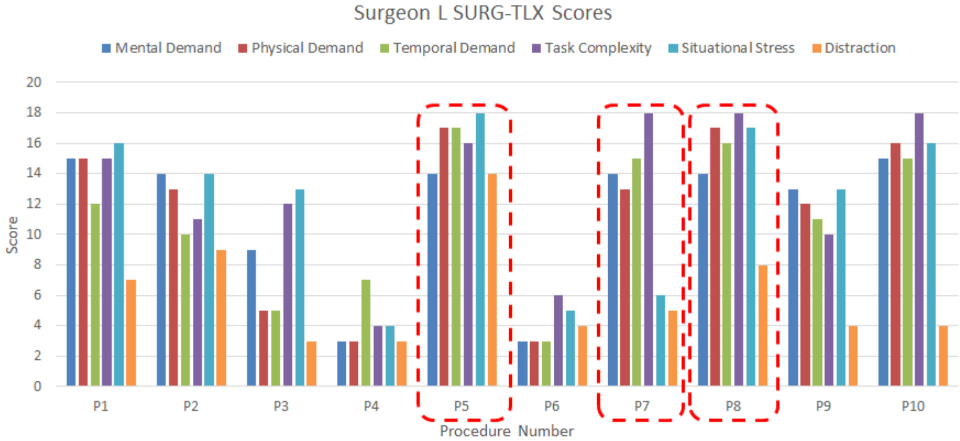


Figure 5.9: Surgeon L's SURG-TLX scores for each procedure he was present. Surgery P5, P7 and P8 were the ones in which an aneurysm rupture occurred during the surgeons' intervention. L was main during those.

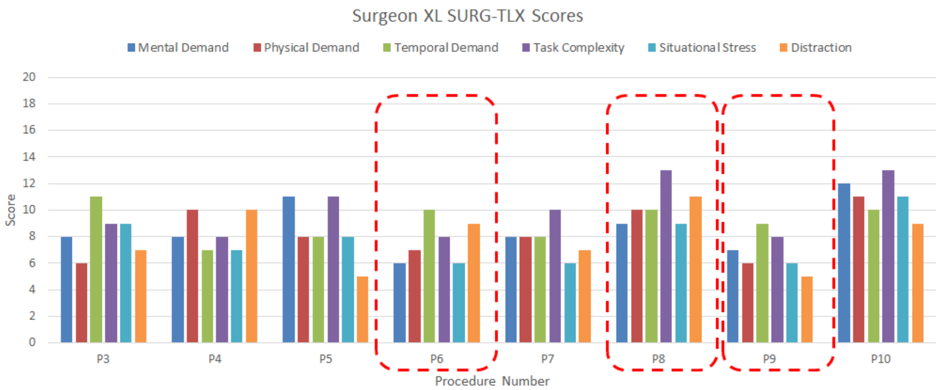


Figure 5.10: Surgeon XL's SURG-TLX scores for each procedure he was present. Surgery P5, P7 and P8 were the ones in which an aneurysm rupture occurred during the surgeons' intervention. XL was Assistant during those.

Table 5.7: Surgeon L's Spearman's correlation coefficients between physiological and psychological parameters

Parameter	**CI (%)**	**AVNN (ms)**	**SDNN (ms)**	**pNN20 (%)**	**pNN50 (%)**	**LF/HF**
STAI pre	0.334	-0.334	-0.334	-0.303	-0.334	0.149
STAI pos	0.706*	-0.724*	-0.589	-0.675*	-0.650*	0.288
SURG TLX	0.909**	-0.933**	-0.884**	-0.921**	-0.902**	0.561
Mental Dem.	0.736*	-0.772**	-0.711*	-0.736*	-0.711*	0.529
Sit. Stress	0.957**	-0.976**	-0.866**	-0.976**	-0.957**	0.476
Task Cimplex.	0.620	-0.656*	-0.681*	-0.681*	-0.656*	0.706*

Correlation on N = 10 .
**p<0.05; * p<0.01 .

5.2.3.4 Discussion

Regarding the physiological behavior associated to exchanges between the surgeons, one can infer an increase in cardiovascular strain occurs in surgeon L after he exchanges to main surgeon – his CI increases considerably while HRV (AVNN, SDNN, pNN20 and pNN50) decreases. The case shown in Figure 5.8 shows how noticeable this change is regarding pNN20, supporting the results from Table 5.3. This behavior can be due to surgeon L taking on a more active and responsible role, which should take a much higher mental focus, compared to the previous one. However, we should address this fact on the surveys in future work in order to prove this assumption, since no similar study was found in the literature.

This stress-associated pattern (increase in CI and LF/HF ratio and decrease in several other HRV parameters) is even more noticeable when L is clipping the aneurysm. That moment is crucial, since a wrong placement of the clip can lead to a rupture of the aneurysm, which is the worst possible outcome. When rupture occurs, the cardiovascular strain is even higher, with HRV parameters reaching minimum values and LF/HF ratio reaching the highest overall. Furthermore, L reported a higher cognitive workload in the procedures where a rupture occurred, identifying those with some of the highest task complexity and situational stress scores as well as with some of the highest STAI values (see Figure 5.9 and Table 5.6). Supporting these findings, Table 5.7 shows strong correlations ($p<0.05$) between the complexity score and some of the stress parameters mentioned – it is positively correlated with LF/HF and negatively correlated with the mentioned HRV parameters. Furthermore, increases in CI and decreases in several HRV parameters (AVNN, SDNN, pNN20 and pNN50) are very strongly correlated ($p<0.01$) with the increase in the Situational Stress score (i.e. how anxious did they feel while performing the procedure). Comparing this with results in Table 5.3, one can infer that aneurysm clipping and rupture indeed induce stress in surgeon L. Cognitive workload and STAI-pos scores relative to moments after the procedure are very strongly correlated ($p<0.01$) with most of the mentioned parameters as well, supporting a relationship between the complexity associated with the procedure and the induced mental and physiological stress.

Furthermore, the mental demand score seems to be correlated with the same physiological changes as well. It has been also positively correlated with cognitive workload and the situational stress subscale and the STAI-POS score. It can then be concluded that surgeries reported as being more stressful can also induce considerable levels of cognitive workload and mental fatigue in the subjects.

As for XL's physiological behavior, changes between the surgery's different moments do not follow L's pattern, but are still interesting to discuss nonetheless.

First, his physiological behavior does not suffer any significant alteration following the moments before and after the exchange in role (compared to surgeon L). Second, results from Table 5.5 show no noticeable changes between events (compared to the first cuts moment). One possible explanation for this can be related to the fact that he perceives both parts of the procedure (as main and as assistant) as equally demanding, therefore not triggering practically any changes in his behavior. This is supported by the SURG-TLX scores presented in Figure 5.10 – they are very similar and lower than L's in most cases. Since stress is not caused by the event itself, but by the individual's perception of it, this result goes in agreement with the work of Lazarus and Folkamn [166].

Regarding the usage of pNN20 for stress event identification, interesting results were obtained. In Table 5.4 and Figure 5.8 it is noticeable how this parameter changes with the events, unlike the one which is more recurred to in the literature (pNN50). Analyzing the SDNN, we can see that this parameter decreases to values much lower than 50ms during the more stressful events (clipping and rupture), supporting the usage of a lower threshold for a better evaluation of HRV.

5.2.4 Conclusion

Both studies show that neurosurgery can be a stressful and mentally demanding procedure, leading to different changes in cardiac behavior and cognitive function.

Regarding the differences between both studies (moreover, the different genders of the surgeons), the changes in LF and HF distributions seen in 5.7 seem to be related to the surgeon's genders which is also supported by the literature [167]. however, more cases are needed with a male and a female surgeon to better solidify this finding. Exchanging role, from assistant to main surgeon, seems to induce a measurable degree of cardiac strain in one of the subjects. However, this situation should be addressed subjectively as well in order to confirm the relationship between the changes in role with increase in stress. Furthermore, there are also noticeable changes when one of the surgeons (L) is operating the brain directly. The other (XL) does not seem to be as exposed to stressful events, showing practically no physiological changes between the different events. However, his subjective appraisal also does not change with the procedures, unlike L's. More cases are needed to ensure that this behavior is consistent, especially when he is performing as main surgeon.

SURG-TLX shows to be a feasible tool to address cognitive workload and its relation with different physiological parameters as well as with stress and fatigue. Furthermore, it supports the fact that the more stressful situations in intracranial aneurysm procedures are highly mentally demanding as well. Again, more cases are needed in order to obtain better correlations and consolidate our findings. This tool also shows interesting results in mental fatigue assessment. Furthermore, stress leads to a significant decrease in the surgeons SDNN, leading us to believe that a lower threshold (like 20ms) should be used to assess this kind of behavior instead of the 50ms widely used in the literature.

Concluding, this study shows the feasibility of using wearable technology to identify stressful events in surgery procedures, as well as to study physiological responses according to the role (main or assistant). Furthermore, we complement this approach with the surgeons' subjective appraisal of stress and cognitive workload, which have shown to be correlated.

5.3 Firefighters

Firefighters can be exposed to very aggressive environments during their work routines, as mentioned previously in section 3.3.4. However, it is still difficult to estimate the physiological load placed among firefighters during a real-life emergency due to, mainly, the very strenuous conditions (heat, humidity) [168]. Thus, laboratory designs arise as one of the methods to assess stress, providing the feasibility of an experimental environment, as well as the possibility of monitoring the physiological responses [169]. Therefore, this study aims to assess firefighters psycho-physiological stress reactions and fatigue levels through physiological monitoring while completing standardized laboratory stress tasks and a short term fitness test.

5.3.1 Protocol and Tools

For this study we only were able to gather, successfully , data from 4 different firefighters from a Portuguese firefighter unit. The runs took place in July 2015. They were labeled FF1, FF3, FF4 and FF6 and were 59, 25, 28 and 29 years old respectively. None of the subjects had coffee before being submitted to this study.

VJ was again used to gather ECG data from the participant. Data regarding EDA, a measure of the glandular secretion (see section 3.1.3), was also collected recurring to a Bitalino Board, which was placed in a adjustable pocket strapped to the participants waist and the sensors placed in the hand of the subject. Visual Analog Scales (VAS) (see Appendix F) were used to measure stress and fatigue levels between the different tasks. We recurred to this method because of its simplicity and short duration. Since different tasks are going to be presented, a longer and more complex survey is not as fitting due to the frequency of time in which the subjects will have to complete this. Participants started by completing a demographic and medical questionnaire and other self-report questionnaires. Then, they were fitted with the mentioned sensors. Figure 5.11 illustrates the structure of the study before and during the data collection.

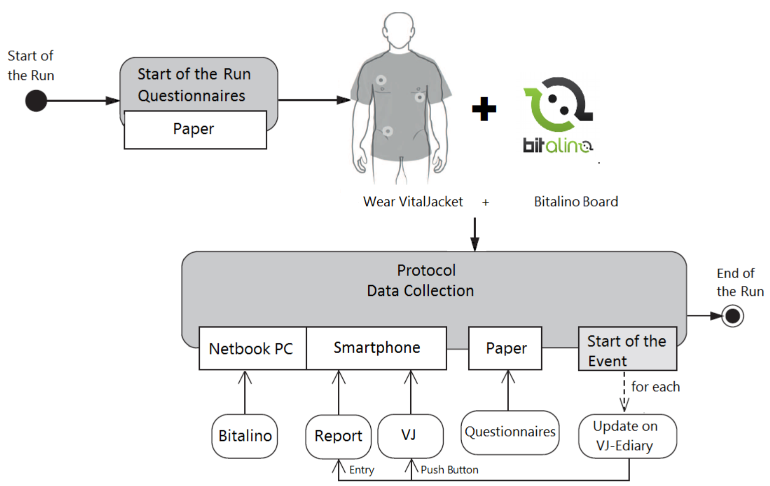


Figure 5.11: Structure of each monitored Run.

A baseline reading was performed during the first 5 minutes. Afterwards, different tasks were presented, intercalated with 5 minute rest intervals:

- **Reaction Time (RT) task 1** - In this task the subject has to respond to a stimulus that appears in the PC screen by clicking a button as fast as possible. The *stimuli* corresponds in either an arrowhead pointing to either left or right on top of a square filled with a sinewave grating pattern in the center of the screen. The user needed to select the correct button direction with each arrow. This *stimuli* was generated by a Matlab® routine developed by one of the group's researchers [170]. The purpose of this test is induce mental fatigue by requiring focus by the participants to complete the task [171].

- **Trier Social Stress Test** - The Trier Social Stress Test (TSST) is a protocol that induces stress in laboratory setting by asking the participant to deliver a 3-5 minutes speech and to perform an arithmetic task (e.g. count down from 1022 in steps of 13 for two minutes). If a mistake is made during the second task, the participant must restart the count. All this is done in front of an evaluation committee that do not respond emotionally to the subject's actions [172].

- **Reaction Time task 2** - Similar to the first reaction time task.

- **Fitness test** - The YMCA fitness test was chosen in order to induce physical fatigue into the subject. The test consists in a 3 minutes of exercise, during which the participant step up and down at 24 cycles (up-up-down-down) a minute [173]. Immediately after 3 minutes of stepping, the participant will be asked to sit down for 5 seconds. Then, for the following 60 seconds, the heart beat count will be registered (by analyzing the ECG signal). The step platform height used was of approximately 30.5 cm. In order to correctly count the 24 cycles a metronome was used as well.

At the end of each task, the subjects were required to fill VAS surveys regarding perceived stress and mental fatigue levels. An extra VAS scale regarding physical fatigue was given at the start of the protocol and at the end of it. The protocol took approximately 70 minutes in average meeting the expected duration. An visual summary of it is presented in Figure 5.12.

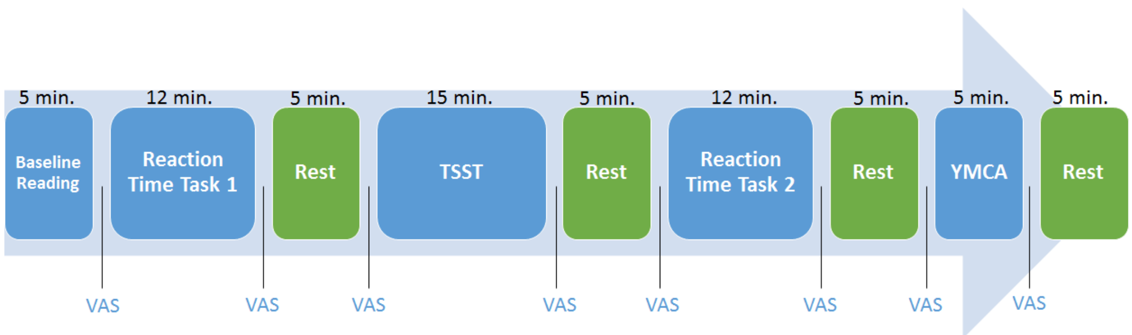


Figure 5.12: Protocol's Worklow.

5.3.2 Results and Discussion

Since it was only possible to submit 4 different firefighters to this protocol, no correlation between physical and psychological variables was possible (because there was only 1 case for each subject). However, their individual responses to each task can still be discussed. Furthermore, unlike in other studies, HR is assessed instead of CI, due to the fact that, as we will see, the baseline values obtained were biased by the psychological state of the subjects.

Looking at the subject FF1's results from Table 5.8, it can be noted that there is a low HRV accompanied by an high HR during the Baseline time, compared to other tasks. Moreover, the Stress VAS score is higher than in the first task as well. From this result, it can be concluded that the subject was not completely relaxed in the beginning of the study. A possible explanation for this is the anxiety he experienced due to the fact that they did not know any information about this experiment and what tasks he would have to perform and what he would be exposed to. Also, the presence of evaluation panel could also induce more pressure in the subject, making him feel more stressed. This physiological pattern was seen with subject with FF4, who shows considerable low levels of HRV (SDNN = 23.1 ms, pNN20 = 7.7%)and high HR (99 bpm) during this time compared to any other subject. However, both reports of Stress did not match this finding. Subjects FF3 and FF6 do not show such accentuate changes from baseline to other events.

At the end of the first RT, subject FF1 reported an higher value for mental fatigue but an lower one for stress. Regarding the first, this was expected, since an RT does require some focus and therefore, can induce some mental fatigue. The decrease in the reported stress is followed by an increase in HRV (SDNN and pNN20 increase) and decrease in HR and the LF/HF ratio, which, as discussed before [19], is an behavior associated with relaxation. However, subjects FF3 and FF4, reported the same stress and mental fatigue values, while their LF/HF decreased. The possible reason for this is due to the fact that after performing the first task the subjects' anxiety decreases due to the fact that they now have the notion of the type of tasks to which they will be subjected. Furthermore, they do not feel this anxiety as stressful therefore they do not perceive themselves as being less stressed. FF6 reports matches his physiological behavior since the changes registered are not as considerable as in the other subjects. Regarding the changes in Mental Fatigue values, only FF1 reported a change. But, since he was also exposed to some stress, no conclusion can be taken from this results.

The TSST task is, supposedly the more stressful task, as mentioned in the previous section. The reported stress VAS value value increases in all subjects after this task SDNN and pNN20 values decrease, with an increase in HR and LF/HF, which support that the goal of this task was achieved, even though the subject seems to feel more stressed in the beginning of the study. Furthermore, it is during this task the skin conductance experiences the greatest increase, which means that there is an increase in glandular secretion during this time. Again, as stated before, this is a symptom of stress and thereby corroborates the fact of the subjects experiencing stress while performing the TSST. However, an increase in mental fatigue is also reported by subjects FF3 and FF4. Since they are demanded to develop a speech, this is possible. However, this happens while also being exposed to an stressful event therefore no other conclusions can be taken from the results. Finally, even though some of the lowest pNN20 and the highest HR and LF/HF values are seen during the fitness test for all subjects, the SDNN during that time increases significantly to the highest value as well, contradicting the pattern seen during stressful events. This last occurrence is due to the fact that this value takes in consideration the subjects heart rate while performing the task and the HR is increasing considerably. Therefore, it is natural that a great variation between heart beats exists between the beginning of the task and the end. However, the reported physical fatigue increased considerably compared to the baseline value. Since this was the only task where any physical activity was demanded, and that the values of reported stress and mental fatigue have not changed from the previous task, it can be concluded that the this test did indeed induce physical fatigue to the subjects.

Table 5.8: Overall results for subject FF1, 59 years old.

Event	Physiological Parameters					Psychological Parameters		
	SDNN (ms)	**pNN20 (%)**	**LF/HF**	**HR (bpm)**	**EDA (μS)**	**Stress**	**Mental Fatigue**	**Physical Fatigue**
Baseline-Rt1	39.4	30.2	2.0	85	0.93	4	3	3
RT1-Rest1	66.7	52.7	1.1	78	0.93	3	4	N/A
Tsst-Rest2	59.4	47.9	1.6	82	0.95	4	4	N/A
RT2-Rest3	73.8	69.2	1.1	67	0.95	3	4	N/A
Fitness-Rest4	115.5	40.0	2.2	88	0.96	3	4	5

Table 5.9: Overall results for subject FF3, 25 years old.

Event	Physiological Parameters					Psychological Parameters		
	SDNN (ms)	**pNN20 (%)**	**LF/HF**	**HR (bpm)**	**EDA (μS)**	**Stress**	**Mental Fatigue**	**Physical Fatigue**
Baseline-Rt1	58.1	52.8	3.3	86	0.90	4	3	0
RT1-Rest1	39.1	51.4	2.4	85	0.91	4	3	N/A
Tsst-Rest2	37.3	62.4	2.1	80	0.94	6	5	N/A
RT2-Rest3	50.9	61.3	1.8	76	0.99	3	5	N/A
Fitness-Rest4	58.8	47.8	3.3	93	1.00	3	5	4

Table 5.10: Overall results for subject FF4, 27 years old.

Event	Physiological Parameters					Psychological Parameters		
	SDNN (ms)	**pNN20 (%)**	**LF/HF**	**HR (bpm)**	**EDA (μS)**	**Stress**	**Mental Fatigue**	**Physical Fatigue**
Baseline-Rt1	23.1	7.7	2.4	99	0.87	4	3	1
RT1-Rest1	25.7	20.4	1.6	91	0.92	4	3	N/A
Tsst-Rest2	44.4	32.8	1.5	88	0.96	7	5	N/A
RT2-Rest3	39.5	32.1	2.0	85	0.96	4	5	N/A
Fitness-Rest4	68.2	43.1	4.2	87	0.99	4	5	8

Table 5.11: Overall results for subject FF6, 28 years old.

Event	Physiological Parameters					Psychological Parameters		
	SDNN (ms)	**pNN20 (%)**	**LF/HF**	**HR (bpm)**	**EDA (μS)**	**Stress**	**Mental Fatigue**	**Physical Fatigue**
Baseline-Rt1	67.8	51.3	1.7	75	0.82	3	5	2
RT1-Rest1	75.8	52.6	2.0	81	0.88	3	5	N/A
Tsst-Rest2	92.8	56.3	3.0	75	0.93	5	5	N/A
RT2-Rest3	72.1	59.0	1.6	67	0.95	4	5	N/A
Fitness-Rest4	147.7	42.4	1.6	100	0.98	4	5	3

5.3.3 Conclusion

Even though this study included a low number of subjects, some conclusions can be taken. First and foremost, the physiological values gathered during baseline were biased by the anxiety felt by some of the participants. This values were supposed to be gathered during rest, without any interferences, in order to be compared with the values obtained during the execution of the tasks. Therefore, it seems this values should be gather some time after the tasks are finished so that the values represent reliably the subjects data during absolute rest and with no anxiety.

The TSST and Fitness tasks seem to fulfill their roles as stress and physical fatigue inducers, respectively, according to the subjects reports. However, TSST also induces some mental fatigue which is also expected but undesirable.

Regarding the first RT task, no conclusions were drawn for the mental fatigue induced during this time, due to several reasons. First, no rest data (baseline) existed to compare the physiological values with. Second, no considerable mental fatigue was perceived by the subjects during the realization of this task. The same can be said for the second RT task. Therefore, one of the improvements to be made to this study is the inclusion of a task solely aimed at inducing considerable levels of mental fatigue, and this task should be taken separately from any other stress task to avoid any interference. However, several of the tests that exist in the literature to induce considerable mental fatigue consume large amounts of time, lasting more than 70 minutes (e.g. driving simulation [174]), which was the duration of the entire protocol, and such a long study is not pretended. Therefore, other approaches need to be discussed to tackle this problem.

Furthermore, no visible changes were seen in physiological behavior between the oldest subject (59) and the other subjects who were much younger (25,27 and 28 years old).

Finally, a much wider dataset needs to be acquired to draw reliable conclusions. However, this study did help in understanding the protocol's errors and misconceptions, enabling therefore its improvement to, ultimately, achieve the established goals.

Chapter 6

Conclusions and Future Work

This thesis provides insight to the physiological changes associated with stress and also tries to approach mental fatigue in professionals in different environments through the use of different protocols.

A deep review of the state-of-the-art in this area has been presented. This addresses different vital points for the successful development of a study of Stress and Fatigue, such as the more reliable monitoring parameters, tools and also how, recently, other authors have been successfully approaching this problem.

As for the developed tools, these can improve the reliability of the studies performed, as well as decrease the errors associated with the registering of events and its analysis. Nonetheless, there is still room for several improvements that should be addressed as future work as well:

- Regarding the VJ E-Diary app, one possible improvement is the connection of the app to an online, private database, where all the saved data is archived, so that information regarding all the runs can be assessed. This would be shared with the VJ Assembly so that the report could automatically be upload to the correct folder without any interference from the user.

- VJ Assembly is still a very primitive tool, in the way that it just reads already processed data in order to present it to the user. Therefore, several improvements can be made in order to turn it more reliable and time efficient. Integrating the QRS detector and the SenseMyHeart service with the Matlab routine is one of the goals established for the near future. This will require constant cooperation with the developer of the service so that some adjustments can be made considering the Matlab® platform. Ultimately, the user will only need to provide the raw files generated by the hardware and VJ E-Diary, and VJ Assembly will perform all the other steps required to arrive at the final results.

As for the developed studies, one main improvement to be made is the increase of the number of monitored subjects so that reliable conclusion can be drawn. However, the data collected from different professionals was still valuable and worth of interesting discussion.

Regarding police officer's monitoring, some stressful events were identified. Also, it seems that this professionals are exposed to stress frequently enough to experience chronic stress. However, further studies need to be done to this same individuals to reliable diagnose such disorders. Other parameters, besides HRV,should be used, since this professionals are in frequent motion during their activities, which has influences in the autonomic balance. One of the possibilities is to implement an EDA monitor to evaluate changes in glandular secretion.

The study of surgeons in an operating room is highly innovative and has provided relevant conclusions. Stressful events were successfully identified and the relationships with cognitive workload and mental fatigue were also interesting to discuss. The SURG-TLX shows to be a very reliable tool to identify both Stress and Fatigue in surgical procedures. Furthermore, due to the interesting results here presented, there is considerable interest from the surgeons to further develop this study to an wider range of surgical procedures, therefore enabling the comparison of induced stress and cognitive workload with each surgery. It is expected to intrude a protocol based on the one here presented.

The developed experimental protocol for firefighters still needs to be improved. The biased baseline data influences the analysis of the dataset greatly since there is no feasible data to compare with. This disable an reliable study of how significant are the subjects' changes both psychologically as physiologically when performing the different tasks. Furthermore, mental fatigue was not addressed successfully in this experiment. However, stress was identified during the different tasks, as was physical fatigue.

Overall, another interesting conclusion from this studies is that the LF/HF parameter, even though it has been regarded as a good parameter for stress appraisal, should not be the only variable used to draw conclusions in this area, as some studies in the literature have done. It is also important to look to other parameters that translate symptoms associated with stress, (e.g. variation between heart beats and skin conductance). Also, it is shown that the change of the pNNx threshold from 50 ms (pNN50) to 20 ms(pNN20) appears to be more adequate for identification of acute stress.

It can be concluded that stressful events were successfully identified, in some cases, both physiologically and psychologically, in the different studies. Furthermore, the development of tools to better identify events with monitored physiological parameters has shown to be an improvement to this type of studies and helped researchers have a more efficient analysis of the data. Mental fatigue is still a topic of discussing in the area, and the methods for its physiological monitoring still need to be improved. However, the SURG-TLX questionnaire seems to be an reliable tool to identify it during surgical procedures.

Concluding, the present work has enable the improvement of different studies in Stress and Fatigue monitoring which may be of enormous importance for the design of effective interventions in order to reduce stress and fatigue levels in different professionals.

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Appendix A

SPNC’15 - Monitorização do Stress Cardiovascular em Cirurgias de Clipagem de Aneurismas

Formulário para Submissão de resumo

Autor que apresenta
Nome **Rui António Matos Tuna**
Email rui.tuna@hotmail.com
Telemóvel 936203142
Forma de Apresentação Preferida

Poster ☐	Comunicação Oral X
Vídeo Cirúrgico ☐	

Área de comunicação
Neuroncologia ☐
Estereotáxica e Funcional ☐
Vértebro-Medular ☐
Nervo Periférico ☐
Vascular X
Trauma ☐
Pediátrica ☐
Autores
Rui Tuna (1,2), Gonçalo Pimentel (4), António Vilarinho (1,2), Rui Vaz (1,2,3), João Paulo Cunha (4,5)
Instituições:
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Nota: O resumo não pode exceder as 300 palavras. O formulário deve ser gravado com o TÍTULO do trabalho e deverá ser enviado para o email: secretariado@spnc.pt

Resumo: (Os resumos deverão ser estruturados e incluir obrigatoriamente as seguintes secções: Introdução, Material e Métodos, Resultados, Conclusões**)**

Monitorização do Stress Cardiovascular em Cirurgias de Clipagem de Aneurismas

Resumo:

A atividade cirúrgica em geral é potencialmente indutora de stress, sendo a cirurgia de clipagem de aneurismas, um exemplo da tensão a que está sujeito o cirurgião. A importância da avaliação e compreensão deste fenómeno reside na evidência do prejuízo técnico e de julgamento que advém dos elevados níveis de tensão, assim como do potencial impacto a nível da saúde do cirurgião.

Material e Métodos:

Um neurocirurgião do Hospital de São João, saudável, foi monitorizado durante 9 cirurgias de clipagem de aneurismas. De forma a obter os dados, o cirurgião usou o VitalJacket, t-shirt com electrónica embebida e microeléctrodos que permite a monitorização contínua do ECG e atividade, obtendo assim informação acerca da variabilidade cardíaca com base em variáveis de tempo (AVND, SDNN, pNN20, pNN50) e de espectro (LF, HF, LF/HF); permite também a monitorização da Intensidade Cardiovascular (IC). Simultaneamente, os principais eventos cirúrgicos foram registados. A utilização da monitorização do ECG como avaliação do stress cardiovascular está demonstrada em estudos psicofisiológicos e do domínio da bioengenharia, sendo os parâmetros obtidos uma medida da atividade do sistema nervoso autónomo.

Resultados:

A análise da tabela permite verificar o stress cardiovascular imposto nesta abordagem cirúrgica, sendo o 2º. clip definitivo indutor de maior tensão que o primeiro. A ruptura de um aneurisma impõe naturalmente o maior stress cardiovascular registado no cirurgião. A presente avaliação mostra um aumento do rácio LF/HF em situações de tensão, consistente com a descrição da literatura do efeito dominante do Sistema Nervoso Simpático sobre o Sistema Nervoso Parassimpático.

Evento	N	IC (%)	AVNN (ms)	SDNN (ms)	pNN20 (%)	pNN50 (%)	LF/HF
Incisão cutânea	9	5,2%	650	145,2	32,7	7,8	2,3
1º. Clip	9	42,5%	510	29,6	3,5	0,1	3,4
2º. Clip	3	51,9%	506	29,7	3,2	0,1	3,3
Rotura Aneurisma	2	61,1%	452	18,5	0,1	0	3,8

(Avaliação da média dos parâmetros de variabilidade cardíaca nas cirurgias avaliadas)

Conclusão:

O presente estudo confirma o stress cardiovascular induzido na clipagem de aneurismas intracranianos.

Appendix B

IEEE EMBC 2015 - Cardiovascular Strain and Autonomic Imbalance in Neurosurgeons

Cardiovascular Strain and Autonomic Imbalance in Neurosurgeons

G. Pimentel, A.Vilarinho, Rui Vaz and J. P. Silva Cunha, *Senior Member, IEEE*

***Abstract*— We monitored cardiovascular intensity (CI) and heart rate variability (HRV) time and frequency domain features from two neurosurgeon's electrocardiogram (ECG) signal using state-of-the-art comfortable wearable ECG and activity monitors, during 4 aneurysm surgeries. Results show an increase in CI and a significant decrease in time domain HRV parameters in specific events. Frequency-domain HRV parameters also showed a clear imbalance for the main surgeon (L). We conclude that wearable technology may be helpful in designing stress coping strategies for these professionals.**

I. Introduction

Neurosurgery is a particularly stressful occupation due to the sensibility and complexity of the area tackled. Moreover, intracranial aneurysm ruptures rise as one of the most difficult procedures due to the short time window available for correcting the problem. Therefore, it is expected that this surgeries induce high levels of stress to the performing surgeon and, consequently, affect their skills.

II. Materials & Methods

Two healthy neurosurgeons - one male (L, 49 years), and one female (M, 38 years) - from a Portuguese university hospital were monitored during four intracranial aneurysm procedures where the clipping technique was used to correct the detected aneurysm. Cardiac monitoring was possible recurring to a wearable electrocardiogram (ECG) T-shirt (VitalJacket®) [1]. In order to extract heartbeat information from the ECG recordings, an algorithm based on the one developed by Pan and Tompkins [2] was implemented, with improvements from P. Hamilton [3]. To extract heart rate variability (HRV) frequency parameters, we recurred to the Lomb Periodogram [4]. The analysis was performed using a window size of 300 s with an overlap of 50% between windows for better resolution. Following the guidelines presented in the literature [5], different time (AVNN,SDNN,pNN50) and spectral domain parameters (LF,HF) were used to study the existence of cardiovascular strain. pNN20 was also taken in consideration due to interesting results obtained by Schaaff *et al.* [6]. We also analyzed cardiovascular intensity (CI) - shown in (1) - which represents a comparison between the current heart rate (HR) (HR_{curr}) and the maximum theoretical HR (HR_{max}) as well as the user's rest HR (HR_{rest}). Calculation of the maximum HR (HR_{max}) was done following the work of Tanaka *et al.* [7].

$$CI = \frac{HR_{curr} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \qquad (1)$$

III. Main Results

Average results for surgeon L's CI and HRV parameters for the four surgeries are presented in Table I, where N is the number of surgeries where the event occurred. Besides this results, a predominance of the LF component over the HF component for the main surgeon (L), over an entire surgery, is depicted (LF/HF>3), while there is a more balanced distribution associated to the assistant surgeon (LF/HF<2).

TABLE I.
AVERAGE CI AND HRV PARAMETERS FROM SURGEON L

Event	*N*	*CI (%)*	*AVNN (ms)*	*SDNN (ms)*	*pNN20 (%)*	*pNN50 (%)*	*LF/HF*
1st Cut	4	7.6	723	57.2	32.1	4.1	3.1
Def. clipp.	4	38.5 ↑	519↓	33.4 ↓	4.4 ↓	0.2 ↓	3.6 ↑
Aneu. Rupt.	1	64.9 ↑↑	446 ↓↓	21.6 ↓↓	0.17 ↓↓	0.0 ↓↓	4.5↑↑

IV. Conclusions

We show the feasibility of using wearable technology to identify stressful events in surgery procedures. This possibility may be of enormous help in designing stress copping strategies for these professionals as well as in other professions, with minor adaptations.

*This work is financed by the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within project UID/EEA/50014/2013 granted to INESC TEC and PTDC/EEI_ELC/2760/2012.

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IEEE Engineering in Medicine and Biology Society (EMBS)

CARDIOVASCULAR STRAIN AND AUTONOMIC IMBALANCE IN NEUROSURGEONS

Gonçalo Pimentel (INESC-TEC & FEUP), **António Vilarinho** (HSJ), **Rui Vaz** (HSJ) and **João Paulo Silva Cunha** (INESC-TEC & FEUP)

Motivation

Neurosurgery is a particularly **stressful** occupation due to the sensibility and complexity of the area tackled. Moreover, intracranial aneurysm ruptures rise as one of the most difficult procedures due to the **short time window available** for correcting the problem. Therefore, it is expected that this surgeries induce **high levels of stress to the performing surgeon** and, consequently, **affect their skills.**

Materials and Methods

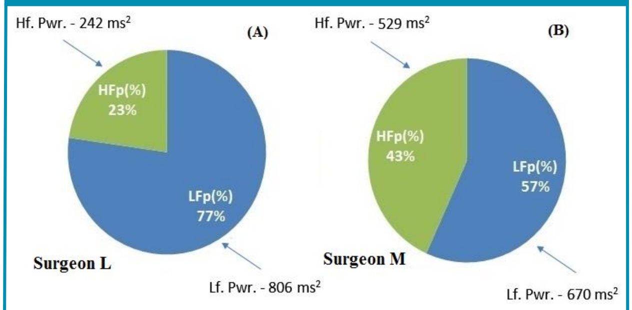
- **2 healthy neurosurgeons** - one male (L, 49 years), and one female (M, 38 years), were monitored during **4 intracranial aneurysm procedures**;
- Cardiac monitoring was possible recurring to a wearable electrocardiogram (ECG) T-shirt (**VitalJacket**®) – 1 lead @ 500Hz;
- **Heart beat detection** possible with algorithm based on the one developed by Pan and Tompkins, with improvements from P. Hamilton. To extract **heart rate variability** (HRV) frequency parameters, we recurred to the Lomb Periodogram;
- **Cardiovascular Intensity** (CI) and **Time and Spectral parameters** were extracted (AVNN, SDNN, pNN20, pNN50, LF/HF).

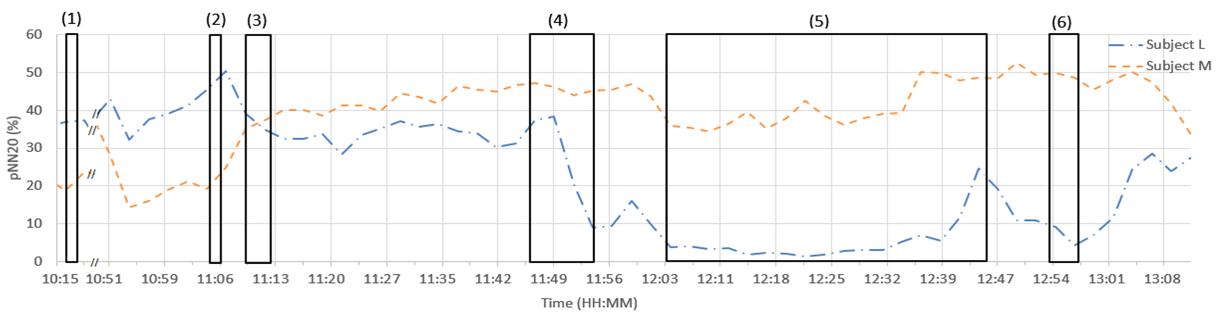
Results

AVERAGE CI AND HRV PARAMETERS FROM SURGEON L

Event	N	CI (%)	AVNN (ms)	SDNN (ms)	pNN20 (%)	pNN50 (%)	LF/HF
1st Cut	4	7.6	723	57.2	32.1	4.1	3.1
Def. clipp.	4	38.5 ↑	519 ↓	33.4 ↓	4.4 ↓	0.2 ↓	3.6 ↑
Aneu. Rupt.	1	64.9 ↑↑	446 ↓↓	21.6 ↓↓	0.17 ↓↓	0.0 ↓↓	4.5 ↑↑

ROLE'S PHYSIOLOGICAL DIFFERENCES





(1) – Start
(2) – Dura Mater
(3) – Exchange
(4) – Aneurysm Reached
(5) – Prov. and Def. Clipp.
(6) – End

Improvements

Several limitations were found in this study and should be addressed in the future, like :

- Surgeons should be of the same **gende**r;
- **Individual's perception** should be taken into account as well (through surveys);
- A **higher number** of surgeries.

Conclusions

- **Wearable Technology** can be used to **identify stressful events** in surgery procedures.;
- The methods described may be of enormous help in **designing stress copping strategies for these professionals** as well as in **other professions**, with minor adaptations.

__Acknowledgments__ - This work is financed by the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within project UID/EEA/50014/2013 granted to INESC TEC and PTDC/EEI_ELC/2760/2012.

Appendix C

IEEE EMBC 2015 - Cardiovascular Strain and Autonomic Imbalance in Neurosurgeons during Intracranial Aneurysm Procedures - *4 Page Paper* (Rejected)

Cardiovascular Strain and Autonomic Imbalance in Neurosurgeons during Intracranial Aneurysm Procedures

G. Pimentel, A.Vilarinho, Rui Vaz and J. P. Silva Cunha, *Senior Member, IEEE*

***Abstract*—It is known that excessive levels of occupational stress affect professionals' technical and non-technical skills and surgeons are no exception. Furthermore, there are few studies in the literature that approach this problem in surgeons and none could be found for neurosurgeons. In this work, we propose a novel method for monitoring stress-induced cardiovascular strain and autonomic imbalance during intracranial aneurysm procedures. Furthermore, we aimed not only to obtain overall cardiovascular strain measures from those procedures but also to be able to detect occurrence of stressful events and compare their impact in the surgeon autonomic balance profile. We monitored cardiovascular intensity (CI) and heart rate variability (HRV) time and frequency domain features from surgeon's electrocardiogram (ECG) signal using state-of-the-art comfortable wearable ECG and activity monitors in 4 aneurysm surgeries with two surgeons (main and assistant). Results show an increase in CI and a significant decrease in time domain HRV parameters in specific events reaching its most significant change in a rupture event. Frequency-domain HRV parameters also showed a clear imbalance for the main surgeon role. The method was successfully validated for the aimed purpose and will be part of a wider surgery stress coping study in the near future.**

I. Introduction

Everyday surgeons are put under tremendous mental pressure in order to perform skillful surgeries where the patient's life is almost always at risk. Amongst this professionals are neurosurgeons which carry some of the most critical and demanding procedures.

Furthermore, some situations need to be addressed as soon as the patient enters the hospital. An example of this is the rupture of an intracranial aneurysm. By definition, an aneurysm is a weak area in a blood vessel wall that causes it to balloon out, while being filled with blood. As it grows, it may rupture, leading to bleeding, which can result in life threatening complications [1]. In case an aneurysm occurs in the brain, the risk of the procedure becomes even higher, due to the difficult access to the affected area and the sensitivity of it. To correct this, surgeons can recur to different approaches. One of them, known as clipping, consists in the placement of a clip in the aneurysm's neck (Fig 1) in order to stop blood from flowing in. Besides, this type of aneurysms are very hard to detect, and often the person that arrives at the operating room already suffered from a subarachnoid hemorrhage caused by the ruptured aneurysm, aggravating the conditions in which the surgeons will perform. Furthermore, this type of surgeries is expected to last several hours. In order to tackle the exhaustion that comes from such a long procedure, normally two surgeons are present during the surgery and they exchange role (between main and assistant) according to the skill and experience they have to assess the problem.

It is then natural that, due to all the pressure induced by the aforementioned factors, surgeons are exposed to stress during this type of procedures, degrading their health and quality of life. Cardiovascular strain is one of the consequences of such exposure and health degradation. In order to prepare the body to "fight or flight", the brain, through the Sympathetic Nervous System (SNS), a branch of the autonomous nervous system (ANS), activates certain body mechanisms [2]. The heart is one of the affected organs, being its behavior altered in order to provide a better blood flow to muscles. This is done by increasing the Heart Rate (HR) and decreasing the variability between heart beats (i.e. Heart Rate Variability (HRV)), inducing high levels of cardiovascular strain. Furthermore, low HRV has been associated with an increased risk of cardiac events and even death [3]. Besides, it has been reported that excessive levels of intra-operative stress can compromise both technical and nontechnical skills of the surgeons [4]. This can result in the degradation of the overall surgical performance of the professional and, therefore, of patient outcome.

Although different studies have been reported in the area of surgeon monitoring, few have assessed individual events during the procedures recurring to physiological data. Instead, global measures of cardiac activity of the procedure compared to a previous period [5], as well as during sleep and surgery [6], are present in the literature for stress level comparisons. However, while being useful to prove the

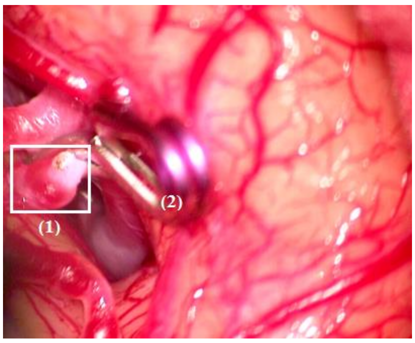


Figure 1. Picture taken from one of the microscope's recordings of an aneurism surgery, after an aneurism (1) was successfully corrected with the placement of a clip (2) in its neck.

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existence of occupational stress, this approach does not allow to identify the main sources of the stress itself so that better coping training can be targeted. Moreover, to our knowledge, no study assessed physiological monitoring of surgeons during neurosurgery procedures. Due to the sensibility and complexity of the area tackled, as well as the unpredictability of the need for an intracranial aneurysm intervention, it becomes intriguing to understand how neurosurgeons cope with the situations that this kind of procedures entails. Furthermore, prophylactic approaches can only be optimized if the stress sources/events are identified.

Therefore, the purpose of this study is to devise a methodology that is able to evaluate which neurosurgery events induce a higher stress-related cardiovascular strain in surgeons and how they currently cope with it, according to their role (main or assistant), through assessment of their Cardiac Intensity (CI) and HRV. In order to perform this study, state-of-the-art wearable technology was used as a non-intrusive method to obtain high quality electrocardiogram (ECG) signal from the professionals during intracranial aneurysm procedures (Fig. 1), which was then processed for extraction of different parameters for a posterior analysis. Furthermore, we discuss how currently different surgeons cope with neurosurgery demands taking into consideration the data extracted.

II. Data Collection and Annotation

A. *Participants*

Two healthy neurosurgeons - one male (L, 49 years), and one female (M, 38 years) - from a Portuguese university hospital were monitored during four intracranial aneurysm procedures. They always performed the clipping technique to correct the detected aneurysm.

B. *Intracranial Aneurysm Procedure*

In order to reach the affected area, the surgeons first need to cut through several layers of the head in order to expose the brain. This includes a craniotomy, which consists in the removal of part of the bone from the skull. After the last layer, the Dura Mater, is cut through, the surgeons will then start opening the path, through the brain, to the aneurysm. Before clipping, control of the blood flow in the area around the aneurysm is needed in order to prevent its rupture. Therefore, one or more provisory clippings are placed across the affected blood vessel until an optimal environment is reached. Afterwards, the placement of the definitive clip can be done. It is during this moment that an aneurysm rupture can occur, due to the pressure that this clip will exert in the area. Sometimes, more than one clipping is needed due to the physiology of the aneurysm. Surgeon L, being the most experienced, performed the definitive clippings in all the surgeries. All this steps are summarized in Fig. 2.

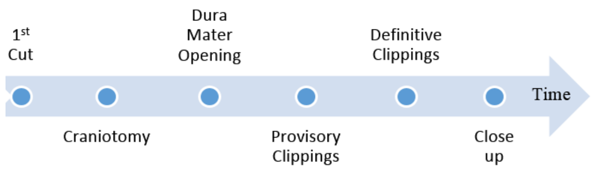

Figure 2. Workflow of an intracranial aneurysm procedure recurring to the clipping technique.

C. *Materials*

To collect data, the surgeons wore, under their scrubs, a VitalJacket® [7]. This is a product from BioDevices S.A. which consists of a very light and comfortable t-shirt embedded with microelectronics that allows continuous gathering of clinical quality ECG signal up to five days.

This ECG data is recorded using one lead and the system has several mechanisms for noise reduction for achieving high clinical quality cardiac signal. An embedded box processes and stores the signal on a SD memory card which can also be accessed on a personal computer or a mobile device using Bluetooth. The ECG data was recorded at 500 Hz. The huge advantage of this product relies in its design, which enables a continuous recording without interfering with the user's daily activities. This is crucial for surgeon's monitoring since they must be at their best while performing their activities. No discomfort whatsoever was reported by the professionals in the operating room using this device.

D. *Data Annotation and Dataset*

Together with the ECG data recorded by the VitalJacket®, all surgeries were reported by a nurse, which wrote the main events - craniotomy, clipping, rupture (if occurred), etc. - with the corresponding time of occurrence, in Greenwich Mean Time (GMT).

With this setup, we were able to record a total of 26 hours of clinical-quality ECG during four surgeries from two surgeons. In one of the surgeries, an aneurism rupture occurred.

III. Methods

A. *QRS Detection*

In order to extract heartbeat information from the ECG recordings, an algorithm based on the one developed by Pan and Tompkins [8] was implemented. Further improvements were made taking in consideration the work by P. Hamilton [9]. This algorithm detects R peaks in the ECG recordings and then outputs the data in a format compatible with Physionet tools used in Section III-B.

B. *HRV Analysis*

To extract HRV time and spectral domain features from the signal, we recurred to the algorithms and methods provided by Physionet [10].

The analysis was performed using a window size of 300 s with an overlap of 50% between windows for better resolution.

Following the guidelines presented by the task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [11], different time and spectral domain parameters were used to study the existence of cardiovascular strain.

As for time domain parameters, we recurred to the Average (AVNN) and Standard Deviation of all NN (SDNN), expressed in ms as well as the percentage of the number of pairs of successive NNs that differ by more than 20 and 50 ms compared to the total number of NN intervals, normally referenced as pNN20 and pNN50, respectively [11].

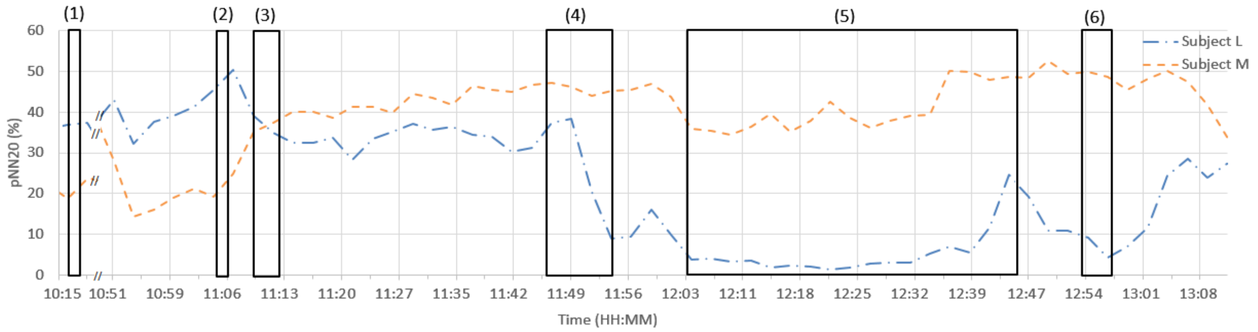

Figure 3. Surgeons' pNN20 changes registered over one of the surgeries. First incision and the opening of the Dura Mater occurred in (1) and (2), respectively, and performed by surgeon M. Afterwards, surgeon L stepped in as the main surgeon (3). Aneurism was reached in (4), and dissection near that area was perfomed as well to expose the aneurism. Several provisory clippings (5) were placed by surgeon L in order to obtain an optimal environment for the final clipping. Definitive clip was placed in (6).

For a better understanding of the strain induced in the heart, we recurred to the CI which takes in account the subject's characteristics. Calculation of the Maximum HR, was done recurring to the definition provided by Tanaka *et al*. [12]. To study the spectral domain, we computed the power spectral density (PSD) of both the low frequency (LF) component of 0,04-0,15 Hz as well as the High frequency (HF) component of 0,15-0,4 Hz and their ratio - LF/HF.

The study of the spectral power of different frequency bands is of great interest due to the influence of the PSNS in the HF component, as well as the mediation by the SNS and PSNS of the LF component [11]. Taking this into account, spectral analysis was used to assess cardiac autonomic modulation and, therefore, stress-induced cardiovascular strain.

IV. Results

A. *Detected Events*

Average results for surgeon L's CI and HRV parameters (AVNN, SDNN, pNN20, pNN50, LF/HF) for the four surgeries are presented in Table I. Aneurysm rupture only occurred in one of the cases. During the first clipping, HRV was considerably lower than during the first cut (SDNN – avg. 33,4 ms vs. 57,2 ms; pNN20 - avg. 4,4 ms vs. 32,1 ms). CI increased as well during this event (avg. 38,5% vs. 7,6%). When the rupture of the aneurysm occurred, CI reached the maximum value of any moment in any of the surgeries (64,9%), while HRV decreased to a minimum. Furthermore, the LF/HF parameter, regarded as one of the best indicator of physiological stress, reached the highest value (4,5) during this time, when compared to the other events.

In Fig. 3, a plot of the temporal behavior of pNN20 during one of the surgeries is presented. When placing provisory clips the pNN20 values decreased to global minima, in this case. Furthermore, the same behavior can be seen during the placement of the definitive clip. These changes, during definitive clipping, were found in every procedure for the main surgeon (L).

TABLE I.
AVERAGE CI AND HRV PARAMETERS FROM SURGEON L

Event	*N*	*CI (%)*	*AVNN (ms)*	*SDNN (ms)*	*pNN20 (%)*	*pNN50 (%)*	*LF/HF*
1st cut	4	7,6	723	57,2	32,1	4,1	3,1
Def. clipp.	4	38,5	519	33,4	4,4	0,2	3,6
Aneu. Rupt.	1	64,9	446	21,6	0,17	0,0	4,5

B. *Surgeon Coping*

M was the surgeon in charge of removing the different layers that protect the brain. After cutting through the Dura Mater, she switched roles with surgeon L, and this can be seen Fig. 3 as well (M's HRV started to increase when this occurred, while L's decreased). Furthermore, there was no relevant changes in the pNN20 values during the provisory and definitive clipping for surgeon M.

Differences can also be seen in the spectral distribution of each surgeon. For a better visualization of the spectral components, we calculated the percentage of HF (HFp) and LF (LFp) compared to the sum of LF with HF. The following charts, presented in Fig. 4, were obtained by computing the mean spectral values for each 5 minute segment analyzed during an entire surgery (the same procedure as in Fig. 3) for surgeon L and M respectively. Fig. 4A shows a predominance of the LF component over the HF component for the main surgeon, while there is a much more balanced distribution associated to M (Fig. 4B).

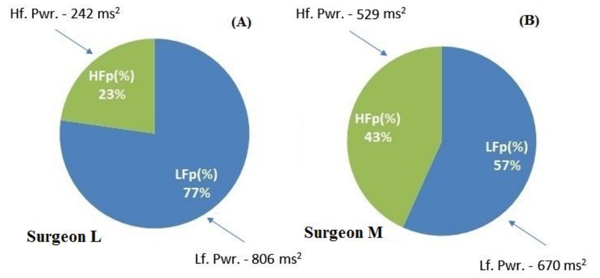

Figure 4. HF and LF distribution for the Main Surgeon (A), as well as for the assistant surgeon (B), during one of the procedures.

V. DISCUSSION

Analyzing Table I, it can be verified that the 20 ms threshold value used for HRV evaluation (pNN20) presented good results, taking into consideration the SDNN for each action. This is also the reason that the change in the pNN50 values between the events is so small compared to pNN20.

L's CI increased during the definitive clipping, when compared to the first cut, while HRV (SDNN, pNN20) decreased. In other words, it seems that surgeon L is exposed to high cardiovascular strain during the clipping event. This is probably due to the self-reported perception of being a risky maneuver that increases the possibility of rupture, inducing high levels of mental pressure to the surgeon. The rupture of the aneurysm induces the highest cardiovascular strain in surgeon L, as it was expected, since it is the worst outcome that can occur during this type of procedures. HRV decreases with this changes (SDNN, pNN20, pNN50) to minimum values. Finally, supporting all this findings, an increase in LF/HF ratio is observed, which shows, a dominance of the SNS over the PSNS – a typical indicator of a stressful situation, according to the literature [11].

There is also clear difference in the cardiac behavior of each surgeon in Fig 3. When surgeon L stepped in to take the lead in the surgery, his HRV started to decrease, achieving minimum values when he started to analyze the area where the aneurysm is and performed several provisory clippings. A similar behavior was also registered when he placed the definitive clip. During these events, surgeon M's HRV did not change considerably, and stayed at higher values than the ones she had before the exchange. This findings allow us believe that L's heart was exposed to a higher strain than M's, probably due to the responsibility that his actions would have in the patient's life. This interpretation also matches the self-report of surgeon L. Furthermore, when comparing the HF and LF distribution of both surgeons, differences were also found. There is a clear predominance of the LF component when compared to the HF one in Fig 4A (LF/HF >3), which is relative to surgeon L's ECG. However, the same is not true for subject M (Fig. 4B), who has a more balanced LF and HF distribution.

VI. CONCLUSION + FUTURE WORK

We have developed a method for detection of stressful events and have shown its capacity to detect that some events are more "stressful" than others for the performing surgeon. An overall measure of cardiovascular strain during a neurosurgery procedure is also possible to obtain. This study shows that there is a clear possibility of occurrence of cardiovascular strain in neurosurgeons, which can lead to an overall decay of their skills and health, impacting, ultimately, surgery outcome. Even though this is a preliminary study, some results could already been deducted from the data obtained, showing the usefulness of the developed methodology. However, several improvements are still needed in order to assess, reliably, how and when cardiovascular strain occurs in neurosurgeons. In this cases, we have only studied stress as a physiological response. According to *Lazarus* and *Folkman* [13], stress should take into account the individual's perception as well. Even though we considered the self-report of the surgeons, no structured protocol for subjective assessment was followed. Therefore, a subjective literature-approved survey for the analysis of the professional's perceived stress before, during and after the surgeries should be implemented with the support of psychologists. Finally, future studies should use a larger sample and focus in only one gender, in order to obtain more accurate and feasible data. These results have also practical implications, drawing the attention for the need to understand surgeons stress levels, identify sources of cardiovascular strain, and thus opening the possibility to design a psychological intervention in order to better help them coping with daily working stress and consequently perform better. A wider surgery stress coping study will be performed in the near future using the presented methodology.

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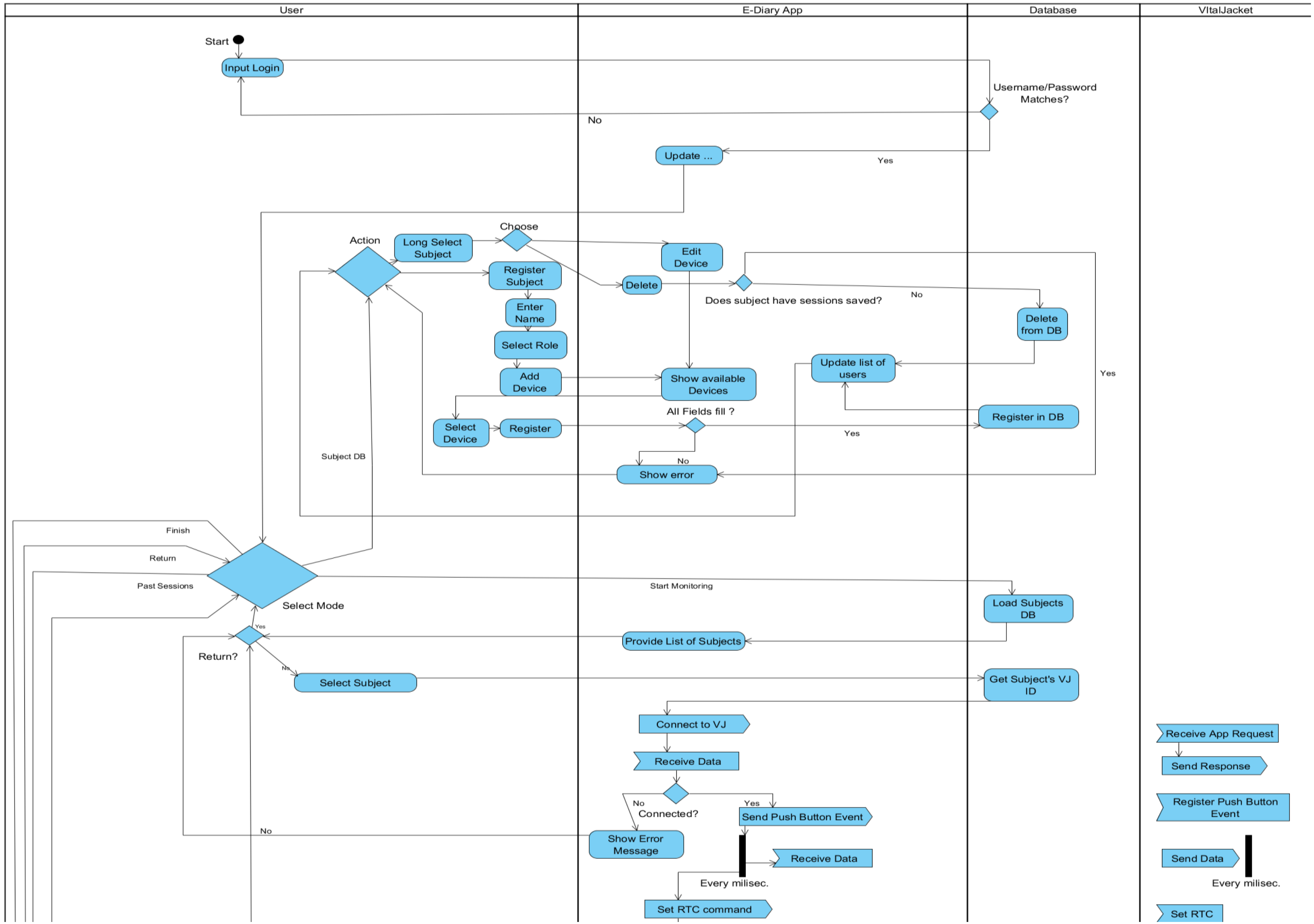
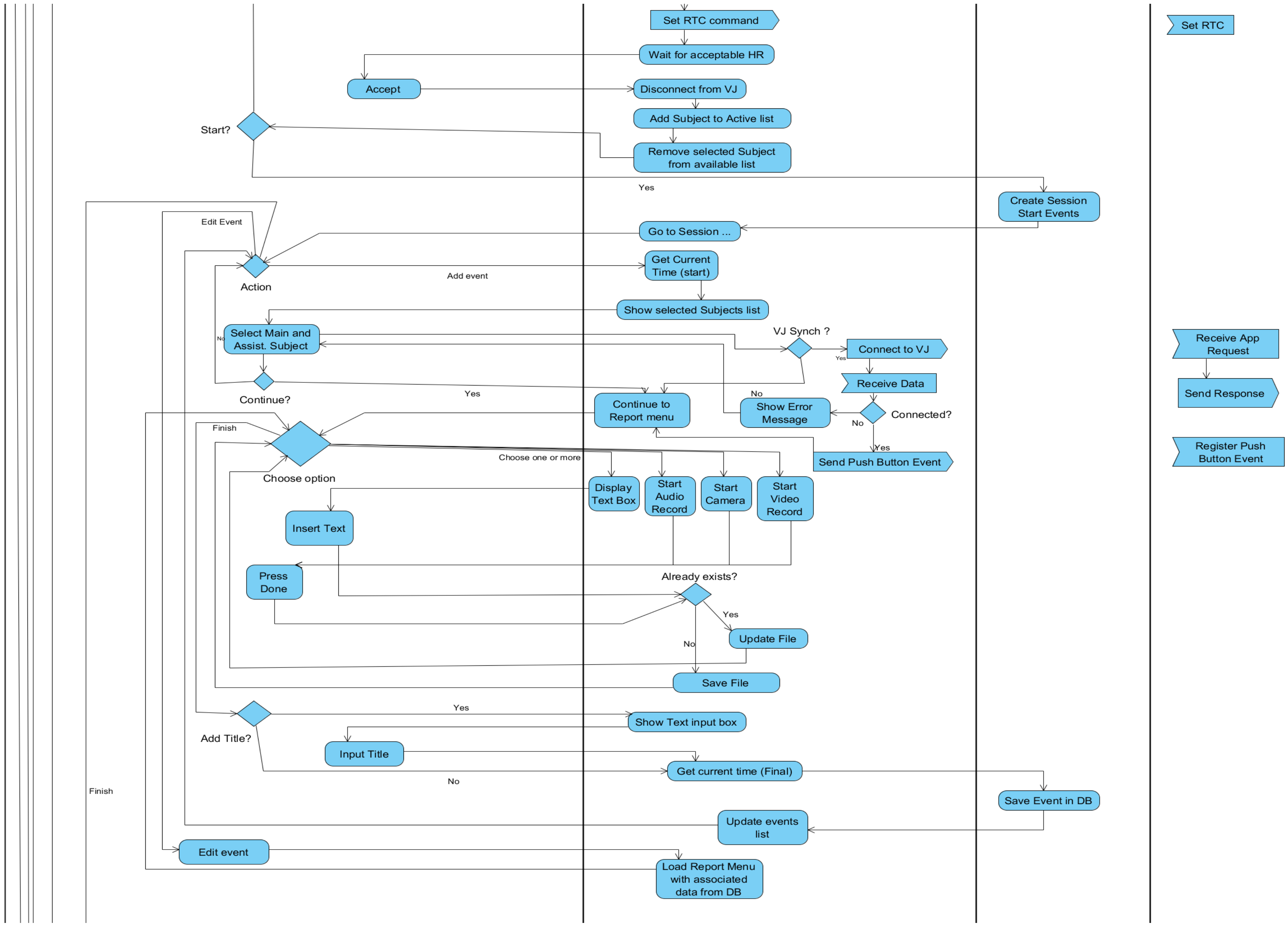
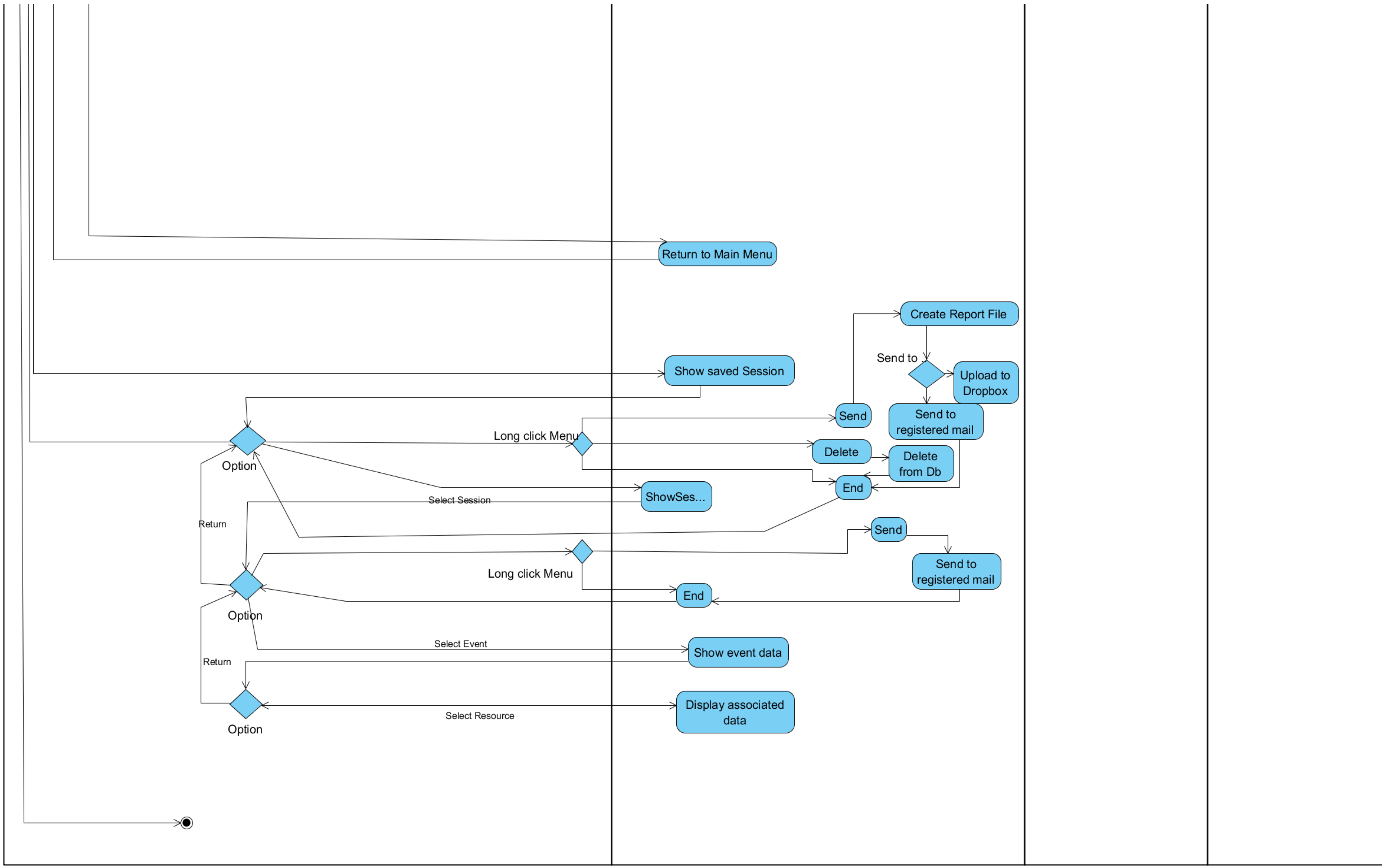
Appendix D

Full Activity Diagram for the VJ E-Diary app


User
E-Diary App
Database
VItalJacket
Start
Input Login
Username/Password
Matches?
No
Update ...
Yes
Action
Long Select
Subject
Choose
Edit
Device
Register
Subject
Delete
Does subject have sessions saved?
No
Enter
Name
Delete
from DB
Select Role
Update list of
users
Yes
Add
Device
Show available
Devices
All Fields fill ?
Register in DB
Select
Device
Register
Yes
Subject DB
No
Show error
Finish
Return
Past Sessions
Select Mode
Start Monitoring
Load Subjects
DB
Yes
Provide List of Subjects
Return?
No
Select Subject
Get Subject's VJ
ID
Connect to VJ
Receive App Request
Receive Data
Send Response
No
Yes
Connected?
Send Push Button Event
Register Push Button
Event
No
Show Error
Message
Receive Data
Send Data
Every milisec.
Every milisec.
Set RTC command
Set RTC



Set RTC command
Wait for acceptable HR
Accept
Disconnect from VJ
Add Subject to Active list
Start?
Remove selected Subject from available list
Yes
Create Session Start Events
Edit Event
Go to Session ...
Get Current Time (start)
Action
Add event
Show selected Subjects list
VJ Synch ?
Select Main and Assist. Subject
No
Connect to VJ
Yes
Receive Data
Continue?
Yes
No
Continue to Report menu
Show Error Message
Connected?
Finish
No
Yes
Send Push Button Event
Choose one or more
Choose option
Display Text Box
Start Audio Record
Start Camera
Start Video Record
Insert Text
Press Done
Already exists?
Yes
Update File
No
Save File
Yes
Show Text input box
Add Title?
Input Title
Get current time (Final)
No
Finish
Save Event in DB
Update events list
Edit event
Load Report Menu with associated data from DB
Set RTC
Receive App Request
Send Response
Register Push Button Event


Return to Main Menu
Create Report File
Send to
Upload to Dropbox
Show saved Session
Send
Send to registered mail
Long click Menu
Delete
Delete from Db
Option
End
Select Session
ShowSes...
Return
Send
Long click Menu
Send to registered mail
End
Option
Select Event
Show event data
Return
Select Resource
Display associated data
Option

Appendix E

Surveys Used for Appraisal of Surgeons Stress and Cognitive Workload

ID:____________________

Questionário de Auto-Avaliação

Código: ___________________

Data: ___/___/____

Hora de início: ___:___

Pré - Operatório

Leia cada afirmação e, em seguida, circule o número mais adequado para a direita da declaração que melhor indique como se sente agora, neste momento.

	De Modo Nenhum	Um Pouco	Moderadamente	Muito
Sinto-me calmo/a	1	2	3	4
Estou tenso/a	1	2	3	4
Estou chateado/a	1	2	3	4
Estou relaxado/a	1	2	3	4
Estou contente	1	2	3	4
Estou preocupado/a	1	2	3	4

ID:____________________

Código: ___________________

Hora de fim: ___:___

Pós – Operatório

Leia cada afirmação e, em seguida, circule o número mais adequado para a direita da declaração que melhor indique como se sente agora, neste momento.

	De Modo Nenhum	Um Pouco	Moderadamente	Muito
Sinto-me calmo/a	1	2	3	4
Estou tenso/a	1	2	3	4
Estou chateado/a	1	2	3	4
Estou relaxado/a	1	2	3	4
Estou contente	1	2	3	4
Estou preocupado/a	1	2	3	4
-	-	-	-	-
Estou irritado/a	1	2	3	4

Por favor, avalie o procedimento marcando " X " na cada uma das seis escalas no ponto que melhor se encaixa sua experiência. Por favor, leia as descrições com cuidado.

Exigência Mental **Quão mentalmente fatigante foi o procedimento?**

Muito Pouco Bastante

Exigência Física **Quão fisicamente fatigante foi o procedimento?**

Muito Pouco Bastante

Exigência Temporal **Quão apressado ou acelerado foi o ritmo do procedimento?**

Bastante Lento Bastante rápido

Complexidade do procedimento **Quão complexo foi o procedimento?**

Muito Pouco Bastante

Stress situacional **Quão ansioso se sentiu enquanto realizava o procedimento?**

Muito Pouco Bastante

Distrações **Quão perturbador foi o ambiente operacional?**

Muito Pouco Bastante

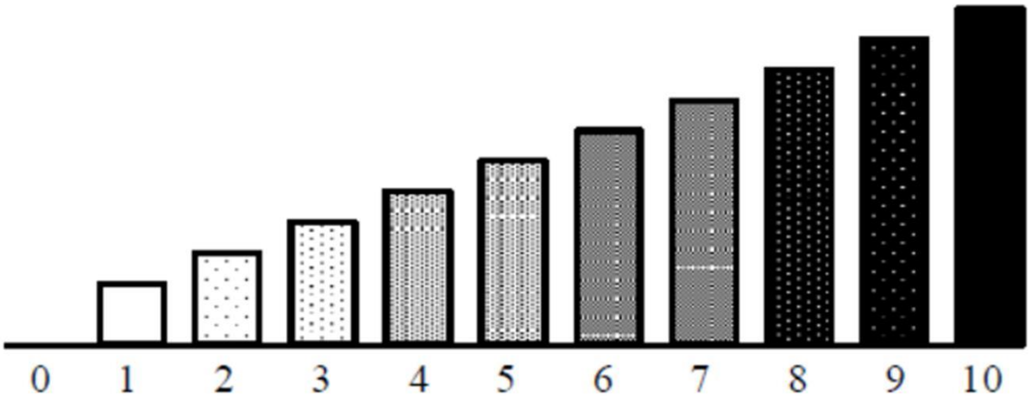
Tensão/dor muscular **Sente, de momento, alguma tensão ou dor muscular?**

Muito Pouco Bastante

Appendix F

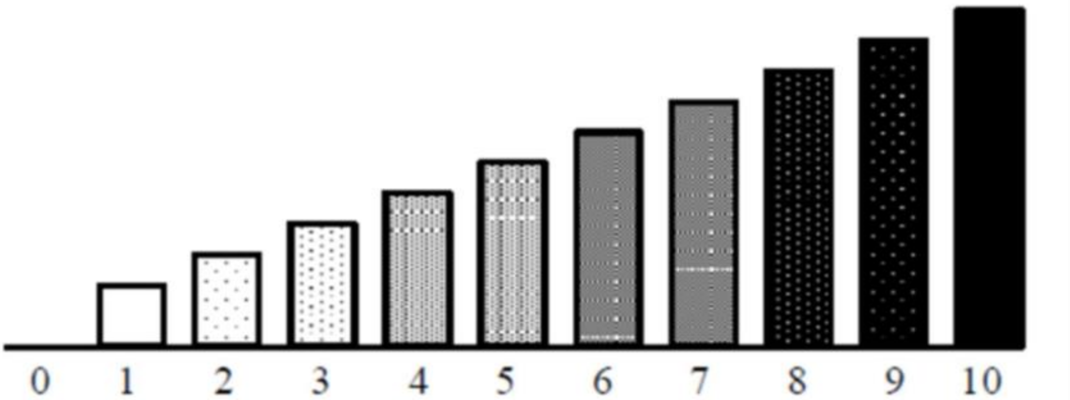
Visual Analog Scale for Assesment of Stress and Fatigue during the Firefighters Laboratorial Tasks

Por favor indique a intensidade de fadiga que sente neste momento:



Nenhuma fadiga **Fadiga severa**

Por favor indique a intensidade de stress que sente neste momento:



Nada stressado **Muito stressado**